NAVSHIPS 250-538

U. S. NAVY
DIVING MANUAL

Navy Department
Washington 25, D.C.

NAVSHIPS 250-538 (Part 3)
Change Number 1

U. S. NAVY DIVING MANUAL

PART 3

SELF-CONTAINED DIVING

CHANGE NUMBER 1

SEPTEMBER 1958

Navy Department
Washington, D. C.

For sale by the Superintendent of Documents, U.S. Government Printing Office, Washington 25, D.C. - Price $3.25

Change Number 1

CHANGES TO BE MADE IN INK.

Page 5 - section (3.1.2), paragraph (6), line 3, delete "for use near neutral buoyancy", and insert "to have near - neutral buoyancy when in use."

Page 5 - section (3.1.2), paragraph (7), line 3, insert "rigs" after the word scuba.

Page 6 - section (3.1.2), paragraph (10), line 3, after the word "resistance" insert "; i.e., inability of the inhalation circuit to deliver flow at a high demand rate."

Page 6 - section (3.1.2), paragraph (10), line 5, after the word "capacity," insert "; i.e., insufficient absorptive area to take up all the CO_2 in each cycle with a resultant CO_2 build-up."

Page 8 - section (3.1.2), paragraph (18), line 2, delete "decide", and insert "dictate".

Page 8 - section (3.1.2), paragraph (18)(b), line 4, delete "probably", and insert "generally".

Page 10 - section (3.1.3), paragraph (6), line 11, after the word "the", insert "work of breathing may be intolerable to the diver and if he does tolerate it, damage to the lungs may result".

Page 10 - section (3.1.3), paragraph 6, line 12, delete "Even if he does, his lungs may be injured".

Page 10 - section (3.1.4), paragraph (1), line 11, delete "the", and insert "these".

Page 10 - section (3.1.5), paragraph (1), line 5, delete "Most of the medical problems of diving are discussed fully in part 1."

Page 11 - section (3.1.5), paragraph (3), line 6, delete ":".

Page 11 - section (3.1.5), paragraph 6, line 8, delete "ascent in panic", and insert "a panicky ascent."

Page 11 - section (3.1.5), paragraph 9, line 9, delete "the article on emergency ascent", and insert "section 3.8.1., paragraph 4."

Page 12 - section (3.1.5), paragraph (15), line 10, insert period after the word "oxygen". Insert "The nitrogen" after the period.

Page 12 - section (3.1.5), paragraph (19), line 6, delete "standing diving table", and insert "Navy Standard Air Decompression Table."

Page 12 - section (3.1.5), paragraph (22), line 8, delete "carbon-dioxide-build-up", and insert "carbon-dioxide-build-up."

Page 51 - section (3.5.2), paragraph (6), line 7, after the word "canister" insert "relative."

Page 61 - section (3.6.5), paragraph (7), line 5, delete "3-54 and insert "3-53."

Page 68 - section (3.6.9), paragraph (7), line 2, delete "ejet", and insert "jet."

NAVY DEPARTMENT, BUREAU OF SHIPS,
1 June 1959.

The U.S. Navy Diving Manual (NAVSHIPS 250–538)—consisting of four parts—supersedes the Bureau of Ships Diving Manual (NAVSHIPS 250–880).

The revised Manual has three objectives: (1) to assemble and present all technical information now available; (2) to provide a vehicle for rapid dissemination of new developments; and (3) to authorize the use of specific practices that assist personnel in the field to perform their duties.

Part 4 of the U.S. Navy Diving Manual is issued herewith. All four parts of the revised Manual have been published and issued to holders of the Bureau of Ships Diving Manual which is now obsolete.

R. K. JAMES,
Rear Admiral, USN,
Chief, Bureau of Ships.

SPECIAL NOTE:

A publication is of value only insofar as it is maintained current and informative. The U.S. Navy Diving Manual (NAVSHIPS 250–538) must reflect all new developments and current procedures in the diving field.

All individuals and activities engaged in diving are authorized and requested to submit constructive criticism and recommendations for improvement of the manual direct to the:

Officer in Charge
U.S. Navy Experimental Diving Unit
NWP, Washington 25, D.C.

This same procedure is already in effect for submission of originals of activity diving logs (NAVSHIPS 1000) and copies of diving accident reports (NAVMED 816).

The Experimental Diving Unit is assigned responsibility for periodic assembly of the field recommendations into proposed numbered changes. These proposed numbered changes will also include information on equipment, techniques, and procedures as they are developed.

The Bureau of Ships is responsible for publication for approved changes to the U.S. Navy Diving Manual. Changes proposed by the Experimental Diving Unit will be forwarded to the Chief, Bureau of Ships via the Chief, Bureau of Naval Personnel and the Chief, Bureau of Medicine and Surgery for approval.

NAVSHIPS 250-538

U. S. NAVY DIVING MANUAL

PART 1

JANUARY 1959

Navy Department
Washington 25, D. C.

U. S. NAVY DIVING MANUAL

PART 1

GENERAL PRINCIPLES OF DIVING

CONTENTS

PART 1

CONTENTS

TABLES AND ILLUSTRATIONS

CONTENTS

TABLES AND ILLUSTRATIONS—Continued

SECTION 1.1 INTRODUCTION

1.1.1 THE HISTORY OF DIVING

(1) History gives no record of the date when diving first began or who the first divers may have been, but man's curiosity probably led him into the water and under its surface at a very early stage. Like some of the native pearl and sponge divers who continue the primitive art, the first divers probably used no equipment at all except perhaps a stone to get them to the bottom more rapidly. Although unaided divers have achieved remarkable depths and durations of dive, it is not likely that the early divers often exceeded 1 or 2 minutes of submergence or 80 to 100 feet of depth.

(2) Written records provide accounts of some very ancient diving exploits. Most of these were connected with naval warfare. For example, Xerxes is said to have used combat divers; and over 400 years before Christ, Herodotus told the story of Scyllis, a famous Greek diver who was employed by Xerxes to recover treasure from sunken Persian ships. When the job was done, the conqueror decided to detain Scyllis but the diver went over the side during a storm, threw the whole fleet into confusion by cutting the anchor cables, and then completed his escape by swimming 9 miles to Artemisium. Alexander the Great used divers to destroy the boom defenses of Tyre about 333 B.C., and Aristotle wrote that Alexander himself descended in some sort of a diving bell. Divers were used in at least six naval battles and sieges between 400 B.C. and 1795 A.D. In the early 1800's Spanish warships still carried men whose duties were swimming and diving for the fleet, although no breathing appliances were used.

Early efforts

(3) Several of the ancient accounts indicate that crude means of supplying the diver with air were sometimes used. About 77 A.D., the historian Pliny referred to military divers who breathed through tubes which were supported at the surface by a float. In a famous treatise on warfare written about 375 A.D., Vegetius described diving hoods equipped with air pipes.

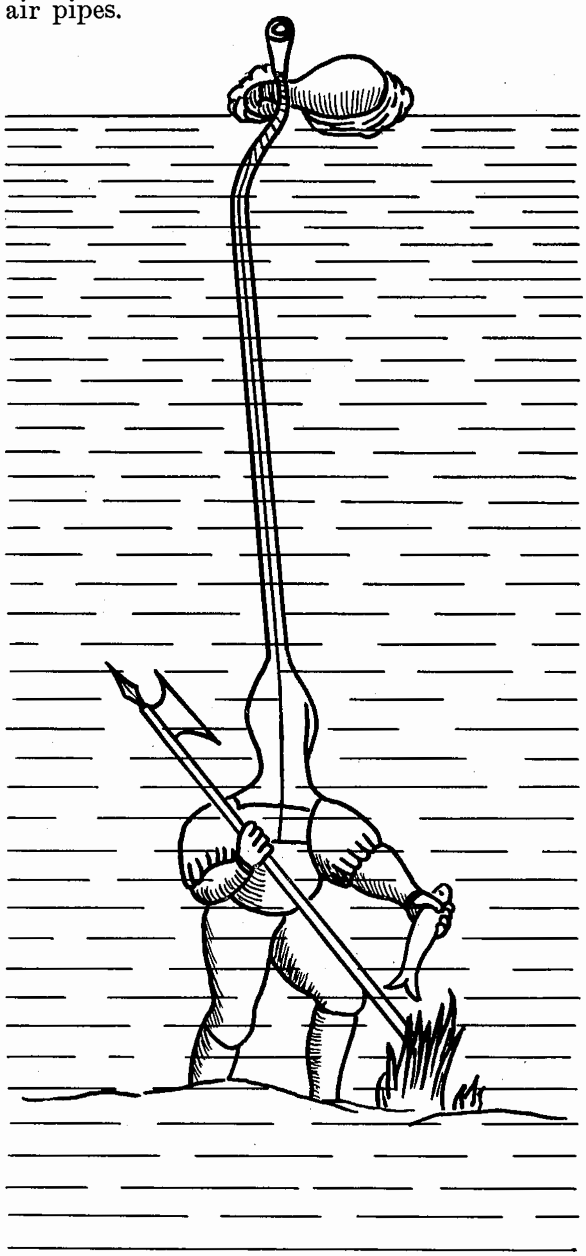


FIGURE 1-1.—Diving Hood of Vegetius

Diving developments 1500 to 1800

(4) Interest in diving increased after 1500, and many different rigs were designed. In 1511, the book written by Vegetius in 375 A.D. was printed, and a drawing of the diving hood described by him (fig. 1–1) became the first design for diving dress to be found in a printed book. Even before this, the remarkable artist Leonardo Da Vinci had sketched diving outfits and hand fins along with submarines and flying machines and other marvels yet-to-come. In 1524, Vallo designed a leather helmet which was slightly more advanced than that of Vegetius. This one at least provided eye-ports, and its leather pipe was reinforced with iron rings and held up by a disk-shaped float. If they were ever built, such rigs could not have been used in water much over the diver's head. In 1680, Borelli proposed an outfit (see 3.1.1) which would probably have been the first self-contained diving apparatus—if it had been built and if it could have been used, which is unlikely.

(5) Although little of the equipment designed before 1800 was very practical, the underwater accomplishments of the period were surprising in many ways. A primitive snorkel submarine (propelled by 12 oarsmen) was making regular trips on the Thames around London about the time the Pilgrims landed in America. Diving bells and crude diving helmets were used for work on wrecks as deep as 60 feet, and reasonably practical air pumps were developed before the end of the 1700's.

Diving developments 1800–1900

(6) The advent of compressors started the development of diving as we think of it today. With the ability to maintain an air pocket against greater and greater pressures for longer and longer times came the physiological problems of working under pressure. As each problem was encountered, its solution was sought through the combined efforts of the scientists and the men willing to try again.

(7) The divers of the 1800's were true adventurers advancing into the unknown. They had no knowledge of how well their equipment would work or against what tests it would be pitted. They had no knowledge of what the pressure, the compressed air, or the combination of all three would do to them. And the harbors around Europe were just as black then as they are now. We owe much to these individualists. (The most important development of this period, the "closed-dress" invented by Augustus Siebe in 1837, is discussed in pt. 2.)

(8) One of the most famous divers of the 1800's was Alexander Lambert. His most noted exploit took place when a tunnel, which was being built under the Severn River in England, flooded in 1880. Using the forerunner of oxygen rebreathing apparatus, he went alone down a vertical shaft and far into the tunnel through masses of floating debris. In order to shut an iron door so that the tunnel could be pumped out, he was forced to return to the surface to get a wrecking bar. On his second trip into the blackness, he finished the job. Three years later, the tunnel flooded again and Lambert was hired to repeat the job. He tried to use the same equipment, but this time he was poisoned either by the high oxygen pressure or by carbon dioxide. He barely managed to escape with his life, but he tried again the next day using a surface-supplied rig and was able to complete the job. In 1885, Lambert forced his way through three decks and into the strongroom of a wreck at 162 feet. He recovered nearly half a million dollars in gold, but the job gave him a case of the bends which forced him to retire. There were as yet no adequate decompression tables. These had to wait for the work of Professor Haldane and his associates in 1907. (See section 1.1.4.)

Diving in the U.S. Navy

(9) Not much is actually known about the beginning of diving in the United States Navy. Although good work evidently was done at shallow depths in the early days, very little was accomplished in deep diving. Largely as a result of the efforts of Chief Gunner George D. Stillson, an active development program was started in 1912 to check the practicability of Haldane's stage method of decompression

and to improve the standard Navy diving gear to permit deeper dives. Extensive tests were conducted in diving tanks ashore and later from U.S.S. *Walke* in Long Island Sound. The value of the work was evident in the salvage operations on the submarine U.S.S. *F–4* off Honolulu in 1915. On that job, divers descended to 304 feet—a depth which is probably a record for useful diving in the standard rig with air as the breathing medium.

(10) After the *Walke* tests, a diving manual was issued; and the Navy Diving School was established at the Naval Torpedo Station at Newport, R.I. This school was discontinued when the United States entered World War I. Personnel of the school and some of its graduates formed a nucleus for the overseas salvage division, which was established as a unit of the United States Naval Forces abroad. Throughout our participation in the war, these divers rendered valuable service in salvage operations along the French coast.

(11) The need for further development of diving was strongly emphasized by two tragic accidents which occurred in the mid-twenties. On 25 September 1925, U.S.S. *S–51* was rammed by the steamship *City of Rome* and sank in 132 feet of water off Block Island. Only three of the crew survived. At that time, only 20 Navy divers were qualified to dive deeper than 90 feet, and only six civilian divers on the east coast of the United States were willing to dive in 132 feet of water. Salvage operations commenced on 26 September 1925 but were interrupted by winter storms. The *S–51* was finally raised on 5 July 1926 and towed to U.S. Naval Shipyard, Portsmouth, N.H. The many difficulties encountered were made more serious by the fact that so few divers had been trained to work at such a depth.

(12) On 17 December 1927, the Coast Guard Cutter *Paulding* collided with U.S.S. *S–4* (SS–109) just to the southward of the extreme tip of Cape Cod. *S–4* immediately sank in 102 feet of water with all personnel on board. Divers reported signs of life in the boat 22 hours after the collision. The salvage vessel *Falcon* succeeded in ventilating the compartment, but bad weather forced her to cease operations. Rescue attempts were terminated on 24 December 1927. This accident underlined the need for some means of getting personnel out of a disabled submarine. On 27 December 1927, the salvage phase began. Again the work was hampered by a shortage of divers qualified to work at the depth involved. Only 24 were available. *S–4* was raised on 17 March 1928 by divers working from U.S.S. *Falcon.*

(13) Even before the loss of these submarines, there was concern over the possibility that rescue and salvage operations would be needed in much deeper water. Divers could not retain their mental clarity and effectiveness when breathing air at great depths, so some other breathing medium was needed. In late 1924, the Navy's Bureau of Construction and Repair (now the Bureau of Ships) joined with the Bureau of Mines in investigating the use of helium-oxygen mixtures. The preliminary work was conducted at the Bureau of Mines Experimental Station in Pittsburgh, Pa.

(14) Experiments on animals, later verified by studies with human subjects, clearly showed that helium-oxygen mixtures offered great advantages over air for deep dives. There were no undesirable mental effects, and there was reason to expect advantages in decompression time. In the early part of 1927, the experiment on the use of helium-oxygen had reached the stage where it was desirable to transfer the Experimental Diving Unit from the Bureau of Mines to the Navy Yard, Washington, D.C. (now the U.S. Naval Gun Factory), as a permanent activity under the Bureau of Construction and Repair (now Bureau of Ships). Its mission was to continue the investigation of helium-oxygen and other development work in diving practices and equipment. The Experimental Diving Unit has functioned accordingly up to the present time.

(15) The U.S. Naval School, Deep Sea Divers, was reestablished in 1926–27 at the Washington Navy Yard (Naval Gun Factory). This location was chosen with the view that its proximity to the Experimental Diving Unit would permit expeditious application of approved experimental findings to the standard training curriculum. The school is operated

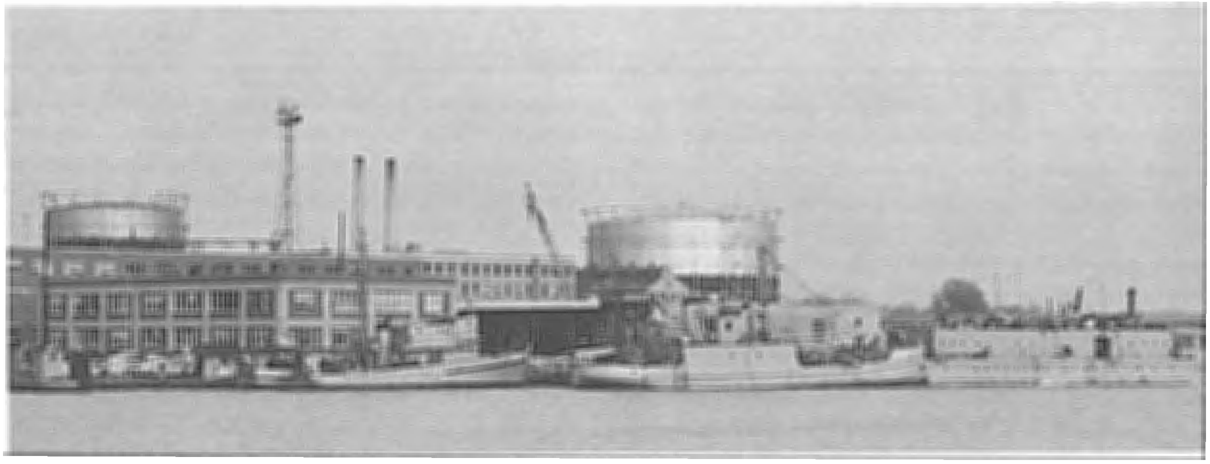


FIGURE 1-2.—U.S. Naval School, Deep Sea Divers.

FIGURE 1-3.—Pressure tank, Experimental Diving Unit. The two wet-pressure tanks in the Deep Sea Diving School are used for training in deep diving; those in the Experimental Diving Unit are employed in the testing of decompression tables and for experimental dives.

FIGURE 1-4.—"Igloo" and recompression chamber, Deep Sea Diving School. Above each pressure tank is an access chamber (igloo), and a recompression chamber (right) is connected to the igloo.

under the cognizance of the Bureau of Naval Personnel. The facilities of the Deep Sea Diving School (figs. 1–2 to 1–6) include two pressure tanks capable of withstanding 350 pounds working pressure and 525 pounds test pressure. Each pressure tank is directly connected to a recompression chamber. Two open tanks are also used for training purposes. Facilities on the Anacostia River outside the school proper include a converted 500-ton covered lighter (YFNX–9) which has been fitted with stations for eight divers. This also contains classrooms, shops, and a storeroom. Various service craft are also employed in training. Of these, the YDT–5 is used for helium-oxygen and air diving in a Potomac River field area. The YSD–39 is used for salvage projects with a sunken LCI in another field area. The YF–336 is used for demolition training off the Naval Powder Factory, Indian Head, Md. Other craft, such as a YDB and an LCPR, serve for local deep sea and scuba training. Among other training aids, a submarine rescue chamber is used for actual descents to a submarine false seat on the river bottom.

(16) The Experimental Diving Unit is equipped with two pressure tanks and recompression chambers which are duplicates of those installed in the Diving School. There are also modern workshops and an excellent laboratory. Both the School and Experimental Unit have gas-mixing rooms for helium-oxygen supply. The recompression chambers at the Experimental Diving Unit are also equipped for altitude experimental work. A great deal of work in altitude studies was done there at the start of World War II.

(17) The submarine disasters of 1925 and 1927 spurred not only further progress in diving but also developments in submarine escape and rescue methods. The years of experimentation which had been devoted to the

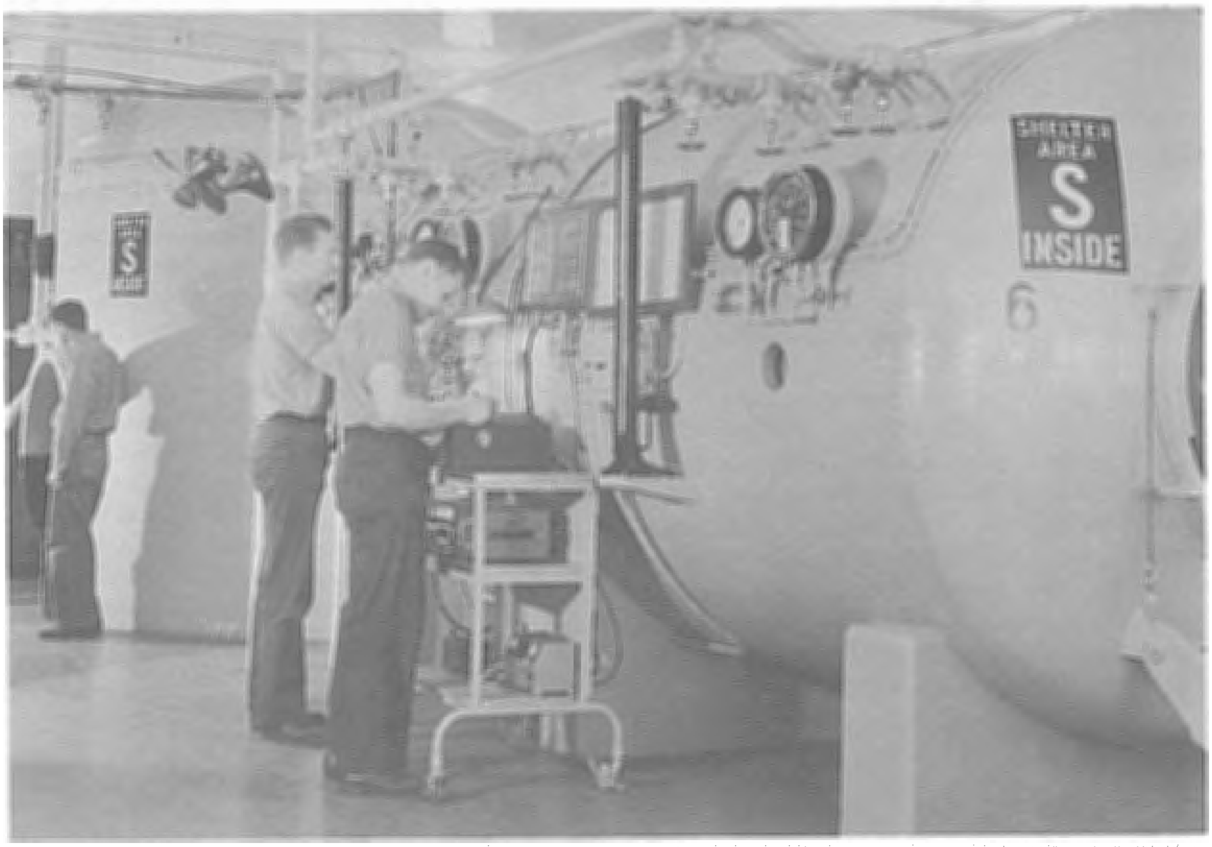


FIGURE 1–5.—"Igloo" and recompression chamber, Experimental Diving Unit. The unit's recompression chambers are used for equipment evaluations and experidental "dry dives" as well as for treating decompression sickness. They are equipped with special instruments for both depth and high altitude pressures.

557535 O - 60 - 2

FIGURE 1-6.—Students learn diving techniques in Deep Sea Diving School open tanks before going on to river diving and pressure tanks.

technique of helium-oxygen diving paid dividends in 1939. On 23 May of that year, U.S.S. *Squalus*, a submarine of the newest type, submerged with its main induction valve open and sank in 243 feet of water off the Isle of Shoals in the North Atlantic. On 24 May 1939, U.S.S. *Falcon*, veteran of the *S-51* and *S-4* jobs, arrived with the rescue chamber. The chamber was first attached to the forward hatch of the *Squalus*, and 33 survivors were safely brought aboard *Falcon* in four trips. The rescue chamber was then attached to the after hatch of the *Squalus*, and the sad word was reported that all was flooded and there were no signs of life.

(18) Salvage work began immediately on the *Squalus*. This resulted in the first field experimental application of helium-oxygen diving. The divers were able to think clearly and work efficiently when breathing helium and oxygen mixtures at the 243 foot depth. Surface decompression with oxygen was also used successfully. On 13 September 1939, the *Squalus* was towed into port following months of heroic salvage work. Had air alone been available for a breathing medium, it is doubtful that the demanding job could have been accomplished. The *Squalus*, rechristened the *Sailfish*, was restored to service and contributed to the victory of World War II.

(19) With the expansion of the United States Navy to include ships specifically designed for ship salvage work and the requirements of diving under wartime conditions, it was necessary to increase the facilities for the training of divers. About the time this expansion was under consideration, a fire broke out in U.S.S. *Lafayette* (formerly the French liner *Normandie*) while it was docked at Pier 88, North River, in New York. In the process of extinguishing the fire, she was capsized. The righting of the liner provided an excellent opportunity for establishing a diving school where practical experience for ship salvage personnel could be obtained. In addition to

the experience that could be obtained on the U.S.S. *Lafayette*, the large number of other diving jobs in the harbor increased the advantages of the location. The Naval Training School (Salvage) was established on a permanent basis in September 1942 to provide for the increased need for divers. During 1946, the school, as the U.S. Naval School, Salvage, was transferred from Pier 88, New York, to Bayonne, N.J. This school was authorized to train and designate salvage divers. In the summer of 1957, the school was disestablished at Bayonne, and the courses for salvage divers and salvage diving officers were moved to the school at Washington.

(20) In addition to the Naval School, Deep Sea Divers, there are diving activities within the fleet and at various naval shipyards which are authorized to train and designate divers second class.

(21) During and after World War II, the Experimental Diving Unit continued the improvement of helium-oxygen equipment and techniques. Dives as deep as 561 feet were made using helium-oxygen gear in the wet pressure tanks. Research in other aspects of diving also continued. One notable advancement was development of tables for surface decompression after air dives, using oxygen to shorten the decompression time appreciably. The Unit's work in recent years has reflected the growing importance of diving with self-contained underwater breathing apparatus (scuba). Many types of such equipment have been developed and tested, and numerous physiological studies concerning the unusual problems of self-contained diving have been conducted.

(22) The military potential of self-contained diving was demonstrated conclusively during World War II. In 1947, the first submersible operations platoon was organized in Underwater Demolition Team Two for the purpose of applying scuba to UDT (Underwater Demolition Team) operations. Men assigned to the platoon were trained in many skills such as underwater reconnaissance, underwater long distance swimming, and the application of these and other techniques to offensive and defensive operations. At the present time, self-contained diving finds many applications in the work of Underwater Demolition Teams and Explosive Ordnance Disposal Units and has proved advantageous for many other underwater jobs. In 1954, the U.S. Naval School, Underwater Swimmers, was established in Key West, Fla., specifically for the training of SCUBA divers.

(23) Divers today are doing more kinds of underwater work and doing it at greater depths, for longer times, and with far greater safety than would have been thought possible a hundred years ago. The progress of the next century may be even more impressive. Certainly, the Navy's efforts to increase the scope and safety of diving will continue.

1.1.2 TYPES OF DIVING EQUIPMENT

(1) The Navy employs several different types of diving equipment depending on the circumstances and the job to be done. A brief description of the types of gear presently in use in the Navy is presented here. Details concerning them will be found in part 2 (Surface-supplied Diving) and part 3 (Self-contained Diving) of this manual. Details concerning special tools and accessories used with both types of diving equipment are provided in part 4 (Diving Accessories).

Surface-supplied apparatus

(2) All of the types in this category are supplied with air or some other suitable breathing medium through a hose from the surface. They are used mainly where the diver's work is confined to a rather small area and where stability rather than great mobility is important. Great depths and other special conditions may also require use of surface-supplied rigs. The fact that air supply duration is not limited is a definite advantage of this type of equipment.

(3) *The deep sea diving outfit* (fig. 1–7) consists of a helmet and watertight dress, weighted belt and shoes, supply hose and control valve, non-return valve, and exhaust valve. The belt and shoes overcome the positive buoyancy of the dress and helmet. The hose supplies the air to the diver, and he controls the quantity with the control valve. The non-return valve prevents the escape of air from the dress back up the hose in the event that

the supply pressure drops due to rupture of the hose or any other accident. The exhaust valve is spring-loaded and adjustable. The balance between control valve and exhaust valve settings governs the pressure in the suit and thus controls the degree of inflation and the buoyancy.

(4) The essential part of the *lightweight diving outfit* (fig. 1–8) is a full face mask. This is supplied with air from the surface through a hose of the type generally used for oxygen. A nonreturn valve and control valve are mounted on the right side of the mask, and an exhaust valve is provided on the left side. This mask can be used alone if desired, allowing the diver almost as much freedom, within limits, as with self-contained apparatus. A light, flexible dress is provided for use with the mask when desired. Since air enters and exhausts direct from the mask without entering the dress, there is no excess of buoyancy with this rig. The weights provided can therefore be much lighter than with the deep sea rig, and they are equipped with a quick release fastening to permit them to be dropped rapidly in an emergency. A lifeline attached directly to the diver's body completes the lightweight outfit.

FIGURE 1–7.—Surface-supplied apparatus: deep sea diving outfit.

FIGURE 1–8.—Surface-supplied apparatus: lightweight diving outfit.

(5) *Helium-oxygen equipment* (fig. 1–9) is basically the same as the standard deep sea outfit. The helmet is modified by the installation of a means of conserving the helium-oxygen mixture by recirculating it through a carbon dioxide absorbent. The exhaust system is provided with a special check-valve arrangement which makes it almost impossible for water to enter.

Self-contained underwater breathing apparatus (Scuba)

(6) The term "self-contained" indicates that the diver carries his breathing medium with him in cylinders and can thus be independent of surface connections. Three types of self-contained apparatus are in present use. Each type may include more than one make or model of unit, but the basic principles and characteristics are essentially the same for all units within the type.

FIGURE 1-9.—Surface-supplied apparatus: helium-oxygen equipment.

(7) *Demand Type* (open circuit scuba) (fig. 1-10) is the simplest type and the one most frequently used. The diver carries large cylinders which are normally charged with compressed air. A special type of regulator supplies air on demand when the diver inhales, and the air is exhausted into the water when he exhales. No rebreathing takes place. The fact that air flows only in response to inhalation requirements helps conserve the supply, but the limited duration of the amount the diver can carry is the principle drawback of demand type gear.

FIGURE 1-10.—Self-contained apparatus: open-circuit scuba.

(8) *Closed-circuit units* (fig. 1–11) employ pure oxygen as the breathing medium. The diver breathes this gas to and from a rebreathing bag through a canister containing carbon dioxide absorbent. No gas is normally exhausted to the surrounding water. Since the body consumes only a small amount of oxygen compared to the total volume of breathing, a relatively small gas supply suffices. Closed-circuit scuba also has the advantage of freedom from bubbles and noise, which can be very important in some tactical applications. (See 1.1.3(8).) The main drawback is the severe limitation of safe depth of use imposed by the possibility of oxygen poisoning.

FIGURE 1-11.—Self-contained apparatus: closed-circuit scuba (Lambertsen amphibious respiratory unit "LARU").

(9) *Semiclosed-circuit scuba* (fig. 1–12) was developed to permit conservation of gas by

FIGURE 1–12.—Self-contained apparatus: semiclosed-circuit scuba (experimental "LES" unit).

rebreathing without the necessity of using pure oxygen. The apparatus is basically like closed-circuit scuba, but a continuous flow of a gas mixture is provided to assure that neither oxygen lack nor excessively high oxygen levels will develop. The diver rebreathes the major portion of the gas, but a certain amount is continually exhausted from the system. Much greater durations can be achieved than with demand type. Generally, mixtures of nitrogen and oxygen (i.e. air with added oxygen) or helium and oxygen are used. This can sometimes provide an added advantage by shortening the decompression time required.

1.1.3 APPLICATIONS OF DIVING

(1) Most of the developments in diving stemmed from the need to accomplish some specific kind of underwater work. As diving itself progressed, and as new tools and techniques were developed, more and more types of underwater activity became possible. Today, men dive for purposes which range from warfare to pure sport. Some of the more important naval applications of diving are described here.

Ship salvage

(2) Raising sunken ships or repairing damaged ones is one of the most important applications of diving in the Navy today. Present-day ship salvage work is a specialized job which can put to use most types of diving equipment and almost every special skill a diver can have. It can require use of pneumatic tools, use of explosives, underwater cutting and welding, and other techniques as well as the specific know-how of salvage work itself. The underwater phases of ship salvage usually consist of repairing damaged ships, raising sunken ships, refloating grounded ships, and clearing harbors. The Navy has several types of salvage ships, most of which are equipped with divers and several types of diving equipment. These ships are capable of performing all varieties of ship salvage work from simple underwater repairs to major refloating operations.

Submarine rescue

(3) Each submarine squadron has a submarine rescue ship (ASR) fully equipped and ready to go to the aid of a submarine in distress. Each carries a submarine rescue chamber and is prepared to perform all kinds of diving. ASR's are the only ships in the Navy equipped for helium-oxygen diving. The role of diving in submarine rescue can be of vital importance. Although the marker buoy released by a sunken submarine is intended to carry the chamber-downhaul cable to the surface, unusual conditions may require a diver to rig it or free it from obstruction. Difficulties with the rescue chamber itself could require diving. In some cases, it would be necessary to attach air hoses to the submarine. In addition to conducting repeated drills and periodic simulated rescue exercises to maintain a high degree of training and readiness, the ASR's provide many useful services, diving and other, to their squadrons and the fleet.

Search and recovery

(4) Practice torpedoes and many other objects must often be located and recovered. All types of underwater search are tedious and time-consuming unless the location is accurately known and the underwater visibility exceptionally good. Even though the use of drags, sonar gear, or electromagnetic detection equipment is often effective and more efficient in search than diving, a diver usually must verify contacts. Where these methods cannot be used, searching becomes wholly the diver's job. Once the object is located, a diver usually must rig lifting lines or other means of raising it.

Inspection and repairs

(5) All types of diving equipment can be utilized for inspections and repairs. Diving inspections are usually conducted more easily and efficiently with scuba equipment because of the diver's mobility. Inspections usually made by Navy divers are ship bottom inspections which may be required for reasons such as suspected damage, leakage, routine checks of sonar equipment, and sea suction troubles. In time of war, bottom inspections would also include search for underwater ordnance. Much repair work on underwater parts of floating equipment can be accomplished by the use of divers, thus eliminating the expense and loss of time necessary for drydocking. This repair work is ordinarily minor although some major repairs have been effected in emergencies. Ship repair work often accomplished by divers includes changing propellers, replacing zincs, minor patching, clearing fouled propellers, straightening bent propeller blades, blanking off sea chests, and repairing minor damage to sonar equipment. Divers are also called upon to repair pipelines, tunnels, bridges, cable moorings, piers, and other structures.

Construction

(6) Navy divers are not usually utilized in construction work, but much work is accomplished by divers in building tunnels, bridges, caissons, and occasionally wharfs and piers.

Tactical diving

(7) Although history indicates that divers were used in war in very early times, tactical diving in military operations is comparatively new in modern warfare. It was developed into a very potent weapon of both offense and defense during World War II. Developments in self-contained underwater breathing apparatus made this application practicable.

(8) Many of the characteristic operations of Underwater Demolition Teams can be conducted without diving equipment, but the ability to approach enemy beaches without surfacing is highly advantageous. In bottom reconnaissance or in location and demolition of underwater obstacles, the operations are primarily diving tasks. Development of surface detection equipment may make it impossible to use surface swimmers because of danger to the men and the probability of giving advance warning of a projected invasion. With self-contained equipment, detection is less probable; and the swimmers retain the advantages of freedom and the ability to make direct observations. Direct attacks on ships require self-contained equipment for work beneath the ships as well as for undetected approach and safe departure. Landing parties with the ability to approach submerged can make successful raids even on closely guarded installations.

(9) Adequate *defense* may also require self-contained diving. Divers may prove to be the only effective defense against individual attacks on shipping. Direct interception of swimmers and underwater hand-to-hand combat are not very probable, but periodic ship-bottom search may be essential. The slow progress of a diver encumbered with surface connections makes self-contained apparatus very desirable for such jobs. Locating and inactivating mines present similar problems If the type of mine or its position precludes working from the surface, diving is the only alternative. The limitations of speed and mobility imposed by surface connections may dictate the use of self-contained equipment.

(10) In situations where proximity to the enemy would expose a surface vessel to undue

danger, self-contained diving may provide the only way to accomplish a variety of underwater jobs in war. The many possible tactical applications of diving, especially with self-contained gear, include even operations undertaken by land forces. Destruction or construction of bridges are examples.

1.1.4 PHYSICS AND PHYSIOLOGY

(1) The forces which act upon a diver underwater are explained by the science of *physics*, which deals with the behavior of all kinds of matter. The effects of these forces on the body are explained by *physiology*, which is concerned with the body's functions and its response to various conditions. Both of these sciences developed within fairly recent times. Archimedes explained buoyancy many centuries ago, but little was known about pressure and its effects until Robert Boyle did his experiments in the 1600's. Practically nothing was known about the composition of air or even the existence and importance of oxygen until Priestley's work in the late 1700's. Understanding of the body's vital functions like breathing and the circulation of blood developed even more slowly. It is not surprising that progress in diving was at a standstill for thousands of years without such knowledge and that even brilliant men designed rigs which could not possibly have worked.

(2) The first real progress in diving came about mainly through increased knowledge of physics and advancements in invention and manufacturing. For example, divers could not go beyond very shallow depths until workable air pumps and hoses became available and were applied. This did not happen until around 1800, about the time steam engines began to be used extensively. Some of the most serious problems of diving naturally did not arise at all until this kind of progress made it possible for men to be exposed to high pressures. Decompression sickness was unheard of until caissons were put into use after 1840. In the years which followed, scores of men were killed or maimed by decompression sickness before the great French physiologist, Paul Bert, experimented with animals and applied existing knowledge to explain this condition in the 1870's. Improvement in decompression methods and the beginnings of recompression treatment followed his work, but needless deaths and suffering continued until investigators like Haldane put the matter on a firmer basis in the early years of our own century. Much the same sequence of events also took place with nitrogen narcosis, oxygen poisoning, and other diving problems.

(3) Today's divers have no cause to look down on their "ancestors" in diving for their ignorance. The average person today, although he enjoys all the benefits of science, knows little more about physics and physiology than they did. In diving, we still face many problems which are unsolved because of our own lack of knowledge. The least every diver can do is to learn the essentials of what is known in these sciences as they apply to diving. The next two sections of this manual are presented to help him do this and to dive more safely and effectively as a result.

SECTION 1.2 UNDERWATER PHYSICS

1.2.1. INTRODUCTION

Basic concepts

(1) We seldom pay much attention to the natural surroundings or atmospheric conditions under which we live. We notice the weather every day but hardly ever stop to think of the fact that the air we breathe is under a certain pressure and has constant composition. When a man tries to leave this normal atmospheric environment by going to high altitude or by descending into the ocean, he soon finds out how important these things are. He learns that he can exist in other environments only to the extent that his body can make adjustments or that his equipment can help by maintaining some semblance of normal conditions.

(2) To understand diving and its effects on the human body, it is necessary to know something about the *physics* of diving. Physics is the science which deals with the properties of *matter* and the way matter behaves under different conditions.

(3) Matter is anything which occupies space and has weight. Matter exists in three states: solids, which have a definite volume and shape; liquids, which have a definite volume but conform to the shape of their containers; and gases, which have neither a definite volume nor shape. All matter exists in one of these states. Any specific kind of matter may exist in more than one state depending on the temperature and pressure. For example, water also exists as ice and steam. In diving, we are primarily interested in liquids and gases.

1.2.2 LIQUIDS

(1) Liquids have definite weight and volume but take the shape of their containers. Compared with gases, liquids are considered incompressible. For the sake of simplicity in this discussion, it is assumed that the volume of a liquid will not change due to changes of pressure or temperature.

(2) Water is the liquid most important to the diver. Pure water is a colorless, tasteless, odorless, transparent liquid. Chemically it consists of two parts hydrogen combined with one part oxygen (H_2O). The taste and color frequently found in water are due to the presence of other substances dissolved or suspended in it.

1.2.3 GASES

(1) All gases have weight and occupy space. Compared with liquids, gases are very light and compressible. They have no definite volume or shape.

Specific gases

(2) Of the great number of gases that exist, only a few are of special interest to the diver. The most important gases are the two main components of air: nitrogen and oxygen.

(3) *Oxygen* (O_2) exists in a free state in the atmosphere, of which it forms approximately 21 percent by volume. It is colorless, tasteless, and odorless. Oxygen alone is capable of supporting life and is used in some instances instead of air as a breathing medium. When breathed too long under increased pressure, oxygen has a harmful effect on the body. This effect is known as oxygen poisoning and is discussed in the section on physiology. (See 1.3.11.) Nothing can burn except in the presence of oxygen, but oxygen alone cannot burn.

(4) *Nitrogen* (N_2) is the other main component of air. It also exists in a free state in the atmosphere and comprises approximately 79 percent by volume. Nitrogen is colorless, odorless, and tasteless. In its free state, it is inert (chemically inactive) and incapable of supporting life or combustion. Under high pressure, nitrogen has an intoxicating effect. (See 1.3.10.)

(5) As the depth of diving increases, an additional gas—*helium* (He)—becomes important to the diver. Helium, when mixed with the proper proportion of oxygen, forms an artificial atmosphere whose breathing resistance and intoxicating effects under pressure are very much less than those of air. This

gas is colorless, odorless, tasteless, and inert. It is exceptionally light, nontoxic, and nonexplosive; and it conducts heat much more rapidly than air.

(6) *Hydrogen* (H) is colorless, odorless, and tasteless. It combines with oxygen in a ratio of 2:1 to form water. This combination takes place as a rapid and hot combustion, and mixtures of hydrogen with oxygen at or near the proper proportions are violently explosive. Hydrogen and oxygen can be mixed in proper proportions to form a satisfactory breathing medium for deep diving, but such mixtures have no important advantage over helium-oxygen mixtures and are technically more difficult to use. Since helium is readily available in the United States, hydrogen has never been used for diving by the U.S. Navy.

(7) In addition to the above gases, which are used alone or in combination to form breathing media, there are two harmful gases with which divers should be familiar. One of these gases is *carbon dioxide* (CO_2). This gas is colorless, odorless, and tasteless in the percentages likely to be encountered by divers; but it has an acid taste and odor in high concentrations. It is a combination of two parts oxygen and one part carbon and is produced by burning organic material and by the normal oxidation of food in the body. Since it is much heavier than air, incombustible, and electrically nonconductive, carbon dioxide makes an excellent fire extinguisher. If a carbon dioxide concentration builds up in a diver's breathing medium, harmful effects result. (See 1.3.5(8).)

(8) The other important harmful gas is carbon monoxide (CO) which is colorless, odorless, tasteless, and highly poisonous. Carbon monoxide is produced by incomplete combustion of carbon-bearing materials when oxygen supply is insufficient. Each molecule has only one atom of oxygen for one of carbon instead of two as in carbon dioxide. Carbon monoxide is found in dangerous concentrations in engine exhausts and in closed compartments where paint or stores have been deteriorating. If it contaminates a diver's air supply, serious consequences can result. (See 1.3.5(17).)

Composition of air

(9) The air we breathe is a simple mixture (not a chemical combination) of nitrogen and oxygen with a little carbon dioxide and traces of certain rare gases. Air also contains water vapor which varies in amount according to the weather conditions. The proportions of the main constituents of dry air are as follows:

	Percent by volume
Nitrogen	79.02
Oxygen	20.94
Carbon dioxide	.04
Rare gases (Argon, Neon, Radon, CO, H, etc.)	Traces

1.2.4 PRESSURE

(1) Pressure is the amount of force per unit area. Force is any push or pull that tends to produce motion. It is commonly expressed in pounds. Area is the surface upon which the force is exerted, usually measured in square inches. Thus pressure is commonly measured in *pounds per square inch* (p.s.i.). Similarly, if one were using the metric system of measurement, pressure would be expressed as grams or kilograms per square centimeter. This is simply another expression of the force per unit of surface area upon which it is acting. Pressure will also support a column of liquid, as in a U-tube or manometer. In certain situations, it is more convenient to express pressure in terms of the height of a column of liquid which it will support. For example, inches of mercury, centimeters or millimeters of mercury, or inches or centimeters of water can be used as units of pressure. In diving computations, pressure is often expressed directly in feet of sea water. Pressure can also be expressed in atmospheres. (See 1.2.4.(5).) (See 1.10.13 for further information concerning various units of pressure and for factors used in converting from one unit to another.)

Kinetic theory of gases

(2) In order to understand the behavior of gases under variations of pressure and temperature, we must consider their molecular structure. Every gas is a collection of extremely small particles called molecules. The

word "kinetic" indicates that these molecules are in constant *motion*, bumping into one another or bounding off the walls of the container. If temperature is reduced, this motion becomes slower, and fewer collisions will occur. Finally, when a certain degree of cold is reached, the molecules become so sluggish that they tend to adhere to one another. At this point, the gas turns into a liquid. Still further down the scale, the molecules "freeze together;" and the liquid becomes a solid. If absolute zero (minus 459.7° F. or minus 273.18° C.) could be reached, all molecular motion would cease entirely.

(3) The molecules in a gas behave much like a swarm of bumblebees flying around in a box and bumping against its walls at random. Each time one bumps into the side, it exerts a momentary push; and if such collisions are frequent enough they add up to a continuous force. If we heat the box, the bees will fly faster and strike its walls more often. If we chill it, they will become sluggish and have fewer collisions. The force on the walls will increase or decrease as a result of the change in temperature.

(4) With molecules in a gas (see fig. 1–13), the tiny impact of each collision is multiplied by billions per second on each square inch of surface and yields a steady and measurable pressure. If we increase the temperature, the speed of each molecule increases correspondingly so that the impacts become both more frequent and more forceful. The net pressure rises accordingly. If we squeeze the same number of gas molecules into half the original space, twice as many collisions will occur in a given length of time, and the observed pressure will be doubled. Therefore, pressure must increase both with increasing temperature and with decreasing volume. If more gas is forced into the same original space, this

→

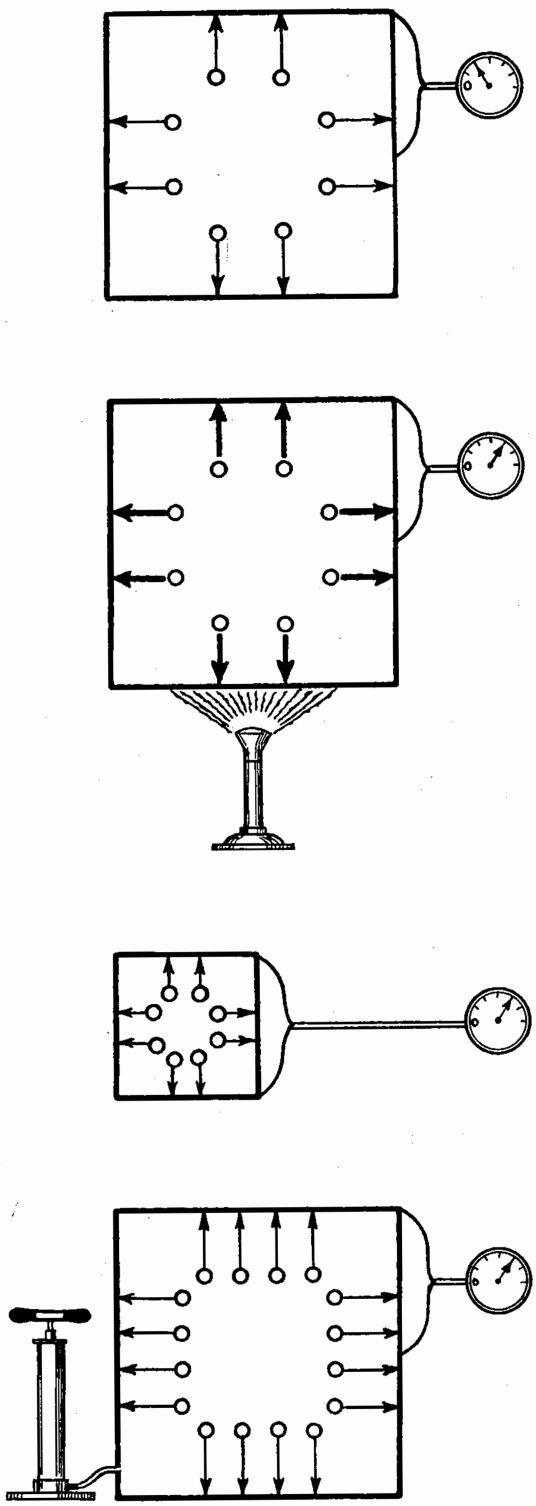


FIGURE 1–13.—Behavior of gas molecules (top to bottom) (a) Pressure is caused by the billions of impacts per second of gas molecules moving in container. (b) Heating the gas increases speed of molecular motion. Increased number and force of impacts causes pressure to rise. (c) Decreasing volume of container increases number of impacts per unit of surface area, thus increasing pressure. (d) Forcing more gas into original container also increases number of molecular collisions and raises pressure.

will also increase the number of collisions and raise the pressure.

Types of pressure

(5) *Atmospheric pressure* is the result of the weight of the atmosphere producing a force on the surface of the earth. This pressure acts in all directions; and almost all structures, including our own bodies, either transmit the pressure freely or are exposed to the same pressure both inside and outside. Its effects are thus usually neutralized or canceled-out, so we often ignore the fact that atmospheric pressure exists. However, if we could take a container and remove all of the air from it, we would find that a pressure of approximately 14.7 p.s.i. was acting on its walls. In other words, the miles of air above a square inch of surface area at sea level weigh about 14.7 pounds. The term "1 atmosphere" is used to denote a pressure of 14.7 p.s.i. For example, a pressure of 147 p.s.i. can be expressed as "10 atmospheres." Indicating pressure in atmospheres is convenient in several situations in diving.

(6) *Gage pressure* indicates the *difference* between the pressure being measured and the surrounding atmospheric pressure. When we say that the pressure in a gas cylinder is 1,000 p.s.i., we mean that the pressure is 1,000 p.s.i. *above* atmospheric pressure. Since ordinary gages can measure only such differences, their "zero" indicates atmospheric pressure. Except where otherwise specified, almost all pressure readings are "gage pressure." When it is desirable to indicate positively that a pressure is "gage," it is customary to express it as *pounds per square inch, gage* (p.s.i.g.).

(7) *Absolute pressure* (see fig 1–14) is the true or total pressure being exerted. This is the gage pressure plus 1 atmosphere of pressure. To obtain the absolute pressure, it is necessary to add 14.7 to the indicated gage reading if this is in p.s.i. Absolute pressure is commonly expressed as *pounds per square inch, absolute* (p.s.i.a.). Absolute pressure can be expressed in any system of units if the amount equivalent to normal sea level atmospheric pressure is added to the "gage" reading. If pressure is being expressed in atmospheres,

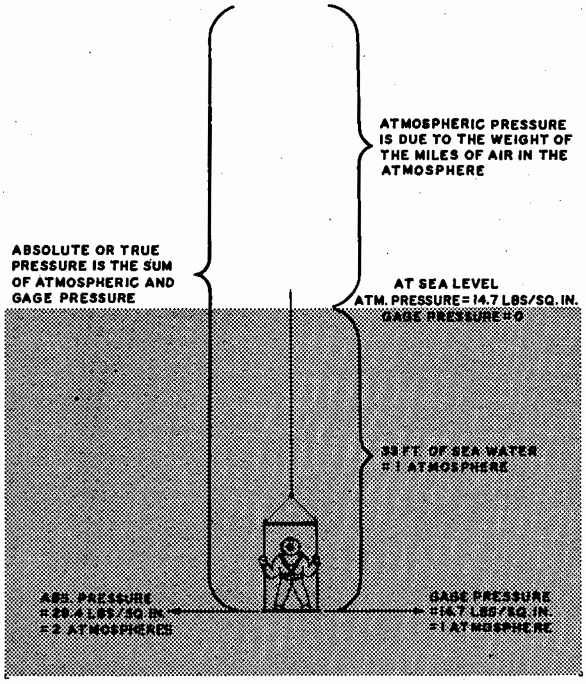


FIGURE 1–14.—Absolute pressure.

1 atmosphere is added to the number. The absolute pressure must always be used in equations describing the behavior of gases.

(8) The exact pressure of the atmosphere at any given place or time is measured by means of a barometer and is called *barometric pressure*. It is usually expressed in inches or millimeters of mercury. Since it is produced by the total weight of the atmosphere above the place of measurement, barometric pressure will be changed by anything which changes this weight. For example, if one ascends on a mountain or in an airplane, there is less atmosphere (and thus less weight of atmosphere) above. The barometric pressure is, therefore, lower, and barometric pressure can be used to measure altitude. Changes in barometric pressure are also caused by factors such as air temperature, the amount of water vapor in the atmosphere, and the movement of masses of air. Although these changes are usually small, they are of great importance in weather prediction.

Liquid pressure

(9) The pressure with which a diver is most directly concerned is that which is

exerted by the surrounding water at his diving depth. In order to understand how this pressure is produced and how it acts, it is necessary to have certain basic information about the behavior of liquids in general. Water will be used for all examples in this discussion because divers are mainly concerned with it, but the information applies to other liquids as well.

(10) The pressure produced by a liquid is the direct result of its weight. A heavy liquid will naturally produce more pressure than a lighter one. When we speak of weight in this sense and want to compare one substance with another, we use *density* as the yardstick. The density of a liquid (or of any other substance) is simply the *weight* of a specified *volume* of the substance (weight per unit volume). For example, we can say that the density of pure (fresh) water is 62.4 pounds per cubic foot. The density of average sea water is 64 pounds per cubic foot because of the added weight of the salts which are dissolved in it.

(11) Water is practically incompressible, so its density remains virtually the same regardless of the depth or pressure applied to it. As a result, the pressure exerted by water is directly proportional to its depth: the pressure exerted by 20 feet of water will be twice that exerted by 10 feet, and so. If a tank 33 feet deep is filled with sea water, the pressure on one square foot of surface area on the bottom will be equal to the weight of the column of water above it. You can think of this as a stack of thirty-three 1-foot cubes of water each weighing 64 pounds. The total weight would thus be 33×64 or 2,112 pounds, acting on one square foot of surface area. Since there are 144 square inches in a square foot, the pressure on each square inch in this case would be $2{,}112 \div 144$ or approximately 14.7 p.s.i.—1 atmosphere of pressure. This is the pressure exerted by the water above. The air above the water is exerting an additional 14.7 p.s.i. of pressure, so the absolute (total) pressure at a depth of 33 feet is 29.4 p.s.i.a. or 2 atmospheres. Each additional 33 feet of descent will add an atmosphere (14.7 p.s.i.) of pressure. The absolute pressure exerted on a submerged body is the pressure of the water plus atmospheric pressure. Each foot of descent increases the pressure by $\frac{1}{33}$ of 14.7 p.s.i., or 0.445 p.s.i. This is a very useful figure to remember. Multiplying the depth in feet by 0.445 gives the water pressure at that depth in p.s.i. Adding 14.7 p.s.i. to this gives the absolute pressure at the depth.

(12) Water pressure, like atmospheric pressure, is transmitted equally in all directions. (See fig. 1–15.) The water pressure exerted on the sides and bottom of a tank is distributed evenly over all the area of the tank regardless of its shape. The pressure at any level in the tank is directly proportional to the depth at that level.

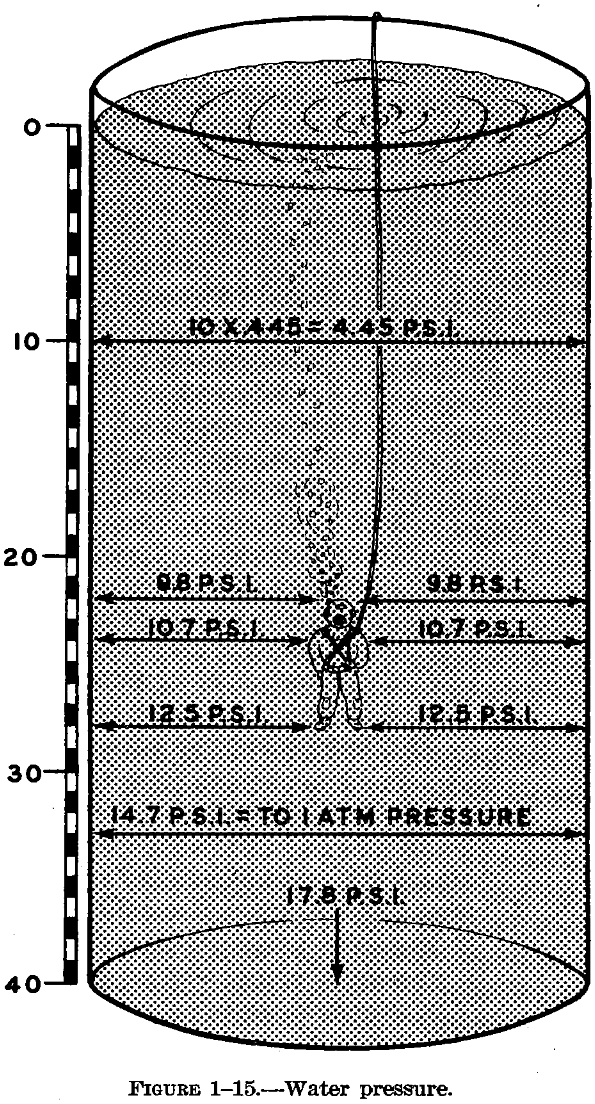


FIGURE 1–15.—Water pressure.

(13) The water pressure on a man who is standing underwater is naturally greater at his feet than at his head. The body as a whole is largely composed of water and can be compared to a man-shaped bag of water. If such a contrivance were submerged, it too would have greater pressure at the feet than at the head; but you would not expect this to damage it or even to change its shape. The water inside the man-shaped bag would transmit the external pressure freely, and at every point the pressure outside would be exactly balanced by an equal pressure inside. If no *difference* of pressure exists across any part of a structure, there will be no mechanical effect. The human body is more complicated than this comparison indicates because it contains air spaces (lungs, sinuses, middle ear); but if the pressure exerted on these spaces is balanced by air at equal pressure inside, the net result is practically the same. The air which accomplishes this equalization is supplied at the proper pressure by the helmet diver's air hose or by the scuba diver's breathing apparatus. A more complete discussion of this subject, and of the effects of failure to equalize pressure in these spaces, is presented in articles 1.2.4(21) and 1.3.7.

Gas laws

(14) The behavior of gases is affected by pressure, volume, and temperature; and these effects are closely interrelated. Several rules (called *gas laws*) which describe the behavior of gases under varying conditions have been formulated and named for their originators. These will be defined and explained. In considering and applying the laws, you must keep several things in mind:

(*a*) Any *unit* of pressure, volume, or temperature can be used, but the *same* unit must be used throughout the calculations. For example, it is all right to use cubic feet or liters or any other unit as the measure of volume, but it is not possible to start out with one and end up with another unless you use a conversion factor. (See 1.10.13.) You can use either the Fahrenheit or centigrade scale for temperature measurements, but you must not switch from one to the other. The same applies to units of pressure.

(*b*) Where pressure is involved, you must use *absolute* pressure (see 1.2.4(7)) in dealing with the gas laws.

(*c*) Where temperature is considered, you must use *absolute* temperature. (See 1.2.4(2) and 1.10.13(8).) To convert to absolute temperature, add 460° to Fahrenheit readings or 273° to centigrade readings.

NOTE.—The *density* of a gas, like the density of a liquid, refers to the weight per unit of volume. In the case of a gas, density depends not only upon the weight of the gas molecules but also upon the number of molecules present in the volume concerned. This, in turn, depends on both pressure and temperature.

(15) *Boyle's law* states that *if the temperature is kept constant, the volume of a gas will vary inversely as the* ABSOLUTE *pressure while the density varies directly as the pressure.* In other words, if the pressure on a gas is doubled, the density also is doubled; but the volume is decreased to one-half of the original volume.

(16) Boyle's law is important to divers mainly in understanding two important things: the compression of gas by the pressure of depth, and the relationship between pressure and volume in air supplies. Figure 1–16 illustrates the effect of depth-pressure, using an open-ended cylinder (or "bell") lowered to various depths as an example. If we assume that the bell is filled with air at normal pressure at the surface and that no air is furnished to it on the way down, the volume and density of the air inside will follow Boyle's law as the pressure exerted by the water increases. At the surface, the absolute pressure is 14.7 p.s.i., or 1 atmosphere. When the bell is lowered to 33 feet below the surface, the water exerts an *additional* pressure of 14.7 p.s.i., so the total (absolute) pressure is 29.4 p.s.i., or 2 atmospheres. As a result, the volume of the air is reduced to one-half of what it was at the surface, and its density is doubled. At 66 feet, the water exerts an excess pressure of 29.4 p.s.i., so the total pressure is 44.1 p.s.i., or 3 atmospheres. The den-

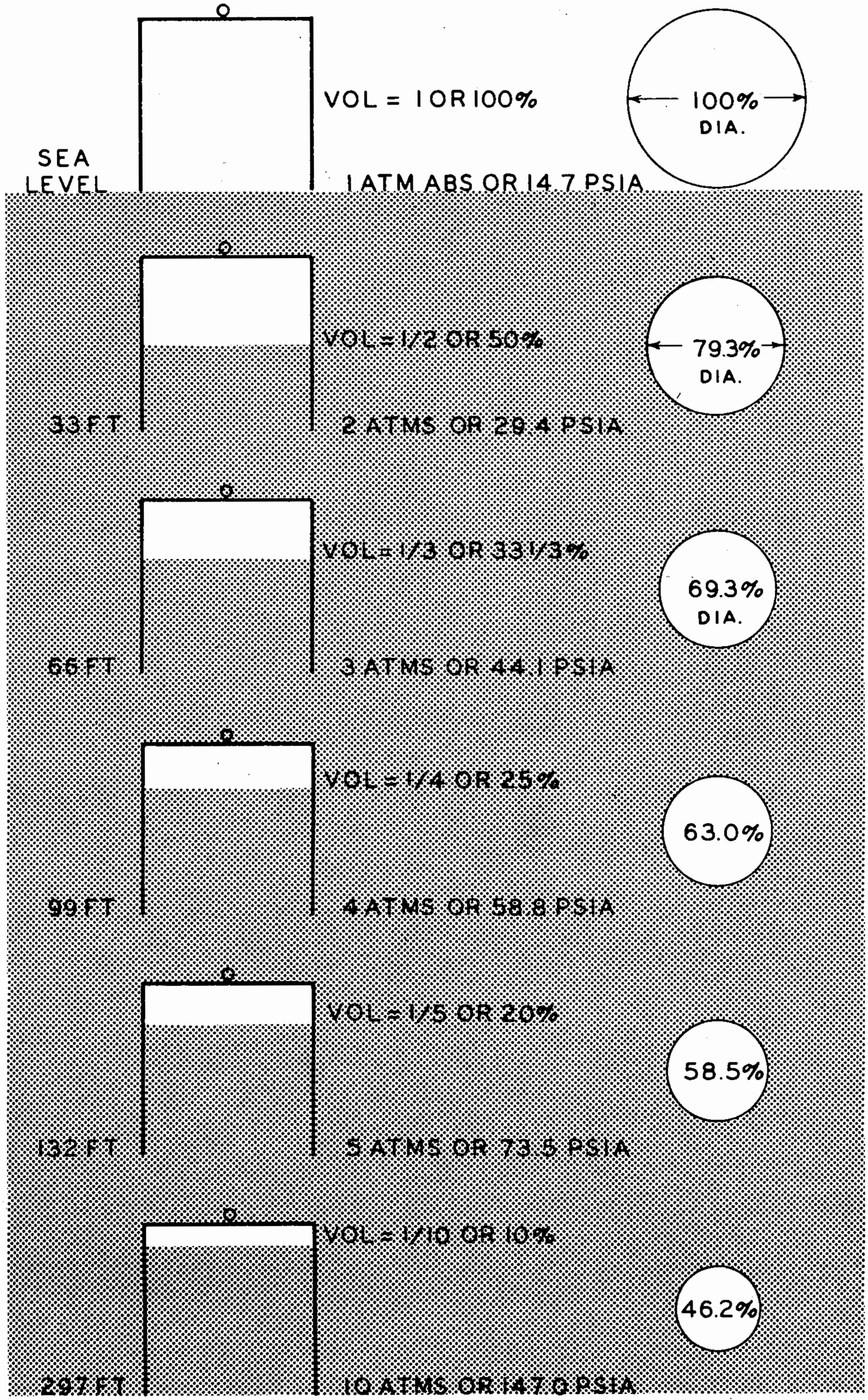


FIGURE 1-16.—Depth, pressure, and volume.

sity is accordingly 3 times what it was at the surface, and the volume is reduced to one-third of the original. At 297 feet, the absolute pressure is 10 atmospheres; so the volume is one-tenth of what it was at the surface, and the density is 10 times as great.

(17) It is important for the diver to notice that the *relative* changes in pressure and the consequent changes in volume are greatest near the surface.

(*a*) This can be seen clearly by noting what happens in terms of units of volume. Let us say that the original volume of air in the bell was 12 cubic feet. Going down to 33 feet compressed the air into a volume of only one half of 12, or 6 cubic feet. Going on down to 66 feet reduced it to one-third or 4 cubic feet, and going to 99 feet reduced it to 3 cubic feet. The actual change in volume with each "atmosphere" of descent thus becomes smaller and smaller the deeper the bell goes.

(*b*) Consider another example: if the bell were refilled with 12 cubic feet of air at 264 feet (9 atmospheres absolute) and then taken down 33 feet to 297 (10 atmospheres absolute), the volume would be reduced to 10.8 cubic feet—a volume-change of one-tenth, or only 1.2 cubic feet compared to the 6 cubic foot change in going from the surface to 33 feet.

(*c*) Note also that the same facts apply on ascent. If the bell contained 1 cubic foot of air at 10 atmospheres, this would expand only to a little over 1.1 cubic feet on ascending 33 feet to a pressure of 9 atmospheres. On reaching 5 atmospheres (132 feet), the air would have expanded only to 2 cubic feet. At 33 feet (2 atmospheres), it would have expanded to 5; and on being brought to the surface, the volume would double to 10 cubic feet. Ascending from 33 feet to the surface thus produced more change in actual volume than did coming all the way up from 297 feet to 33.

(18) Figure 1–16 also illustrates the change in *diameter* of a gas-filled sphere or bubble with increasing depth. The *volume* of gas in this bubble will change in the same way as does the volume of gas in the bell, but the corresponding change in diameter is always smaller than the change in volume. As depth increases and the volume-change becomes less and less, the change in diameter becomes very small indeed. This explains why a gas-filled balloon does not appear to shrink to half its original size in going from the surface to 33 feet and why an ascending bubble does not seem to double its size in rising from that depth to the surface. The distinction between bubble-volume and bubble-diameter also arises in connection with the treatment of decompression sickness (1.3.9(16)).

(19) *Charles' law* states that *if the pressure is kept constant, the volume of a gas will vary directly as the* ABSOLUTE *temperature.* This means that volume increases when temperature is increased and that if the absolute temperature is doubled, the volume will double. If temperature decreases, so does volume. It follows that if volume rather than pressure were kept constant, as by heating air in a rigid container, then the absolute pressure will increase in proportion to the absolute temperature. (Charles' law is sometimes also called the law of Gay-Lussac.)

The general gas law

(20) Boyle's and Charles' laws can be combined to relate pressure, volume, and temperature in a general gas law. This is expressed in the following basic equation:

$$\frac{P_1V_1}{T_1}=\frac{P_2V_2}{T_2}$$

where

P_1=initial pressure (absolute)
V_1=initial volume
T_1=initial temperature (absolute)

and

P_2=final pressure (absolute)
V_2=final volume
T_2=final temperature (absolute)

Note that where either P, V, or T will be the same or nearly so, both "before" and "after," that factor can be canceled out (removed from both sides of the equation). Temperature in example (*a*) and volume in example (*b*) can be omitted in this way, thus simplifying the calculation. They need not even be known. In example (*c*), all three variables change, so the equation must be used as it stands. Except for a value which does not change, you can have *only one unknown quantity* in the equation. Review simple algebra and examine the examples to see how the equation is rearranged to solve for the "unknown" in each case.

(*a*) An air compressor is known to have a maximum intake capacity of 12 cubic feet of free air per minute. How many cubic feet can it deliver to ventilate the helmet of a diver at 165 feet (73.5 p.s.i.g.)? Assume that the air and water temperatures are approximately equal and that the pressure is ample to overcome resistance at the depth.

$P_1=0+14.7=14.7$ p.s.i.a.
$V_1=12$ cu. ft.
$T_1=T_2$ (cancel)
$P_2=73.5+14.7=88.2$ p.s.i.a.
$V_2=?$

Cancel T_1 and T_2 in equation:

$$P_1V_1=P_2V_2$$

Rearrange equation to solve for V_2:

$$V_2=\frac{P_1V_1}{P_2}$$

Substitute values and solve:

$$V_2=\frac{14.7\times12}{88.2}=2 \text{ cu. ft.}$$

Observe that in some problems, like this one, it will simplify the calculations very much to express the absolute pressures in atmospheres rather than in p.s.i.a. Here you would recognize that the absolute pressure at 165 feet is 6 atmospheres, so

$P_1=1$ atm.
$V_1=12$ cu. ft.
$P_2=6$ atm.

and

$$V_2=\frac{1\times12}{6}=\frac{1}{6}\times12=2 \text{ cu. ft.}$$

(*b*) A self-contained apparatus cylinder is charged rapidly to a pressure of 1,785 p.s.i.g. and reaches a temperature of 140° F. in the process. What will the gage pressure be when a diver puts the cylinder on in 40° F. water? (NOTE.—Especially where high pressures are concerned, it is usually accurate enough to use 15 p.s.i. instead of 14.7 for converting to absolute pressure.)

$P_1=1785+15=1{,}800$ p.s.i.a.
$V_1=V_2$ (cancel)
$T_1=140+460=600°$ F. (absolute)
$P_2=?$
$T_2=40+460=500°$ F. (absolute)

Cancel V_1 and V_2, and rearrange equation to solve for P_2:

$$P_2=\frac{T_2P_1}{T_1}$$

Substitute values and solve:

$$P_2=\frac{500\times1800}{600}=1{,}500 \text{ p.s.i.a.}$$

$$1500-15=1{,}485 \text{ p.s.i.g.}$$

(*c*) An air supply tank is known to deliver 10.8 cubic feet of free air at the surface, measured at 80° F., for every 100 p.s.i. drop in tank pressure. What would the corresponding volume be at 132 feet in 40° F. water?

$P_1=1$ atm. (absolute)
$V_1=10.8$ cu. ft.
$T_1=80°+460°=540°$ F. (absolute)
$P_2=5$ atm. (absolute)
$V_2=?$
$T_2=40°+460°=500°$ F. (absolute)

Rearrange equation to solve for V_2:

$$V_2=\frac{P_1V_1T_2}{T_1P_2}$$

Substitute values and solve:

$$V_2=\frac{1\times10.8\times500}{540\times5}=2 \text{ cu. ft.}$$

Squeeze

(21) Normally, pressure itself and the compression of gases under pressure have very little effect on the diver's body. However, when transmission and equalization of pressure fail to occur for some reason, destructive differences in pressure can develop. Accidents which occur as a result of such failures (mainly during descent) can be classified under the term *squeeze*. The most serious accident of this sort can occur when a diver in helmet and dress falls an appreciable distance under water. The sudden increase in external pressure will compress the air in the rig in accordance with Boyle's law. If the amount of air present is

sufficient to keep the rigid helmet full of air at the increased pressure, the internal and external pressures will remain in balance, and there will be no dire consequences. But if all of the available air has been compressed into the helmet, and the inside pressure is still not as high as the outside pressure, the excess of external pressure will act through the dress upon the diver's body and tend to crush him into the helmet. If the unbalanced difference in pressure is large, crushing may actually happen. The fact that a certain distance of descent near the surface causes greater compression of gas than the same amount of descent at deeper depth has been discussed in paragraph 17 of this article. This explains why a diver who falls a given distance during a relatively shallow dive is in greater hazard than one who falls an equal number of feet during a deep dive.

(22) The same end-result of squeeze can follow if the pressure in a diver's airhose drops much below depth pressure for any reason and if his nonreturn valve fails to retain pressure in the helmet. In this case, the helmet is simply vented to lower pressure; and the air is forced out of the rig by the surrounding pressure. With nothing to counterbalance the pressure outside, the entire pressure of the depth will then be acting on the diver's body, tending to force it into the helmet. Even a few p.s.i. can add up to a tremendous force when the effective surface area is considered, so this accident could be fatal even in rather shallow water. Similar accidents can occur with a hose-supplied facemask.

(23) Squeeze can occur on a smaller scale during any descent in which one of the body's air spaces, or any rigid air space attached to the surface of the body, fails to equalize. For example, if a skindiver wears ordinary goggles and tries to go deep with them, he may experience "eye squeeze." When he leaves the surface, the goggles contain air at normal pressure, and no air can be added during descent. As the pressure increases outside, a difference in pressure develops between the inside and the outside of the goggles. If the goggles are made of very soft rubber, they may yield enough to let the pressures equalize by compression of the air; but if they are rigid, the difference will simply increase as the diver descends; and something will eventually have to "give." The external pressure is being transmitted freely throughout the body, so the diver's eyes and the surrounding tissues are under a much higher pressure than the air with which they are in contact. The difference in pressure is acting across them, much as if a suction cup were being applied. This may cause bleeding into the skin and membranes, and possibly much more serious damage may result. The same harmful sequence of events can occur because of unequalized differences in pressure wherever these develop in or on the body. Injuries from these physical effects are discussed further in the sections on physiology (see 1.3.7) and diving hazards (see 1.6.8).

1.2.5 GAS MIXTURES

(1) The diver deals with mixtures of gases, and it is important for him to understand how gases behave in mixtures. Air is the most common mixture. To simplify the discussion, its composition will be considered to be 80 percent nitrogen and 20 percent oxygen. Mixtures of helium and oxygen and of nitrogen and oxygen (in different percentages than in air) are also utilized by the diver.

(2) In any mixture of gases, each of the several gases contained in the mixture exerts its share of the total pressure being exerted. *Dalton's Law* states that *the total pressure exerted by a mixture of gases is the sum of the pressures that would be exerted by each of the gases if it alone were present and occupied the total volume.*

(3) The *partial pressure* of a gas is proportional to the number of molecules of that gas present in a specified volume at a given temperature. If a container were filled with pure (100 percent) oxygen at normal atmospheric pressure, then the partial pressure of oxygen in that container would be 14.7 p.s.i. or 1 atmosphere. In this case, the partial pressure of oxygen would equal the total pressure because no other gas molecules were present. If an equal number of nitrogen molecules were then introduced into the container without letting any oxygen escape and without changing

the temperature, the total (absolute) pressure would become two atmospheres. We now have a gas mixture consisting of 50 percent oxygen and 50 percent nitrogen. The number of oxygen molecules in the container is the same, so the partial pressure of oxygen remains the same: one atmosphere. This is now only half of the total pressure, since the partial pressure of nitrogen is also one atmosphere. If the size of this container were reduced to one half without letting any gas molecules escape, and if the temperature were kept constant, the total pressure would be doubled again: it would now be 4 atmospheres. The number of all gas molecules per unit volume, and the number of molecules of each gas per unit volume, would also be doubled. Therefore, the partial pressures of both nitrogen and oxygen would become 2 atmospheres. Changes in temperature cause changes in partial pressures in proportion to the change in absolute pressure. For example, if a container of gas containing nitrogen and oxygen were heated enough to double the absolute pressure, the partial pressures of the nitrogen and the oxygen would also be doubled. (See art. 1.2.4, par. (19).)

(4) As illustrated in figure 1–17, we may assume that air at 14.7 p.s.i. is 20 percent oxygen and 80 percent nitrogen by volume. The oxygen exerts 20 percent of the total pressure, or 2.94 p.s.i., and the nitrogen exerts 80 percent of the total pressure, or 11.76 p.s.i. If we increase the total absolute pressure exerted by the air to 73.5 p.s.i. or 5 atmospheres, which is equivalent to the absolute pressure maintained within a diver's suit at 132 feet of depth, the oxygen still exerts 20 percent of the total absolute pressure and the nitrogen 80 percent of the total absolute pressure; therefore, the partial pressure exerted by the oxygen is now 14.7 p.s.i. absolute, or 1 atmosphere of pressure; and the partial pressure exerted by the nitrogen is now 58.8 p.s.i. absolute. If we increase the total absolute pressure exerted by air to 220.5 p.s.i., or 15 atmospheres of pressure, which is equivalent to the absolute pressure maintained in a diver's suit at 462 feet under water, the partial pressure exerted by the oxygen still is 20 percent of the total pressure exerted. The partial pressure exerted by the oxygen, therefore, is 44.1 p.s.i. absolute, or 3 atmospheres; and the partial pressure exerted by the nitrogen is 176.4 p.s.i. absolute. The dangers presented by such partial pressures are discussed in articles 1.3.9 to 1.3.12. Observe that although the partial pressure of a gas in a mixture may be insignificant at atmospheric pressure, it may become very important as the pressure of the mixture rises. For example, 2 percent carbon dioxide in a mixture breathed at 132 feet will have the same partial pressure and the same physiological effect (see 1.3.5(8)) that 10 percent carbon dioxide would have at the surface. (The partial pressure of water vapor in a gas mixture can generally be ignored in diving, but it is important in aviation.)

(5) *Gas diffusion* is the process of intermingling or mixing of gas molecules. If two gases are placed together in the same container, they will eventually mix together completely even though the molecules of one gas are heavier than those of the other. This mixing takes place because of the constant motion of gas molecules. For the same reason, gases will also diffuse through the surface of a liquid, throughout the liquid itself, and through thin sheets ("membranes") of many types of material.

(6) The amount of an individual gas which will move through a permeable membrane depends upon the partial pressure (or number of molecules) of the gas on both sides of the membrane. If the partial pressure is higher on one side, the gas will tend to move to the other side until the partial pressures are equalized. In their constant motion, molecules are actually passing through the membrane in both directions at all times; but more will move from the side where they are most numerous. When the partial pressures are equalized, the numbers passing in both directions will be equal, and there will be no further net shift of the gas.

1.2.6 GAS ABSORPTION IN LIQUIDS

(1) When a liquid is exposed to a gas, molecules of the gas will diffuse into the liquid. The process is much like that of gases diffusing

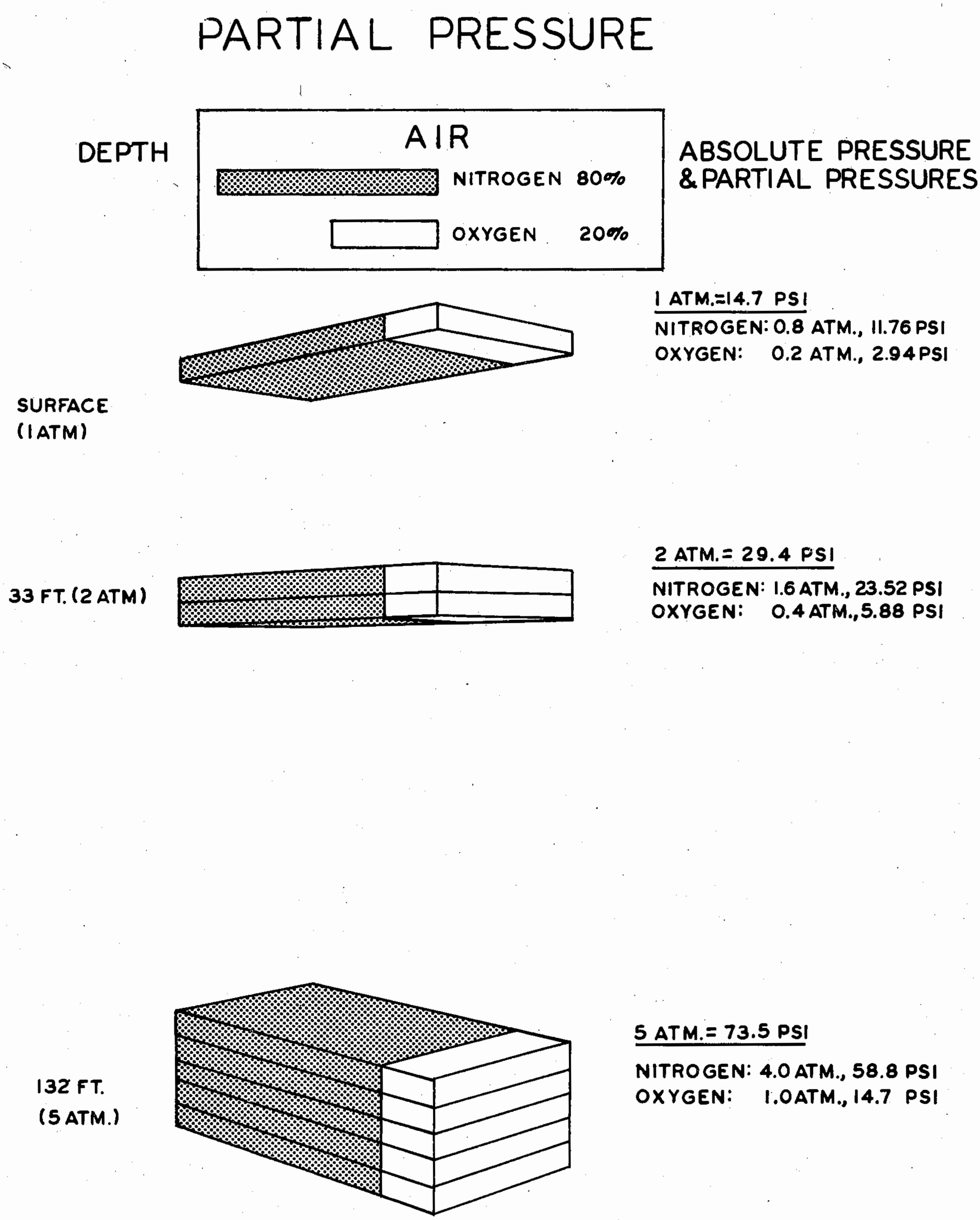


FIGURE 1–17.—Partial pressure. At 5 atmospheres absolute, partial pressure of oxygen in air is approximately equal to partial pressure of pure oxygen at surface.

through a membrane, but here the point of equilibrium is influenced by the solubility of the gas in the liquid—the number of molecules of gas the liquid will take up in solution at a given partial pressure. When equilibrium is reached, the liquid contains the dissolved gas at a *tension* equal to the partial pressure of that gas in the mixture to which the liquid is exposed.

(2) *Henry's Law* states that *the amount of a gas that will dissolve in a liquid at a given temperature is almost directly proportional to the partial pressure of that gas.* (The term *amount*, as used here, refers to the number of molecules, or mass (weight) of the gas. However, at a given temperature and pressure the volume of a gas is proportional to the mass, so we can speak of amounts of dissolved gas in terms of the volume they would occupy in free gaseous form under standard conditions of temperature and pressure at the surface. When a gas is *in solution*, its actual volume is negligible. The volume of a liquid thus shows no increase when gas is dissolved in it.) If a certain quantity of a liquid will absorb 1 quart of a gas at 1 atmosphere of partial pressure, it will take up an additional quart when the partial pressure of the gas is increased to 2 atmospheres. The average man's body contains about 1 quart of dissolved nitrogen from the air he breathes at the surface. If he breathes air at 5 atmospheres total pressure for a long enough period for complete gaseous equilibrium to be reached (up to 12 hours), his body will then contain about 5 quarts of gas (in terms of volume measured at the surface). The *tension* of dissolved nitrogen throughout his body will be equal to the partial pressure of nitrogen in the air in his lungs: about 80 percent of 5 atmospheres, or 4 atmospheres, when equilibrium is reached. (At this point, the man is said to be *saturated* with nitrogen at that pressure.)

(3) If a diver whose body was *saturated* with nitrogen at a tension of 4 atmospheres were suddenly brought up to the surface, the tension of dissolved gas in his body would then be higher than the total pressure surrounding him. The gas would be in *supersaturated* solution, and some of the excess nitrogen would come out of solution in the form of bubbles. This is the cause of decompression sickness. The same situation exists when a bottle of carbonated beverage is opened. In that case, the gas is carbon dioxide; but the same principles apply. As long as the cap is on, the total pressure in the bottle matches the tension of the dissolved gas. When the cap is removed, the pressure on the liquid drops; and the excess pressure of dissolved gas causes bubbles to form. If the pressure in the bottle were released very slowly, the excess gas would gradually diffuse out of the liquid, and no bubbles would form. In a similar manner, a diver can be brought up safely if his ascent is managed in such a way that enough nitrogen can come out by diffusion to avoid dangerous supersaturation. The process of gas absorption and elimination is very important in diving and is discussed further in the section on physiology. (See 1.3.9.)

(4) The basic idea of *solubility* must be distinguished from Henry's law, which simply expresses the effect of partial pressure on amounts of gas dissolved. For example, the solubility of nitrogen in oil or fat is about five times its solubility in water at the same partial pressure. If a certain weight of water will take up about 1 liter of nitrogen at 1 atmosphere, the same weight of fat will take up about 5 liters of nitrogen at the same partial pressure. According to Henry's law, if the partial pressure were doubled, the water would then take up about 2 liters and the fat about 10. The pressure-effect does not change the fact that nitrogen is about five times as soluble in fat as in water. Temperature also affects the solubility of gases: the lower the temperature, the higher the solubility. This is why a warm bottle of carbonated beverage forms bubbles so much more actively than a cold one and why heating water causes bubbles to appear in it long before the boiling point is reached. In this case, air which was dissolved in the water must come out of solution because its solubility decreases as the temperature rises.

(5) The *difference* between the partial pressure or tension of a gas inside a space or liquid and its partial pressure outside is the "driving force" which causes a quantity of a gas to

diffuse through a membrane or in or out of a liquid. The size of the difference is also one of the main factors controlling the *rate* of diffusion. The difference between "internal" and "external" partial pressures or tensions is sometimes called the *gradient* to distinguish it from other pressure-differences not directly concerned with gas transfer. If a gas-free liquid is exposed to a gas, the inward gradient for the gas will be high at first, and the rate at which molecules of gas migrate into the liquid will be high. As the gas tension of the liquid rises, the gradient decreases; and the rate of transfer slows progressively. Because of the decreasing gradient, gas saturation or desaturation of a liquid proceeds rapidly at first but may take a long time to become complete.

1.2.7 BUOYANCY

Archimedes' principle

(1) The buoyant effect of liquids is expressed by *Archimedes' principle.* This states that *any object wholly or partially immersed in a liquid is buoyed up by a force equal to the weight of the liquid displaced.* Figure 1–18 presents an example: A diver, with his helmet and dress, weighs 384 pounds. If he inflates his dress so that he displaces 6.5 cubic feet of water, he will be buoyed up by a force equal to the weight of 6.5 cubic feet of water. Since sea water weighs 64 pounds per cubic foot (see 1.2.4(10)), the buoyant force on this diver would be $6.5 \times 64 = 416$ pounds. This is $416 - 384 = 32$ pounds more than his total weight. Such an "excess" of buoyant force is called *positive buoyancy.* In this example, the diver would actually float with half a cubic foot of his volume out of water. The volume of water displaced would then be 6 cubic feet, the weight of which ($6 \times 64 = 384$ pounds) would just equal his own weight. To give himself *neutral buoyancy*, with which he would neither rise nor sink in the water, the diver could either exhaust one half cubic foot of air from his dress or wear an additional 32 pounds of weight. If he required *negative buoyancy* (being "heavy" in the water), he would have to add still more weight or let out more air.

(2) If the same diver were submerged in fresh water rather than sea water, the buoyant force would be less because the density of fresh water is less than that of sea water. Fresh water weighs 62.4 pounds per cubic foot, compared to 64 for sea water, so the weight of the volume of water displaced would be $6.5 \times 62.4 = 405.6$ pounds instead of 416.

(3) A diver in helmet and dress normally keeps himself negatively buoyant in order to stay down and have a good foothold on the bottom. If he allows his dress to become overinflated, he will gain positive buoyancy and begin to ascend. As he rises, the surrounding pressure decreases, and the air in the suit expands. This increases his displacement and gives him even more positive buoyancy. Unless he can exhaust the excess air promptly, he will continue to rise at an increasing rate. Being carried to the surface in this manner is known as "blowing up." (See 1.6.10.) The reverse of this process occurs if the diver falls or otherwise descends too rapidly. The compression of air in the dress decreases his displacement and makes him increasingly heavy. Other aspects of such an accident (squeeze) have been discussed in article 1.2.4, paragraph 21, and will be explained more fully in article 1.3.7.

(4) Even a surface-swimmer is aware of buoyancy and knows that he is "lighter" in the ocean than in fresh water. Most people can float quite well in sea water, but a few cannot. This is because their average body density is greater than that of the water, and the body thus weighs more than the water it displaces. Two main factors determine whether a man's body will have positive or negative buoyancy. Fat is lighter than muscle and bone and weighs less than water. Therefore a fat man generally floats more readily than a lean man. The other important factor is lung capacity. The air space in a man's lungs buoys him up like a pair of invisible water wings. Lung capacity varies with the individual, and almost everyone has observed that he is more buoyant with a full breath than when he exhales. When a man skin dives (holding his breath), the air in his lungs is compressed as he descends, so he becomes less and less buoyant the deeper

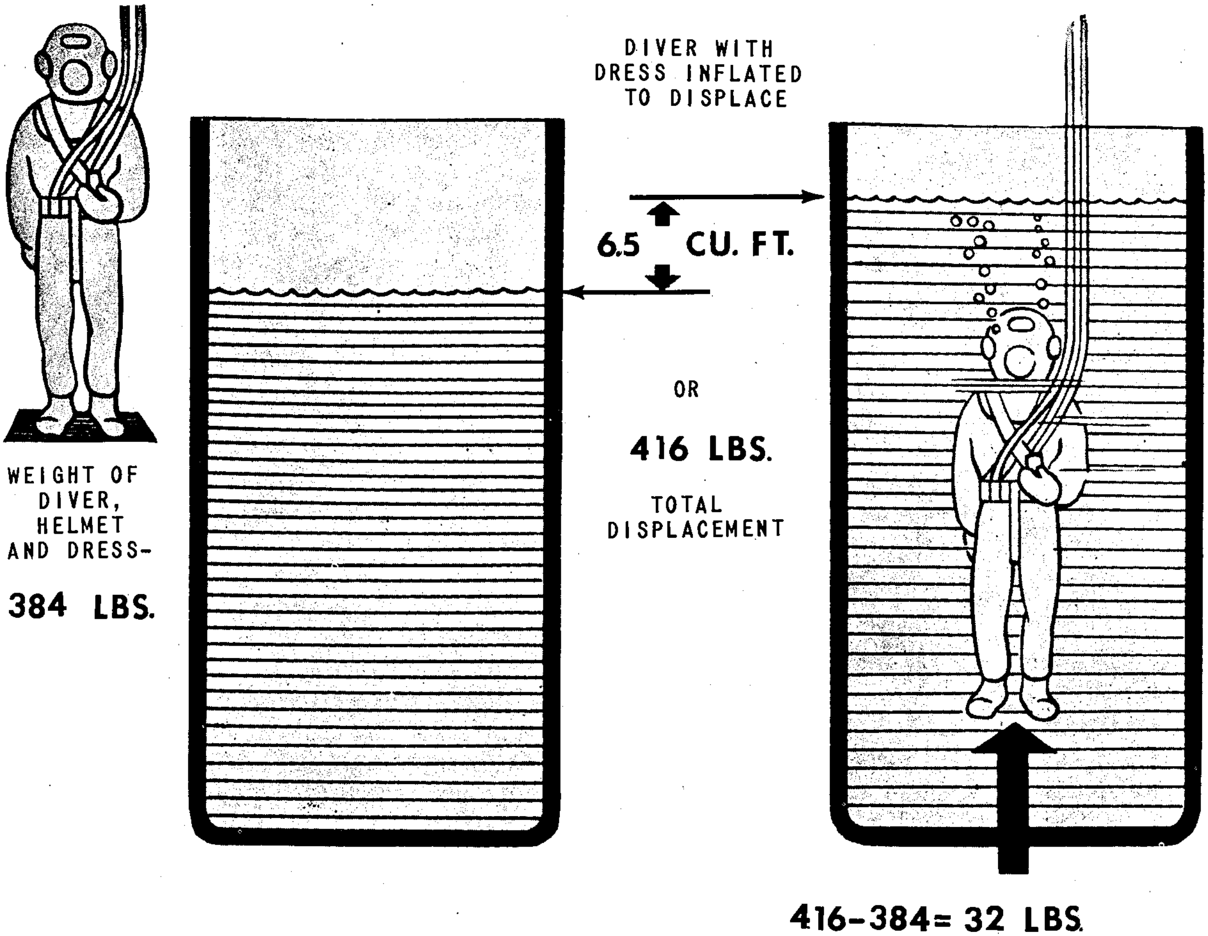


FIGURE 1-18.—Buoyancy (Archimedes principle).

he goes. If he starts with a full breath at the surface, the average man will become negatively buoyant after descending 15 to 20 feet. Some skin divers may find themselves as much as 10 pounds "heavy" at their maximum depth and may have to swim vigorously to start ascent.

(5) A self-contained diver wearing a rubber exposure suit is buoyant because of the air trapped between the suit and his body. He may have to use 5 to 30 pounds of diving weights in order to offset this buoyancy. When he descends, the trapped air is compressed; and he becomes heavier and heavier. In some such cases, the diver may have difficulty returning to the surface without dropping some of his weights.

(6) Another important application of Archimedes' principle is in salvage work where buoyancy is used to raise heavy objects off the bottom. This can be done by sinking an airtight container of suitable size and strength (steel pontoon, collapsible rubber pontoon, etc.) and attaching it to the object. Buoyancy is then obtained by expelling the water or by inflation. The lifting capacity of any container equals the weight of the water it will displace, minus its own weight.

Laws of flotation

(7) The laws based on Archimedes' principle can be summarized as follows:

(*a*) A body sinks in a fluid if the weight of the fluid it displaces is less than the weight of the body.

(*b*) A submerged body remains in equilibrium, neither rising nor sinking, if the weight of the fluid it displaces is exactly equal to its own weight.

(*c*) If a submerged body weighs less than the volume of liquid it displaces, it will rise and float with part of its volume above the surface. A floating body displaces its own weight of a liquid. (The volume of liquid displaced by a floating body has the same weight as the body itself.)

1.2.8 ENERGY

(1) *Energy* is defined as *the capability of doing work.* It exists in several forms and can be changed from one form to another and stored in various ways. Heat, electricity, light, and sound are all forms of energy. Most of the energy we use came originally from the sun in the form of light and heat and was stored chemically by growing vegetation which became fuel or food. When you lift a weight, you are doing work with energy liberated from food by chemical reactions in your body. Even when you speak, you are doing work and transforming a little of your energy into the energy of sound waves. The whole subject of energy is large and complex. Only a few aspects which have special importance because of unusual effects underwater will be taken up here.

Light

(2) Even the process of seeing involves energy. We see an object because the energy of light is reflected from it in different colors and intensities. This light enters the eye and triggers nerve impulses to the brain. We interpret these impulses in certain ways because we are accustomed to the way light behaves in air. Because light behaves a little differently in water, a diver may find that his eyes deceive him. Straight lines sometimes appear bent, and objects appear larger and closer than they actually are. If the water is muddy, the diver may see poorly or not at all. Even if it is relatively clear, natural shadows may be lacking, and colors will be changed.

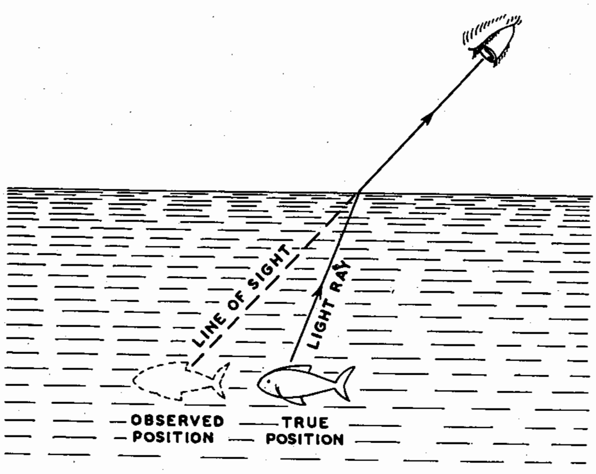


FIGURE 1–19.—Refraction.

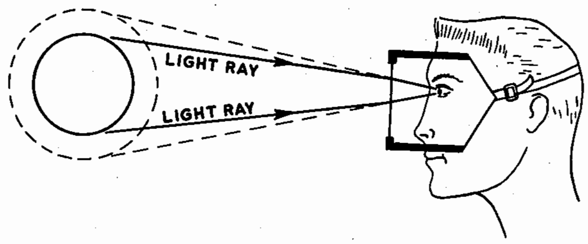


FIGURE 1–20.—Magnification.

(3) When light rays pass from a medium of one density to a medium of a different density, they are usually bent out of their normal course. This effect is known as *refraction.* In the case of light rays being reflected from an object in the water to your eye in the air, the light is refracted or bent in such a manner as to give you a false impression of position and size of the object. This is exactly what happens when a diver peers at an object from his air-filled helmet or face mask. The top of any object he looks at appears to be higher and the bottom appears to be lower. (See figs. 1–19 and 1–20.) This accounts for the deception of size and hence of distance. The distortion ratio caused by this effect is three-fourths. In other words an object actually 20 feet away in the water appears to be only three-fourths of that distance, or 15 feet.

(4) Generally, underwater visibility depends upon four main variables. These are:

(*a*) The various conditions of illumination.

(*b*) Diffusion, or scattering of the light rays.

(*c*) Absorption of light rays in water.

(*d*) Turbidity.

(5) The brighter the day, the greater the amount of light (illumination) that enters the water. Normally, as a diver descends in the water, the total light gradually decreases. However, turbid water may be found in layers.

Thus a relatively clear layer can at times be found under turbid water or at the bottom.

(6) Absorption of light in water is that process whereby light is apparently filtered by the water and reduced in intensity. White light is made up of all the colors of a rainbow. Each color is actually a component of white light. If any of these colors were removed, the light would no longer be white. Such is the case when light penetrates deep enough in water. It first loses its red; then at somewhat greater depths the yellow is filtered out. At this point most objects take on a blue color, and red objects appear black.

(7) Diffusion is the result of light rays being deflected and scattered by water molecules and foreign particles suspended in the water. This reduces the total illumination somewhat. It is beneficial however, since it is responsible for throwing light rays into crevices, caves, and otherwise dark corners. If it were not for this effect, any object not in direct line with the sun's rays would have practically no illumination.

Sound

(8) In our everyday life, we are aware of a multitude of sounds originating about us. They may be in the form of voices as people talk to each other, and they range from harsh ear-splitting noises to the pleasant sound of your favorite music. In all cases though, sound waves have their origin in vibrating matter. At this point several basic facts about sound may be stated. In order to hear, three things must be present:

(*a*) A vibrating body.

(*b*) A transmitting medium (this must be some form of matter).

(*c*) The ear, which receives the sound waves and converts them to impulses your brain can interpret.

(9) Of the three essentials for sound, the transmitting medium is the one most altered in diving. Sound does not behave the same in air as it does in water or even in other gases. For example, the speed at which sound travels in air at standard conditions is about 1,090 feet per second. However, in water it travels more than four times that fast. Likewise, its speed varies greatly in all the different media capable of transmitting it. Generally speaking, the more dense and elastic the medium, the better the sound can be transmitted through it.

(10) Since sound is readily transmitted through either air or water, it would appear that two divers could talk to each other underwater without difficulty. Such is not the case. All but one ten-thousandth of the sound energy is lost when being transmitted from air to water. Hence, for divers to talk to each other underwater or to hear sounds originating in the air above them, these sounds must originally be very loud.

(11) When a mixture of gases containing any appreciable percentage of helium is breathed, the voice acquires an unreal sound like that of Walt Disney's Donald Duck. A similar effect is also observed when breathing air or other gases under high pressure. The greater the pressure, the more pronounced the effect becomes, until at great depths, it is very difficult to understand what a diver is saying. In the case of helium, this effect is due to the higher speed of sound in helium and the effect it has on the resonating quality of the respiratory air spaces which control the sound of your voice.

Heat

(12) Heat is another form of energy. It is closely related to temperature but must be distinguished from it since different substances do not necessarily contain the same amount of heat energy even though their temperatures are the same. Temperature is measured in degrees, usually Fahrenheit or centigrade. Heat is measured in B.t.u.'s (British thermal units) or in calories or kilogram-calories. One B.t.u. is the amount of heat required to raise the temperature of 1 pound of water 1° Fahrenheit. A calorie is the amount of heat required to raise the temperature of a gram of water 1° Centigrade, and a kilogram-calorie is the corresponding amount for a kilogram (1,000 grams) of water. The difference between heat and temperature is illustrated by the fact that a cubic foot of hot air would melt far less ice than a cubic foot of water at the same temperature. The water obviously

contains much more heat energy than the air, and this is not just because it weighs more. A cubic foot of helium requires far more heat to warm it 1° than does a cubic foot of air, and this is true even though the helium weighs less than air.

Heat transfer

(13) Heat is transmitted from one place to another in three ways:

(*a*) *Conduction* is the transmission of heat directly from molecule to molecule through a substance or through materials which are in contact with each other. An unprotected diver loses heat to the water around him mainly by direct conduction through his skin.

(*b*) *Convection* is the transmission of heat by the movement of heated gas or fluid. If the diver were sitting in a tank of water in a cold room, he would lose heat to the surroundings not only by direct conduction through the water but also by movement of the water (called convection currents) produced in the following way: The water next to his body, warmed by conduction, would expand slightly and be lighter than the surrounding water. It would therefore rise; but on reaching the top and walls of the tank, it would lose heat to the room, contract, and sink to be warmed again.

(*c*) *Radiation* is the transmission of heat by invisible waves not unlike radio waves. Every warm object puts out such waves; and if an object is hot enough, it will also produce similar waves which we recognize as light. Although a diver will also lose some heat by radiation, the amount is very small compared to the loss by conduction.

(14) The rate of heat-transfer by conduction depends both on the difference in temperature between the warm object and its surroundings and on the *conductivity* of the materials concerned. Conductivity refers to the ease with which a material transmits heat by conduction. If a material of low conductivity is placed between the warm object and the surroundings, the object is said to be *insulated*. In general, a substance which has little ability to contain heat has low conductivity and makes a good insulator. Water is an extremely poor insulator while air conducts heat poorly and makes a good insulator. Helium, on the other hand, is a poor insulator. The insulation provided by wool clothing, foam materials, and the like, is due mainly to the fact that they place a layer of air between the body and the surroundings and confine it in such a way that convection currents cannot be set up.

(15) Body temperature is normally 98.6° F. (37° C.), and it cannot vary more than a few degrees from this without serious results. The body produces heat continually. On dry land, it loses heat to the air by the three methods of transfer mentioned above, plus evaporation of water from the lungs and skin. As was indicated, only conduction is of much importance underwater. The mechanisms by which the body controls its temperature are discussed in section 1.3.13.

(16) If an unclad diver is in water colder than about 70° F., the temperature-difference and the high conductivity of water will cause heat to be lost faster than his body produces it, and he will chill. Some kind of protection must be provided. If the water is not colder than about 60° F., a snug-fitting suit of wool underwear may suffice. This does not provide much insulation in the usual sense, but it traps a layer of water next to the body. When this is warmed by the body, the temperature difference is decreased, and much less heat is lost than when the body is continually bathed by fresh masses of cold water. In colder water, actual insulation with "dead air space" must be provided. This is done either by wearing wool underwear under a watertight suit or by using a "wet suit" for unicellular foam material that does not lose insulating value even though its surfaces are wet.

SECTION 1.3 UNDERWATER PHYSIOLOGY

1.3.1 MAN AND HIS ENVIRONMENT

(1) In many ways, the body is like a machine; but it is so complicated and so remarkable in what it can do that no man-made mechanism has ever come close to equaling it. The body is made up of living cells—many billions of them—so small that they can be seen only under a microscope. Like all animal matter, these cells burn food materials and oxygen and produce carbon dioxide, water, waste materials, and heat. Such cells can live only if they are kept supplied with food, oxygen, and all the chemicals they need; if the carbon dioxide and other wastes are carried away; and if the gas pressures, acidity, and temperature of their surroundings are kept within close tolerances. Managing all of these things to keep body cells alive in a test tube is a complicated and demanding laboratory operation. But added together and working together in the body as a whole, the billions of cells do all these jobs themselves—and not only "stay alive" but have ability and energy left over for work, play, learning, reproducing their kind, and all that makes up human life.

(2) The cells of the body are of many different types and are organized into numerous kinds of tissue. In turn, the tissues are formed into the many parts, organs, and systems whose inter-working makes life possible for the whole organism. Every cell of every part of the body is surrounded by tissue fluids. These fluids make up the cell's immediate surroundings and transmit, in dissolved form, the materials which the cell needs for its life and the end products it produces. It is in this internal environment of the body that conditions must be kept so constant for the cells to live and function normally.

(3) Even when conditions in the outside surroundings—the external environment—are nearly perfect and require little compensation by the body, maintaining the proper internal environment still requires the work of almost all of the organs and systems. The heart pumps blood to all parts of the body, and the tissue fluids everywhere exchange dissolved materials and gases with the blood. The lungs keep the blood supplied with oxygen and cleared of excess carbon dioxide by bringing air close to the blood in the process of breathing. The digestive system provides food for the blood to carry to the tissues. The kidneys clear the blood of the waste materials it takes up from the tissue fluids. The excess heat produced by the body is lost when the blood reaches the skin, which is cooled by contact with air and by evaporation of fluid from the sweat glands. These are only a very few of the many complex processes which operate all of the time to maintain the internal environment and life itself.

(4) The science of *physiology* is concerned with these functions and processes of the living body: how they operate under normal and abnormal conditions, what changes take place in various diseases, and how the body tries to keep the internal environment constant in the face of changes and unfavorable conditions outside. Physiology is naturally concerned also with methods by which the body's compensation processes can be helped out when they cannot cope with the external environment unaided.

(5) Some of the processes of life and adjustment go on almost automatically, but most of them are controlled by the brain and nervous system and various glands. In most cases, the process and its control go on without any awareness on our part. However, some functions require conscious thought and action. Things like eating when we are hungry and putting on a coat when we get cold are important parts of the job of keeping conditions in the internal environment where they belong. The body can adjust automatically to many unfavorable conditions in the external environment, but there are many places in the world where people would not be able to live at all without "know-how" like the ability to build houses and heat them. When he does diving or high-altitude flying, a man faces a *markedly* abnormal environment. Under such conditions, he can stay alive and do useful work

only because he has *special knowledge* and *special equipment* to help his body's adjustment processes maintain his internal environment.

(6) As far as breathing is concerned, the body has no way at all of adapting itself to a *watery* external environment without artificial aids. If a man wants to stay underwater for more than a few minutes, he must somehow take his "atmosphere" with him; and diving (as we think of it now) remained impossible until reliable ways of doing this were developed. The body also lacks effective ways of compensating for many of the actions of increased pressure at depth and can do little to keep its internal environment from being upset by them. Such effects set definite limits to what a diver can do, and they can give rise to serious accidents. Safe diving becomes possible only through knowing what physiological effects are produced, how much of a limit they impose, and how some of them can be avoided or reduced. A diver's knowledge of these things can be just as important as his own good health and the condition of his gear.

(7) The purpose of this chapter on *Underwater Physiology* is to provide the necessary background information concerning the parts and systems and physiological processes that are especially important in diving. This requires first discussing some *Anatomy* (the way the body is constructed), then taking up the *Physiology* (how living matter functions). Having done this, the chapter then deals with what a diver needs to know about the effects diving can have on the structure and function of the body and what can (or cannot) be done about these effects.

1.3.2 RESPIRATION AND CIRCULATION

Importance

(1) Every cell in the body must obtain energy in order to maintain its life, its growth, and its particular function. The cells obtain this energy from chemical reactions which take place inside of them. The reactions are complicated; but the main end result is a slow, flameless burning (oxidation) of food materials. Like the burning of any material, this oxidation requires not only fuel but also oxygen; and carbon dioxide, water, and heat are produced by it. The process of oxidizing food is called *metabolism*. The use of oxygen and production of carbon dioxide (and the exchange of these gases with the surroundings) is called *respiration*.

(2) Only a few of the body's billions of cells are close enough to the surface of the body to have any chance of obtaining oxygen by direct diffusion from the air or of getting rid of carbon dioxide by the same method. In order to do this, they would have to be spread out in a thin layer over a very large surface. Instead, the exchange of gases takes place via the circulating blood. The blood is exposed to air over a large diffusing surface when it passes through the lungs. When the blood reaches the tissues, the small vessels there provide another large surface where the blood and tissue fluids are in close contact. Gases diffuse readily at both ends of the circuit, and the blood itself has remarkable ability to carry both oxygen and carbon dioxide. This system normally works so well that even the deepest cells of the body can obtain oxygen and get rid of excess carbon dioxide almost as readily as if they were completely surrounded by air.

(3) If the membrane surface where blood and air come close together were just an exposed sheet of tissue like the skin, natural air currents would keep fresh air in contact with it. Actually, this surface is many times larger than the skin area and is folded and compressed into the small space of the lungs, protected inside the bony cage of the chest. This makes it necessary to move air in and out of the space continually, and this is why we have to *breathe*. The process of breathing and the exchange of gases in the lungs is sometimes called *external respiration* to distinguish it from the use, production, and exchange of gases that takes place in the tissues (*internal respiration*).

Steps in the process of respiration

(4) Notice that the whole process of respiration includes six important phases:

(*a*) Breathing, or ventilation of the lungs.

(*b*) The exchange of gases between blood and air in the lungs.

(*c*) The transport of gases by the blood.

(*d*) The exchange of gases between the blood and tissue fluids.

(*e*) The exchange between the tissue fluids and the cells.

(*f*) The use and production of gases by the cells (metabolism).

(5) If any one of these processes stops or is seriously hindered, the cells concerned can no longer function normally or even survive for any length of time. Those in the brain tissue, for example, will stop working almost immediately and will either die or be permanently injured in a few minutes if their supply of oxygen is completely cut off. The respiratory and circulatory *systems*, which carry on these processes, are of vital importance every minute of a man's life. They are also particularly involved in many of the physiological effects of being underwater.

1.3.3 THE CIRCULATORY SYSTEM

Anatomy

(1) The very large surface areas required for ample diffusion of gases in the lungs and in the tissues are provided by the thin walls of extremely small blood vessels called *capillaries*. Every part of the body is completely interwoven with intricate networks (or "beds") of capillaries. In the lungs, these capillaries surround the tiny air-sacs so that the blood they carry can be exposed to air. In the tissues and organs, no cell is more than a slender fraction of an inch away from a capillary which can supply its needs by diffusion through the tissue fluids that surround both the cells and the capillaries.

(2) The circulatory system as a whole is a closed system of tubes which includes the *lung capillaries*, the *tissue capillaries*, the *heart*, the *arteries*, and the *veins*. The heart is the muscular pump which propels the blood throughout this system. The arteries are the vessels which carry blood from the heart to the capillaries, and the veins are the vessels which return blood from the capillaries to the heart. Both the arteries and veins branch and re-branch many times very much like a tree. The "trunks" near the heart are about the diameter of your thumb. The smallest arterial and venous "twigs" in the tissues are so small that you need a microscope to see them. Capillaries provide the connections which let blood flow from the smallest branch arteries into the smallest veins.

The blood vessels

(3) Blood in the arteries is under considerable pressure, so these vessels must be tough and strong. Just as an airhose has layers of rubber to seal it and layers of cord or fabric to give strength, an artery is made of layers of different kinds of tissue. Layers of elastic fibers give the arteries both strength and the ability to increase and decrease their diameter with changes in pressure. This helps keep the pressure fairly constant, maintaining it between pump strokes and thus tending to smooth out the pulsations in much the same way that a volume tank does in an air system. The arteries also contain a layer of muscle cells which are controlled by the nervous system and by certain substances which the body produces. When these muscles contract or relax, they change the diameter of the artery and can influence both the flow of blood to a particular place and the pressure in the system as a whole. The arteries are thus not only the supply hoses but also the control valves of the circulation. Veins are under little pressure and do not have to control flow, so they are thin and weak compared to the arteries. The capillaries consist of only a single layer of thin cells like those which make up the inner lining of the larger vessels.

(4) Although it forms one continuous system of tubes with the same blood flowing throughout, the circulatory system actually consists of two circuits. One of these (the pulmonary circuit) serves the lung capillaries while the other, (the systemic circuit), serves the tissue capillaries. Each circuit has its own arteries and veins and its own half of the heart for a pump. Figures 1–21 and 1–22 show how the system is arranged. In going the whole rounds, blood first passes through one circuit and then through the other; and it

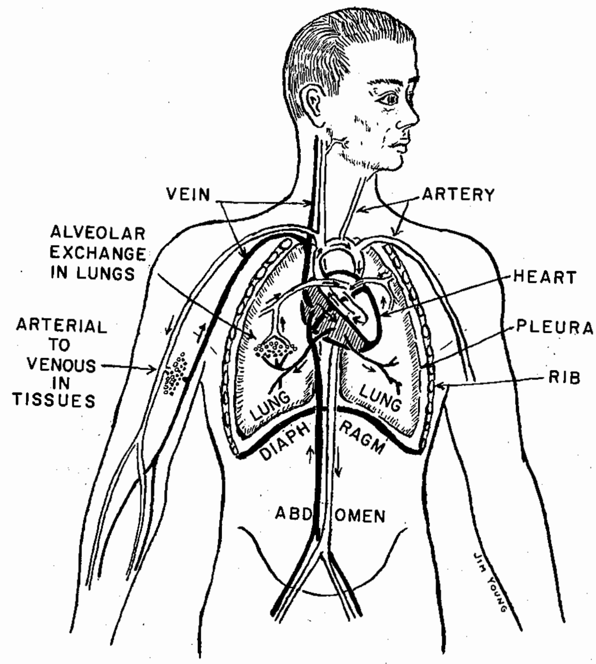


FIGURE 1-21.—Circulatory system.

thus goes through the heart twice in each complete cycle.

The heart

(5) The heart is about the size of a closed fist. It is located in the front and center of

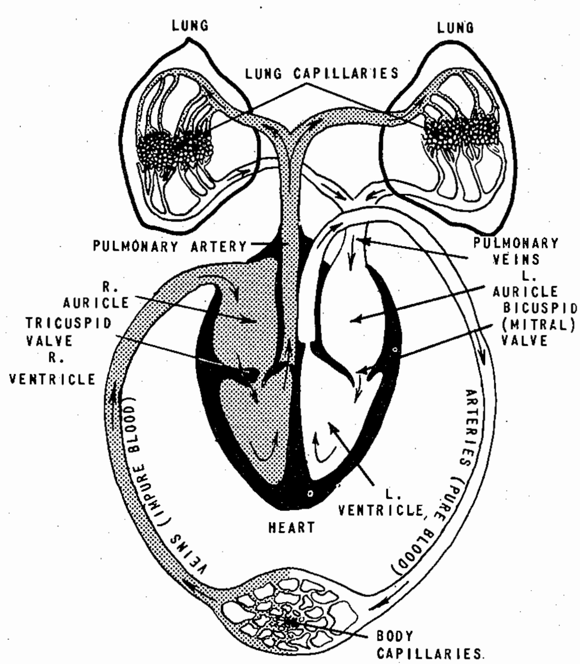


FIGURE 1-22.—Circulatory system in detail.

the chest cavity between the right and left lungs with much of it lying directly behind the breast bone. (See fig. 1-23.) The heart is hollow and almost entirely made up of muscle tissue which forms its walls and provides the pumping action. The interior of the heart is divided lengthwise into two halves which have no direct connection with each other. The left half is the pump for the systemic circuit while the right half belongs to the pulmonary circuit. Each half is divided into an upper chamber (*auricle* or atrium) which receives blood from the veins of its circuit, and a *ventricle*, which takes blood from the auricle and pumps it into the corresponding main artery. Because the ventricles do most of the pumping, they have the thickest, most muscular walls.

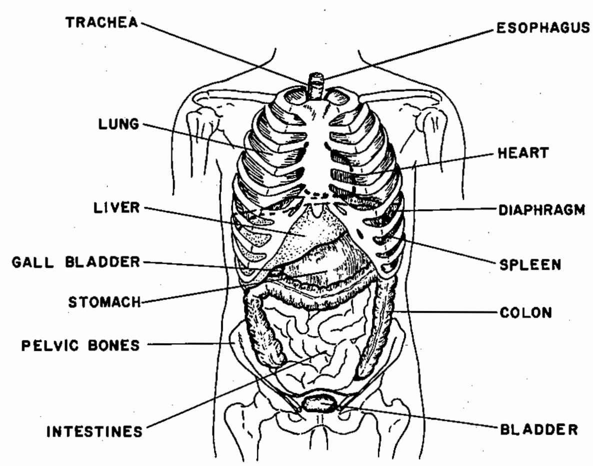


FIGURE 1-23.—Chest and abdominal organs.

(6) Like most pumps, the heart has *check valves* to keep the flow going in the right direction and to prevent back-flow between strokes. There is a valve between each auricle and ventricle and another at the entrance to the main artery on each side. When the heart contracts, the valve between the auricle and ventricle keeps blood from being forced back into the auricle. When the heart relaxes to refill, the valve between the artery and the ventricle prevents backwash and holds pressure in the artery.

The path of a drop of blood

(7) To see how this system operates, look at figure 1-21 or 1-22 and consider the path

a drop of blood follows and what happens to it on the way. A drop of blood leaving a capillary in your right biceps muscle has lost most of its oxygen and is loaded with carbon dioxide. It first flows into larger and larger veins until it reaches the main vein in the upper chest (the superior vena cava). From there it flows into the right auricle and then through the tricuspid valve into the right ventricle. The next contraction (systole) of the heart forces it through the pulmonic valve into the pulmonary artery. The drop of blood then finds its way through the arterial branchings of the lungs into one of the pulmonary capillaries. Here, it comes in contact with air. By diffusion, it loses its excess carbon dioxide and takes up a fresh load of oxygen. Then it returns to the heart via the pulmonary venous system and enters the left auricle. The next relaxation of the heart (diastole) finds it going through the mitral valve into the left ventricle. Next, it is pumped through the aortic valve into the main artery of the systemic circuit (the aorta). It then follows one of the main branches of the aorta and finds itself again in a tissue capillary giving up its oxygen and taking up carbon dioxide. It is now ready for another trip to the lungs and back again. On its next return, the same drop of blood may go through the tissue capillaries of the liver or intestines to pick up food materials, through those of the kidneys to drop off wastes, or to the skin capillaries to be cooled.

The blood

(8) An average man's body contains about 6 liters of blood (NOTE.—In physiology, almost all measurements are made in the metric system. (See art. 1.10.13.) The liter is the usual unit of volume. One liter equals just slightly more than 1 quart: 1.057 quarts.) If the blood were only a simple fluid like water or saline solution, it could perform only a few of its vital functions and would almost completely fail in the respiratory job of transporting oxygen and carbon dioxide. Only a small fraction of the necessary amounts of these gases could be carried in simple solution in the fluid. Oxygen is carried mainly in the red corpuscles of the blood. These are extremely small dish-shaped cells, and there are about 5 million of them in every cubic millimeter of blood—over 300 million in an average-sized drop. These corpuscles are able to carry oxygen because they contain *hemoglobin.* This is a complicated chemical compound which contains iron. It can form a loose chemical combination with oxygen, soaking it up almost as a sponge soaks up water. When hemoglobin has a full load of oxygen, its color is bright red. As it loses oxygen, it becomes increasingly bluish in color. Whether the hemoglobin gains or loses oxygen depends mainly upon the partial pressure of oxygen to which it is exposed. At the normal partial pressure of oxygen in the lungs, the hemoglobin takes up about 98 percent of the total amount of oxygen it can carry. Because the cells are using oxygen, the partial pressure (tension) in the tissues is much lower, and the hemoglobin, therefore, gives up much of its oxygen in the tissue capillaries.

(9) When carbon dioxide dissolves in water, it forms carbonic acid (this is what gives carbonated beverages their special tang). Even if enough carbon dioxide could be carried simply as carbonic acid, this would make the blood far too acid. As it is, the blood contains substances called buffers which can neutralize acid and permit large amounts of carbon dioxide to be carried without excessive acidity. The hemoglobin plays an important part in transporting carbon dioxide as well as in carrying oxygen. The uptake or loss of carbon dioxide by blood depends mainly upon the partial pressure or tension of that gas in the area where the blood is exposed.

(10) In addition to red cells, the blood contains a smaller number of white blood cells of several kinds. These serve a number of functions like fighting infections. The fluid portion of the blood is called *plasma.* It contains a large amount of dissolved material which is essential to life. Those substances concerned with forming blood clots to stop bleeding are among the substances in plasma. Without the clotting ability of blood, a man could bleed to death from even the slightest injury. The fluid portion of blood left after a clot is formed is called *serum.*

Flow, pulse, and pressure

(11) The amount of blood in a man's body does not change very much under normal conditions, and the majority of it is being circulated at all times. However, the rate at which blood is circulated varies greatly depending on the needs of the tissues. If a man is doing hard work, his heart will have to pump several times the volume of blood per minute that it does at rest in order to keep his working muscle cells supplied with the increased amounts of oxygen they need and to take away the extra carbon dioxide. Not only does the heart increase its rate of pumping, but it also increases the extent to which it fills before each beat. The man's pulse—the surge of pressure which can be felt in the arteries when the heart contracts—becomes not only faster but also more forceful. The normal pulse rate is in the neighborhood of 80 beats per minute. The rate can exceed 150 during hard work. The heart pumps over 4 liters of blood through each circuit every minute when a man is at rest, and a volume of 20 liters per minute would not be extraordinary in hard work. This would amount to about 300 gallons in an hour, or twice that if the volume pumped through each circuit is considered!

(12) The *blood pressure* must stay within certain limits. If it is too low, it does not furnish enough driving force to provide a normal flow of blood through the tissues. If it is much too high, there is a risk of bursting some of the more delicate arteries. The blood pressure depends both upon the amount of blood the heart is pumping and upon the resistance of the circuit. Both factors are under the control of the nervous system, which can speed or slow the heart and make the muscle layers of the arteries contract or relax to change their diameter. To aid in controlling blood pressure, the body is equipped with two pressure-sensing devices called *carotid sinuses*. These are located in the neck where the main arteries which supply the head (the *carotid arteries*) make their first branching. By means of nerve impulses, these structures keep the brain informed about the pressure so that it can cause the proper adjustments.

(13) The heart rate and artery diameters are also influenced by certain substances like *epinephrine* (adrenalin). This is produced and secreted into the bloodstream by the adrenal glands in response to nerve impulses from the brain. If a man finds himself in an emergency situation, the brain automatically boosts the secretion and circulation of epinephrine, and this promptly readies his circulatory system for the exertion required by "fight or flight." Epinephrine also stimulates the brain. Usually, a diver must face his emergencies without being able either to fight or to run, so this normal reaction may leave his heart racing, his pulse pounding, and his nerves on edge for no useful purpose. However, it may also give him extra strength and endurance if he needs it.

(14) Blood pressure is customarily measured in millimeters of mercury. The normal average pressure for a young man at rest is about 120 mm. Hg when the heart is contracting (*systolic pressure*) and about 80 mm. Hg when it is between beats (*diastolic pressure*). (100 mm. Hg = about 4½ feet of water.) Both pressures are usually measured at the same time and written down together with systolic above and diastolic below (hence "120/80"). Both pressures increase considerably during exertion and excitement; but if they remain much higher, this indicates some abnormality of the circulatory system. A certain amount of increase is natural with age because the arteries gradually lose some of their elasticity.

Fainting and Shock

(15) The automatic control of blood pressure is occasionally upset temporarily by some unusual stress, and a highly unpleasant emotion (for example, that brought on by pain or even the sight of a gory injury) may sometimes have this effect. When the control is upset, the blood pressure may fall to the point where not enough blood is able to reach the brain. The resulting anoxia can cause dizziness, weakness, nausea, "turning green," and loss of consciousness. By making the victim crumple to the deck, fainting (the medical word is *syncope*) automatically lowers the head and lets more blood reach the brain.

Consciousness usually returns in a minute or two. "Passing out" or "falling out" can often be headed-off by lowering the head, as by sitting down and leaning over. A person who has fainted should be kept stretched out and watched carefully until consciousness and normal color return and until he feels very much better. Elevating the feet and legs often hastens recovery. In the rare instances where recovery does not occur promptly, the victim should be seen by a medical officer. In the meantime, administering oxygen is advisable in these cases. If breathing stops, artificial respiration must, of course, be given at once.

(16) Once in a while, practically the same reaction occurs when a man has to stand still in one spot for a long time (especially in hot weather) or very suddenly stops strenuous exertion. In cases like this, the reason why a man loses consciousness is because blood pools in the lower part of the body and does not flow back to the heart fast enough for the blood pressure to be kept up. Such happenings are very rare in diving, perhaps in part, because immersion cancels out the effects of gravity on the circulatory system, but they are a serious problem in aviation. Rapid changes in direction at high speed produce centrifugal or "G"-forces ("G" stands for gravity) which can pull the flyer's blood to his legs and abdomen and cause syncope or "blackout." The aviator's G-suit offsets this effect by applying external pressure to these parts.

(17) *Shock* is a serious condition brought about by injury with hemorrhage, severe burns, or by a number of other conditions which allow the actual loss of blood or blood fluids from the circulation. Under these conditions, the body cannot keep the blood pressure up, and serious tissue anoxia develops. Unless shock is recognized and treated, death can result from an otherwise nonfatal injury or condition. One clue to its recognition is that the pulse is both very weak and very rapid. (In syncope, the pulse may be extremely feeble, but the rate is usually close to normal.) Treatment of shock requires careful medical attention, and replacement of the blood volume by giving blood, plasma, or a suitable substitute by vein is usually required.

1.3.4 RESPIRATION

The respiratory apparatus

(1) The essential parts of man's respiratory apparatus are the lungs and the air passages leading into them. The chest wall with its ribs and muscles, the diaphragm, and other muscles taking part in the mechanical phase of respiration make up the accessory apparatus which produces the movement of air. The mechanism of taking fresh air into the lungs (inspiration) and expelling foul air from the lungs (expiration) is diagrammatically shown in figure 1–24. By elevating the ribs and lowering the diaphragm, the volume of the chest cavity is increased. According to Boyle's law, a lower pressure is thus created within the chest space and lungs. To equalize this lowered pressure, fresh air automatically rushes into the lungs. When the ribs are again lowered and the diaphragm rises to its original position, a higher pressure is created within the lungs. This causes the foul air to be expelled. In the human chest cavity, there is no space between the outer lung surfaces and the surrounding chest wall and diaphragm as shown in the figure. The membrane which covers the lung surface is in contact with that which lines the cavity. The only normal separation is a film of fluid which allows the membranes to slide freely over each other. However, if the surface of the lung is accidentally ruptured by a sudden excessive pressure inside the lungs, or if the chest wall is perforated by some external means, air will be pulled in between the membranes when the chest expands. An actual air pocket will then exist between the lung and the chest wall. This condition is known as *pneumothorax* (pneumo-air/thorax-chest) and may occur as an accident in diving or submarine escape.

(2) The lungs can be thought of as two elastic bags containing millions of little distensible air sacs. These air sacs or alveoli are all connected to the air passages, which branch and rebranch like the twigs of a tree. Air that enters into the main airways of the lung

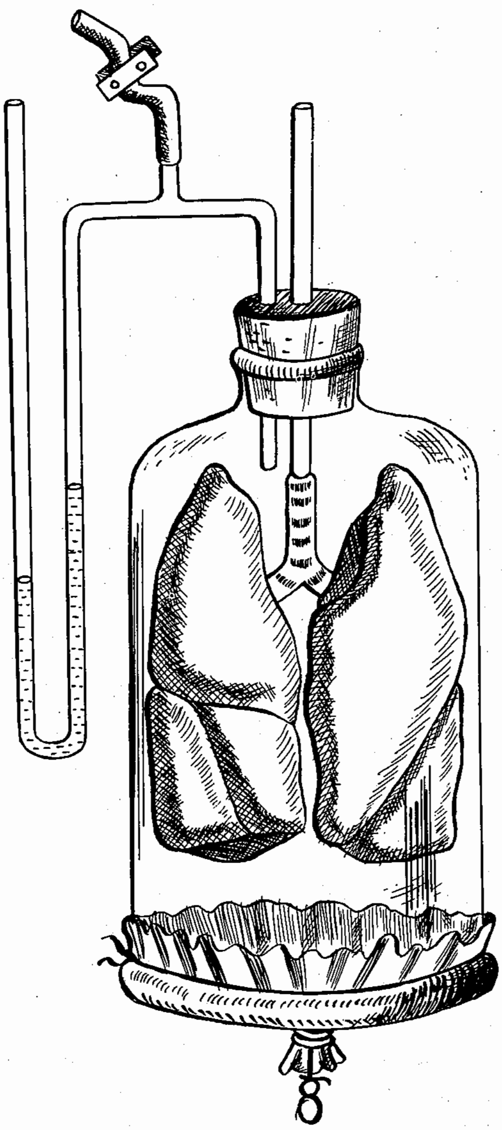


FIGURE 1–24.—Mechanics of breathing: model. Rubber sheet represents diaphragm. Pulling it down enlarges space, reduces pressure in it, and thus causes air to enter lungs and expand them. Enlarging container itself (which represents rib cage) would have same effect. (In the actual body there is no air space between lungs and surrounding chest wall and diaphragm.)

gains access to the entire surface of all these alveoli. Each alveolus is lined with a thin transparent membrane and surrounded by a network of very small blood vessels. These—many millions of them—make up the capillary bed of the lungs. The total surface area of membrane exposed to the air within the lung is tremendous. If this lining could be stripped from all of the sacs and tubes of both lungs and inflated, it would form a spherical balloon about 17 feet in diameter. If it were spread out as a continuous flat sheet, it would cover an area 30 by 30 feet (approximately one-half the area of a single tennis court). This is about 50 times the surface area of the skin of our bodies. Most of the lung membrane has air on one side of it and blood on the other, and diffusion of gases takes place freely in either direction. It is not surprising that the lungs have a tremendous capacity for exchanging gas between the air and the blood.

Terminology and definitions

(3) In order to discuss the process of breathing and other aspects of the respiratory mechanism which are important in diving, the definitions of some terms are given below:

(*a*) A *respiratory cycle* is one complete "breath"—an inspiration followed by an expiration, including any pause that may occur between the movements.

(*b*) *Respiratory rate* (or frequency) indicates the number of complete respiratory cycles that take place in 1 minute. At rest, a normal adult will have a respiratory rate somewhere between 10 and 20 "breaths" per minute. The rate normally increases during work.

(*c*) *Total lung capacity* indicates the total volume of air that the lungs can hold when filled to capacity. It is normally between 5 and 6 liters. (A liter is about the same as a quart. It is the standard unit of volume in the metric system, which is generally used in physiological measurements.) (See fig. 1–25.)

(*d*) *Vital capacity* is the term for the greatest volume of air that a man can expel from his lungs after a full inspiration. In other words, it is the greatest volume of air that can be moved in and out of the lungs in a single breath. The average man's vital capacity is between 4 and 5 liters. (See fig. 1–25.)

(*e*) *Tidal volume* is the volume of air moved in and out during a single normal respiratory cycle. During rest, the tidal volume generally averages about one-half liter. Tidal volume

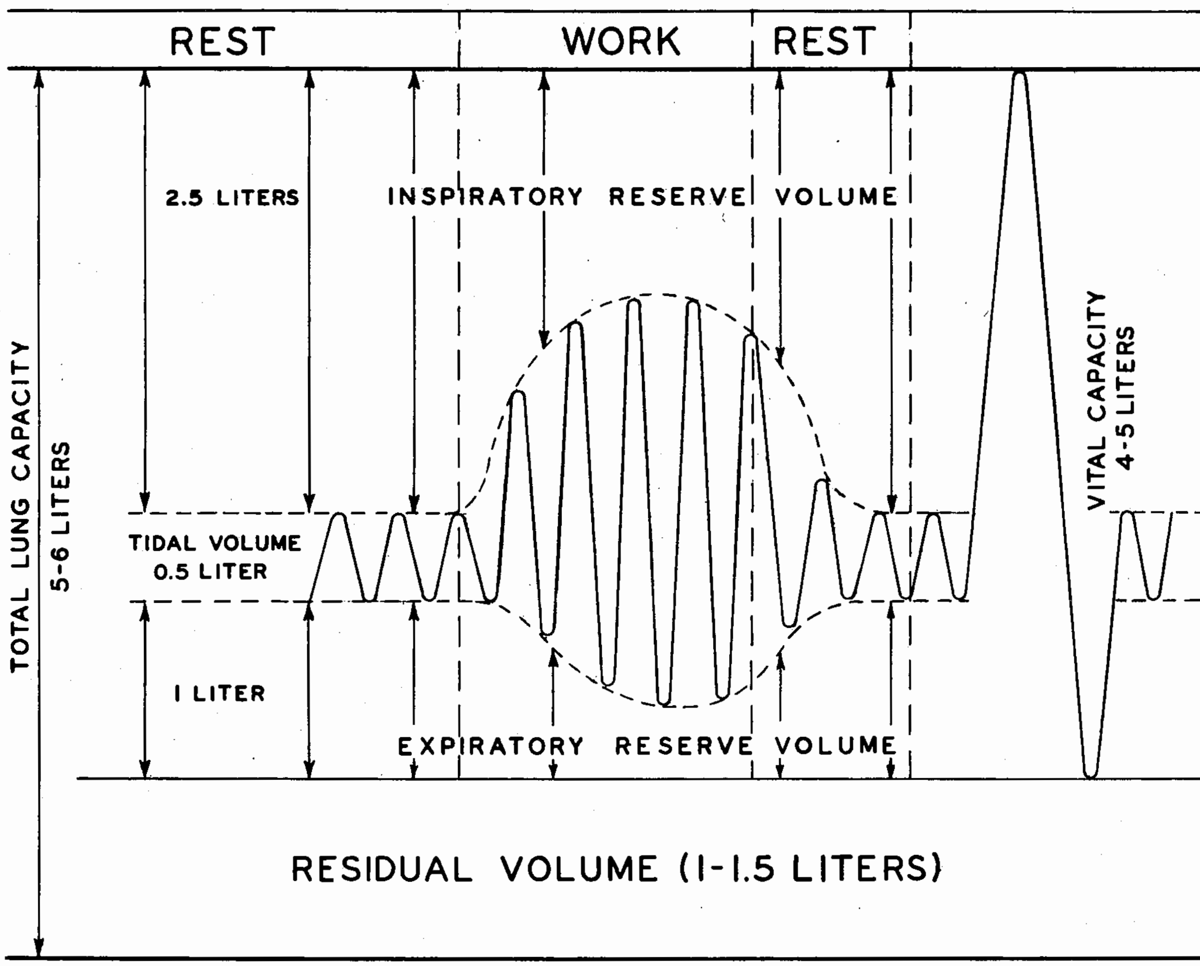


FIGURE 1-25.—Lung volume.

increases considerably during physical exertion. It naturally cannot exceed the vital capacity.

(*f*) *Inspiratory reserve volume* is the amount of air that can be brought in by forcible inspiration after completion of a normal inspiration. It averages about 2½ liters at rest and becomes smaller as the tidal volume increases. (See fig. 1–25.)

(*g*) *Expiratory reserve volume* is the amount of air that can be expelled by forcible expiration at the end of a normal expiration. It normally amounts to about 1 liter during rest and becomes smaller as the tidal volume increases. Note that the sum of the tidal volume and inspiratory and expiratory reserve volumes equals the vital capacity.

(*h*) *Residual volume* is the amount of air that remains in the lungs even after the most forceful expiration. It normally amounts to between 1 and 1½ liters. Note that the sum of the vital capacity plus the residual volume equals the total lung capacity. (All of these relationships are shown by fig. 1–25.)

(*i*) *Respiratory minute volume* (RMV) is the total amount of air moved in and out of the lungs in a minute. Multiplying the tidal volume times the rate gives the respiratory minute volume. Minute volume varies greatly with the body's activity. It is about 6 liters at complete rest and may be over 100 liters during very heavy work.

(*j*) *Maximal breathing capacity* represents the greatest respiratory minute volume which a person can produce during a short period of extremely forceful breathing. In healthy young men, it may average as much as 170 liters per minute.

(*k*) *Respiratory dead space* is that part of the respiratory system which has no alveoli and in which little or no exchange of gas between air and blood takes place. It normally amounts to less than 0.2 liter but becomes larger as the depth of breathing increases. Air which occupies the dead space during each breath does not take part in the active process of breathing. Certain parts of a diver's breathing apparatus can add to the volume of the dead space and thus reduce the proportion of the tidal volume which serves the purpose of respiration. (See 1.3.5(35).) To compensate, the diver must increase his tidal volume.

(*l*) *Net alveolar ventilation* refers to that portion of the respiratory minute volume which reaches the alveoli and exchanges gas with the blood. Multiplying the dead space volume by the respiratory rate and subtracting this from the minute volume gives the net alveolar ventilation.

The respiratory process

(4) With this background, the process of respiration can be explained. The diffusion of gases into a liquid is governed by Henry's Law (see 1.2.6(2)) and Dalton's Law (see 1.2.5(2)). The air we take into our lungs (inspired air) is a mixture of gases that exert a total pressure, at sea level, of 14.7 pounds per square inch (p.s.i.) or 760 millimeters (mm.) of mercury (Hg). (In physiology, pressures are usually expressed in millimeters of mercury rather than pounds per square inch.) Within the alveolar air spaces, the composition of the air (alveolar air) is changed due to the elimination of carbon dioxide from the blood, the absorption of oxygen by the blood, and the addition of water vapor, which exerts a pressure just like any other gas. The air we breathe out (expired air) has still another composition which represents a mixture of alveolar air and the inspired air which remained in the dead space. Table 1–1 shows the partial pressure exerted by the gases present in each type of air.

(5) The blood in the capillary bed of the lungs is exposed to the gas pressures of alveolar air through the thin membranes of the air sacs and the capillary walls. With this exposure taking place over a vast surface area, the gas pressures of the blood leaving the lungs are approximately equal to those present in alveolar air. Roughly, the arterial gas pres-

Barometer 760 mm. Hg.	Partial Pressure		
Gas	Inspired* Air	Expired Air	Alveolar Air
	mm. Hg.	mm. Hg.	mm. Hg.
Oxygen	158.25	116.2	101.2
Carbon Dioxide	0.30	28.5	40.0
Nitrogen	586.45	568.3	571.8
Water Vapor	5.00*	47.0	47.0
TOTAL	760.00	760.0	760.0

*Variable, according to humidity and temperature of inspired air.

TABLE 1–1.—*Partial pressures of gases in lung air.* (*These are average figures for a man breathing air at surface. Expired air contains more oxygen and less carbon dioxide than alveolar air because it includes fresh air from respiratory dead space. At depth, carbon dioxide and water vapor pressures remain about the same, whereas others increase in proportion to absolute pressure.*)

sures are 100 mm. Hg for oxygen, 40 mm. for carbon dioxide, 47 mm. for water vapor and 570 mm. for nitrogen. When this arterial blood passes through the capillary network surrounding the cells in the body tissues, it is exposed to and equalizes itself with the gas pressures of the tissues. Some of the blood's oxygen is consumed by the cells, and carbon dioxide is picked up from these cells. Nitrogen and water vapor, being inert, remain unchanged. The partial pressures of oxygen and carbon dioxide differ between the arterial and venous blood as shown in table 1–2. Note that blood of arterial quality is carried from the lungs to the heart in the pulmonary *veins* and blood of venous quality is carried from the heart to the lungs in the pulmonary *arteries.* (Hereafter in this discussion, the terms arterial and venous will refer to the quality of the blood and not to the kind of vessel through which it is passing.) The values shown in table 1–2 for venous blood represent the approximate partial pressures of gas present within the tissue cells when our bodies are exposed to air at atmospheric pressure. When the venous blood returns to the pulmonary capillaries and becomes exposed to the alveolar air, it becomes arterial blood. Equalization of the partial pressures of gases between the blood and the alveolar air again takes place. Carbon dioxide diffuses from the blood into the alveolar air, lowering its pressure from 46 mm. (venous) to 40 mm. (arterial), and oxygen is absorbed by the blood from the alveolar air, increasing its pressure from 40 mm. (venous) to 100 mm. (arterial). With each complete round of circulation, which normally requires about 20 seconds, this process of gas exchange between lung air and the tissues thus takes place through the medium of the blood.

Control of breathing

(6) When a man works, the amount of oxygen he consumes increases markedly, and so does the amount of carbon dioxide he produces. The amount of blood being pumped through the tissues and the lungs per minute increases in proportion to the rate at which these gases must be transported. As a result, more oxygen is taken up from the alveolar air, and more carbon dioxide is delivered to the lungs for disposal. To keep the blood levels where they belong, the *respiratory minute volume* (and hence the *net alveolar ventilation*) must also change in proportion to the man's oxygen consumption and carbon dioxide output. Breathing is controlled by two types of sensing devices (which are part of the nervous system) and by certain other mechanisms. As a result of the regulatory process and the adjustments they bring about, the arterial blood leaving the lungs usually has about the same oxygen and carbon dioxide levels during work that it did during rest. The maximum "pumping capacity" of a man's heart and respiratory system largely determines the amount of work he can do.

(*a*) The *respiratory center*, a part of the brain itself, is sensitive to the tension of carbon dioxide in the blood. If the tension is

Gas	Gas Tension or Partial Pressure	
	Arterial Blood	Venous Blood
Oxygen	**100 mm. Hg.**	**40 mm. Hg.**
Carbon Dioxide	**40 mm. Hg.**	**46 mm. Hg.**
Water Vapor	**47 mm. Hg.**	**47 mm. Hg.**
Nitrogen	**570 mm. Hg.**	**570 mm. Hg.**
TOTAL	**757 mm. Hg.**	**703 mm. Hg.**

TABLE 1–2.—*Partial pressures of gases dissolved in arterial and venous blood.*

too high, the center causes breathing to increase until the normal level is restored. This mechanism is the main one which controls breathing under ordinary conditions.

(*b*) Sensers called *chemoreceptors* are attached to important arteries. The most important ones are the *carotid bodies* (in the neck) and the *aortic bodies* (near the heart). These chemoreceptors are sensitive mainly to the tension of oxygen in the blood; and when it gets too low, they send impulses to the respiratory center to increase breathing. Low oxygen tension alone does not generally increase breathing markedly until dangerous levels are reached. However, the part played by the chemoreceptors is evident even in such a near normal process as breathholding. (See 1.3.5(41).)

(*c*) Factors such as physical exertion itself influence breathing to an extent not completely explained by the systems just described. Other mechanisms which are less well understood also help regulate breathing, and there are several things about the control of breathing under diving conditions which are simply not known.

Respiratory quantities

(7) There are many situations in diving in which it is important to have an idea of the amount of oxygen a diver is consuming, how much carbon dioxide he is producing, or how much air he needs to ventilate his lungs or his helmet. These factors come into play in determining the adequacy of an air supply for surface-supplied diving, and they are especially important in scuba diving where the diver must carry his breathing medium with him and may or may not be able to carry enough to do a certain job. In "mixed gas" apparatus, the probable oxygen consumption is a large

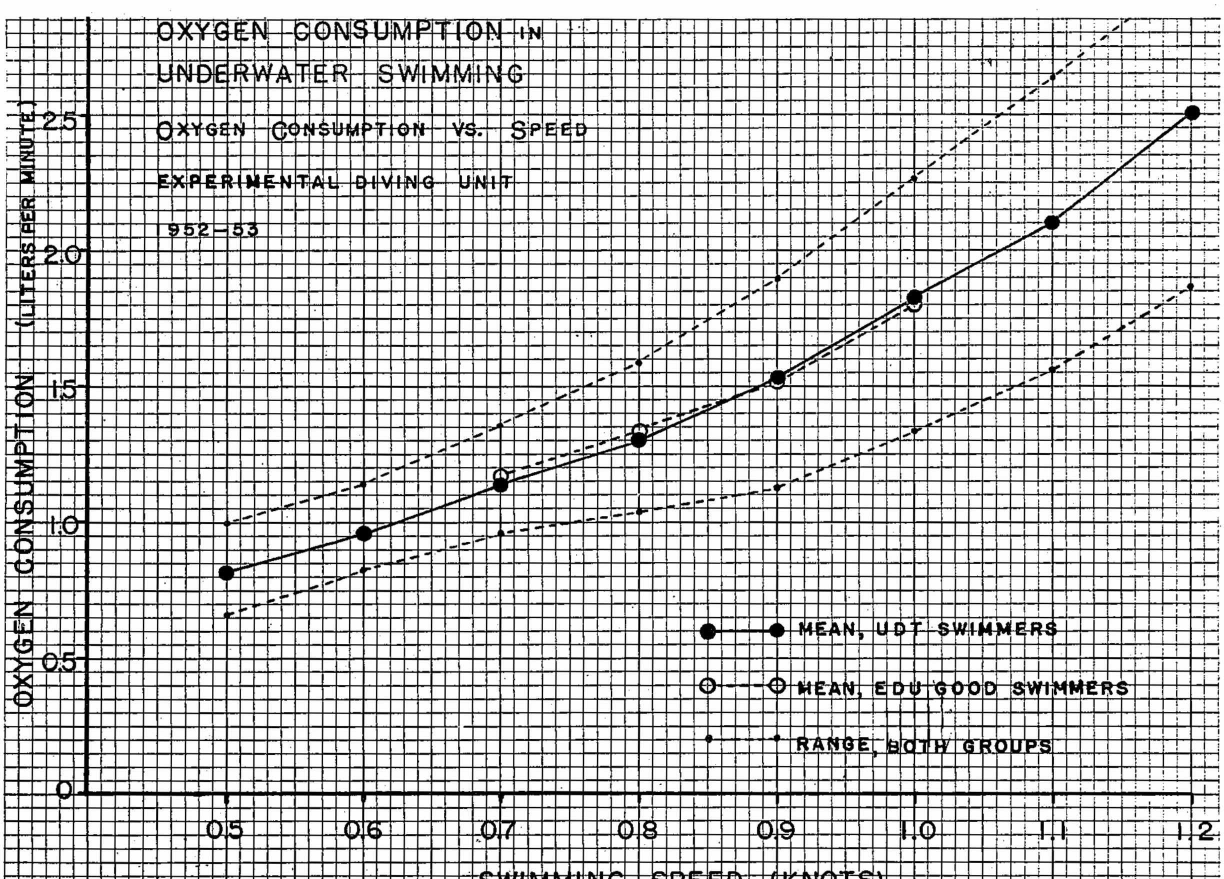


FIGURE 1–26.—Oxygen consumption during underwater swimming.

factor in determining the mixture to be used, the flow rate to provide, and what the diver can do. (See 3.6.5.) It is seldom possible to measure these quantities during a regular dive or to make precise predictions, but a satisfactory estimate can usually be made by referring to data from experimental studies if the nature of a job is known.

(8) The amount of work a man is doing is the main thing that determines the respiratory quantities. A man's oxygen consumption is one of the best indications of his work rate, and the other factors are closely related to it. Table 1–3 gives some comparisons of average oxygen consumption and RMV at various levels of activity on land and underwater. Figure 1–26 gives the results of a study in which oxygen consumption was measured during underwater swimming at various speeds. Notice that with the body at complete rest, a man of average size consumes about 0.25 liter of oxygen each minute to maintain body functions. Just standing around requires about twice this much while light work requires three or four times this amount. A moderate work rate which can be maintained for quite a while by a man in good condition may require up to 2 liters of oxygen per minute. An oxygen consumption rate of 3 liters per minute represents exhausting work for an average man, but a man in excellent condition can consume as much as 4 liters per minute for a short time

TABLE 1–3.—*Oxygen consumption and respiratory minute volume at different work-rates*

Activity [1]		Oxygen consumption [2] in liters/min.[3] (STPD)[4]	Respiratory minute volume [5] liters [3] (BTPS)[6]
REST	Bed rest (basal)	0. 25	6
	Sitting quietly	. 30	7
	Standing still	. 40	9
LIGHT WORK	**Slow walking on hard bottom**	0. 6	13
	Walking, 2 mph	. 7	16
	Swimming, 0.5 knot (slow)	. 8	18
MODERATE WORK	**Slow walking on mud bottom**	1. 1	23
	Walking, 4 mph	1. 2	27
	Swimming, 0.85 knot (av. speed)	1. 4	30
	Max. walking speed, hard bottom	1. 5	34
HEAVY WORK	**Swimming, 1.0 knot**	1. 8	40
	Max. walking speed, mud bottom	1. 8	40
	Running, 8 mph	2. 0	50
SEVERE WORK	**Swimming, 1.2 knots**	2. 5	60
	Uphill running	4. 0	95

NOTES

[1] Underwater activities are in heavy type.

[2] All figures are average values. There is considerable variation between individuals. (See fig. 1–26 for range found in underwater swimming.)

[3] One liter equals approximately one quart.

[4] STPD means standard conditions (see 1.3.4(10)).

[5] The RMV values are approximate for the corresponding oxygen consumption. Individual variations are large.

[6] BTPS means body temperature, existing barometric pressure, saturated with water vapor at body temperature.

(10–15 minutes). A top grade athlete might maintain an oxygen consumption of 5 liters per minute briefly.

(9) Every man's ability to work has a definite top limit because his blood and air pumps have a maximum capacity, and this limits the amount of oxygen he can obtain for his body cells. Anything which makes it harder for a man to breathe (see 1.3.5(24)) or decreases the effectiveness of his breathing (see 1.3.5(35)) will further limit his capacity for work. To permit a man to exceed his normal limits in an emergency, the body has means of letting muscles work for a short time without adequate oxygen. This is called building up an "oxygen debt." The extent to which this can be done is limited, and the required amount of oxygen has to be consumed later; but this ability can save a man's life. The better athlete a man is, the larger the oxygen debt he can build up and the harder he can work in an emergency.

(10) The *number of oxygen molecules* a diver consumes per minute is not influenced by his depth although the *volume* of the oxygen concerned follows Boyle's law. A diver who is working hard enough to consume 2 liters of oxygen per minute at the surface would only consume 1 liter as measured at 33 feet; but the number of molecules he used would remain the same. If he were using a closed-circuit oxygen rebreathing apparatus (see 3.5.0), his oxygen consumption would, therefore, deplete the supply cylinder at the same rate regardless of his depth. To permit accurate comparisons, oxygen consumption should be expressed in terms of volumes as measured under *standard conditions* at the surface (zero degrees centigrade, 760 mm. Hg barometric pressure, and dry gas). The abbreviation "STPD" indicates these conditions.

Carbon dioxide output

(11) The production of carbon dioxide closely follows the consumption of oxygen. For every liter of oxygen consumed, a man will normally produce close to a liter of carbon dioxide. As with oxygen consumption, the number of molecules involved does not change with depth. The ratio between the amount of carbon dioxide produced and the amount of oxygen consumed is called the *respiratory quotient.* This can range from 0.7 to 1.0, depending on a man's diet and how hard he is working. The average value for a working diver is about 0.9. This means that nine-tenths of a liter of carbon dioxide is produced for every liter of oxygen consumed.

Volumes of breathing

(12) The amount of air a man must move in and out of his lungs depends upon the amount of oxygen he must take in and the amount of carbon dioxide he must lose in order to maintain the normal levels of those gases in his body. Consequently, the volume of his breathing is closely related to his oxygen consumption and his carbon dioxide production. At the surface, the RMV is normally slightly over 20 times the oxygen consumption. This ties in with the fact that expired air contains roughly 5 percent less oxygen and 5 percent more carbon dioxide than inspired air. As shown in table 1–3, the RMV can range from about 6 liters at rest to 100 or more during very severe exertion.

(13) Under normal conditions at the surface, and especially under usual diving conditions where the partial pressure of oxygen is increased by compression of more molecules into the same volume of air, we breathe mainly to eliminate excess carbon dioxide. If we succeed in doing this, an ample supply of oxygen is generally assured. The actual *volume* of air required to eliminate carbon dioxide and keep the body's carbon dioxide tensions at a certain level does not change noticeably with depth. A man who is doing the same amount of work and holding the same arterial carbon dioxide tension will, therefore, have almost exactly the same RMV—in terms of volume as measured at his depth—regardless of how deep he goes. Because of the compression of gas, this means that the number of molecules of air (and the volume as measured at the surface) increase in proportion to the absolute pressure. This is why a demand apparatus cylinder which suffices for an hour at a certain work rate at the surface may last only about 30 minutes at

33 feet or 15 minutes at 99 feet. If a man's actual lung ventilation does decrease at depth, this means that he has either reduced his carbon dioxide production by slackening his work rate or has allowed his carbon dioxide tension to rise. (See 1.3.5(13).)

Ventilation of the lungs

(14) The relationships between carbon dioxide production and ventilation are important enough to deserve further consideration. They apply to numerous questions about breathing, breathing apparatus, and the ventilation of diving helmets.

(15) Actually, the body strives not so much to get rid of carbon dioxide as it strives to maintain the proper tension of that gas in the arterial blood and throughout the system. Losing too much carbon dioxide by overbreathing (hyperventilation (see 1.3.5(45)) can upset the function of the body as badly as retaining an excess of that gas (see 1.3.5 (10)). As has been previously explained, the normal tension of carbon dioxide in the arterial blood is about 40 mm. Hg. Since arterial blood and alveolar gas are in equilibrium with each other as far as carbon dioxide is concerned, the arterial tension depends on the alveolar partial pressure of that gas; and this must, therefore, be kept at about 40 mm. Hg. What 40 mm. Hg represents in terms of percentage depends upon the absolute pressure, so the percentage of carbon dioxide in the alveoli must decrease with increasing depth.

NOTE

The effects of carbon dioxide depend upon the *partial pressure* of that gas. Therefore, for example, breathing 1 percent carbon dioxide at 132 feet (5 atm. abs.) will have the same effect on a diver as if he were breathing 5 percent carbon dioxide at the surface (1 atm. abs.). *This is true because the partial pressure of carbon dioxide is the same in both cases.* Since it is customary to think of carbon dioxide and its effects in terms of percentages at the surface, the term *surface equivalent percentage* is often used. In the foregoing example, you could say that the "surface equivalent" of 1 percent carbon dioxide at 132 feet is 5 percent carbon dioxide. Six percent would be the "surface equivalent" of 2 percent carbon dioxide at 66 feet (3 atm. abs.) or of 3 percent carbon dioxide at 33 feet (2 atm. abs.), and so on.

(16) At the surface, the total pressure is 1 atm. or 760 mm. Hg. The water vapor tension at lung temperature is 47 mm. Hg. This leaves $760-47=713$ mm. Hg as the total *gas* pressure. Carbon dioxide must account for about 40/713, or 5.6 percent of the gas pressure; therefore, enough gas must be brought in by alveolar ventilation to make up the remaining 94.4 percent of the gas pressure and volume. If the body is producing 2 liters of carbon dioxide per minute (volume as measured at lung temperature) and delivering this amount to the alveoli, the total volume of gas brought into the alveoli each minute *must* be such that 2 liters equals 5.6 percent of it. Knowing this, it is easy to calculate what the total gas volume of alveolar ventilation must be. *One* percent of the volume would be $\frac{2 \text{ liters}}{5.6}$ or about 0.36 liters; and the total must be 100 times that, or 36 liters. Under these conditions, if breathing brings 36 liters of fresh air *into* the alveoli in a minute, oxygen consumption will remove about 2 liters of oxygen, 2 liters of carbon dioxide will be added, and the *exhaled* volume of alveolar gas will also be about 36 liters. (Note that this figure does not represent the total lung ventilation. Dead space ventilation must be added. See example (*c*) in paragraph 20 of this article.)

(17) At depth, the *partial pressure* of carbon dioxide in the alveoli must still remain at about 40 mm. Hg. At 4 atm. (99 feet), the total pressure will be $760 \times 4 = 3{,}040$ mm. Hg. Again subtracting the water vapor tension of 47 mm. Hg, the total *gas* pressure is $3{,}040-47 = 2{,}993$ mm. Hg. The alveolar percentage of carbon dioxide is now only $\frac{40}{2993}$, or about 1.34 percent. If the diver's carbon dioxide output remains at 2 liters per minute (in terms of volume at the surface), the actual volume of carbon dioxide reaching his alveoli at 99 feet is $2 \div 4 = 0.5$ liter. The volume of fresh air required (measured at the depth) is now $\frac{0.50}{1.34} \times 100 =$ about 37 liters. Were it not for the water vapor factor, the volume would have been exactly what it was at the surface—36 liters. The difference is so small that it can usually be ignored. The question of depth can thus almost always be

neglected in the calculation of lung ventilation, provided that it is understood that the answer represents *volume as measured at the depth concerned.* (Where only *rough* estimates are being made, the water vapor tension and the difference between volumes measured at "STPD" and at "lung temperature," etc. can also be neglected.)

Ventilation of a helmet

(18) The amount of air needed to ventilate a helmet can be estimated in the same way as net alveolar ventilation, and the situation may be easier to visualize. The diver pours carbon dioxide into the helmet at a certain rate, and the supply hose pours air in at a certain rate. The air and the carbon dioxide mix together and come out the exhaust valve. Once a steady situation has been reached, carbon dioxide and air must both leave at the same rate that they enter, so the amount of carbon dioxide coming out in the exhaust every minute is the same as the diver's carbon dioxide production. Since the air and carbon dioxide are mixed in the helmet, the percentage of carbon dioxide in the exhaust is the same as that in the helmet. If the diver is producing 2 liters of carbon dioxide per minute and we wish to keep the carbon dioxide concentration in the helmet at 1 percent, then we must use enough air so that 2 liters equals 1 percent of the total volume coming out the exhaust. The total in this example must therefore be 200 liters. Basically, the situation is the same as in alveolar ventilation. As in that case, the required volume (as measured at depth) is virtually the same, regardless of depth. Observe that neither the volume of the suit and helmet nor the amount of air the diver is breathing need to be considered: only the CO_2 production.

Ventilation formula and examples

(19) The arithmetic involved in the estimation of lung or helmet ventilation can be summed up in one simple formula:

$$V=\frac{C}{D-A}\times 100$$

Where:

V=Volume of ventilation, as measured at depth concerned.
C=Carbon dioxide output, volume as measured at the surface.
D=Desired percentage of carbon dioxide (in alveoli or helmet).
A=Percentage of carbon dioxide in gas used for ventilation.

NOTES

(1) All volumes must be expressed in the same units. For example, if carbon dioxide output is expressed in *liters per minute,* the volume of ventilation will also be in liters per minute.

(2) *Percentage of carbon dioxide* must be expressed as the *surface equivalent* percentage. (See par. 15 of this article.)

(3) The exact conditions of measurement of gas volumes are not specified (temperature, water vapor tension, etc.); but under ordinary conditions, the range of variation of these factors does not produce any serious errors in *rough* estimates.

(4) Rearrangement of the formula permits solving for any one of the variables if the other two are known.

(20) Some of the questions which can be answered by using this formula are illustrated by the following examples:

(*a*) A diver in suit and helmet is doing moderate work and producing 1.2 liters of carbon dioxide per minute. How much CO_2-free air must be used to ventilate his helmet to keep the partial pressure of carbon dioxide from exceeding the equivalent of 1 percent at the surface?

Solution (apply the formula):

$$V=\frac{1.2 \text{ liters}}{1-0}\times 100=120 \text{ liters (about 4.2 cubic feet) per minute}$$

(NOTE.—This is about the volume (4.5 cubic feet) normally allowed for in calculating the air supply for helmet diving. If the diver works harder without greater ventilation, the percentage of carbon dioxide in the helmet must obviously rise. For example, if this diver's carbon dioxide output were doubled, his equivalent helmet percentage would rise to 2 percent, etc. The amount of increase in ventilation required by harder work and the results of failing to increase the ventilation are shown in the next few examples.)

(*b*) How much air would be required to keep the equivalent percentage of CO_2 at 1 percent if the same diver were doing very hard work and producing 3 liters of carbon dioxide per minute?
Solution:

$$V=\frac{3}{1-0}\times 100=300 \text{ liters (about 10.5 cu. ft.) per minute}$$

(*c*) If the diver is producing 1.2 liters of carbon dioxide per minute and breathing the surface-equivalent of 2 percent CO_2 from his helmet, what *net alveolar ventilation* will he require to keep his arterial CO_2 tension at 40 mm. Hg?

Solution: First recall that 40 mm. Hg is equal to 40/713 or 5.6 percent CO_2 in surface terms. Then apply the formula.

$$V=\frac{1.2 \text{ liters}}{5.6-2}\times 100=\frac{1.2}{3.6}\times 100=33.4 \text{ liters}$$
(about 1.2 cu. ft.) per minute

(*d*) What net alveolar ventilation would suffice if the same diver had access to CO_2-free air from a demand apparatus?
Solution:

$$V=\frac{1.2. \text{ liters}}{5.6-0}\times 100=21.4 \text{ liters (about 0.76 cu. ft.) per minute}$$

(NOTE.—The percentage of CO_2 in the inspired air makes a large difference in the volume of breathing required to maintain a normal carbon dioxide level in the body.)

(*e*) What *respiratory minute volume* would this net alveolar ventilation require if the diver's total *dead space* (his own and that in the scuba) were 0.6 liter and his respiratory rate were 20 breaths per minute?
Solution: He must use $0.6\times 20=12$ liters to ventilate his dead space each minute, and this volume must be added to the net alveolar ventilation. His respiratory minute volume is thus $21.4+12=33.4$ liters (about 1.2 cu. ft.).

(*f*) This same diver, working at the same rate with the same demand apparatus, tries hard to save air. He cuts his respiratory rate to 10 breaths per minute and reduces his net alveolar ventilation so much that his arterial CO_2 tension rises to 60 mm. Hg (high enough to produce some symptoms of carbon dioxide intoxication). How much does he save by ventilating the dead space only half as often? How much air does he save altogether?
Solution: By ventilating the 0.6 liter total dead space only 10 times a minute, the diver uses $0.6\times 10=6$ liters per minute for this purpose. This is a saving of 6 liters over his previous rate of 20 breaths per minute. The CO_2 tension of 60 mm. Hg is equivalent to about 8.4 percent of CO_2 in surface terms, neglecting the water vapor tension. Apply the formula to find his approximate net alveolar ventilation.

$$V=\frac{1.2}{8.4-0}\times 100=14.3 \text{ liters per minute}$$

Adding the dead space ventilation of 6 liters, this gives him a respiratory minute volume of 20.3 liters, and the total saving is 13.1 liters. (Note that the saving of air is considerable but that over half of it is at the expense of having a potentially dangerous carbon dioxide level. In a demand apparatus with less dead space, the reduction of respiratory *rate* would have contributed even less to the saving.)

(21) Thinking about the examples above should clear up a number of points about the relationship between a diver's work rate, his breathing, the amount of air required to ventilate his helmet, and the like. Note for example, that a diver using a demand apparatus needs much less air than is required to ventilate a helmet. He draws only an amount equivalent to his respiratory minute volume from the cylinders, while it takes several times that amount to keep carbon dioxide washed out of a helmet adequately. Also, the helmet diver is always receiving at least a small amount of carbon dioxide in his inspired air; and this makes it necessary for him to breathe at least a little more. However, a large dead space in a self-contained apparatus will cancel out most of the gain as far as the diver's breathing is concerned. Saving air by "controlled breathing" involves the danger of excessive carbon dioxide levels in the body. In a closed-circuit or semi-closed apparatus where oxygen is rebreathed through a carbon dioxide absorbent, trying to cut down on the volume of breathing serves no purpose at all. It can-

not change oxygen consumption or carbon dioxide production in the least. It can only lead to a rise in alveolar and arterial carbon dioxide tensions. The effect of absorption failure and CO_2 build up on breathing in such a system is illustrated by example (*c*) in paragraph 20 of this article. If a diver's natural adjustments fail to increase his breathing when there is an increase in either his CO_2 production or the inspired CO_2 level, his body tensions of that gas must rise, and the results can sometimes be serious. (See 1.3.5(12).)

1.3.5 RESPIRATORY PROBLEMS IN DIVING

(1) Many of a diver's physiological problems come about because he is underwater and exposed to the pressures of depth. However, some of the difficulties related to his respiratory processes can occur at any depth or even on dry land. What these conditions have in common is that getting oxygen to the tissue cells or getting carbon dioxide out (or both) is prevented or hindered at some stage. Depth, or the fact of submergence, may modify these problems as the diver faces them, but the basic difficulties remain the same.

Anoxia

(2) The term *anoxia* (or *hypoxia*, which has about the same meaning) is applied to any situation in which the tissue cells are failing to receive or utilize enough oxygen to maintain their life and normal function. The many steps in the path of oxygen from the atmosphere to its metabolic use by a tissue cell have been mentioned. (See 1.3.2(4).) Anoxia can result from interference with any phase of the process; so, there are many possible causes of anoxia and many situations in which it can develop. However, only a few of these are of much importance in diving.

(3) One of the most obvious causes of anoxia is lack of anything to breathe, as when a scuba diver loses his mask or mouthpiece and is exposed directly to the water, or when his air supply fails completely. In other situations, there may be enough "air" to move in and out of the lungs but not enough oxygen available in this air. This condition can develop if a man is shut up in a closed space, in a burning building where oxygen is consumed by fire or displaced by smoke, in a closed compartment where the oxidation of fresh paint or deteriorating stores has used up the oxygen, and in many similar situations. The same sort of thing can happen in a poorly purged closed-circuit or rescue-breathing appliance which contains enough nitrogen to permit continued breathing but in which the oxygen is consumed without adequate replacement. A continuous-flow semiclosed circuit apparatus (see 3.6.6) will produce anoxia for the same reason if the flow of oxygen-bearing gas mixture ceases or falls off appreciably. Situations of this sort are the most serious causes of anoxia in diving.

(4) Anoxia will stop the normal function of *any* tissue cell in the body and will eventually kill it, but the cells of brain tissue are by far the most susceptible to its effects. Unconsciousness and death can occur from brain anoxia before the effects on other tissues become very prominent. Unconsciousness will develop almost at once in sudden, severe anoxia. But, if anoxia is less severe or develops gradually, other symptoms of interference with brain function will appear. The "higher functions" are the first to be affected, just as they are in alcoholic intoxication. The ability to concentrate and think clearly, fine control of the muscles, and the ability to perform delicate or skill-requiring tasks are decreased at an early stage. Confusion, faulty judgment, emotional instability, real interference with muscle function, and difficulty in standing and walking will follow. The victim of anoxia is usually unable to understand that he is in trouble or to be concerned about his condition. In fact, he may have the sensation of "feeling better and better" while drousiness and weakness increase and consciousness is finally lost. In this respect, gradually developing anoxia is very much like intoxication with alcohol.

(5) When anoxia develops, pulse rate and blood pressure increase as the body tries to offset the anoxia by pumping more blood, and a small increase in breathing may also occur. However, none of these reactions are sufficient to serve as warnings, and very few individuals

are able to recognize the mental effects of anoxia in time to take effective action. Blueness (cyanosis) of the lips, nailbeds, and skin develops when the hemoglobin in the blood is unable to take up oxygen and regain its red color on going through the lungs. However, this blueness is of no value as a warning sign to a diver and is seldom a *reliable* indicator of anoxia even for a trained observer on dry land. The truth of the matter is that there is *no* natural warning by which a man can be sure of detecting the onset of anoxia. It is the "sneaky" nature of anoxia which makes it a particularly serious hazard in any situation where it can develop without other warnings. A diver who loses his air supply is in danger from anoxia, but he knows he is in trouble and usually has time to do something about it. He is much more fortunate than the man who steps into an oxygen-depleted atmosphere or who gradually uses up the oxygen in a rebreathing rig which contains an excess of nitrogen.

(6) It is the *partial pressure* of oxygen which determines whether the amount of oxygen in a breathing medium is adequate or not. For example, air contains about 21 percent oxygen and thus provides an oxygen partial pressure of about 0.21 atm. (0.21×1 atm. $= 0.21$ atm.). This is ample, but a drop to 0.16 atm. (16 percent oxygen at the surface) will cause the onset of anoxic symptoms. If the oxygen partial pressure goes as low as 0.12 atm. (12 percent at surface), most individuals will become anoxic to the point of being nearly helpless. Consciousness is usually lost at about 0.10 atm. (10 percent at surface), and much below this level, permanent brain damage and death are only a matter of time. If the total pressure is low, as at high altitude, 21 percent oxygen will not be adequate. In diving, a lower percentage will suffice as long as the depth pressure is sufficient to maintain an adequate partial pressure of oxygen. For example, 5 percent oxygen should be enough if the diver is at 100 feet (5 percent oxygen $\times 4$ atm. $= 0.20$ atm. partial pressure of oxygen); but ascent would rapidly render him anoxic unless the oxygen percentage were increased.

(7) If a man suffering from severe anoxia is not rescued promptly, the interference with brain function will produce not only unconsciousness but also failure of the centers which produce breathing. The heart usually continues beating for a time beyond this point. If the victim is given fresh air before his breathing stops, he will usually regain consciousness shortly and recover completely. If breathing has stopped but heart action continues, artificial respiration may succeed in getting enough oxygen to the brain to revive the respiratory center so that spontaneous breathing will resume in time. In such a case, there may already be serious damage to the higher centers; but even in these cases almost complete recovery of normal function may eventually occur. If heart action has ceased, there is little hope of reviving the victim by the usual methods. However, it is very difficult to be certain that the heart has stopped completely, so efforts at resuscitation must be continued until the victim is pronounced dead by a medical officer. Occasionally, a man whose heart has stopped can be restored to life if his chest is opened promptly and the heart's pumping action is accomplished by hand (*cardiac massage*). This operation should be attempted only by a medical officer, and unless it can be done almost at once following the stoppage, the chances of revival are extremely small.

Carbon dioxide excess

(8) An excess of carbon dioxide in the tissues (sometimes called hypercapnia) can be caused by anything which interferes with any step of the normal process of carbon dioxide transport and elimination. It can thus have many different causes. In diving, carbon dioxide excess usually occurs either because of an abnormal amount of the gas in what a man is breathing or because something keeps him from breathing enough to get rid of the carbon dioxide his body is producing. The effects of carbon dioxide in the body depend upon the tension (partial pressure) of the gas. When there is carbon dioxide in the inspired air, both the concentration (percentage) and the total pressure therefore must be considered.

For example, two percent carbon dioxide breathed at 132 feet (5 atm. abs.) will have the same physiological effect as 10 percent carbon dioxide breathed at the surface.

(9) The amount of carbon dioxide in fresh air is very small (only about 0.04 percent). The gas is produced by oxidation and can thus be found in much larger concentrations in the presence of a fire, in closed spaces under certain conditions, in engine exhaust, and the like. In most of these situations, either lack of oxygen or the presence of carbon monoxide is a more serious problem. The use of carbon dioxide fire extinguishers is a special situation in which carbon dioxide from an external source can be a problem. Under most circumstances in diving, the source of excess carbon dioxide is a man's own metabolic precesses. To maintain the proper level of carbon dioxide in his body, a man must breathe enough to dilute the carbon dioxide which is being produced and delivered to his lungs; and if breathing is to be effective, the air available for breathing can contain only a small amount of carbon dioxide. Inadequate ventilation of the helmet, failure of the carbon dioxide absorption system in a closed-circuit rig, and such circumstances may lead to an excess of carbon dioxide in the inspired gas. The relationships between carbon dioxide output, lung ventilation, helmet ventilation, and the like have been discussed in 1.3.4(12–21).

(10) An excess of carbon dioxide in the body causes several different reactions. The most important ones in diving are those which affect the *brain*. In carbon dioxide excess, as in anoxia, all tissues are affected; but brain tissue is the most susceptible. In several ways, the effects on brain function are similar to those of anoxia. Confusion, loss of ability to think clearly, drowsiness, and such effects become more severe as the degree of excess increases. A man who breathes as much as 10 percent carbon dioxide will generally lose consciousness. Around 15 percent and above, muscular spasms and rigidity occur. Permanent brain damage and death are much less likely than in the case of anoxia. If a diver loses consciousness solely because of excess carbon dioxide in his breathing medium and does not drown, he generally revives rapidly when given fresh air. He will usually be quite normal within 15 minutes, and the aftereffects rarely include more than symptoms like headache, nausea, or dizziness.

(11) An increase in the tension of carbon dioxide in the body normally affects the *respiratory center* in the brain to produce an increase in breathing, mainly an increase in the tidal volume. This is the body's attempt to bring the carbon dioxide tension back toward a normal level. If the condition is caused by carbon dioxide in the inspired gas, the increase in breathing will be roughly proportional to the concentration of carbon dioxide. At the surface, an inspired concentration of 2 percent will generally produce a measurable increase in respiratory minute volume, but the change is seldom large enough to be noticed by the diver. With 5 percent carbon dioxide, the increase is almost always sufficient to produce an uncomfortable sensation of panting and shortness of breath. However, there are large differences between individuals in the way their breathing reacts to carbon dioxide; and the amount of work a diver is doing, his depth, and his breathing medium also can influence the extent to which carbon dioxide will alter his breathing. At what point a man will *become aware* of an increase in his breathing also varies with his own characteristics, what he is doing, and similar factors.

Shallow water blackout

(12) Ordinarily, increased breathing is definite and uncomfortable enough to warn a diver before the concentration of carbon dioxide becomes very dangerous from the standpoint of brain effects. In some individuals under certain conditions, however, the increase in breathing may not be great enough to serve as a warning; and if the carbon dioxide level continues to rise, it may reach the point of causing unconsciousness. None of the *other* effects of carbon dioxide are reliable as warnings, so a subnormal respiratory reaction can make carbon dioxide excess as "sneaky" a hazard as anoxia. In addition, a diver who notices an increase in his breathing but fails to

take effective action promptly may soon become unable to help himself. Accidents in which a diver loses consciousness, presumably from carbon dioxide excess without an adequate respiratory warning, are called *shallow water blackout*.

(13) Another aspect of an insufficient respiratory response to carbon dioxide is the possibility that a man can, in effect, poison himself. This can happen if a man does not breathe enough to eliminate as much carbon dioxide as he is producing. A number of accidents in which divers have lost consciousness underwater for no apparent reason have been explained on this basis. Deliberately cutting down on breathing to save air in the use of open-circuit scuba is accomplished successfully by many divers but may be hazardous for some individuals. Restraint of the desire to breathe must not be overdone. Conditions which seem to make "self-poisoning" with carbon dioxide more likely include unusual exertion, high partial pressures of oxygen, greater depths, and certain defects of breathing apparatus such as excessive dead space (see 1.3.5(35)) and high breathing resistance (see 1.3.5(24)).

Other effects of carbon dioxide

(14) Abnormally high carbon dioxide tensions in the body not only alter brain function and breathing but also produce several other effects. Blood pressure and heart rate (pulse) are increased. If the exposure to carbon dioxide is ended abruptly, there is occasionally a brief drop in blood pressure which is sufficient to cause fainting. Carbon dioxide excess also dilates the arteries of the brain. This may help explain the headaches often associated with carbon dioxide poisoning, but these are more likely to occur following the exposure than during it. It is believed that the great increase in blood flow through the brain which results from dilation of the arteries explains why carbon dioxide excess speeds the onset of oxygen poisoning. (See 1.3.11(15).) Excess carbon dioxide during a dive is also believed to increase the likelihood of decompression sickness, but the reasons are less clear. Unfortunately, effects like changes in pulse and blood pressure are of no value as warnings to the diver. Others, like headache, unusual sweating, fatigue, and a general feeling of discomfort, may warn a diver if they occur and are recognized; but they are not very reliable as warnings.

Asphyxia, Suffocation, Strangulation

(15) The term *asphyxia* indicates the existence of *both* anoxia and carbon dioxide excess in the body. It will result from cessation of breathing or serious interference with breathing from any cause. Breathing an atmosphere which is both low in oxygen and high in carbon dioxide will also produce it. In many situations, carbon dioxide excess or anoxia occur separately, so the more specific terms should be used where possible. However, if anoxia is severe or prolonged enough to stop a man's breathing, carbon dioxide excess will rapidly develop, and the condition will then be true asphyxia. The term *suffocation* is sometimes used to indicate cessation of breathing from any cause or the asphyxia that results.

(16) *Strangulation* indicates a choking or throttling stoppage of breathing due to obstruction of a man's airway. This can be the result of such mishaps as a crushing injury to the windpipe, lodgment of an inhaled object like a cud of gum or a false tooth, spasm of the larynx, marked swelling of the lining of the air passages, the tongue falling back into the throat of an unconscious man, or the inhalation of water, saliva, or vomitus. A victim of strangulation will generally struggle violently, trying to breathe in spite of the partial or total obstruction. This struggle may continue even after he has lost consciousness from asphyxia. But when the asphyxia reaches a certain point, the attempts to breathe will cease. The possibility of strangulation must be, therefore, considered in any individual who is unconscious and not breathing. Artificial respiration will produce little or no movement of air in the presence of strangulation. Therefore, checking the freedom of the airway as thoroughly as possible is one of the very first steps in resuscitation. The possibility of strangulation is also the main reason

for keeping the victim's face down so that the tongue will fall forward and fluids can drain from the mouth. If it is evident that strangulation exists and that the victim cannot be relieved promptly by any other means, making an opening in the middle of the trachea (windpipe) below the larynx (voice box) may be the only way to save the man's life. This operation is called *emergency tracheotomy.* It can be performed with a penknife. The chance of doing harm in the process is not great when compared to the certainty of death when strangulation is unrelieved. (The incision is made in the midline of the neck (not across), 2 finger-breadths below the point of the Adams apple. At least one ring of cartilage in the windpipe must be cut through to make a satisfactory opening, and the opening must be held open.)

Carbon monoxide poisoning

(17) *Circumstances:* The presence of carbon monoxide (CO) (see 1.2.3(8)) in a diver's air supply is a serious potential danger. Possible sources, methods of analysis, safe limits, and methods of removal are discussed in articles 1.10.9 and 1.10.10.

(18) *Mechanism:* Carbon monoxide causes its harmful effects by combining with the hemoglobin in the red cells of the blood and rendering it incapable of carrying oxygen to the tissues. When this has happened, tissue anoxia develops even though the supply of oxygen to the lungs is ample and the arterial oxygen *tension* remains high. Hemoglobin takes up carbon monoxide about 200 times as readily as it does oxygen. This is why very small concentrations of CO can be very dangerous. In spite of the displacement of oxygen, hemoglobin combined with CO has a bright red color. As a result, a man who is anoxic because of carbon monoxide poisoning does not show the cyanosis (blueness) often seen in other types of anoxia. In fact, sometimes victims of CO poisoning can easily be recognized as such because of the unnatural redness of the lips, nail beds, and sometimes of the skin.

(19) *Symptoms:* Because anoxia is the basic difficulty in carbon monoxide poisoning, the symptoms are almost identical to those of other types of anxoia. (See 1.3.5(4).) The greatest danger is that unconsciousness can occur without reliable warning signs. When the concentration of carbon monoxide is high enough to cause rapid onset of poisoning, the victim may not even be aware of weakness, dizziness, or confusion before he succumbs. When development of toxicity is more gradual, symptoms like tightness across the forehead, headache and pounding at the temples, or nausea and vomiting may be noted in some cases. If these occur and are recognized as warnings, prompt action may save a man's life; but they cannot be depended upon.

(20) As in the case of anoxia because of low oxygen concentration in the breathing mixture, being at depth may tend to offset the effects of carbon monoxide poisoning to some extent. The greater partial pressure of oxygen in air breathed at depth will force more oxygen into simple solution in the blood and compensate somewhat for the loss of hemoglobin's ability to carry oxygen to the tissues. Prominent effects of carbon monoxide, therefore, might not appear in a diver until he tries to come up. This adds to the treacherous nature of carbon monoxide poisoning and further emphasizes the importance of *prevention.*

(21) *Treatment:* The first step in treating carbon monoxide poisoning is to get the victim into fresh air. If he is not breathing, artificial respiration must be started at once. If oxygen is available, it should be given as soon as possible. The administration of oxygen increases the amount of oxygen which reaches the tissues in spite of the inactivated hemoglobin, and it also greatly increases the rate at which the hemoglobin is freed of carbon monoxide and returned to its active state. If adequate ventilation of the lungs is maintained, breathing carbon monoxide-free air will eliminate most of the carbon monoxide from the blood in a few hours. With oxygen breathing, the majority of the hemoglobin will be reconverted in 30 to 90 minutes. Use of an oxygen-carbon dioxide mixture has been thought to speed the process even further, but its practical value is now considered questionable.

(22) All of the considerations related to unconsciousness and resuscitation must be observed. (See 1.6.4.) This includes evaluating the possibility that another accident or injury may have occurred in addition to carbon monoxide. Often, recompression will be warranted simply because air embolism and cerebral decompression sickness cannot be ruled out in an unconscious diver. There is no objection to recompression of a carbon monoxide poisoned diver. As a matter of fact, administration of oxygen at a safe pressure in the chamber has been shown to be of great value in carbon monoxide poisoning. However, the defect of blood oxygen transport *does not* eliminate the possibility of oxygen poisoning. Therefore, the same limits of oxygen exposure as used in the treatment tables must be observed. (Neither oxygen inhalation nor the use of an oxygen-operated resuscitator is safe deeper than 60 feet or for longer than 30 minutes at that depth.) At deeper depths, the increased oxygen partial pressure of the air itself should be of considerable help in getting more oxygen to the tissues and hastening the elimination of carbon monoxide.

(23) If a victim of carbon monoxide poisoning resumes breathing and regains consciousness after a reasonably short period of treatment, the chances of complete recovery are good. The outcome is not so favorable if he remains in a coma for an extended period. This may indicate that considerable brain damage has occurred.

Excessive resistance to breathing

(24) Breathing requires work even under normal conditions. Just as there are limits to the amount of any kind of work a man can do, there are limits to his ability to do the *work of breathing*. When a man exerts himself physically, his breathing must increase. If his work of breathing reaches its limits in the process, he also reaches the limit of his ability to do physical work. If a disease process either increases the work of breathing or decreases the ability to do that work, a man will find that his work capacity is also limited. For example, a patient with severe asthma may have to work so hard to breathe that all he has strength to do is lie in bed and struggle for each breath.

(25) Any breathing appliance is bound to increase the work of breathing to some extent. One which has high *breathing resistance* may increase it so much that adequate breathing is difficult even during ordinary exertion and impossible during hard work. Such an apparatus would not only be unpleasant to use but could endanger a man's life in a situation which required exceptionally hard work. Breathing resistance of the gear is not a problem in helmet-type diving equipment, but it is an important consideration in all of the usual types of self-contained breathing circuits.

(26) In a man's own respiratory system and in breathing appliances used on dry land, much of the work of breathing goes into moving air through the various air passages. *Airway resistance* is likewise a highly important factor in self-contained equipment. In demand type units, the demand regulator itself may be a serious "bottleneck" if it is not well designed and properly maintained. The resistance from this source will become worse with increasing depth because the compression of the air requires more and more molecules to pass through the small openings in the regulator with each breath. In any type of self-contained apparatus, restrictions in the breathing tubes, valves, or other components will cause resistance. Any abrupt changes in diameter of the passages, any projections into the air stream, or any sharp changes in direction of flow will add to the difficulty by producing *turbulent* flow. When turbulence is present, the density of the breathing medium becomes a very important factor in resistance. For this reason, the resistance of a badly designed system will increase markedly with increasing depth and increasing compression of the gas. The same sort of changes take place to some extent even in a man's own airways, so an increase in breathing resistance may be noticeable at greater depths even in a helmet or in a dry recompression chamber without any breathing appliance.

(27) In diving equipment, the fact of being underwater at any depth introduces another

factor which influences breathing resistance. Every suit-and-helmet diver knows that he cannot expand his chest against the outside water pressure unless he keeps his suit somewhat inflated nearly to the waist. If he does not, he is in much the same condition as a man who tries to breathe through an overlong "snorkel" tube. In that case, the air in the lungs is at surface pressure and thus does not balance the pressure of the water outside the chest. Even at 2 or 3 feet of depth, the unbalanced outside pressure is enough to prevent full expansion of the chest by the inspiratory muscles. The same difficulty arises if a man holds a demand valve or breathing bag over his head when under water and tries to inhale from it. If such a procedure is carried to extremes, the unbalanced *hydrostatic* pressure not only prevents inhalation but also introduces the risk of *thoracic squeeze*. (See 1.3.7(6).)

(28) Unbalanced hydrostatic pressure is a source of considerable breathing resistance even in more usual situations underwater. It is difficult to locate demand valves, exhaust valves, breathing bags, and the like so that lung pressure and the external pressure on the chest are exactly balanced. The ideal position for these components apparently would be at the *suprasternal notch* (the notch at the top of the breastbone), but this location is seldom practical. If a man is swimming horizontally with a type of open circuit scuba that places the demand valve at the back of his neck, this means that the demand valve diaphragm is at least 6 inches higher than the optimal point. In order to get air on inspiration, the man must therefore develop a negative pressure of at least 6 inches of water in his respiratory tract to overcome the hydrostatic imbalance. This is in addition to the negative pressure required to open the valve and overcome the airway resistance. About the same thing would be true if he were wearing the breathing bag of a closed circuit rig on his back. A demand valve or breathing bag located *below* the optimum point would have the opposite effect; the diver would have to develop an extra amount of positive pressure in his lungs in order to exhale. Up to a certain point, the body can accommodate itself to such effects of unbalanced hydrostatic pressure without apparent ill-effects or great discomfort.

(29) Even if the various types of breathing resistance do not add up to more *work of breathing* than a diver can do, he is less comfortable and less effective in his work than he would be with a more ideal system. In addition, the respiratory muscles become fatigued just as other muscles do; and the amount of resistance they can overcome decreases with time. A unit that is usable for a short dive may not be satisfactory for a long one if much work is required. One of the most important things to realize is that the compression and increased density of air makes the breathing resistance of almost any scuba increase considerably with depth. A unit which seems good enough close to the surface may prove to be almost unusable at depth. All these factors are carefully considered in the evaluation of equipment for Navy use, but even the best units available leave room for improvement.

(30) Except in an extreme emergency, a man is not likely to breathe against resistance high enough to do serious damage to his lungs. Generally, soreness of the respiratory muscles is the only prominent after-effect of a dive with gear which has poor breathing characteristics. The limitation of the amount of work a man can do is usually the most serious aspect of excessive resistance. However, one additional factor should be mentioned. As the work of breathing increases, the body appears to reach a point at which it will accept a rising arterial carbon dioxide tension rather than do all the respiratory work required to keep the carbon dioxide tension down. The point at which this occurs probably differs considerably between individuals. In some, it is possible that an excess of breathing resistance could lead to some degree of carbon dioxide intoxication and related problems. In any case, it makes good sense to use the easiest-breathing equipment available, to maintain it in the best possible condition, and to try to remedy the condition (or at least slow down) when breathing resistance seems unusually high.

Overexertion

(31) Almost everyone has had the experience of being "all out of breath" from working too hard or running too fast. The respiratory response to exertion takes a short time to develop fully, so it is possible for a man to exceed his normal work capacity by quite a margin before he realizes that he has done so. Under normal conditions on land, this is seldom a serious problem. The shortness of breath normally passes rapidly when the work is cut down or stopped. In addition, most men learn about what their capacity for exertion is. A runner expects to be short of breath after a sprint, and he knows that he can't use his top speed at the beginning of a mile race.

(32) Underwater, and especially with increasing depth, the problem of overexertion is considerably more serious. Because of the added breathing resistance in self-contained apparatus (and in a man's own airways at greater depth), the work of breathing is increased and the capacity for physical exertion is cut down. A burst of effort which would scarcely affect him on land may bring a diver to the point of real air hunger. If the breathing apparatus is especially poor, he may not be able to get enough air no matter how hard he works for it. The feeling of impending suffocation is far from pleasant, and it has led more than one inexperienced diver into panic and a serious accident.

(33) An experienced diver will generally have a good idea what his limits are with the gear he is using. When he uses unfamiliar equipment, he will build his work rate up gradually so that he will not exceed the limits and suddenly be faced by severe shortness of breath. If he does find himself in that kind of distress, he can avoid panic because he knows the sensation will pass before long if he stops or reduces his work rate.

(34) Overexertion has other aspects besides those concerned with breathing. There are definite limits to what a man's muscles can do, and it is not easy to judge how much strength one has in reserve. A diver who wastes energy or tires himself unnecessarily may find that it is difficult to complete what he has to do. A man who lets himself get "out of shape" may discover that what was once a normal work rate now tires him very quickly. Even a man in good athletic condition can expect to have some sore muscles the next day if he overdoes an activity to which he is not accustomed.

Excessive dead space

(35) The dead space of the respiratory tract has been discussed in 1.3.4(3). Any type of breathing apparatus will add to the dead space to some degree depending upon the internal volume and arrangement of its parts. The effect of added dead space in a breathing circuit can be understood by considering what would happen if a man breathed through a long tube having an internal volume of 1 liter. When the man exhaled, he would leave the tube filled with alveolar gas. He would then take this gas back into his lungs on the next inspiration, and he would not obtain pure air unless he inhaled more than 1 liter. In effect, he would have to increase his tidal volume by an amount equal to the volume of the added dead space in order to maintain normal ventilation of his lungs. In this case, each breath would have to be 1 liter larger than he would otherwise need. The tube would contain a liter of fresh air at the end of each inhalation, and this would be blown out on the next expiration without ever having gotten to the lungs. Not only does the man have to do more work in the process of breathing, but also must waste a considerable amount of air.

(36) In actual breathing equipment, dead spaces as large as a liter are not likely to be found; but certain full-face masks, for example, can add ½ liter or more. If a man used such equipment and increased his breathing accordingly, the rate at which he used air would increase enough to make quite a difference in the duration of the supply. The necessary increase in tidal volume due to the dead space might seriously limit his ability to do hard work. On the other hand, failure to increase his breathing to compensate for the dead space would cut down his net alveolar ventilation and let his arterial carbon dioxide tension rise. Actually, an increase in carbon

dioxide tension will happen to some degree with any amount of added dead space. The effect of dead space is never likely to be compensated completely since the increase in breathing itself comes about because of an increase in carbon dioxide tension. The larger the dead space is, or the less responsive a man's respiratory center is to carbon dioxide, the higher then tension will be. Symptoms of CO_2 intoxication (see 1.3.5(8)) may result from excessive added dead space in some individuals under some conditions.

(37) In designing and evaluating breathing apparatus, it is naturally desirable to concentrate on having the least possible dead space. However, reducing it to the absolute minimum is not always possible because of other requirements. For example, a mouthpiece-type apparatus generally adds less dead space than one with a full-face mask; but if the unit is intended for use in a situation requiring voice communication and must be able to receive a microphone, then a mask must be used.

(38) The amount of exhaled air which a rig will return to a man's lungs on inhalation (the *effective* dead space volume) cannot be determined just by looking at a circuit and measuring the volume of parts which appear to be "dead." A well-designed mask may have considerably less effective dead space than the actual volume of space inside, and the dead space of a mouthpiece circuit sometimes proves unexpectedly large. In evaluation of equipment, effective dead space is measured with a machine which simulates a man's breathing and determines how much exhaled gas is actually "given back" with each breath.

Breathholding

(39) Diving *without* breathing apparatus requires breath holding during submergence, and methods of prolonging the length of time the breath can be held are always of interest to skindivers and the like. The discomfort which forces a man to resume breathing arises largely from the two main mechanisms concerned with the control of breathing (1.3.4 (6)). Rising carbon dioxide tension stimulates the respiratory center directly while falling oxygen tension stimulates it via the chemoreceptors. As the degree of stimulation increases, it becomes more and more difficult to restrain the urge to breathe; and at some point, the individual will "break" and resume breathing.

(40) To some extent, experience and willpower influence the amount of respiratory "drive" a man can tolerate before breaking. In addition, individuals differ in the sensitivity of their control mechanisms, so one man will not have as strong a desire to breathe as another even though his oxygen and carbon dioxide tensions have reached the same level. Both of these factors help explain why one man has greater breath-holding ability than another. The improvement in breath-holding ability which occurs with practice is probably due mainly to changes in the "willpower" factor, but there is some evidence that sensitivity of the controls may be reduced over a long period of frequent skindiving.

(41) It is the combined effect of rising carbon dioxide tension and falling oxygen tension that produces the drive to resume breathing. Consequently, anything that slows the rate of change of either one will increase the duration of breath-holding. The breath can be held longer with lungs nearly full than at the normal inspiratory or expiratory position. Presumably this is because full lungs provide a larger reservoir of oxygen and a larger space for carbon dioxide. Hyperventilation (overbreathing) (see par. 46) prolongs breath holding because it lowers the carbon dioxide tension initially and thus lets more time elapse before this reaches the level of stimulation. It makes very little difference in the oxygen tension. Breathing oxygen prior to breath holding leaves the lungs filled with oxygen and thus keeps the body's oxygen tension at or above the normal level for a considerable period. This generally increases the breath-holding time even more than hyperventilation does. A diver at depth can hold his breath longer than he can at the surface, probably because of the increased number of oxygen molecules compressed into his lung air. If oxygen-breathing and hyperventilation are combined (hyperventilation with oxygen), the breath-

holding time can be extremely long—over 10 minutes in some recorded cases.

(42) All of these maneuvers for prolonging breath holding involve some degree of potential risk in skindiving. For example, hyperventilation lets the oxygen tension drop close to the anoxic level before the breakpoint is reached. If a man hyperventilates and then dives to a considerable depth, he will be able to hold his breath comfortably for quite a period of time. He has not only blown off carbon dioxide, but the depth pressure helps maintain the partial pressure of oxygen in his lungs. However, when he finally ascends, the partial pressure of oxygen in his lungs will drop sharply. He may experience a severe increase in the desire to breathe before he can reach the surface, and in some cases skindivers have lost consciousness from anoxia during ascent under these conditions. Breathing oxygen before a breath-hold dive permits a man's carbon dioxide tension to reach a high level before he is obliged to resume breathing. Under some conditions, the carbon dioxide tension may be high enough to have harmful effects. Hyperventilation with oxygen appears to be a particularly hazardous procedure for prolonging breath holding especially when a man exercises while holding his breath.

(43) Hyperventilation with air before a skindive is almost standard procedure and is reasonably safe if it is not carried too far. Hyperventilation should not be continued to the point of actual dizziness, and the diver should start to surface as soon as he notices a definite urge to resume breathing. Underwater breath-holding contests and attempts to set records for underwater swimming distance and the like should be avoided. Disturbances of heart action have resulted from feats of this kind, and over-enthusiastic breath-holding has even resulted in a number of fatal accidents.

(44) Every few years, someone comes up with the discovery that providing a little rebreathing bag will permit extension of diving time without an air supply. It is reasoned that rebreathing lung air with the bag permits relatively fresh air from the dead space (mask, mouth, and windpipe) to be washed down into the lungs and thus lengthen the time a skindiver can get along without surfacing for air. This is partly true, but the process is not as simple and safe as it sounds. Research has shown that letting a man rebreathe his own stale air (or even mixtures which contain *less* oxygen and *more* carbon dioxide!) will keep him fairly comfortable for a while even when his oxygen and carbon dioxide levels have already passed their normal "breakpoints." A rebreathing device therefore would increase both of the potential hazards of prolonged breath-holding. While some individuals could probably use it safely, a man whose respiratory control mechanisms were relatively insensitive (or who tended to be "carried away" by his underwater pursuits) might be placed in real danger. Adding any carbon dioxide absorbent to such a rig would guarantee the development of serious anoxia unless the lungs were initially filled with oxygen.

Hyperventilation

(45) *Hyperventilation* is the term applied to breathing *more* than is necessary to keep the body's carbon dioxide tensions at the proper level. It has already been discussed in the preceding paragraphs in connection with breath-holding. If carried to an extreme, hyperventilation can be as undesirable and dangerous as conditions involving interference with breathing. *Unintentional* hyperventilation is most often triggered by nervous tension and can be experienced by otherwise normal individuals in stress situations anywhere. It is also brought on by anoxia and is a common and serious problem in aviators. Divers using self-contained equipment for the first few times are likely to hyperventilate to some extent largely because of anxiety. Hyperventilation has little effect on the body's oxygen levels, but it can reduce carbon dioxide tensions to the point of producing serious symptoms.

(46) Symptoms of abnormally low carbon dioxide tension (hypocapnia) can be produced by voluntary hyperventilation—taking a number of deep breaths over a short period of time as in preparation for a breath-hold dive. Under these circumstances, one rarely develops more than lightheadness and tingling sensations; but

when a man hyperventilates over a longer period without realizing that he is doing so, additional symptoms such as weakness, headaches, numbness, faintness, and blurring of vision may appear. Often, a nervous sensation of suffocation starts the process and continues in spite of it. The anxiety caused by the symptoms may lead to a further increase in breathing, and a vicious circle can thus develop. Severe hypocapnia with muscular spasms, loss of consciousness, and shock may be the end-result. Clear-cut cases this severe are extremely rare in diving, but the possibility deserves being remembered. Milder instances are probably common.

(47) Unsuspected hyperventilation is considered responsible for many of the vague symptoms which lead otherwise healthy people to seek medical attention. Mild cases are probably brought on by many familiar anxieties. Simply explaining the process may be sufficient to interrupt it. In more severe cases, having the individual rebreathe his expired air from a rubber bag or paper sack for a short while (less than a minute at a time because of the possibility of anoxia) may relieve the symptoms and permit him to stop hyperventilating.

Hypoglycemia

(48) A condition which is not due to respiratory difficulties but which can sometimes be confused with them is *hypoglycemia* (an abnormally low blood sugar level). Sugar, actually dextrose (glucose), derived from food, is the body's main fuel. It is carried to the tissues by the blood; and if the blood level falls for some reason, the functions of the tissues will be disturbed. The brain is especially sensitive to lack of dextrose. The highly variable symptoms can sometimes closely resemble those of other conditions in which brain function is affected, including carbon dioxide intoxication, anoxia, carbon monoxide poisoning, and even oxygen poisoning (see 1.3.11) and air embolism (1.3.8). Some of the more common symptoms are unusual hunger, excessive sweating, numbness, chilliness, headache, trembling, dizziness, confusion, lack of coordination, anxiety, and fainting. In severe cases, loss of consciousness and convulsions may occur.

(49) There are several possible causes of hypoglycemia. Simply missing a meal will tend to reduce the blood sugar level, but the body normally can draw on its stored supplies to keep the level close to normal for a long time. A few individuals who are otherwise in good health will develop some degree of hypoglycemia if they do not eat at fairly frequent intervals. Severe exercise on an empty stomach will occasionally bring on the symptoms even in a man who ordinarily has no abnormality in this respect. The body secretes *insulin* to promote the normal use and storage of glucose. People with *diabetes* do not secrete enough insulin and for this reason have an excess of glucose in their blood. They must take insulin by injection to avoid the symptoms of the disease and to keep their blood sugar level where it belongs. If they happen to take too much, or if some factor like unexpectedly hard work reduces the amount needed, serious hypoglycemia can develop rapidly. This is the main reason why diabetics are considered "bad risks" in diving.

(50) If hypoglycemia is present, giving sugar by mouth (or by vein, if the victim is unconscious) will relieve the symptoms promptly and prove the diagnosis. If a diving operation is going to require going without food for an unusually long period, eating protein foods like meat before-hand will provide a longer and steadier supply of dextrose than will loading up on starches and sweets. The latter procedure can actually cause trouble in some individuals by causing the body to secrete an excess of insulin. A diver who often experiences definite weakness (or other symptoms mentioned) when he misses meals should have a medical workup to determine whether hypoglycemia is the cause and, if so, why he is particularly susceptible to it.

1.3.6 EFFECTS OF PRESSURE

(1) The purpose of the following sections is to apply the principles of physics and physiology previously covered to a study of the changes that take place in the body upon application and release of excess pressures. The effects of increased pressures on the body can be divided into primary and secondary phe-

nomena; the former include the mechanical effects of pressure upon the body cells and spaces, the latter cover the physiological effects which are due to altered partial pressures of gases in the breathing medium.

Effects of pressure applied equally to all parts of the body

(2) The body can stand tremendous pressures without any change due to the pressure itself. As was explained in the section on physics (see sec. 1.2), this is true if air has free access to all surfaces of the body including the linings of the natural air spaces in the body—lungs, airways, middle ear spaces, and sinuses. Under these conditions, pressure itself has no effect even on the blood pressure and circulation. If the *pressure difference* between the inside of an artery and the surrounding area is measured at depth, it will prove to be the same as it was at the surface even though the depth-pressure is very high. The *absolute* pressure in the artery has simply gone up along with the surrounding pressure. One might wonder for example, why the brain is not crushed by a collapse of the protective skull around it. This accident would be possible if the brain were enclosed in a "skull box" containing air at atmospheric pressure. But the solids and fluids of the brain and its coverings occupy the entire space of the skull box and are subjected to the same compressive force as are the scalp and skull bones. The entire body (with the exception of the air spaces) is completely made up of fluids and solids which are virtually incompressible and which transmit pressure freely.

Effects of unequal application of pressure

(3) If, for any reason, a rigid air space in the body (or one attached to its surface) is sealed off and thus is unable to equalize pressure on descent, damage can result. (See 1.2.4(21).) In such a situation, even a pressure difference as small as one-sixteenth of an atmosphere (about 1 pound per square inch or 2 feet of sea water) can begin to alter the normal shape of tissues by causing congestion and swelling and by causing the tissues to bleed. Such changes, if allowed to continue, may cause actual destruction of tissue as well as pain and shock.

(4) Unequal application of pressure can also occur on ascent if some air-containing structure which did equalize on descent fails to do so when the diver heads for the surface. This occurrence is actually quite rare because most of the spaces will usually vent the expanding air easily on ascent even if they gave trouble going down. The main danger-spot is the lungs. If the diver should happen to hold his breath during ascent, he may shortly be in serious trouble with *air embolism* or one of the related accidents to be described later.

Indirect effects of pressure

(5) Section 1.2 discussed *partial pressures* (see 1.2.5(3)) and explained how the partial pressure of every gas present in a mixture increases when the total pressure is elevated, as by descent. The increase in the partial pressure of a gas can have two types of effect. For one thing, the amount of any gas which is dissolved in the blood and tissues depends upon its partial pressure. When the partial pressure increases, so does the amount in solution. In the case of inert gases like nitrogen and helium, the excess amount may cause trouble on ascent by coming out of solution as bubbles. The second type of effect appears with gases like oxygen, nitrogen, and carbon dioxide which not only go into solution but have specific actions on body tissue. These actions are in proportion to the partial pressure of the gas. Even if these actions are not noticeable under ordinary conditions, they will increase, sometimes to the point of causing troubles like nitrogen narcosis and oxygen poisoning, when the partial pressure is increased sufficiently. Effects of this kind will be taken up when the more direct ones have been covered.

1.3.7 EFFECTS OF PRESSURE DURING DESCENT

The ears, sinuses, and teeth

(1) The human body contains several natural air spaces which, because of their small entrance passageways, often cause trouble when excess pressures are applied to the body. The

most important of these are the middle ear spaces and the nasal accessory sinuses.

(2) The anatomy of the ear is diagrammatically shown in figure 1–27. The ear drum completely seals off the outer ear canal from the middle ear space. When pressure is applied to the body, the outer surface of the ear drum is subjected to the same pressure as are all surfaces of our body. To counterbalance this strain, air pressure must also reach the inner surface of the ear drum. This is accomplished by the passage of air through the narrow eustachian tube which leads from the throat to the middle ear space. Should this tube be blocked by mucus or an overgrowth of tissue, this equalization of pressure on both sides of the ear drum cannot take place and severe pain will result. If the drum continues to be subjected to this one-sided pressure, it will bulge inwardly with such force as to tear blood vessels, cause hemorrhage, and finally rupture. Meanwhile, the lining of the space itself is also being affected. Its blood vessels are transmitting the full external pressure while the space with which they are in close contact remains at lower pressure. If this situation continues, the vessels will expand, start to leak, and finally burst. The pain produced before rupture of the drum often becomes so intense as to prevent further descent of the diver. Returning to normal pressures brings about immediate relief. Very often a slight blockage of the eustachian tube

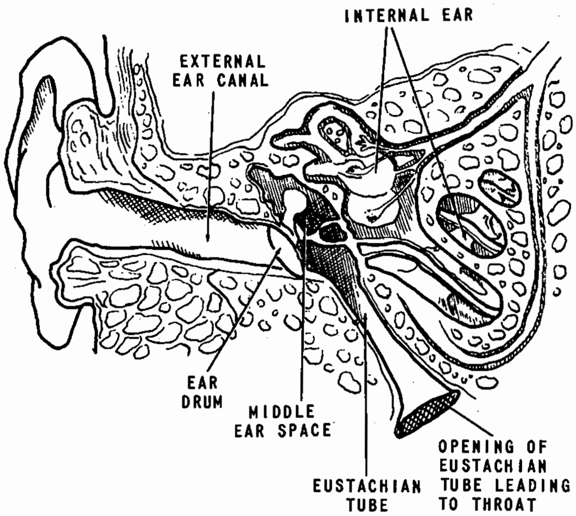


FIGURE 1–27.—Anatomy of the ear.

by mucus can be overcome by holding the nose and lips tightly and exerting inside pressure by forced expiration. Yawning and swallowing movements and moving the jaw around may also be helpful in opening the eustachian tubes.

(3) The nasal accessory sinuses are shown diagrammatically in figure 1–28. All sinuses are located within hollow spaces of the skull bones and are lined with mucus membrane continuous with that of the nasal cavity. Essentially the sinuses are small air pouches which connect with the nasal cavity through narrow passages. If pressure is applied to the body, and passages to any of these sinuses are obstructed by mucus or tissue growths, pain will soon be experienced in the affected area. The situation will be very much like that described in the middle ear. With normal air pressure in the sinuses and an excess pressure applied to the tissues surrounding these incompressible spaces, the same relative effect is produced as if a vacuum were created within these spaces. Swelling of the lining membranes and, if severe enough, hemorrhage into the sinus spaces, will take place. This process represents an effort on the part of nature to balance the relative negative air pressure with swollen tissue, fluid, and blood. A "squeeze" on the sinuses actually takes place. The pain produced may be severe enough to prevent further descent of the diver. Unless damage has already occurred, a return to normal pressures will bring about immediate relief as in the case of pain from the middle ear. If such difficulty has been encountered during a dive, the diver may often notice a small amount of blood on his handkerchief when he clears his nose on reaching the surface.

(4) If a tooth becomes painful during descent, this suggests the presence of a small gas pocket in the pulp or in a part of the tooth where soft tissues can be "squeezed." If a diver is wearing a tight-fitting hood or ear plugs, he can develop an external ear squeeze when the trapped air is compressed in the canal on descent. Tissue damage, hemorrhage, and finally an outward rupture of the ear drum will occur in an external ear squeeze. This is the reason divers do not wear ear plugs.

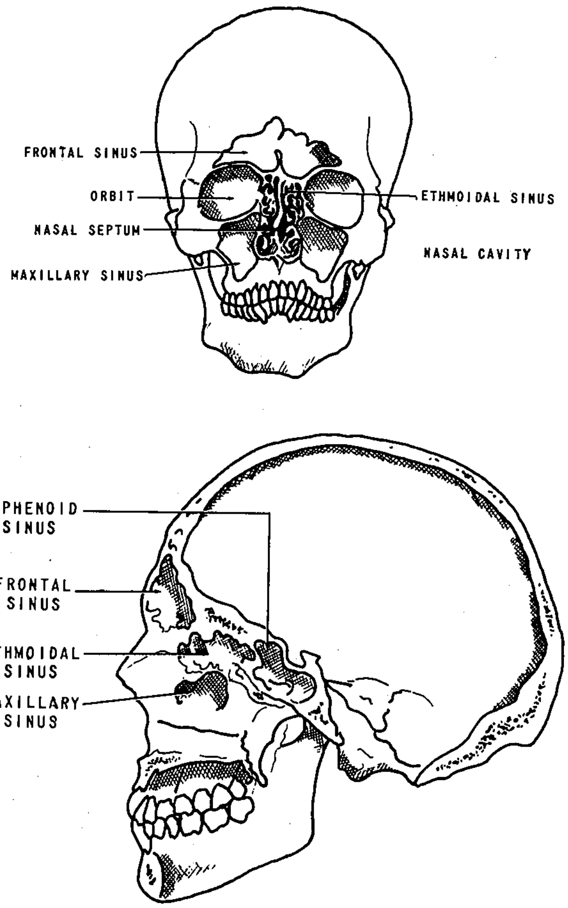


FIGURE 1–28.—Nasal accessory sinuses.

When a hooded suit must be worn, air (or water in some types) must be allowed to enter the hood to equalize pressure in the ear canal. Once in a great while, ear drum rupture occurs on ascent. This is probably caused by an obstruction of the eustachian tube after equalization had been accomplished on descent. Usually, the tube vents air on ascent much more readily than it admits it during descent. When rupture of the eardrum occurs in a man who is diving with his ears exposed to *cold water*, the entry of cold water into the middle ear will cause a violent upset of his sense of balance. He will become extremely dizzy (true *vertigo* in this case), will usually become nauseated, and may vomit. While this reaction is going on, he will probably lose all sense of position and direction. Fortunately, the reaction usually subsides in a minute or so as the water in the ear warms up to body temperature.

Face or body squeeze

(5) Another type of "squeeze" encountered in diving is that produced when the air pressure within the face mask or helmet suddenly drops below the pressure of the surrounding water. This condition may occur in two ways: (1) when the air pressure within the supply lines suddenly drops either by failure of the supply or by bursting or parting of the air lines; (2) when a sudden increase in the depth of the diver is not compensated for by an increased air supply. The physical mechanism of damage is the same as that in middle ear or sinus squeeze, but the resulting injury is on a much larger scale. If such an accident occurs while using a facemask with rigid eyeglass mountings, the most easily damaged tissues are the membranes that cover the surface of the eyeball and that line the lids and spaces around the eyeball. There will be bleeding into these tissues, and bleeding can also occur in the socket behind the eyeball, forcing the eyes forward. If the accident occurs when using a deep-sea suit, the shoulders and body may be forcefully pushed into the helmet space with fatal results. It is because of these possibilities that a nonreturn valve in the supply line at the helmet or mask is so essential in all surface-supplied diving procedures. Exposure suits, sometimes worn by shallow water or self-contained divers, can also present a problem of equalization of pressure. Any "dry type" suit will contain air spaces. Since the suit material has some body to it, these spaces cannot flatten out completely; and a little air space is left between the suit material and the skin. During descent the skin may be "squeezed" into these spaces causing discomfort and possibly some bleeding into the area. External ear squeeze is often part of this picture if the suit is hooded. Admitting a little air to the suit will permit the spaces to equalize.

The Lungs—thoracic squeeze

(6) The effects of unequal air pressure on the lungs are illustrated by the skin diver who makes a dive by merely holding his breath.

Like any other diver, he is subjected to a compressive force of one additional atmosphere for every 33 feet of descent, but he has no source of air to compensate for the compression which results. At a depth of 100 feet, for example, the total pressure acting on his body amounts to about 4 atmospheres. At this depth, the amount of air which was present in his lungs on the surface, usually about 6 liters, is compressed to one-fourth its original volume, or 1½ liters. This amount approximates the residual volume of the lungs—the amount of air left in the lungs after the most forceful expiration. The depth to which the breath-holding diver can descend is therefore limited by the ratio of total lung volume to residual volume. Should the diver descend further, the additional pressure will be unable to compress the chest walls or elevate the diaphragm further without injury. Injury will take the form of squeeze. Blood and tissue fluids will be forced into the lung alveoli and air passages where the residual air is under less pressure than the blood in the surrounding vessels. This amounts to an attempt to relieve the negative pressure within the lungs by partially filling the air space with swollen tissue, fluid, and blood. Considerable lung damage, therefore, results. If severe enough, it may prove fatal. If the diver descends still further, death will result from crushing of the chest walls, similar to the collapse of a sealed tin can which is lowered into deep water.

Pressure and increased gas density

(7) Another direct effect of pressure concerns the way gas behaves when it is under pressure. Breathing is more difficult at depth because the number of molecules packed into a given volume of gas is increased in direct proportion to the absolute pressure, but the volume of each breath and the respiratory rate remain about the same. For example, the air breathed at 100 feet is approximately four times as dense (as heavy) as the air at the surface. If open circuit gear is being used at 100 feet, each breath involves pulling four times as many molecules through the demand valve. In poorly designed or improvised equipment, the extra effort required for breathing at depth will be quite noticeable and possibly limiting. Even moving air through the respiratory passages inside the body requires about twice as much effort at 100 feet as at the surface, and the maximum breathing capacity is approximately cut in half. The extra work expended in the process of breathing alone reduces the overall ability to do heavy work at depth. The compression of gas also reduces the duration of the air supply of open circuit scuba in direct proportion to the absolute pressure.

1.3.8 EFFECTS OF PRESSURE DURING ASCENT

Air embolism

(1) *Traumatic air embolism* is a serious potential complication of diving caused by an excess of air pressure inside the lungs. It occurs most frequently in the submarine escape procedures or in emergency ascents from dives made with the lightweight outfit or scuba. The conditions which bring about this accident are directly opposite to those which produce lung squeeze. The immediate cause is holding the breath during ascent. For example, if an individual ascends to the surface from 100 feet, the air within his lungs will tend to expand to four times its original volume. If this expanding air fills the lungs completely and is not allowed to escape, a pressure is built up within the lungs which is greater than the pressure surrounding the chest. This pressure overexpands the lung and ruptures its air sacs and blood vessels. Air is then forced into the pulmonary capillary bed, and bubbles are carried to the left chambers of the heart. From there, they are pumped out into the arteries. Any bubble which is too large to go through an artery will lodge and form a plug (embolus). The tissues beyond the plug will then be deprived of their blood supply. The consequences depend upon the area or organ where the blockage occurs. The brain is frequently involved; and when it is, the symptoms are usually extremely serious. Unless the victim is recompressed promptly to reduce the size of the bubble and permit blood to flow again, death may follow. The symptoms and treatment are

discussed more fully in the section on diving hazards. (See 1.6.3.)

(2) If, in test, one purposely holds his breath during ascent, a sensation of discomfort will be felt behind the breast bone and a feeling of actual stretching of the lungs will urge one to exhale at periodic intervals. A condition of fright, however, can apparently cause a spasm of the throat muscles, sealing the main lung passageway, and thus bring about overexpansion of the lungs. Under these circumstances, death has occurred in ascent from depths of only 15 feet. At least one case of air embolism has followed ascent from the bottom of a swimming pool. On the other hand, safe ascents can be made from depths of more than 100 feet without any breathing appliance, provided the individual exhales continuously during his ascent. Every diver should make it an absolute rule always to breathe normally and continually during ascent. If he is out of air or his gear is not working and he cannot breathe, then he must *exhale* as he comes up.

Other consequences of excess lung pressure

(3) Ascent with failure to exhale can lead to three other conditions that may either accompany air embolism or occur separately:

(*a*) *Mediastinal emphysema* is the result of air having been forced into the tissues about the heart, the major blood vessels, and trachea (windpipe) in the middle of the chest. If the volume and pressure of this air is great enough, serious symptoms may result. (See 1.6.3.)

(*b*) *Subcutaneous emphysema* is the result of air having been forced into the tissue beneath the skin, most often found around the neck. It is often associated with mediastinal emphysema. (See 1.6.3.)

(*c*) *Pneumothorax* is the result of air having been forced into the potential space between the lung covering and the lining of the chest wall. An air pocket formed within the chest cavity, yet outside the surface of the lung, offers considerable difficulty if encountered while under increased pressure since there is no exit for the trapped air. As the pressure decreases on ascent to the surface, the volume of the trapped air pocket increases and does so at the expense of collapsing the lung on the affected side and pushing this collapsed lung and the heart toward the opposite side of the chest. The lung collapse and shifting of the heart's position are serious developments because they interfere with both breathing and the circulation.

Overexpansion of the stomach and intestine

(4) While a diver is under pressure, gas formation may take place within his intestines, or air may be swallowed and trapped in his stomach. On ascent this trapped gas expands and occasionally causes enough discomfort to require stopping until it can be expelled. Continuing ascent in spite of marked discomfort may result in actual harm. Chewing gum during a dive can cause air swallowing and should therefore be avoided.

1.3.9 INDIRECT EFFECTS OF PRESSURE

(1) The conditions previously described come about because of *differences in pressure* which damage body structures in a direct, mechanical manner. The indirect or secondary effects of pressure are the result of changes in the partial pressures of individual gases in the diver's breathing medium. The mechanisms of these effects include saturation and desaturation of body tissues with dissolved gas and the modification of body functions by abnormal gas tensions. This section is concerned with the uptake of inert gases like nitrogen and helium in a diver's body at depth, with the process of *decompression*, which aims to eliminate excess gas safely, and with the result of failure to accomplish this: *decompression sickness.*

Nitrogen absorption and elimination

(2) When a person resides at sea level, his blood and all his tissues become saturated with dissolved nitrogen at a tension (partial pressure of dissolved gas) equal to the partial pressure of nitrogen in his lung alveoli—about 570 mm. Hg. (See 1.3.4(4).) If the person is then exposed to a breathing medium other than air or is taken to altitude or depth, this

will change the partial pressure of nitrogen in his alveoli. His blood and tissues must then either lose or take up nitrogen in order to reach equilibrium (state of balance) with the new alveolar nitrogen pressure. (See 1.2.6.) The process of taking up more nitrogen is called absorption, saturation, or nitrogenation. The process of giving up nitrogen is correspondingly called elimination, desaturation, or denitrogenation. The chain of events is essentially the same in both of these processes even though the direction of change is opposite. In diving, we are interested in both; saturation when the diver is exposed to an increased partial pressure of nitrogen at depth, and desaturation when he returns to the surface. Basically, the same processes occur with helium and other "inert" gases as with nitrogen.

(3) The sequence of events in the process of saturation can be illustrated by considering what will happen in the body of a diver taken rapidly from the surface to 100 feet of depth. To simplify matters, we can say that the tension of nitrogen in his blood and tissues on leaving the surface is roughly eight tenths (0.8) of one atmosphere. When he reaches 100 feet, his alveolar nitrogen pressure will be about 0.8 of 4 atmospheres or 3.2 atmospheres, while the blood and tissues remain temporarily at 0.8. The "partial pressure difference" or *gradient* between the alveolar air and the blood and tissues is thus 3.2–0.8=2.4 atmospheres. This gradient is the "driving force" which makes molecules of nitrogen move (by diffusion) from one place to another. Consider the following events and factors in the diver at 100 feet:

(*a*) As blood passes through the alveolar capillaries, nitrogen molecules move from the alveolar air into the blood. By the time the blood leaves the lungs, it has reached equilibrium with the new alveolar nitrogen pressure. It now has a nitrogen tension of about 3.2 atmospheres and contains about four times as much nitrogen as it did before.

(*b*) When this blood reaches the tissues, there is a similar gradient; and nitrogen molecules move from the blood into the tissues until equilibrium is reached.

(*c*) The volume of blood in a tissue is relatively small compared to the mass of tissue, and the blood can carry only a limited amount of nitrogen. Because of this, the volume of blood which reaches a tissue over a short period of time loses its excess nitrogen to the tissue without increasing the tissue nitrogen tension very greatly.

(*d*) When the blood leaves the tissue, the venous blood nitrogen tension is equal to the new tissue nitrogen tension. When this blood goes through the lungs, it again reaches equilibrium at 3.2 atmospheres.

(*e*) When the blood returns to the tissue, it again loses nitrogen until a new equilibrium is reached.

(*f*) As the tissue nitrogen tension rises, the blood-tissue gradient decreases. Reaching equilibrium thus involves less loss of nitrogen from the blood and less gain of nitrogen in the tissues. The rate at which the tissue tension increases, therefore, becomes less rapid as the process proceeds. However, each volume of blood which reaches the tissue gives up some nitrogen and thus increases the tissue tension somewhat until complete saturation, in this case at 3.2 atmospheres of nitrogen, is reached.

(*g*) Tissues which have a large blood supply in proportion to their own mass have more nitrogen delivered to them in a certain amount of time and, therefore, approach complete saturation more rapidly than tissues which have a poor blood supply. (See fig. 1–29.)

(*h*) If a tissue has an unusually large capacity for nitrogen, it will take longer for the blood to deliver enough nitrogen to saturate it completely. Nitrogen is about five times as soluble in fat as in water. Therefore, fatty tissues require much more nitrogen and much more time to saturate them completely than "watery" tissues do even if the blood supply is ample. A fatty tissue with a poor blood supply saturates very slowly indeed.

(*i*) In the diver at 100 feet, the blood continues to take up more nitrogen in the lungs and to deliver more nitrogen to tissues until all of his tissues have reached saturation at a tension of 3.2 atmospheres of nitrogen tension. A few of his "watery" tissues which have an

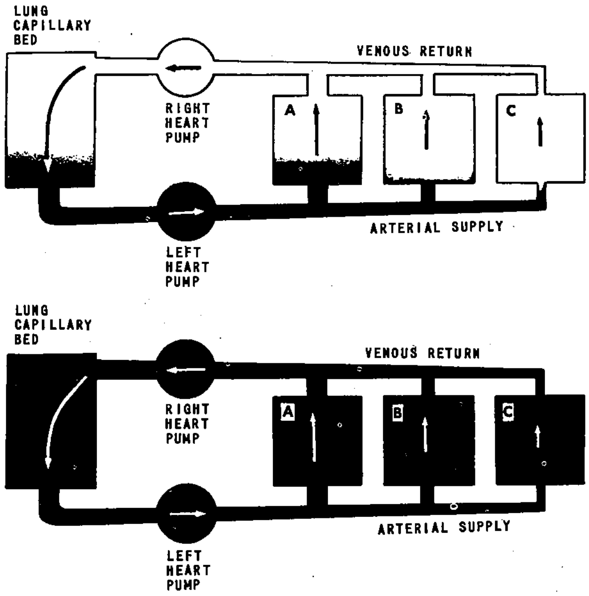


FIGURE 1–29.—Saturation of tissues. Shading in diagram indicates saturation with nitrogen or helium under increased pressure. Blood becomes saturated on passing through lungs, and tissues are saturated in turn via blood. Those with large supply (like A) are saturated much more rapidly than those with poor blood supply (like C) or an unusually large capacity for gas, as fatty tissues have for nitrogen. In very abrupt ascent from depth, bubbles may form in arterial blood or in "fast" tissue (like A) even though body as a whole is far from saturation. If enough time elapses at depth, all tissues will become equally saturated, as shown in lower diagram.

excellent blood supply will be almost completely saturated in a few minutes. Others, like fat with a poor blood supply and perhaps some watery tissues with exceptionally meager blood flow, may not be completely saturated unless the diver is kept at 100 feet for 12 hours or longer.

(*j*) If he is kept at this depth of 100 feet until saturation is complete, the diver's body will contain about 4 times as much nitrogen as it did at the surface. If he is of average size and fatness, he contained about one liter of dissolved nitrogen and therefore will contain about 4 liters at 100 feet. Since fat holds about five times as much nitrogen as lean (watery) tissues, much of the diver's nitrogen content will be in his fatty tissue, and an obese diver will contain considerably more nitrogen than a lean one.

(*k*) An important fact about nitrogen saturation is that the process will require the same length of time regardless of the nitrogen pressures involved. For example, if this diver had been taken to 33 feet instead of 100, it would have taken just as long to saturate him completely and to bring his nitrogen pressures to equilibrium at that pressure. In this case, the original gradient between alveolar air and the tissues would have been only 0.8 atmospheres instead of 2.4 atmospheres. Because of this, the amount of nitrogen delivered to tissues by each round of blood circulation would have been smaller from the beginning. Less nitrogen would have to be delivered to saturate him at 33 feet, but the slower rate of delivery would cause the total time required to be the same.

(4) The process of desaturation is the reverse of what was described above, but the general idea is basically the same. Consider what would happen *if* the same diver were saturated at 100 feet and then *could* be brought immediately to the surface:

(*a*) The diver's blood and tissues contain dissolved nitrogen at a tension of 3.2 atmospheres when he leaves 100 feet. When he reaches the surface, his alveolar nitrogen pressure is back to the normal 0.8 atmospheres. There is now a gradient of 2.4 atmospheres tending to drive the nitrogen out.

(*b*) As the blood goes through the lungs, it loses nitrogen to reach equilibrium with the alveolar nitrogen pressure. When it returns to the tissues, it is thus able to take up nitrogen until it reaches the same nitrogen tension as that in the tissue.

(*c*) The amount of nitrogen each volume of blood can take up is limited, so the tissue nitrogen pressure cannot fall to the new level at once; but each round of circulation transports some nitrogen from the tissue to the lungs, and the tissue tension gradually falls.

(*d*) The rate of blood flow and the amount of dissolved nitrogen in the tissue influence the rate just as they did in the saturation process. Also as in that process, the rate of nitrogen transport decreases as the difference in tensions between the tissue and the incoming blood becomes smaller—as the gradient decreases. (See fig. 1–30.)

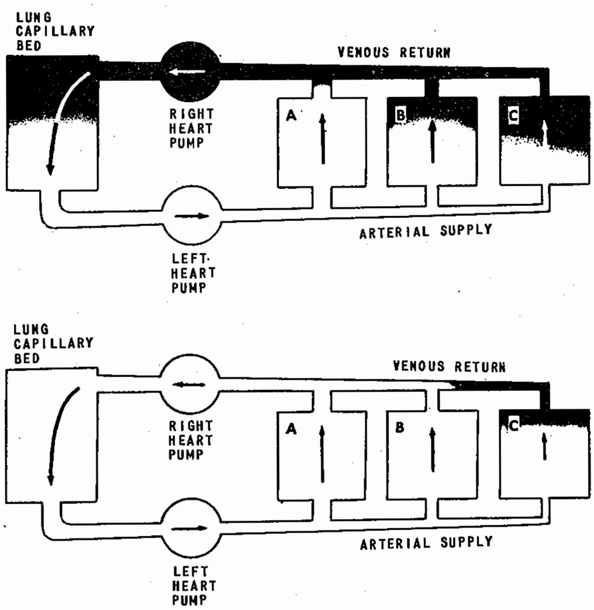


FIGURE 1-30.—Desaturation of tissues. The desaturation process is essentially the reverse of saturation. When pressure of inert gas is lowered, blood is cleared of excess gas as it goes through lungs. Blood then removes gas from tissues at rates depending on amount of blood that flows through them each minute. Tissue with poor blood supply (as C in upper sketch) or large gas capacity will lag behind and may remain partially saturated after others have "cleared." (See lower diagram.) If dive is long enough to saturate such tissue, long decompression stops are required to desaturate it enough so that bubbles will not form in it on ascent.

(*e*) Like saturation, complete desaturation to a new level may take 12 hours or more. Again, the length of time required is the same regardless of the original gradient. If the diver had returned to the surface from 33 feet instead of 100, it would take just as long for his tissues to return to equilibrium at 0.8 atmospheres of nitrogen pressure.

(5) Note that we said "*if* the diver *could* be brought immediately to the surface from 100 feet." The fact of the matter is that this *could not* be done without injuring him. If his tissues were saturated at 100 feet and thus contained dissolved nitrogen at a tension of 3.2 atmospheres, returning to the surface would reduce the *total* pressure of the tissues to only 1 atmosphere. To have a dissolved-gas tension higher than the total pressure sounds like a physical impossibility. In a sense, it is. If a tissue is *supersaturated* with gas to this degree, the gas will come out of solution in the form of bubbles. This results in *decompression sickness*, which will be discussed later on.

(6) Fortunately, the blood and tissues can hold gas in supersaturated solution to some degree without serious formation of bubbles. Otherwise, it would be impossible to bring a diver up at all from any depth if any of his tissues had reached saturation during the dive. As it is, a diver can be brought up at least part of the way regardless of how deep or how long his dive was. This creates an "outward gradient" for the dissolved gas, and the desaturation which occurs as a result permits him to be brought up further after some period of time.

(7) The great contribution to diving which was made by Professor Haldane and his associates in 1907 consisted of putting this matter of stepwise ascent on a firm basis. They observed that it was possible to bring a man up directly to the depth at which the total pressure was not less than about half the tension of dissolved nitrogen in any of his tissues. In other words, they found that the blood and tissues could hold dissolved gas at a tension which was about twice the total pressure. For example, a diver who was saturated at 33 feet could be brought directly to the surface, while a diver saturated at 100 feet could be brought up nearly to 33 feet. These observations formed the basis for *stage decompression*, which has long been accepted as the most practical, most time-saving, and safest method of bringing a diver up from a dive too deep or too long for immediate surfacing.

(8) By bringing the diver up as far as safely possible initially, stage decompression provides a considerable outward gradient for nitrogen. In actual practice, the diver is then kept at his first decompression stop long enough to desaturate sufficiently to permit safe ascent to a stop 10 feet shallower. The process is continued until he can be brought all the

way to the surface. When he reaches the surface, the diver's body still contains nitrogen in supersaturated solution in some tissues; but throughout the process the extent of supersaturation has been kept within limits that are normally safe. We have said that both saturation and desaturation take the same length of time, but this is true only when the outward gradient is the same as the original inward gradient. Unless the diver can be surfaced immediately, the outward gradient is necessarily kept smaller by the stepwise ascent. However, since part of the desaturation can safely proceed at the surface, the total time of ascent is not invariably as prolonged as the slower rate of desaturation would indicate.

(9) In actual diving, a man is very seldom left at depth long enough for all of his tissues to become completely saturated with nitrogen. In a very short dive, only his "faster" tissues —those which saturate rapidly—will come close to complete saturation, while those which saturate slowly may not take up enough gas even to approach dangerous supersaturation on ascent. Since the "fast" tissues also lose nitrogen rapidly, they may desaturate considerably even during the ascent to the first stop. Within certain limits of depth and time, direct ascent is possible. Within other limits, a few minutes at 10 feet provide enough decompression. Of course, this is not the case in longer, deeper dives.

(10) By making certain assumptions, it is possible to calculate the approximate degrees of saturation existing in the body after any length of time at depth. Using Haldane's principle and information obtained by subsequent studies and experience, it is then possible to compute the depths and durations of decompression stops which should permit bringing the diver back to the surface safely and efficiently. The *decompression tables* are based on such calculations, checked by hundreds of test dives.

(11) *Standard decompression* represents the process of bringing a diver to the surface with stops at various depths as described above, breathing the original gas mixture (usually air) throughout. This is the form of decompression most frequently used, but other methods of decompression are possible. For example, it has been found that a diver can tolerate a serious degree of supersaturation in his tissues for a few minutes if he is promptly put back under pressure. This makes it possible to use *surface decompression*, where the diver spends only part of his decompression time in the water and is then brought to the surface and rapidly placed in a recompression chamber to complete the process. (See 1.5.5.)

(12) *Oxygen decompression* takes advantage of another fact about desaturation and bubble formation: It is the gradient or partial pressure difference between the tissues and the alveolar air which causes denitrogenation of the tissues. It is the difference between tissue gas tension and the total external pressure on the body which is involved in bubble formation. If this distinction is understood, the principle of oxygen decompression should be clear. If the diver can breathe oxygen during his decompression stops, the nitrogen pressure in his alveoli is reduced nearly to zero. This produces the largest possible outward gradient for nitrogen and brings nitrogen out of the tissues even more rapidly than would breathing air at the surface. At the same time, the total pressure on the body is maintained so that formation of bubbles is no more likely than it would be during air-breathing at that stop. The result is a tremendous saving of decompression time. The use of oxygen for decompression is possible only at depths where oxygen can be breathed safely (1.5.7(1)), and it is frequently not practical to supply a diver with oxygen. However, oxygen decompression is an integral part of helium-oxygen diving technique (see 1.5.4 and pt. 2), and it is also used routinely in connection with surface decompression (1.5.5(5)). (It is sometimes suggested that substituting another gas, as for example switching to helium-oxygen during decompression from an air dive or vice versa, would accomplish the same thing as shifting to oxygen. It is true that this would produce a high outward gra-

dient for the original gas and that its elimination would be hastened. However, a high inward gradient would also be produced for the second gas. The resulting rapid uptake of this gas would tend to cancel out the beneficial effect. It is the *total* tension of dissolved gases in the tissues which evidently determines bubble formation.)

(13) Although the foregoing discussion was concerned mainly with the absorption and elimination of nitrogen, the basic principles presented are also true for helium. However, there are differences between the two gases that cause the actual decompression procedures following their use in diving to be quite dissimilar. Not all of these differences and their consequences are as yet fully understood. One important difference between nitrogen and helium is the fact that helium, while it is about as soluble in water as nitrogen, is much less soluble in fat. Since fatty tissues thus have far less capacity for helium, they will saturate and desaturate with that gas much more rapidly than they do with nitrogen. This appears to give helium the advantage of requiring less decompression for long, deep dives than is required when air is the breathing medium. However, the present helium-oxygen decompression tables actually require longer decompression for many depths and times than do the air decompression tables. It now appears probable that increasing understanding of the behavior of helium in the body will permit more favorable use of that gas from the standpoint of decompression. If this proves to be true, new tables will be computed, tested, and issued. Until that can be accomplished, helium-oxygen mixtures will continue to be used mainly because they provide freedom from nitrogen narcosis (see art. 1.3.10) in deep dives rather than because they offer much advantage in decompression.

(14) "High-oxygen" mixtures, those which contain a higher concentration of oxygen than that of air, can sometimes be used as the breathing medium to reduce the decompression time required by dives. As has been shown, the need for decompression stops on ascent stems from the fact that the body takes up inert gas in solution while the diver is at depth. It does so because of the increased partial pressure of the gas in the alveoli. The example of a diver breathing air at 100 feet was used, and it was pointed out that his blood and tissues tend to reach equilibrium with the 3.2 atmosphere (approximate) partial pressure of nitrogen in his alveoli. If this diver breathed a 60 percent nitrogen-40 percent oxygen mixture at 100 feet instead of air, the nitrogen pressure in his alveoli would be about 2.4 atmospheres. This is the nitrogen pressure normally present when breathing air at 66 feet. With this breathing medium, a 100-foot dive would, therefore, require only the much shorter decompression time of a 70-foot dive. The extent to which this principle can be applied is limited by the fact that the partial pressure of oxygen is necessarily increased, and exposure to oxygen must be kept within safe limits of both pressure and time. (See 3.6.5 and 1.5.7.) Helium-oxygen diving technique normally involves the use of mixtures containing as much oxygen as is considered safe for the dive involved in order to keep decompression time to the minimum. Therefore, the "mixture" principle is routinely applied in helium-oxygen diving.

(15) *Oxygen* will go into solution in the blood and tissues in added amounts when its alveolar partial pressure is increased in somewhat the same manner that nitrogen and helium do. However, the tissues are always consuming oxygen so the tissue tension of that gas never can be as high as its alveolar partial pressure. The amount of oxygen transported to the tissues is seldom enough beyond what the tissues are using to permit a high degree of saturation to develop. Also, when the external pressure is reduced on ascent, the tissues can use up any excess oxygen fairly readily. The amount of oxygen present along with other gases may contribute to bubble formation when this occurs, but only in extreme circumstances does it appear to be an important factor. Pure oxygen would probably be an ideal breathing medium from the standpoint of decompression if it could be used for deep diving. Actually, the limits of exposure (see 1.5.7),

which must be imposed because of the danger of oxygen poisoning, restrict pure oxygen to depths and times which present no decompression problems even with air as the breathing medium.

Decompression sickness

(16) When a diver's blood and tissues have taken up nitrogen or helium in solution at depth, reduction of the external pressure on ascent can produce a state of supersaturation, as has been discussed. (See 1.3.9(5).) If the elimination of dissolved gas, via the circulation and the lungs, fails to keep up with the reduction of external pressure, the degree of supersaturation may reach the point at which the gas no longer can stay in solution. The situation then resembles what happens when a bottle of carbonated beverage is uncapped.

(17) Liberation of bubbles can apparently take place either in the blood or in a supersaturated tissue. A bubble in the bloodstream would produce symptoms by blocking circulation. One in the tissue could put stretch or pressure on nerves or cause actual tissue damage. The symptoms which result depend on the location and size of the bubble or bubbles. They consist of pain in joints, muscles, or bones when a bubble is in one of these structures. Bubble formation in the brain can produce blindness, dizziness, paralysis, and even unconsciousness and convulsion. When the spinal cord is affected, paralysis or loss of feeling in some part of the body can occur. Bubbles in the lungs can cause asphyxia or "chokes." Skin bubbles produce itching or rash or both. Unusual fatigue or exhaustion after a dive is probably also due to bubbles, but their location is not known. Many other symptoms can be caused by bubbles in unusual locations. Decompression sickness which affects the central nervous system (brain or spinal cord) or lungs can produce serious disabilities and may even threaten life if not treated promptly and properly. When other areas such as joints are affected, the condition may produce excruciating pain and lead to local damage if not treated, but life is seldom threatened.

(18) *Treatment* of decompression sickness is accomplished by recompression—putting the victim back under pressure to reduce the size of the bubbles and to cause them to go back into solution. This is generally done in a *recompression chamber* but can sometimes be accomplished in the water if a chamber is not available. It must be done in a specified manner. Further discussion of the symptoms of decompression sickness and a complete discussion of treatment are presented in the section on diving hazards. (See 1.6.2.)

(19) *Prevention* of decompression sickness is generally accomplished by following the decompression tables correctly. However, unusual conditions either in the diver or in connection with the dive will produce a small percentage of cases even when this is done. It was found that to be absolutely safe under all possible circumstances, the decompression time specified would have to be far in excess of that normally needed. On the other hand, under ideal circumstances, some individuals can ascend safely in less time than the tables specify. This must not be taken to mean that the tables contain an unnecessarily large safety-factor. As a matter of fact, the tables generally represent the minimum decompression time which will permit average divers to surface safely from normal working dives without an unacceptable incidence of decompression sickness.

(20) Factors in the diver which apparently favor the development of decompression sickness even when the tables are followed include age, obesity, excessive fatigue, loss of sleep, alcoholic indulgence and its after-effects, various illnesses, and anything which contributes to poor general physical condition and poor circulatory efficiency. Unusually heavy exertion during the dive and extremes of temperature can have unfavorable effects. Heavy work speeds up the circulation and increases the uptake of inert gas at depths. Exercise during decompression, although it hastens elimination of inert gas from some tissues, often increases the incidence of decompression sickness. Anything which impedes blood flow in some area during decompression can favor bubble forma-

tion. Keeping a leg or an arm in a cramped position is an example.

1.3.10 NITROGEN NARCOSIS

(1) Continuing the subject of *indirect effects of pressure* brings up the fact that the possibility of bubble formation on the ascent is not the only undesirable result of exposure to increased partial pressures of nitrogen. When a diver breathes air at depth, the nitrogen produces an intoxicating effect similar to that of alcohol, anesthetic gases, or narcotic drugs. Some individuals are much more susceptible to this effect than others, but most divers are not aware of it until they reach about 100 feet of depth. Beyond 100 feet, the effect increases rapidly. Few divers can work very effectively much beyond 200 feet. Only very exceptional men are capable of doing useful work down to 300 feet; and this depth is considered the limit for diving with air as the breathing medium.

(2) Nitrogen narcosis decreases the ability to work and causes changes in the mood. Just as alcohol affects different men to different degrees and in somewhat different ways, the response to nitrogen is not always the same; but a slowing-up of mental activity and a fixation of ideas are usually present. The diver finds it difficult to concentrate or to figure things out, and he may not be able to remember what he is supposed to do or even what he has already done. His reflexes and reaction times are slowed down. His observations will often be inaccurate, and he is likely to reach wrong conclusions about what to do.

(3) The greatest hazard of nitrogen narcosis is that it may keep the diver from caring about the job or even about his own safety. An unusually stable and experienced diver will be reasonably productive and safe at depths where others fail. He is familiar with nitrogen narcosis, is keenly aware of the extent to which it impairs him, and makes a strong conscious effort to carry on in spite of it. He knows that he must be unusually careful, that he must spend more time and effort making even the simplest observations and decisions, and that any relaxation of his conscious effort can lead to failure or a fatal blunder.

(4) The exact mechanism by which nitrogen under pressure produces it narcotic effect is not known. The exact mechanism of action of anesthetic gases like nitrous oxide (laughing gas) and cyclopropane is not known, either; but the effects have much in common. It is probably correct to regard nitrogen as an anesthetic gas which happens to be so weak that it has no noticeable effect under normal conditions. When the "dose" (the partial pressure) is increased, the anesthetic effects of nitrogen become evident and increase progressively. The same relationship between pressure and effects is also true for other anesthetic gases. For example, nitrous oxide is not potent enough to produce complete surgical anesthesia by itself at the surface, but it becomes so when it is administered in a pressure chamber. The anesthetic potency of an "inert" gas (one which does not enter into actual chemical reactions in the body) is related to its solubility in oil (fat). If such a gas is exceptionally soluble in fat, it is generally a potent anesthetic. (The physiological concept which relates solubilities and anesthetic potency is known as the *Meyer-Overton theory.*)

(5) The fact that helium is relatively insoluble in fat has already been noted. The fact that it produces very little narcotic effect even at great diving depths makes helium very valuable for deep diving. If a diver breathes a helium-oxygen mixture, he can do useful work as deep as 600 feet and probably even deeper. The tremendous amount of decompression time required for such deep dives, even when the time at depth is only a few minutes, is what limits their practicability.

(6) Other inert gases such as argon, krypton, and xenon are not useful in diving because they have even greater narcotic effects than nitrogen. In fact, xenon is about equal to nitrous oxide as an anesthetic even at the surface. Except for hydrogen, which is more difficult to use because of the danger of explosion, helium is the only gas known to be useful for deep diving.

1.3.11 OXYGEN POISONING

(1) The fact that oxygen is essential to life has been stressed throughout this chapter, and

the specific effects of oxygen-lack (anoxia) have been discussed in detail 1.3.5(2)). It may not seem reasonable that there could be such a thing as *too much* oxygen, but this is an important fact for a diver to realize.

"Low-pressure" oxygen poisoning

(2) Even on dry land at normal pressure, it is possible for high concentrations of oxygen to have undesirable effects. For example, if more than 60 percent oxygen is breathed at the surface for a long enough period (many hours, or even days, are required), lung irritation may develop; and if the exposure is continued further, a form of pneumonia with actual lung damage may follow. This is not actually much of a problem since such long exposures rarely happen except in hospitals, and the usual methods of giving oxygen (oxygen tents and the like) rarely give the patient as much as 60 percent oxygen. (More than this is seldom required for medical treatment.)

(3) Occasionally, a patient who has had a serious lung disability for a long time will lose consciousness when he is given oxygen. This is because he has been suffering from both anoxia and carbon dioxide excess for so long that his respiratory center no longer reacts to carbon dioxide, and he breathes only because of the stimulating effect of anoxia on his chemoreceptors. (See 1.3.4(6).) Giving him oxygen "satisfies" his chemoreceptors, so they no longer impel him to breathe. The decrease in breathing which follows permits his carbon dioxide level to reach the point of causing unconsciousness. This phenomenon is mentioned here because it has some resemblance to "shallow-water blackout." (See 1.3.5(12).) It is not "oxygen poisoning" in a true sense.

(4) Premature babies often have a hard time surviving. Modern medical procedures saved many who would otherwise have died, but a number of them became blind. Some remarkable medical detective work finally showed that the blindness resulted from giving them too much oxygen for their respiratory difficulties. Now, oxygen treatment is limited to the minimum required for survival; and blindness in premature babies has become a rare thing.

"High-pressure" oxygen poisoning

(5) Divers do not have to worry about lung damage or blindness from oxygen-breathing, but they can have serious problems of their own with it. The divers' kind of oxygen poisoning does not enter the picture except with partial pressures of oxygen *above* those produced by breathing oxygen at the surface—somewhere above 1 atmosphere. When it occurs, "high-pressure" oxygen intoxication mainly affects the brain. If it goes far enough, it can cause convulsions (fits, seizures) very much like those of epilepsy. The convulsion itself rarely harms a man, but it can lead to a number of mishaps underwater.

(6) The *minimum* partial pressure of oxygen which can cause this kind of trouble is not precisely known. "High-pressure" oxygen poisoning can definitely happen with an oxygen partial pressure of 2 atmospheres. (A man could expose himself to this by breathing 100 percent oxygen at 33 feet or 50 percent oxygen at 99 feet—or air at around 280 feet.) A few cases have been reported at lesser pressures, and the time limits specified take this possibility into account. (See 1.5.7.) The lower the oxygen pressure, the longer the time before symptoms develop. The safe periods at lower pressures are longer than most dives are likely to be.

(7) Since the partial pressure of oxygen (not the percentage) is what counts, a diver can run into this problem not only when he is breathing pure oxygen but also with nitrogen-oxygen or helium-oxygen mixtures. Trouble is unlikely when breathing air because of the depths required and the limits imposed by other factors like nitrogen narcosis and decompression. Oxygen poisoning can be a problem in diving not only because oxygen and "high-oxygen mixtures" have to be used for some operations but because oxygen is used in decompression from helium-oxygen dives and in the treatment of decompression sickness. Operationally, high oxygen partial pressures are most likely to be encountered in the use of closed and semiclosed-circuit apparatus and with helium-oxygen equipment. In all of these

cases, the dive must be planned to conform with the safe limits of exposure, oxygen percentage, depth, and time.

(8) Several factors besides the partial pressure influence the length of time before symptoms appear.

(*a*) *Exertion* is one of the most important factors. Most men at *complete rest*, can breathe pure oxygen for as long as 2 hours at 60 feet, and almost everybody can tolerate 30 minutes of oxygen-breathing at rest at that depth. But if a man does light work, his safe time at 60 feet will drop to 10 or 15 minutes. For an average working dive, anything over 10 minutes at 40 feet is considered unduly hazardous.

(*b*) *Excess carbon dioxide* is another very important factor. Even a rather small amount of carbon dioxide in the inspired gas, less than the concentration likely to make the diver uncomfortable, can shorten the "latent period" considerably.

(*c*) There are also very great *individual differences* in susceptibility to oxygen poisoning. Some men can stand much greater exposure to oxygen than others, and an individual's tolerance also can vary quite a little from day to day. The "oxygen tolerance test" (see 1.5.7, 1.8.2(2)) which requires breathing pure oxygen for 30 minutes at 60 feet in a dry recompression chamber, is designed to detect those who are unusually susceptible. The reasons for individual differences are not known.

(*d*) A number of other factors, like temperature, also affect oxygen tolerance; but their influence is less clear-cut than that of exercise and carbon dioxide.

Symptoms of oxygen poisoning

(9) Sometimes early evidences of oxygen poisoning appear before convulsion. If recognized, these may give a man enough warning so that he can prevent further trouble by lowering the partial pressure of oxygen by ascent or other means. (He should also rest, and hyper-ventilating may aid in averting more serious symptoms.) The warning symptoms most often noted, in approximate order of their likelihood of occurrence, are:

(*a*) *Muscular twitching.*—(This usually appears first in the lips or elsewhere in the face, but it may affect any muscle.)

(*b*) *Nausea.*—(This may come and go periodically.)

(*c*) *Dizziness.*

(*d*) *Abnormalities of vision or hearing.*—("Tunnel vision"—loss of ability to see things to the sides—is one of the more frequent visual symptoms.)

(*e*) *Difficulty in breathing.*—(The diver may have air-hunger, sense an increase in "breathing resistance" for no apparent reason, or have trouble taking a full breath into his lungs.)

(*f*) *Anxiety and confusion.*

(*g*) *Unusual fatigue.*

(*h*) *Incoordination* (clumsiness, etc.)

(10) Remember that these warnings do not always appear and may not be definite or early enough to be recognized in time for effective action. Note also that *some* of them can be caused by difficulties other than oxygen poisoning (including even the very opposite condition, anoxia). However, if any one of them is definite, it usually represents a bodily "signal of distress" of some kind and deserves to be heeded. *Twitching* is the clearest warning of oxygen poisoning, but it may be a late one. If a man can surface and breathe air at normal pressure for a while after the onset of symptoms, this will restore much of his tolerance and permit him to resume oxygen breathing. The exact period required to restore normal tolerance completely in man has not yet been determined.

(11) As has been indicated, *convulsions* are the most important consequence of poisoning with excess oxygen. Convulsions can be set off by a number of things besides oxygen; such as various injuries to the brain and other diving accidents like air embolism (see 1.3.8 (1)) and severe decompression sickness. In epilepsy, they come on spontaneously, usually without known cause. Fever will sometimes produce them in young children. Overdoses of certain drugs result in convulsions, and sometimes seizures are deliberately produced by drugs or electricity in the treatment of

mental illness (shock therapy). During a convulsion, the individual loses consciousness; and his brain sends out uncontrolled and completely disorganized volleys of nerve impulses to his muscles. At the height of the seizure, all of the muscles are being stimulated at once and lock the body into board-like stiffness. The brain soon fatigues, and the number of impulses drops off. In this phase, the random impulses to various muscles may cause violent thrashing and jerking for a minute or so. Sometimes, involuntary urination and defecation, and occasionally erection and ejaculation, take place during the convulsion. After the convulsive phase, the brain is completely tired out; and "post-convulsive depression" follows. During this phase, the patient is usually unconscious and quiet for a while, then semiconscious and very restless. He will then usually sleep off and on, waking up occasionally but not being fully rational. The phase of depression sometimes lasts as little as 15 minutes, but an hour or more is not uncommon. At the end of it, the individual will often become alert rather suddenly and complain of no more than fatigue, muscular soreness, and possibly a headache. After an oxygen convulsion, the diver will usually remember clearly the events up to the moment when consciousness was lost but will remember nothing of the convulsion itself and little of the depressed phase.

(12) Despite its rather alarming appearance, the convulsion itself is usually not much more than a strenuous muscular workout for the victim. In oxygen convulsions, even the possible danger of anoxia during breathholding in the "stiff" phase is eliminated. The tongue may be chewed when the jaw takes part in the jerking phase, and once in a great while a bone gives way under the strain of the contracting muscles. The main dangers are from what may happen during the process. If convulsion occurs in a recompression chamber, one tender should be able to keep the man from thrashing against hard objects and hurting himself. Complete restraint of the movements is neither necessary nor desirable. Inserting a mouth-bit (2 or 3 tongue-depressors wrapped in adhesive, or practically anything but a metal object or fingers) between the teeth during the chewing phase will avert damage to his tongue. Breathing almost invariably resumes spontaneously, and turning the man on his stomach with face to one side usually prevents respiratory obstruction. In suit-and-helmet, convulsion might lead to blowup or squeeze; but bruises and chewed tongue are more likely to be the only consequences. Bringing a diver up rapidly during the height of convulsion could possibly lead to air embolism. In the use of scuba, the consequences of convulsions are likely to be more serious, with drowning as the main danger. This is an example of a spot where using the "buddy system" in self-contained diving can mean the difference between life and death. (See 3.1.5(32).)

(13) Even if a man with oxygen poisoning continues to breathe oxygen, the convulsion will almost always cease in a few minutes and be followed by a quiet interval of several minutes. If the oxygen partial pressure is then lowered, there will seldom be a further seizure. Usually, the convulsive phase is over before any drug could be injected to stop the fit, and such treatment is necessary only in the extremely rare cases where convulsion continues after lowering the oxygen pressure.

(14) If a man with oxygen convulsions is prevented from drowning or otherwise injuring himself, he can expect to recover promptly and have no lasting effects. Nor will he be any more or less susceptible to oxygen poisoning in the future. He may be more inclined to think he has "warning symptoms" during subsequent exposures to oxygen, but this is most likely a psychological matter.

Mechanism

(15) The actual mechanism of oxygen poisoning remains unknown in spite of many theories and much research. At one time, it was believed to be caused by the retention of carbon dioxide in the tissues. During exposure to high oxygen pressures, there is so much dissolved oxygen in the blood that the tissues do not remove as much oxygen from the hemoglobin as usual. This keeps hemoglobin from playing its full role in the transport of carbon dioxide from the tissues, but

the resulting increase in actual tissue tensions of that gas is far less than that required to produce carbon dioxide "convulsions." (See 1.3.5(10).) It is much more likely that oxygen has a direct effect of its own, possibly interfering with the enzyme systems of cell metabolism. The fact that carbon dioxide excess does speed the onset of convulsions is probably due to the fact that it increases blood flow to the brain and gives it a larger "dose" of oxygen. The influence of exercise remains unexplained.

Prevention

(16) From the diver's standpoint, *prevention* of oxygen poisoning is the most important thing. He should not use oxygen where there is no good reason for doing so. (For example, there is no point in charging open-circuit gear with oxygen.) When the use of oxygen is advantageous or necessary, he should apply sensible precautions like being sure the breathing apparatus is in good order, *observing the depth-time limits*, avoiding excessive exertion, and heeding abnormal symptoms if they appear. (Also see sections 1.5.7, 1.6.6, and 1.7.)

1.3.12 BREATHING MEDIUMS

(1) In view of the number of problems which come up because of what a diver *breathes*, a summarizing discussion of the various gases which he *can* breathe may be useful.

Air

(2) Since it is the most available breathing medium, air is naturally the one most commonly used in diving. It is also the most satisfactory for most purposes. It has the disadvantage of requiring decompression in dives beyond certain depths and time. (See 1.3.9 (7) and 1.5.) Nitrogen narcosis (see 1.3.10) also limits the depth to which it can be used. In most surface-supplied diving, air is the only practical breathing medium to use. Special arrangements are generally required to make other gases practical with air-hose equipment. In self-contained diving, air can be used safely only with demand type equipment; and the limited duration of the supply in this kind of rig can be a serious drawback especially in deeper dives. The noise and bubbles of demand type gear can also be a serious disadvantage in some diving operations.

Oxygen

(3) Except as employed in decompression procedures, oxygen is advantageous *only* when used with closed-circuit apparatus, and only oxygen *can* be used in such equipment. The advantages include freedom from bubbles, almost completely silent operation, and maximum utilization of the gas. A small supply lasts a long time, and the duration of supply is not altered by depth. The main disadvantage of oxygen is the limitation of safe depth and time of use. (See 1.3.11.) Oxygen does not produce decompression sickness, but decompression is not a problem anyhow within the depth-time range where oxygen can be used.

Nitrogen-oxygen mixtures

(4) Air is the most common nitrogen-oxygen mixture. It contains about 79 percent nitrogen and 21 percent oxygen. An artificial mixture with *less nitrogen* and *more oxygen* has the advantage of requiring less decompression than air for a dive of the same depth and duration. Safe, efficient use of nitrogen-oxygen mixtures requires *special equipment*, usually semiclosed-circuit types. As in the use of oxygen itself, the possibility of oxygen poisoning restricts the safe depth and duration for use of "high oxygen" mixtures. Nitrogen-oxygen does little to reduce the problem of nitrogen narcosis because the oxygen limits are generally more restrictive than those imposed by narcosis. Use of nitrogen-oxygen mixtures requires careful selection of percentage, flow-rate, and the like. The expected depth, duration, and type of work must be considered carefully. (See 3.6.0.)

Helium-oxygen mixtures

(5) Avoidance of nitrogen narcosis in deep dives is the main purpose of using helium-oxygen mixtures. The present tables (see sec. 1.5) offer little or no advantage in the use of helium rather than nitrogen from the

standpoint of decompression except in long, deep dives (see 1.3.9(13)). Helium-oxygen can be used in demand type, but the limited duration of supply at depth usually offsets the advantages. The fact that decompression from a helium-oxygen dive may be longer and requires a shift to oxygen on ascent also adds complications. Use of helium-oxygen mixtures in semiclosed-circuits eventually may find valuable applications. At present, helium-oxygen is confined mainly to surface-supplied diving with equipment specially designed for the purpose. (See part 2.)

(6) As with nitrogen-oxygen mixtures, the percentage of oxygen must be kept within safe limits for the depth and duration of the dive to prevent oxygen poisoning. In dives deeper than about 300 feet, this requires using less than 21 percent oxygen.

(7) Incidental effects of helium-oxygen mixtures include a striking change in the diver's voice, (see 1.2.8(11)), more rapid loss of body heat in cold water (see 1.3.13(15)), and decreased airway resistance in breathing (see 1.3.5(26)).

Hydrogen-oxygen mixtures

(8) Hydrogen has roughly the same properties as helium as far as diving is concerned. The main complication is the fact that hydrogen-oxygen mixtures are highly explosive unless the percentage of oxygen is kept very low.

Other gases and mixtures

(9) It has been pointed out in preceding paragraphs that any gas not actually used by the body is capable of producing decompression sickness (see 1.3.9(13)) and that all of the gases which have been investigated, except helium and hydrogen, are at least as "narcotic" under pressure as nitrogen (see 1.3.10(6)). It does not seem likely that any existing gas would be more satisfactory from these standpoints than those in use.

(10) Another suggestion involves shifting from one inert gas to another during the course of a dive or the subsequent decompression. (See 1.3.9(12).) Although switching to another gas will cause the first to come out of solution, the second gas will go *into* solution at a similar rate. It is not very likely that the procedure could reduce the final amount of dissolved gas to an important extent.

(11) The decompression advantage of increasing the oxygen content of the breathing medium has been mentioned in sections 1.3.9 (14) and 1.3.12(4). The possibility of oxygen poisoning limits the application of this principle rather severely. However, it has also been observed that exposure to near-normal oxygen partial pressure tends to restore a man's oxygen-tolerance. (See sec. 1.3.11(10).) It is possible that providing "breaks" of proper duration would let a diver use a mixture of much higher oxygen content than otherwise and thus reduce his need for decompression greatly. Working out such a procedure even to the point of safe tests would require a great amount of study and experimentation, but the eventual means of breaking through the "depth-time barriers" of diving may lie in some procedure such as this.

1.3.13 EFFECTS OF TEMPERATURE

(1) Extremes of temperature—most often *cold* water—can sometimes limit a diver's ability to stay submerged and do useful work more severely than any of the other physiological problems discussed so far. A man can live and function effectively only if the temperature in his body remains close to normal: 98.6° F. (37° C). The body has amazing ability to keep this aspect of its internal environment constant, but the natural adaptive mechanisms can go only so far in the face of extremes in the external surroundings. Beyond a certain point, protection has to be provided; and if this is not effective enough, several unfavorable consequences can follow.

Regulation of body temperature

(2) The body produces heat all of the time, and it must continually lose an amount of heat equal to that produced (and no more) in order to keep its temperature constant. The amount of heat produced depends mainly on the degree of exertion and is proportional to the oxygen consumption. A man at complete rest produces enough heat every hour to warm about 2 liters of ice cold water up to body

temperature. If he is doing very heavy work, he could warm nearly 23 liters (about 6 gallons) of ice water to body temperature in the same time. If a man doing moderate work could lose no heat at all, his body temperature would rise to 110° F. in less than an hour; and such a temperature would probably cause his death.

(3) Under ordinary conditions on dry land, the body has no trouble losing heat. If the surrounding air is cooler than the body, heat will be lost by conduction, convection, and radiation. (See 1.2.8(13).) In addition, some moisture is always evaporating from the skin and this helps cool the body. If the rate of heat-loss needs a boost, the control system will cause sweating; and the evaporation of the extra moisture cools the skin further. Evaporation-cooling permits heat-loss even if the surrounding air is warmer than the body—as long as it is not so humid that sweat can't evaporate rapidly enough. The faster air moves over the body surface, the more rapid cooling will be, especially if the air is cool and dry. When the air is both hot and damp, the body may produce more heat than it can lose; and this can seriously limit the amount of work a man can do.

(4) In a normal range of temperatures, the body can control the rate of heat-loss rather readily. In the warmer part of the range, this is done mainly by turning the flow of sweat up or down to produce more or less evaporation-cooling. At lower temperatures, the rate of loss depends mainly on the difference between skin temperature and air temperature, and the control system can vary the skin temperatures by "valving" more or less blood to the skin. This is done via the nerves which control the muscle layers of the small arteries in the skin. (See 1.3.3(3).) The cooler the skin, the less heat is lost.

Heat-loss underwater

(5) Submerging the body causes several changes in temperature regulation. Cooling by evaporation is no longer possible, and conduction becomes the main method of losing heat. Water conducts heat away from the body so much more rapidly than air that a man can chill in water at a temperature which would be uncomfortably warm in moist air. Warming water requires about 3,000 times as much heat as warming the same volume of air to the same extent. In addition, an unclad diver's body is constantly bathed by unwarmed water, especially if he is moving about; so heat loss can be very rapid if the water is much cooler than the body.

(6) Because sweating and evaporation can no longer provide additional cooling, being submerged in water at or above body temperature will prevent any heat loss. If a man is working hard and producing much heat, even temperatures above 86° F. (30° C.) can cause eventual overheating. This is not often a problem in diving, but water this warm is found in some parts of the world; and it is much more difficult to protect the body against excessive heat than against cold.

Tolerance to cold water

(7) A diver is much more likely to encounter cold water than water which is too warm. The temperature he can tolerate without protection depends mainly on the amount of work he is doing. If he is producing a lot of heat, it will take longer for his body temperature to fall to an uncomfortable level. There are also differences between individuals. A fat man has more built-in insulation and can generally hang onto body heat better than a lean man. The body has a considerable amount of heat stored up in it and does not lose heat all at once; so in a certain range of temperatures, an unprotected man can stand cold water if he does not have to remain in it too long. Figure 1–31 gives some information about approximate times at various temperatures and at what levels protection becomes necessary.

Effects of cold

(8) When the surroundings are too cold, the body concentrates on keeping the most vital parts as warm as possible. To do this, it will let the temperature of the skin and extremities fall, reducing the rate of heat-loss to the minimum. When a man is comfortable, his average *skin* temperature is about 93° F. (34° C.). If it falls below 88° F. (31° C.),

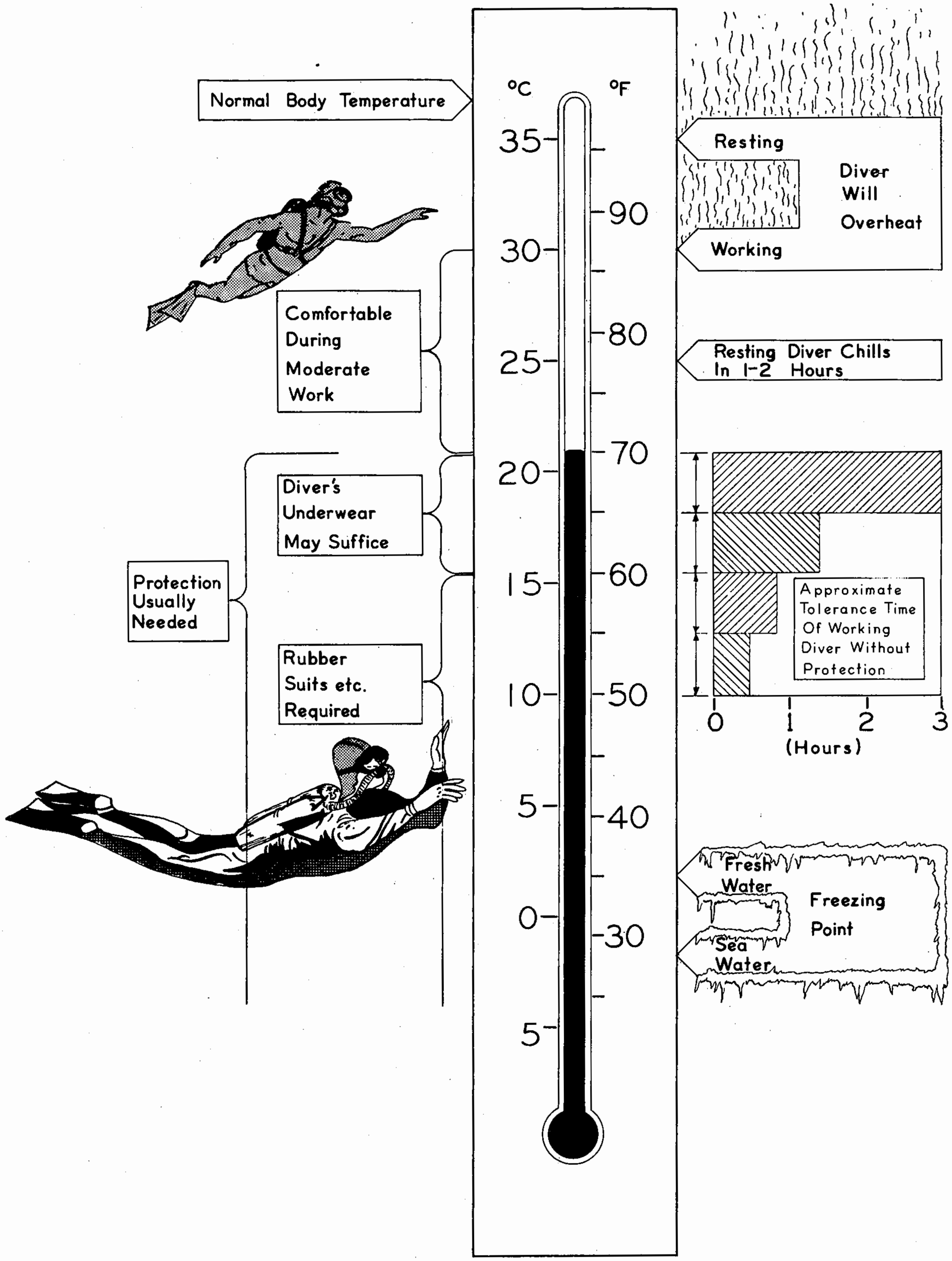


FIGURE 1-31.—Effects of water temperature.

he begins to feel uncomfortably cold. At about 86° F. (30° C.), the control system causes him to start *shivering*. Since shivering involves muscular work, it is a means of increasing heat production to slow the drop in temperature. If the temperature continues to fall, discomfort shortly becomes extreme. The hands (and to a lesser extent the feet) tolerate cold better than the body surface as a whole; but letting the skin temperature of the hands fall below about 60° F. (15° C.) will produce intolerable pain.

(9) Chilling, even if not severe enough to threaten life or cause permanent harm, produces more serious effects than just discomfort and shivering. Loss of the sense of touch and the clumsiness of cold hands can make it very difficult for a diver to do useful work or even control his gear. Shivering causes a general lack of coordination and may even make it difficult for a scuba diver to hang onto a mouthpiece. A man's ability to think clearly may also be seriously affected by cold. All of these effects can definitely increase the risks involved in a dive.

(10) Actual freezing of the hands or feet is not very probable even in icy sea water, nor is a diver likely to be in cold water long enough for long-exposure cold injuries like "immersion foot" to develop. However, a milder form of local injury, called *chillblains*, is possible especially if the exposure is long and the body as a whole is chilled in the process. (In this condition, subsequent warming causes the affected part to become swollen, red, hot, and tender; and itching may be severe.) The ability of an unprotected man to survive in really cold water is limited. At about 40° F. (5° C.), some men will die within an hour.

(11) In some situations, personnel at the surface are more likely to suffer from cold exposure than the diver, or the diver may be more likely to chill after surfacing than when he is submerged. Such circumstances are beyond the scope of this discussion, but they should be kept in mind. Adequate cold-weather and foul-weather gear must always be provided.

Cold water protection

(12) A diver in deep sea dress can usually wear enough underwear to keep himself warm in cold water for a reasonable period. Keeping his hands warm enough to retain touch and dexterity are likely to be his main problem. A scuba diver has more difficulty with cold. He generally prefers to wear no more than swim trunks, but figure 1–31 shows that the range of temperatures where he can do this is very limited. If the water is not too cold, or if the dive is short, simply wearing wool underwear may be sufficient. This merely cuts down on the amount of cold water which circulates next to his skin.

(13) Colder water requires actual insulation. (See 1.2.8(14).) Wearing a rubber suit over bare skin is of little more value than wet wool underwear since effective insulation requires placing a layer of air between the body and the water. Such a layer is provided by wool underwear or other cloth materials which trap air in their interspaces. To be effective, these must be worn under a watertight rubber suit, and leaks or excessive sweating will destroy the insulating value. Unicellular plastic materials have gas trapped in small bubbles in the body of the material. These are effective insulators, and since the bubbles do not communicate with each other or with the outside, the surfaces can be wet without loss of insulating properties.

(14) Since insulation requires air in some form, a self-contained diver who is protected well enough against very cold water may have trouble with buoyancy as well as with bulk and clumsiness. Compression of the trapped air with increasing depth will decrease both buoyancy and insulation. With a closed dry suit, it is generally possible to equalize the internal pressure to prevent "suit squeeze" (see 1.3.7(5)), and doing so will also offset the loss of insulation. Unicellular underwear under a dry suit cannot be compensated in this way.

(15) The fact that helium conducts heat much more readily than air has already been mentioned in section 1.3.12(7). This means that a helium diver in suit and helmet derives much less protection from wool underwear

than he ordinarily would. This, in turn, led to the development of electrically heated underwear for helium diving (pt. 2). Completely satisfactory protection of scuba divers who must work in arctic waters may require some similar means of providing additional heat. A number of heating principles might be employed.

Warming a chilled diver

(16) A diver who surfaces from a cold dive needs to regain body heat as rapidly as possible. If it can be provided, a hot shower is one of the best methods of rewarming. The man should at least change promptly into dry, warm clothes if at all possible. A few minutes of vigorous exercise will help stop continued shivering. Hot, nourishing fluids like soup are useful. The traditional shot of brandy, if available, will give a feeling of warmth by opening up the skin arteries and increasing blood flow. However, this will only speed the loss of body heat if the surroundings are still cold; so it is better to hold the spirits until rewarming by other methods is underway.

Effects of overheating

(17) Excessively high temperatures are not common in diving; but in some climates and waters, they may affect both divers and personnel at the surface. It is necessary to assure an ample intake of fluids under hot conditions, and additional salt is also needed. Work should be kept to the practical minimum.

(18) Mild degrees of overheating can cause dizziness, headache, restlessness, difficulty of breathing, and fast pulse. If the condition is not relieved, it can proceed to *heat exhaustion* (heat prostration). In this condition, the victim becomes faint and weak and collapses. He will continue perspiring, and usually the skin is cold and clammy in spite of elevated body temperature. Usually, letting the victim rest in a cooler place and giving him a weak salt solution to drink (if he is still conscious) will bring about recovery; but medical assistance should be obtained if he fails to respond promptly. If a man suffers excessive salt-loss from sweating, muscular twitching and cramps may occur.

(19) *Heat stroke* is an extremely serious consequence of overheating. Collapse is usually sudden, and the body temperature rises sharply. *The skin is dry and very hot*, and the pulse is extremely fast. *This is an acute emergency.* Unless the body temperature is lowered promptly by vigorous measures and other medical treatment provided, death or permanent brain damage can result.

1.3.14 UNDERWATER EXPLOSIONS

(1) The possibility of exposure to underwater blasts exists in several applications of diving. In cases like demolition of underwater obstacles, the use of explosives is usually under control of the personnel concerned. If such an operation is properly carried out, the risk of hazardous exposure is small. This will not always be the case in work with underwater explosive ordnance. It is certainly not the case in operations where, for example, the enemy may use underwater explosives as a deterrent to the offensive operations of self contained divers.

Factors determining degree of injury

(2) Severe injury and death can result from the effects of blast following a nearby air or underwater explosion. The factors which determine the degree of injury sustained by affected personnel are:

(*a*) Proximity of the explosion.
(*b*) Size and character of the explosive.
(*c*) Medium through which force is transmitted.
(*d*) Degree of submersion of diver.
(*e*) Protection of the diver.
(*f*) Modifying factors such as character of bottom in shallow water.

(3) *Proximity and size of the explosive* are considered together because the approximate total force exerted by a blast wave on a diver can be calculated from a formula which involves both. The pressure exerted at a given

distance by an underwater explosion of tetryl or TNT is expressed by the formula:

$$P=\frac{13{,}000\sqrt[3]{W}}{d}$$

Where:

P=force in pounds per square inch
W=weight of explosive in pounds
d=distance of explosion from diver (feet)
$\sqrt[3]{\ }$="cube root of")

A sample calculation shows that a 600-pound charge at a distance of 50 feet exerts a pressure of 2,180 pounds per square inch. A pressure of 500 p.s.i. is sufficient to cause injury to the lungs and intestinal tract; so one over 2,000 p.s.i. would certainly be fatal.

(4) An explosion produces a *shock wave* which travels through air or water in all directions in a manner somewhat like the spread of ripples produced by dropping a stone into a pool. The initial compression wave (high pressure peak) is produced by the violent liberation and expansion of gas during the detonation. A low pressure wave (less pronounced) follows as a result of the subsequent collapse of the mass of expanded gas. The compression wave is the most destructive factor.

Mechanism of injury

(5) If the pressure of an underwater compression wave is above 500 p.s.i. when it reaches the surface of the water, the surface at that point will literally be torn to shreds and blown up as finger-like projections of water. This "shredding effect" also helps explain the mechanism of blast-damage to the body. In many ways, the damage is also like a very abrupt and forceful local *squeeze*. The "solid" parts of the body are not damaged because they are largely composed of water and are incompressible. The pressure wave is simply transmitted through them without any disturbance, just as the pressure of depth is transmitted. But when the pressure wave arrives at one of the body's airspaces, the situation is different. Even if the space has nonrigid walls (like an air pocket in the gut), the air does not compress and equalize the pressure at the same rate that the surrounding incompressible parts transmit it. This lets a large *difference of pressure* develop just as it does when the compression wave hits the free air at the surface of the water. In the body, it is mainly the tissues forming the walls of the space (or tissues nearby) which tend to be "shredded."

(6) The lungs and intestines are the most vulnerable areas. Since the head also contains air spaces, damage to these and to the central nervous system can also occur if the diver's head is underwater.

Influence of various factors

(7) The character of the explosive makes a difference not only because of variations in the total force but because the "rate" of explosion influences the nature and transmission of the pressure wave. An explosive which detonates very rapidly will produce a compression wave which has high pressure but very brief duration. If the detonation is less abrupt, the maximum pressure is lower but is sustained longer, and the wave does more damage at longer range underwater. The "transmitting medium" is important because the incompressible nature of water lets it transmit the blast pressure with more force than air will.

(8) The degree of injury is influenced by the diver's degree of submergence simply because parts which are out of water are unaffected by an underwater blast. Being underwater will provide a diver protection in case of an air blast. Sometimes, the depth of the water and the type of bottom influence the degree of injury. In some situations, reflections of the pressure wave from a hard bottom can apparently add to the damage.

Protective measures

(9) *Protective clothing* made of materials like foam rubber and kapok offers some protection against the effects of underwater blast. However, the bulk and buoyancy of the amount of material required for significant protection is considerable and rather impractical in diving. Use of rigid material in conjunction with a foam substance may increase the effectiveness of protection.

(10) If a diver expects an underwater explosion and has time to take any action, he should attempt to reach the surface and get as much of his body out of the water as possible, taking advantage of anything that he can climb up on or use for flotation. If he must remain in the water, he should float or swim face up to put the thicker tissues of his back between the vulnerable organs and the explosion. It is useless to cover the mouth or rectum because the mechanism of injury does *not* involve air or water being forced through these openings. If there is time, the diver should obviously get as far away from the expected location of the explosion as possible. If an air or surface blast is expected, the diver should stay submerged and go deeper if he can.

Management of casualties

(11) A man who is exposed to an underwater blast of any severity should receive medical attention whether or not he appears to be seriously injured. One reason for this is that even a seemingly minor intestinal injury will sometimes produce a delayed perforation of the bowel. Such a development requires prompt surgical treatment.

1.3.15 NUCLEAR RADIATION

(1) The effects of nuclear weapons include blast, heat, and prompt radiation flux of the explosion itself as well as delayed effects due to fall out and contamination. Of these effects, contamination resulting from bomb detonation is apt to be of most concern in diving. Beach landings of underwater demolition personnel and use of advanced land bases for diving operations could involve risks due either to previous explosions and fall out or to deliberate spreading of radioactive fission products by the enemy.

(2) Land contaminated by deposition of radioactive material is likely to present a great hazard to personnel. In a surface or underwater burst, contamination from bomb debris and some induced radioactivity are the main factors. Water tends to become less radioactive than land because of dispersion, dilution, and settling out. The bottom may become dangerously contaminated. The necessity of working on ships and other structures exposed to nuclear explosion can present special problems for divers.

(3) When diving operations are undertaken in a radioactive area, a preliminary survey should be made. Land, water, the bottom, and any other possible sourse should be investigated. If a radiation hazard of any degree exists, personnel should be equipped with dosimeters and all appropriate limits and precautions observed.

(4) The use of radioactive isotopes for various purposes is likely to become more frequent in diving as it has in industry. Proper handling of such materials and ample safeguards are of vital importance and should conform to recognized radiological safety precautions.

1.3.16 MISCELLANEOUS PROBLEMS

Sunburn

(1) A diving operation often involves more exposure to cold and other discomforts in its surface phases than underwater. Sunburn does not sound like a diver's problem, but it can be a serious one. Everyone knows that the effects of excessive exposure to the sun never appear until it is too late, but it is very easy to forget this fact. Severe sunburn is disabling not only because of the discomfort but because the natural functions of the skin (like those of heat-regulation) are interfered with. In addition, a bad burn produces toxins that are picked up by the blood and affect the body as a whole. A badly sunburned man is not only extremely uncomfortable but really sick—and useless as a diver for some time.

(2) Gradual exposure to the sun can be accomplished by sensible use of clothes and protective creams. ("Suntan oils" are not usually adequate for long exposures.) The neck and face are especially sensitive in men who have not built up their tolerance. Unnecessary exposure to the sun is unwise even when it no longer produces actual sunburn. Long-term exposure ages the skin and increases the chance of developing skin cancer.

(3) Remember that sunburn can result from reflected sunlight as well as from direct rays.

Sunburn can also occur on a hazy, overcast day as well as in bright sunlight.

Seasickness

(4) The possibility of seasickness exists not only on ships and diving boats but also underwater under some conditions and during decompression in rough seas. A seasick diver is operating under a real handicap, and vomiting as a result can be a serious hazard especially in the use of scuba. Men who are unusually susceptible should not be divers. Drugs used to prevent seasickness may be helpful, but most of them can make some men too sleepy and sluggish to be safe or useful underwater. Unless a man knows that he is not unduly affected, he should not use such a drug before a dive.

General

(5) Most of the problems and accidents discussed in this chapter are also summarized in section 1.6. (Diving Hazards), with indication of situations where they are likely to occur and with concise lists of symptoms and of steps useful in the prevention, detection, and handling of accidents. Treatment of various accidents is covered in more detail. A number of hazards not covered in this chapter, especially those which involve mechanical injury or combinations of several physiological problems, are also discussed in section 1.6.

SECTION 1.4 BASIC DIVING PROCEDURE

1.4.1 ORGANIZATION AND PLANNING

Command responsibility

(1) The responsibility of the commanding officer is clearly defined in the U.S. Navy Regulations. He may at his discretion delegate authority to his subordinates for the execution of details. Such delegation of authority shall in no way relieve him of his continued responsibility for the safety, well-being, and efficiency of his entire command.

(2) An officer must be assigned the responsibility for any and all diving performed by the command. He is known as the *diving officer*. In the absence of a qualified diving officer (BuPers Manual Arts. C–7313, C–7314, C–7315, and C–7316), any officer may be assigned. Such officer must study all diving publications currently in use and make certain that all safety regulations are observed and that all diving is conducted in accordance with good diving practice. An enlisted *diver* whose competency, responsibility, and reliability are commensurate with the particular operation, may be designated as the *diving supervisor*. The term "diving supervisor" as used in the manual denotes that person, officer or enlisted, who has been delegated the authority to take charge of a particular diving operation. One person, the diving supervisor, must be in complete charge at the scene. No diving operation may be commenced without a diving supervisor. To fulfill his responsibility and maintain proper *standards*, a good diving officer confers with the diving supervisor at such times as do not interfere with the proper conduct of the operation. Under no circumstances does he tolerate violations of outlined procedures. This manual is in a looseleaf binding for the benefit of the man with a better method. Instructions in the "Special Note" in the front of this manual give the procedure to follow in recommending an improvement.

Planning and foresight

(3) Diving, as much as *any* military operation, emphasizes the necessity for planning and foresight. Bottom time is a premium. The diver must be placed on the job under the absolute optimum conditions of knowledge, equipment, ability, safety, and freedom from distractions. Topside assistance must be well organized and capable. Failure to consider any item of available information during the planning stage may result in failure of the diving operation. Time spent by the supervisor in determining conditions under which he will work will inevitably result in greater efficiency once the job is commenced. Circumstances such as changing weather conditions often prohibit a second attempt to complete diving operations which failed because the supervisor did not initially select the proper equipment, personnel, or procedure. Most important, the lives of many divers have been jeopardized by lack of foresight and failure to consider all eventualities.

(4) With the amount of individual emphasis demanded by the size of the job, analyze and plan your job as outlined below. If any phase produces information that you should have considered in a previous step, reconsider the original analysis and re-plan that step.

(*a*) *Objective.*—Decide exactly what it is that you want to accomplish. Review carefully to assure yourself that it is feasible and necessary.

(*b*) *Procedure.*—First and foremost, establish that the objective cannot be realized more simply by surface seamanship and rigging. Then outline a general plan. Consider all phases right up to completion and securing.

(*c*) *Peculiar hazards.*—All diving is essentially hazardous. Protection against normal hazards is the reason for minimum personnel qualification requirements, standardized procedures, and equipment specifications. The fact that the diving supervisor is qualified to conduct the type operation at hand presupposes that he will combat normal hazards with standard practice. At the same time, almost every diving operation will have conditions that are particularly hazardous or might easily generate a hazardous condition. Review the entire outlined procedure and include all special precautions necessary to combat such conditions.

(*d*) *Surface conditions.*—Surface conditions include weather, sea, topside equipment and personnel. Equipment and personnel include that outside of the command as well as that within the command. The surface conditions important to consider are either those available for use if required or those that constitute a potential hazard to the diving operations. Take all present and expected surface conditions into account in the planning phase.

(*e*) *Underwater conditions.* — Underwater conditions include the work site, the depth, the tide, current and visibility underwater, and the type of bottom. Make certain that every one of those elements is used to your advantage.

(*f*) *The dive.*—The "dive" includes more than the simple process of descent, work, and ascent on the part of the diver. The organization and personnel topside are just as critical in the final analysis as the individual ability of the diver himself. Most military diving operations require much preparatory and supporting effort. The most common failing of diving supervisors is to over-plan the dive itself while under-planning all of the preparatory and supporting work. Plan the dive properly. Select your diving and supporting equipment. Outline your intended plan to your entire crew. Include plans for emergencies and any additional special items. Properly organize and train your surface crew to do their assigned jobs in support of the diver. Give your diver step by step instructions on what he is to accomplish. At the same time, organize and detail additional topside personnel in such a manner as to have the lines, the shackles, the tools and countless additional equipment ready to go to the diver the moment they are needed. Do this through subordinate petty officers with a minimum of confusion and you are a good diving supervisor.

Additional notes to the diving supervisor

(5) Make every effort to detail *all* routine work. Even when your problems as the leader appear small, make it a habit to keep yourself above the minor jobs. You will find that you can always use time to review and improve on your plans for the next phase. Most important, you have to be ready for the contingency that you haven't planned.

(6) There is an exception to the above general rule. In many instances a preliminary dive will be of great value in deciding on the correct course of action. Confine yourself to a preliminary dive and a final inspection dive, if they are necessary.

(7) Bear in mind that changing or unforeseen conditions may require changes in the original plan. In order to meet this possibility, you must have one or more alternatives available. A successful plan must be flexible.

(8) Some of the most regrettable accidents in diving have come about as a result of diving operations becoming routine. When the same type of diving is repeated day after day, there is a strong tendency to relax and lay aside the plans and preparations for emergencies. When you see this happening, visualize a few of the casualties that could happen. Hold a drill emergency, if necessary.

Preparations

(9) As outlined below, many important preparations must be made prior to commencement of actual diving. The majority will apply only to a particular type of diving apparatus or operation. Specific preparations applicable to surface-supplied diving and self-contained diving are covered in their respective sections of this manual.

(*a*) Insure that all necessary equipment is at hand.

(*b*) Check all equipment to insure proper operation.

(*c*) Insure that all who need to know are informed that diving operations are to commence.

(*d*) Ascertain location of nearest medical facilities and recompression chamber and availability of transportation to same.

(10) For additional guidance in preparations, refer to section 1.7 (General Safety Precautions) and part 2 or 3, as applicable to the diving apparatus being used.

(11) Specific preparations are commented upon and expounded in the following articles.

Depth limits

(12) Except in emergencies, or in exceptional circumstances, safe diving practices require limitations on the maximum depths and times of dives. These limitations shall not be exceeded except by specific authorization of the officer in charge of the diving operations or by higher authority. The following table summarizes these limitations.

Depth (feet)	*Limit for—*	*Notes*
25	Breathing 100% O_2 (or its "equivalent oxygen depth" when breathing gas mixtures) while working or swimming.	(a)
36	Non-designated diver in an emergency situation.	(b)
60	Scuba; normal working limit.	(b)
60	Lightweight diving equipment; normal working limit.	(b)
130	Lightweight diving equipment; maximum working limit.	(b)
130	Scuba; maximum working limit.	(b) (c)
150	All divers except first class and master.	
170	Diving without a medical officer and recompression chamber at the scene.	(d) (e)
190	Surface-supplied deep-sea (air); normal working limit.	(e)
250	Surface-supplied deep-sea (air); maximum working limit.	(f)
300	Surface-supplied deep-sea (air); absolute limit.	(f)
440	Surface-supplied deep-sea (H_eO_2); practical working limit.	(g)

NOTES

(a) For time limit at 25 feet, and for other depth/time relationships, see article 1.5.7.

(b) Do not exceed the "no decompression" limits of table 1–6. Dives requiring decompression may be made if considered necessary by the officer in charge of the diving operations. The total time of a scuba dive (including decompression) must never exceed the duration of the apparatus in use—disregarding any reserves.

(c) Certain operational swimmers (as EOD, UDT) are authorized to dive to greater depths when required.

(d) A medical officer and a recompression chamber are required, on the scene, for all helium-oxygen diving operations using deep-sea equipment.

(e) Do not exceed the limits of table 1–5. Table 1–9 is computed for *exceptional* exposures and is intended only for exceptional and emergency situations. Such situations defy complete assurance of safety when using the table.

(f) Do not exceed the limits of table 1–9.

(g) This is based on a practical consideration of working time vs. decompression time.

1.4.2 THE DIVER

Qualification

(1) The diver must be qualified and designated in accordance with section 1.10 of this manual. The diving supervisor will check the diver's qualifications to insure that the diver is currently qualified in the type of apparatus to be used and for the work to be accomplished.

Condition

(2) Diving equipment is only as good as the man using it, and the man using it can only be as good as his body will allow. It is imperative that the diver keep himself in good physical condition by means of training and proper medical attention. A complete physical examination prior to each dive is obviously impractical. The medical officer and corpsman should take an active personal interest in the condition of their men. Encourage them to report any symptom or condition which might interfere with or prevent them from diving. Do not penalize or ridicule the diver who, for any reason, seriously desires not to make a certain dive. Assess psychological adjustment to diving and other specific duties. Disqualify the man who evidently dislikes diving or often demurs for insufficient reasons. The diving supervisor and medical officer should know their divers as individuals. This personal interest and relationship will contribute greatly toward keeping the divers both physically and mentally fit for diving.

(3) Maintain a high degree of physical fitness for optimum performance. All diving activities, ships included, should set up a continuing physical training program and encourage exercise like running, swimming and skin diving. In order for any physical training to be beneficial, it must be continuous and consistent. Divers should have a well-balanced diet. Adequate sleep is imperative if the diver is to be efficient.

(4) The diving supervisor, with the aid of the medical officer and corpsman, must insure that the diver is fit to make a dive. He must:

(*a*) Determine that the diver feels fit.

(*b*) Prohibit diving with *any degree* of alcoholic intoxication or evidence of its after effects.

(*c*) Avoid diving with respiratory or middle ear disease.

(*d*) Avoid diving with skin or external ear infections.

Standby diver and the "buddy-system"

(5) Any thorough preparations for a diving operation must include provisions for a "standby diver" or "swim buddy" depending upon the type of diving apparatus employed. In an operation employing surface-supplied diving equipment a "standby diver" must be designated. This diver will be dressed to the extent that he can be put into the water almost immediately to go to the aid of the distressed diver. Standard deep sea diving practice dictates that the diver be completely dressed except for weighted belt and helmet. When using lightweight gear, the same procedure should be followed if the dress is being worn. The important thing is to visualize an emergency and see if you can get help to the diver in time to be of material assistance.

(6) When self-contained diving equipment is being used, the "buddy system" is a must. There has never been a recorded case of accidental drowning when this system is being used. Self-contained divers swimming or working as "buddies" must remain in sight of each other at all times and be prepared to render assistance to each other as required. Under conditions of extremely low visibility, use a "buddy line." A short length of line (preferably nylon) with a snap hook at each end makes a good "buddy-line."

1.4.3. EQUIPMENT

(1) Diving equipment is being constantly improved and changed through the advance of new diving techniques. It is important that the modern diver keep abreast of equipment developments. The diving officer and the diver must know the capabilities and limitations of any equipment which they use.

Selection (appropriateness)

(2) There are many factors involved in determining the type of equipment to be em-

ployed on a job. The prime consideration is the safety of the diver. In order to make the proper selection, the diving supervisor must be aware of the relative merits of surface-supplied equipment and self-contained gear. The capabilities and limitations of each type of gear can very often be the determining factor in deciding whether to use self-contained, shallow water, or deep sea rig.

(3) Before starting a job, an initial inspection dive should be made and the information obtained therefrom should be carefully evaluated. This intelligence will enable the diving supervisor to select the type of equipment to be used based on the conditions and the work to be performed.

Approved equipment

(4) Diving equipment will not be used operationally unless it has received official evaluation and *approval*. Trials of experimental gear and modification of present equipment may be conducted only at designated activities, such as the Experimental Diving Unit, or by others when specifically authorized by competent authority. When evaluating new or modified equipment, the diving supervisor will give special consideration to the safety of the personnel involved and insure that all trials are properly supervised and safeguarded.

Maintenance

(5) The importance of proper maintenance cannot be overemphasized. Equipment must be in optimum condition at all times. A routine of periodic inspections and preventative maintenance must be established and adhered to rigidly. This applies to all equipment regardless of the amount of usage. Diving equipment which is not in constant use is frequently susceptible to deterioration and damage. Records on all outfits and major components must be kept. Correct any defect, however minor, before using any equipment. Keep an adequate supply of spare parts on hand. Maintenance, handling, and storage is covered in detail in part 2 for surface-supplied equipment and part 3 for self-contained. The schedules and precautions set forth in parts 2 and 3 must be strictly adhered to by all diving activities.

1.4.4 DIVING CRAFT

General

(1) The type of craft utilized for any diving operation will depend upon the characteristics of the job and the diving apparatus to be used. In many diving operations it is not feasible to work from the deck of a vessel, or the location may be inaccessible to a large craft. In these cases, small craft should be utilized, insuring that the craft is adequately equipped to support the type of apparatus to be used. Small craft are also used when the diving jobs are of relatively short duration or are performed at different points over a wide area. When a diving job entails months of diving in a small area, it may be convenient to build a diving float.

Surface-supplied diving craft

(2) The diving equipment and diving personnel for surface-supplied diving are generally assigned to tenders, repair ships, salvage vessels, submarine rescue ships, diving barges or floats, and shore based diving units. In diving operations where it is not feasible or practicable to work from one of these craft, any suitable small craft may be equipped or converted for diving. However, before any attempt is made to rig a small craft for diving, the following basic requirements must be considered:

(*a*) Adequate space for storage of equipment.

(*b*) Adequate space for diving platform.

(*c*) Adequate space for diving crew.

(*d*) Seaworthy hull.

(*e*) Engine in good condition.

Scuba diving craft

(3) Self-contained divers are able to work from almost any type of craft due to their mobility. However, whenever possible, diving directly from large vessels or from the shore should be avoided. For an immediate "base of operations," it is preferable to utilize a small power craft moored as close as possible

to the scene. The craft must be kept free to cast off immediately to recover a diver in difficulty. Enable the divers to enter the water and return without difficulty through use of a small ladder or stage. A line marked at 10-foot intervals should be rigged over the side in order to provide a convenient procedure for decompressing the scuba divers. A seven-man rubber boat is an ideal diving craft since it can be used for a diving platform as well as a recovery boat for the divers. There must be ample room for the diving crew to dress and for the storage of additional equipment. Provisions should be made to keep the divers warm and comfortable before and after dives.

1.4.5 SURFACE CONDITIONS

(1) In planning a diving operation, careful consideration must be given to the surface conditions which will be encountered at the scene of the operation. This includes the state of the sea, weather, tide, currents, presence of other ships, and any other surface conditions which could affect the operation.

Sea

(2) Upon arrival at the scene of the operation, local sea conditions must be studied to determine whether the diving craft can be moored and divers put over the side. Diving operations must not be commenced in rough seas, unusual tides or currents, or any other conditions which in the opinion of the diving supervisor might unnecessarily jeopardize the security of the divers. Working around or under small vessels is quite hazardous in rough seas.

(3) If divers are required to spend long periods in small craft under adverse sea conditions, seasickness can become a serious problem. (See 1.3.15.)

Other ships

(4) If the diving operation is to be conducted in a crowded harbor or waterway, it might be necessary to have the immediate area cleared and patrolled. All ships in the vicinity must be notified of impending diving operations. Display proper visual signals in a prominent place on the diving craft during the operation to warn other ships or craft entering the area.

Visibility

(5) Except in an emergency, diving operations must not be conducted during periods of low visibility in any area where there is danger of the diving craft being run down by another vessel. The self-contained diver, when not tended from the surface, is particularly vulnerable in low visibility, because he can become lost and is without means of relocating the diving craft.

Miscellaneous

(6) In diving, personnel on the surface often suffer more from exposure than the submerged diver, particularly in small craft. The effects of air temperature must be considered in extreme climates. Tenders may suffer from frostbite in a cold climate or heat exhaustion in hot weather. Sunburn can be a serious problem particularly if the men have not had the benefit of gradual exposure. The diving supervisor must consider the elements in planning his dives and insure that all personnel have adequate clothing to protect them under the prevailing conditions.

(7) Readiness for accident and recompression are two important factors that must be considered in preparing for any diving operation. The presence of a medical officer trained in diving and a recompression chamber are always desirable. Many occasions will arise, however, where neither is available. In these cases the officer responsible for the operation must make the decision to proceed if the diving is to be done in water of a depth requiring considerable decompression. Military necessity may at times require that the diving be done in the absence of these facilities. If there is a chamber nearby, the activity maintaining the chamber should be notified of the possible need for assistance in order that it will be ready if needed. A rapid means of transportation to the chamber should also be available. It is mandatory that a first aid kit be available on all diving operations and, if feasible, a hospital corpsman should be present.

(8) Give some thought to the matter of surface communications prior to commencing a job. On any diving operation there is a possibility of three general needs arising:

(*a*) Need for command decisions.

(*b*) Need for equipment and supplies.

(*c*) Need for medical services in case of accidents.

(9) If the supervisor permits himself and his crew to be isolated, considerable delay and confusion may be encountered when an unforeseen circumstance arises. As a general rule, arrangements should be made to communicate with the following individuals:

(*a*) The officer in tactical command.

(*b*) The officer or activity who will supply additional tools, replacement parts, and food if needed.

(*c*) The activity having a medical officer trained in diving.

(*d*) The activity having a recompression chamber.

(*e*) The nearest medical facility having an ambulance.

1.4.6 UNDERWATER CONDITIONS

Depth

(1) Whether to use deep sea, lightweight, or self contained diving equipment will depend on the depth of water as well as upon the purpose for which the dive is being made. Depth of water is, therefore, a basic consideration. Determine depth accurately prior to the start of diving operations. This information is also necessary to determine what, if any, decompression is necessary. The effect of depth on light conditions underwater is discussed in article 1.2.8.

(2) To determine depth accurately, use the pneumofathometer whenever feasible. The pneumofathometer consists of an oxygen hose of sufficient length to reach the depth to be measured, an air supply of greater pressure than the maximum depth and an accurate gage, both connected to the surface end of the hose. Leave the hose open at the bottom end and send it to the depth to be measured. Do this by attaching it to the diver or to a weighted object. When the bottom end is positioned, blow out the hose with the air supply. Secure the air and read the depth on the gage.

Bottom conditions

(3) Bottom conditions have a decided effect on a diver's ability to move about and his ability to see. In general there are six main types of bottoms which will be described individually.

(*a*) *Rock.*—This type of bottom may be either smooth or jagged. If the latter, care must be used to keep from getting lines caught on protruding rocks or wreckage. Deep sea divers have no difficulty walking on this type bottom although they must be careful not to fall off ledges. If confronted with an obstruction or wreckage, it is better to go over it than around it. However, if it becomes necessary to go around such an obstruction, the diver should note carefully which side he is passing on so that he can avoid returning on the wrong side. Visibility is not impaired by sediment stirred up as the diver walks around.

(*b*) *Coral.*—Coral bottoms are solid but practically always jagged. The diver normally has no difficulty moving around, but gloves are recommended to protect the hands against the sharp and painful cuts which otherwise result from contact with this type bottom. As with jagged rock, great care should be taken to prevent fouling the air and life lines and to prevent falling. Visibility is not impaired by bottom conditions.

(*c*) *Gravel.*—Gravel bottoms normally provide a good base for the diver, permitting easy movement and a relatively smooth flat surface. Occasionally a diver will encounter sloping bottoms with loose gravel. These are often difficult to move around on since such gravel frequently causes the diver to slip and fall. As with rock and coral, visibility is little affected by the diver's movements on the bottom.

(*d*) *Shell.*—Bottoms composed principally of broken shells are sometimes encountered. The shells are usually mixed with sand or mud. Where a shell-sand mixture exists, the divers movements are not impaired, and visibility is little affected by movement. A shell-mud mixture is more susceptible to penetration. The degree to which a diver will sink into the bottom will depend on how much mud is present. Visibility is affected since the mud is stirred up and clouds the water. As the proportion of mud increases, the diver will find it increasingly difficult to see and move around.

(*e*) *Sand.*—Many bottoms are composed mainly of sand. Sand packs hard and even if other materials are present they are usually packed in with the sand. The diver, therefore, can walk around freely on this type bottom and visibility is not normally impaired.

(*f*) *Mud.*—Mud is composed of silt and clay in varying amounts. This very common type bottom restricts a diver's movements. The fact that a diver sinks into mud up to his knees, waist, or even over his head is not a serious matter. He may easily get loose by inflating his suit and wiggling around. It is difficult to walk around on such a bottom; and crawling, assisted by proper and periodic inflation of the diving suit to decrease negative buoyancy, may be the only possible way to move around. Since the slightest movement will stir up the sediment and cause clouds of mud to decrease visibility, movement in mud should be curtailed as much as possible. The diver should orient himself so that the current, if any, will carry the silt away from his work. The only hazard involved in diving in mud is the inability to see such objects as wreckage, pilings, and other types of debris. The self contained diver has a decided advantage on a mud bottom in that he can work and move about without touching the bottom and stirring up mud. Thus his visibility is better. However, visibility is often quite limited close to a mud bottom even when the bottom has not been stirred up.

(4) Harbor and channel areas of continental United States are usually sandy although mud areas exist in many.

Tides and currents

(5) A diver at 50 feet depth can just barely feel the wave motion of surface waves which have a length of 100 feet. Wave motion becomes more noticeable as the waves increase in height or as the diver moves into shallower water.

(6) There are various types of currents which the diver may encounter, and they will have an effect upon all divers regardless of the diving equipment worn. The deep-sea diver wearing a lifeline and heavy weights will be affected less by currents than the diver wearing self-contained diving gear, and will be able to work in stronger currents. Rip currents are seaward-moving streams which return the water carried shoreward by waves. They often reach 2 knots and usually extend 1,000 feet to ½ mile off shore. These currents are primarily of concern to the self contained diver. Aside from local inshore currents, divers will also encounter currents due to tides and other factors. If understood, they can be used to the diver's advantage. Since current direction and velocity will vary with depth, tide, and bottom configuration, current tables must be used with caution since these show only surface conditions. Normally, current velocity decreases with depth. In many places where the tidal currents are rapid, diving time may be limited to periods of slack water. The strongest current speeds in which a diver can do useful work vary from 2 to 2.5 knots. An additional heavy weighted belt will be necessary in currents of 1.5 knots and above. A self contained diver is handicapped by even a small current of less than 1 knot.

Visibility

(7) The effects created by light after it enters water are discussed in article 1.2.8. The fine particles in water are called debris and consist of fragments of organic matter or mud. Pure water is transparent, but when debris is present the water becomes turbid and objects disappear as in a fog. Underwater visibility varies depending on the locality, general water condition, and type of bottom. In tropical waters, visibility is usually quite good; and it is frequently possible to see over 100 feet at 30 fathoms depth. Channel and harbor areas are usually quite turbid due to sediment-laden rivers emptying into these areas. Ships and strong currents passing through a channel frequently stir up the bottom. Visibility is frequently zero and seldom more than 15–20

feet maximum in such areas. Rainy seasons and plankton which increase in spring and fall also contribute to a decrease in visibility.

Temperature

(8) Divers are extremely sensitive to change in temperature because water is a better heat conductor than air. Heat prostration may occur in water above 86° F. if the diver is working. It can be expected even if at rest in water above 96° F. While there is no diving equipment at present which will protect a diver against heat, a regular deep-sea dress provides considerable protection against cold water. If the dress has no leaks, and if he wears heavy woolen underwear and gloves, the diver can work in any water regardless of how cold it is. One possible problem is freezing of the moisture in the diver's air hose. Care must be taken to prevent the air hose from becoming blocked off. Protective dress is always necessary for scuba divers in water colder than 60° F. or if the diver is going to be in water colder than 68° F. to 70° F. for more than an hour. When a diver becomes uncomfortably cold, his power to concentrate and his efficiency drop off rapidly.

1.4.7 THE DIVE

(1) Diving procedures vary greatly depending on the type of equipment used, but certain basic procedures apply to all types of diving. No matter what the conditions are or what equipment he uses, the diver is acted upon by the same weight of water and encounters the same problems of breathing gases under pressure. Specific diving procedures for the various types of equipment are discussed in detail in the applicable sections of the manual.

Diving signals

(2) The three basic means of communication used by divers are visual communications, voice communications, and line pull signals. Visual communications are limited to conditions of good visibility and therefore are most applicable to scuba diving. Visual communication may be accomplished by writing on a slate, by hand signals, or by any easily understandable gesture. A system of hand signals designed for scuba diving is presented in article 3.2.2.

(3) It is possible for divers to talk to each other directly if they are close enough together, but the conversation is difficult to interpret (see art. 1.2.8). Electrical means of voice communication prove more satisfactory, particularly when using deep sea diving equipment. Electrical means of voice communication are in the process of development for diving in self contained and lightweight equipment. Specific procedures for the use of the divers "intercom" are contained in another section of the manual.

(4) Line pull signals remain the basic means of communication whenever the diver is connected to the surface by the lifeline. Line pull signals are not affected by conditions of visibility or by electrical equipment failures and are therefore the most dependable means of communication for any type of diving. Line pull signals have been standardized for the Navy and their use must be understood by all Navy divers. Special signals for particular operations may also be arranged between the diver and the tender. Special signals applicable only to helium-oxygen diving are included in part 2 of this manual.

(5) Line pull signals consist of a series of sharp, distinct pulls, strong enough for the diver or tender to feel but not so strong as to pull the diver away from his work. When sending signals, take all slack out of the line first. Repeat signals until answered. Continued failure to answer a signal may indicate too much slack in the line, a fouled line, or an accident to the diver. Notify the supervisor immediately if the diver fails to respond. The problem of loss of communication is covered in article 1.6.16. Signals are answered when received with two exceptions. Answering the emergency signal "haul me up" results in too much loss of time. Also the diver will never answer the signal "come up" until he is ready to leave the bottom. If he is unable to leave the bottom at that time, he should communicate the fact by "intercom" or by use of the "I understand you" signal followed if necessary by the applicable emergency signal. Many of the standard line pull signals may be

used not only on the lifeline and air hose but also on any other line with which the diver is working.

(6) Signals from tender to diver:

Signal	*Meaning*
1 pull	Are you all right? (When diver is descending, 1 pull means stop.)
2 pulls	Going down. (*During ascent*, you have come up too far. Go back down until I stop you.)
3 pulls	Standby to come up.
4 pulls	Come up.
2–1 pulls	I understand, *or* answer the telephone.

(7) Signals from diver to tender:

Signal	*Meaning*
1 pull	I am all right. on on Bottom
2 pulls	Give me slack, *or* lower me.
3 pulls	Take up my slack.
4 pulls	Haul me up.
2–1 pulls	I understand, *or* answer the telephone.
3–2 pulls	Give me more air.
4–3 pulls	Give me less air.

(8) Emergency signals from the diver:

Signal	*Meaning*
2–2–2 pulls	I am fouled and need the assistance of another diver.
3–3–3 pulls	I am fouled but can clear myself.
4–4–4 pulls	Haul me up immediately.

The diving supervisor must try to find out the nature of the emergency as soon as possible, since in some cases it may be necessary to bring the diver to the surface with decompression.

(9) Searching signals are employed so that the tender can direct his diver as he moves along the bottom. A 7-pull signal from the tender to the diver means that the diver will interpret the signals following as searching signals. A 7-pull signal to a diver who is already using searching signals means that these are no longer to be used. Only the tender may originate searching signals. It is not necessary for a diver to take himself off searching signals before originating a signal, as no signal from the diver will be interpreted as a searching signal. In interpreting the direction in which the diver is ordered to move, he will face or assume he is facing his lifeline, or the descending line if he is using a circling line attached to the descending weight. In sending signals to the diver, the tender must take into consideration the diver's position in relation to his lifeline or descending weight:

SEARCHING SIGNALS

Signal	*Meaning*
1 pull	Stop and search where you are.
2 pulls	Move directly away from the tender if given slack. Move toward the tender if a strain is taken on the lifeline. If using the circling line, move away from the weight.
3 pulls	Move to your right.
4 pulls	Move to your left.

(10) Use the following procedure when working with lines on the bottom. To send a relatively light object to the surface, the diver signals 1–2–3 pulls, which means "send me a square mark." The tender bends a short piece of line, about 3 feet long, to the lifeline and then signals 3 pulls meaning "take up the slack." The diver hauls in the slack until he reaches the square mark and then signals 1 pull "stop." After he has attached the object to be lifted to his lifeline with the square mark, he signals 3 pulls meaning "take up the slack." When the object reaches the surface, the tender detaches it from the lifeline and signals 1 pull "are you all right." All signals are answered as sent. The procedure for lifting a heavier object is similar. The diver signals 5 pulls "send me a line." The tender selects a line adequate for the weight to be lifted and bends the bitter end to the lifeline. When the tender signals 3 pulls, the diver takes up the slack until the bitter end of the line is in hand. After signaling 1 pull "stop," he removes the line from his lifeline and signals 3 pulls on his lifeline. When the tender has taken all of the slack out of the lifeline, he signals 1 pull "are you all right." The diver then makes the line fast to the object to be lifted and commences signaling on it. Signals used on the line are: 1 pull "stop lifting," 2 pulls "slack the line," 3 pulls "take up the slack," and 4 pulls "haul it up." All pulls, whether on the lifeline or any other line, are answered as sent.

Tending the diver

(11) From the time diving operations are first planned, the thoroughness with which the

tenders understand and carry out their duties will, to a considerable extent, determine the success or failure of the operation and safety of the diver. The most effective assistance can be given by the tender who is familiar with the equipment, safety precautions, conditions, and difficulties that are inherent in diving. It is preferable that the tenders be experienced divers. If this is not possible, the diving officer is responsible that personnel designated as tenders are properly instructed in the topside duties. It is the tender's responsibility and duty to insure that the diver receives proper care while topside and in the water. Before sending the diver down, he must thoroughly check all equipment for proper operation.

(12) Generally, the topside duties are divided into handling communications, tending lines, and insuring an adequate flow of air. The usual means of communication between diver and tender is by intercom. However, it is important that the basic hand signals listed in the preceding paragraphs, plus any supplementary signals originated to fit a particular type of job, be memorized and practiced so that they will be recognized instantly in the event of intercom failure or when using gear not fitted with an intercom.

(13) The tender must always keep himself informed as to the depth of the diver. Inasmuch as fathometers, lead lines, descending lines, stage lines, or payed out lifeline and airhose cannot be used to determine depth with accuracy, a simple and accurate device called a pneumofathometer has been developed. Depth is determined by means of an air supply, a depth gage calibrated in feet of sea water, and an oxygen hose. This oxygen hose is made up with the diver's lifeline and airhose, the open end terminating at about the breast plate level. In self contained diving it may be hung off on a weight. To take a reading, blow air through the hose until it escapes at the open end, then secure the air supply. The pressure remaining in the oxygen hose is that necessary to balance a column of water corresponding to the depth of the open end of the hose and is read directly on the gage in feet. While the diver is standing, add 5 feet to determine bottom depth. This device is especially valuable in determining decompression stops during ascent when the diver has been swept from the descending line.

(14) The tender should contact the diver frequently by intercom or hand signal while the diver is on the bottom and on the stage to ascertain if all is well. The tender must give the diver a few minutes' notice before the expiration of the diver's times on the bottom so that the diver can make the necessary preparation prior to his ascent and not exceed the limit of his stay on the bottom.

The timekeeper

(15) The diving officer or supervisor must appoint a qualified diver as timekeeper. The timekeeper must keep an accurate record of time required for the diver to reach the bottom, the depth of dive, the time of exposure on the bottom, the time of ascent to the first stop, and the time spent at each subsequent stop during the ascent. This data must be carefully kept and recorded in the diving log. The timekeeper must at all times have the Navy Standard Decompression Tables at hand and be prepared to advise the diving supervisor or tenders at any moment what decompression procedure should be used. In case of any doubt or borderline determinations of decompression procedure, he must decide in the diver's favor (i.e. choose the next deeper table or next longer time of dive). If a predetermined bottom time has been planned for the dive, the timekeeper must be sure to notify the tender and supervisor well in advance so that the diver may be brought up on schedule. No additional duties may be assigned to a timekeeper if they in any way interfere with or distract his attention from his primary duty. He may, however, be assigned such additional duty as observing the diver's air supply pressure. A timekeeper will not normally be required to keep time on more than two divers at once.

Entering the water

(16) Before the diver enters the water, the diving supervisor must insure that all equip-

ment is working properly and that the diver knows exactly what he must do. The depth of the water must be accurately determined by lead line or other reliable means. The standby diver or buddy must be ready. Proper preparation or briefing will save considerable time and effort and may make the difference between a successful job and a complete failure. Where a lifeline to the surface is used, the tender must also be properly briefed. An experienced tender can tell a great deal about the diver's progress and problems by the feel of the lifeline. Due to the diver's limited efficiency and time, the job should be planned so that all possible work is done on the surface.

(17) Proper procedures for entering the water depend on the equipment used and are covered in the applicable section of this manual. The rule of "look before you leap" applies to all diving. Landing on another diver's head can be painful to all concerned. Before leaving the surface, a final check is made to see that all gear is working properly. All the equipment must be functioning properly before leaving the surface.

(18) The descent should be made as rapidly as possible (but not to exceed 75 feet per minute), provided that the diver is in complete control of the rate of descent. An uncontrolled descent can result in a squeeze, ruptured eardrums, or injury from hitting material on the bottom. The rate of descent will depend on the diver's experience, the type of gear worn, the conditions of visibility, and the diver's ability to equalize the pressure in his ears and sinuses. If the pressure is not equalized, continued descent results in a ruptured eardrum. A diver should never continue to descend if he is unable to equalize the pressure. Pain in the ears may be relieved by yawning, swallowing, or blocking the nostrils and making a strong effort to breathe out. Ascending a few feet will also relieve the pain in most cases. If these remedies do not succeed in equalizing the pressure in the ears and relieving the pain, the diver must return to the surface and should not dive again during the same day.

Working on the bottom

(19) After reaching the bottom, but before starting any work, the diver should make any necessary adjustments of his breathing supply and buoyancy to adapt himself to conditions on the bottom. A few minutes spent in considering the work to be done from all angles and planning the method to be used is also necessary. No matter how thorough the topside briefing, the final plan of attack must always be the decision of the diver. An experienced diver can make his work much easier by proper use of his equipment. For instance, a deep sea diver can lift heavy weights on the bottom by hooking his arms under the object to be lifted and holding his chin button. The increase in buoyancy of his suit does most of the work. Specific techniques depend on the equipment used and may be found in the applicable parts of the manual.

(20) When working on the bottom, the diver must never become so engrossed in his work that he forgets about his own condition. It is possible to work to the point of exhaustion on the bottom without realizing it. Failing to pay attention to the condition of the air supply may easily result in unconsciousness.

Ascent

(21) After completing his task, the diver prepares to ascend. This may involve sending tools to the surface, final inspection of the job, and clearing any fouled lifeline or air hose. The diver must never ignore the tender's signal to come up. At times it is a strong temptation to remain on the bottom a few more minutes to complete a task, but the tender is aware of conditions which the diver is unable to see for himself and must be obeyed. If the diver is unable to come to the surface due to fouling of lines or any other cause, he should make the situation known to the tender by any possible means. The tender, on the other hand, must never ignore the diver's signal to haul him up. The rate of ascent must be under control at all times. Excess speed of ascent can result in blowing up due to overexpansion of air in the deep sea outfit.*

*Blowup is a serious accident. It is discussed in detail in article 1.6.10.

(22) Regardless of the type of equipment, in all dives using the air decompression tables, ascend at the rate of 60 feet per minute. In the event you exceed the 60 feet per minute rate:

(*a*) If no decompression stops are required, but the bottom time places you within 10 minutes of a schedule that does require decompression; stop at 10 feet for the time that you should have taken in ascent at 60 feet per minute.

(*b*) If decompression is required; stop at 10 feet below the first listed decompression depth for the time that you should have taken in ascent to the first stop at 60 feet per minute.

In the event you are unable to maintain the 60 feet per minute rate of ascent:

(*a*) If the delay was at or near the bottom; increase the bottom time, by the difference between the time used in ascent and the time that should have been used at the rate of 60 feet/minute. Decompress according to the requirements of the total bottom time. This is the safer procedure.

(*b*) If the delay was near the surface, increase the first stop by the difference between the time used in ascent and the time that should have been used at the rate of 60 feet per minute.

NOTE.—When employing the table for *surface decompression using oxygen*, a rate of ascent of *25 feet per minute* must be used.

(23) The necessity for decompression depends upon the time and depth of dive. Particularly cold dives and those involving exceptionally hard work require additional decompression. Careful planning of bottom time and decompression time is necessary, particularly where the air supply is limited, as in the case of the scuba diver. A scuba diver must know the required decompression time before he makes his dive and must have a means of keeping track of time and depth. Use a descending line plainly marked at 10 foot intervals for decompression of the scuba diver. For surface-supplied diving, mark the lifeline so that the tender can know the diver's depth. When long decompression stops are necessary, a decompression stage should be used so that the diver may rest while decompressing. When the stage is used, mark the line to the stage to determine the diver's depth.

(24) In case of emergency it may be necessary to bring the diver to the surface before he has completed his decompression. (See article 1.5.6 for the management of such situations.) In any emergency, it is the responsibility of the diving supervisor to weigh the dangers of decompression sickness against the hazard of remaining in the water. The problem is particularly serious when no recompression chamber is available. The detailed procedure of decompression is explained in section 1.5.

(25) The chief danger in surfacing is in coming up under the diving boat or float, with resulting damage to the head. The possibility of injury of this nature exists in all diving but is most serious in self contained. Fortunately, the self contained diver is, in most cases, better able to see what is above him and with reasonable care can avoid injury.

(26) After completing a dive, the diver should remain in the vicinity of the recompression chamber or facility for underwater recompression for at least one hour. This time should be extended to twelve hours for any dive requiring decompression.

(27) A dive performed within twelve hours of surfacing from a previous dive is a repetitive dive. Limit the equivalent single dive schedule of repetitive dives to table 1–5. No repetitive dives falling in the limits of table 1–9 are permitted. Nor are repetitive helium-oxygen dives with surface-supplied equipment permitted.

SECTION 1.5 DIVING TABLES

1.5.1 GENERAL

The tables and procedures outlined herein have been developed to provide safety from the hazards of decompression sickness and oxygen toxicity described in section 1.3. At the same time, the tables have been made as efficient as possible in order that they will be the least possible hindrance to diving operations.

1.5.2 AIR DECOMPRESSION TABLES

General

(1) The air decompression tables comprise:

(*a*) Decompression Procedures (table 1–4).

(*b*) U.S. Navy Standard Air Decompression Table (table 1–5).

(*c*) "No Decompression Limits and Repetitive Groups" (table 1–6).

(*d*) Surface Interval Credit Table (table (1–7).

(*e*) Repetitive Dive Timetable (table 1–8).

(*f*) Standard Air Decompression Table for Exceptional Exposures (table 1–9).

(2) Regardless of the type of diving apparatus, for all dives where air is the breathing medium, use these tables as prescribed.

(3) Use these tables in conjunction with the Equivalent Air Tables (table 1–10) for dives where a nitrogen oxygen mixture is the breathing medium. (See art. 1.5.3 and sec. 3.6.)

Single dives

(4) A single dive is the first dive of the day. It is denoted by an exposure to a specific depth in feet for a specific time in minutes. An example would be 134 feet for 14 minutes. The depth is the maximum depth attained. The time is the actual bottom time. Bottom time is the elapsed time between leaving the surface in descent and leaving the deepest depth in ascent. A combination of depth and time listed in the decompression tables is called a dive schedule. All dives are included and covered in the next deeper and next longer schedule. Do not interpolate.

Repetitive dives

(5) Any dive performed within 12 hours of a previous dive is a *repetitive dive.* The period between dives is the *surface interval.* Decompression following a repetitive dive requires special consideration. This is because dissolved inert gas from the previous dive remains in the body at the *beginning* of the repetitive dive.

(6) A detailed consideration of all the factors involved would be prohibitively complicated. A simplified and workable solution is based on the degree of saturation of the "120 minute half-time tissue" (Experimental Diving Unit Research Report 6–57 documents the calculations and tests). The basic idea of this approach involves considering the previous dive, the surface interval, and the repetitive dive together as a whole to yield an *equivalent single dive.* For the *depth* of the equivalent single dive, the *actual* depth of the repetitive dive is used. But the *bottom time* is the sum of the actual time plus an additional amount of time to take into account the residual nitrogen from the previous dive and surface interval.

(7) Upon surfacing from a dive, the diver is catalogued by table 1–5 or 1–6 into one of 16 lettered *repetitive groups* in accordance with the amount of inert gas left in his body. During the surface interval the diver loses inert gas and is given "credit" for the loss by means of table 1–7 which shows the change from one group to another for various time intervals on the surface. For every depth of dive, there is a certain time of exposure that would bring the diver to the same degree of saturation as that represented by each repetitive group. This time, based on the residual inert gas from previous dive and surface interval, is called the *residual nitrogen time.* In table 1–8, residual nitrogen time is expressed as a number of minutes for various depths (in 10-foot increments) and for each repetitive group designation. The bottom time of the *equivalent single dive* is then obtained by adding this residual nitrogen time to the actual

bottom time of the repetitive dive being considered. The proper decompression for the ascent from the repetitive dive may then be found in the Standard Air Decompression Table (table 1–5) by using the actual depth of the repetitive dive and the equivalent single dive bottom time. Successive repetitive dives may be handled similarly.

U.S. Navy Standard Air Decompression Table

(8) The Standard Air Decompression Table (table 1–6) covers the normal range of diving. The depth limit is 190 feet and the bottom time limit for each depth is approximately 12,000 divided by the depth. This is an arbitrary time, but it is a good maximum for normal practice. Stay within the limits of this table for all routine air dives.

(9) Details on the use of the Standard Air Decompression Tables are:

(*a*) Time of decompression stops in the table is in minutes.

(*b*) Enter the tables at the listed depth that is exactly equal to or is the next greater than the maximum attained during the dive.

(*c*) Select the bottom time listed for the selected depth that is exactly equal or is next greater than the bottom time of the dive.

(*d*) Use the decompression stops listed on the line for the selected bottom time.

(*e*) For any repetitive diving, use the repetitive group designation listed on the same line (or if no decompression is required, obtain the repetitive group from table 1–6).

(*f*) Maintain the diver's *chest* as close as possible to each decompression depth for the number of minutes listed.

(*g*) The rate of ascent *between* stops is not critical. Commence timing each stop on arrival at the decompression depth and resume ascent when the specified time has elapsed.

(10) Specific examples of the use of the table are:

(*a*) You made a single dive to 82 feet for 36 minutes. You wish to determine the proper decompression procedure: The next greater depth listed in the table is 90 feet. The next greater bottom time listed opposite 90 feet is 40 minutes. The proper decompression procedure is therefore a 7 minute stop at 10 feet in accordance with the 90/40 schedule.

(*b*) You made a single dive to 110 feet for 30 minutes. You know that the depth did not exceed 110 feet. You wish to determine the proper decompression procedure: The exact depth of 110 feet is listed. The exact time of 30 minutes is listed opposite 90 feet. Decompress according to the 110/30 schedule unless the dive was particularly cold or arduous or conditions will prohibit accurate decompression. In any of these cases go to the 110/40, the 120/30 or the 120/40 schedule at your own discretion.

"No Decompression Table"

(11) The "No Decompression Table" is officially and more accurately titled *"No Decompression" Limits and Repetitive Group Designation Table for "No Decompression" Schedules.* It is a new table required by repetitive diving. It is no longer sufficient merely to know where decompression requirements begin. In repetitive diving you must know the amount of nitrogen remaining in the tissues from any dive, no matter how short or shallow. The repetitive group designations provide that information.

(12) Repetitive group designations are given for depths of 10 feet to 40 feet in 5-foot increments and for depths of 40 feet to 300 feet in 10-foot increments. Opposite each depth and each repetitive group is listed the maximum bottom time which will allow the diver to remain within the group. On the assumption that it is the operational limit, the times for 10 to 25 feet end at about 5 hours. From 40 feet on, the times end at the "no decompression" limit.

(13) The "no decompression" limits listed in this table for depths of 40 feet and greater are useful in planning operations. The diver may surface directly ("no decompression dive") as long as the bottom time is less than the maximum listed for the depth. For depths not greater than 33 feet, direct surfacing is permissible regardless of the bottom time.

GENERAL INSTRUCTIONS FOR AIR DIVING

Need for Decompression

A quantity of nitrogen is taken up by the body during every dive. The amount absorbed depends upon the depth of the dive and the exposure (bottom) time. If the quantity of nitrogen dissolved in the body tissues exceeds a certain critical amount, the ascent must be delayed to allow the body tissue to remove the excess nitrogen. Decompression sickness results from failure to delay the ascent and to allow this process of gradual desaturation. A specified time at a specific depth for purposes of desaturation is called a decompression stop.

"No Decompression" Schedules

Dives that are not long or deep enough to require decompression stops are "no decompression" dives. Dives to 33 feet or less do not require decompression stops. As the depth increases, the allowable bottom time for "no decompression" dives decreases. Five minutes at 190 feet is the shortest and deepest "no decompression" schedule. These dives are all listed in the No Decompression Limits and Repetitive Group Designation Table for "No Decompression" Dives, ("No Decompression Table" (table 1-6)) and only require compliance with the 60 feet per minute rate of ascent.

Schedules That Require Decompression Stops

All dives beyond the limits of the "No Decompression Table" require decompression stops. These dives are listed in the Navy Standard Air Decompression Table (table 1-5). Comply exactly with instructions except as modified by surface decompression procedures.

Variations in Rate of Ascent

Ascend from all dives at the rate of 60 feet per minute.

In the event you exceed the 60 feet per minute rate:

(1) If no decompression stops are required, but the bottom time places you within 10 minutes of a schedule that does require decompression; stop at 10 feet for the time that you should have taken in ascent at 60 feet per minute.

(2) If decompression is required; stop 10 feet below the first listed decompression depth for the time that you should have taken in ascent at 60 feet per minute.

In the event you are unable to maintain the 60 feet per minute rate of ascent:

(1) If the delay was at or near the bottom; add to the bottom time, the additional time used in ascent. Decompress according to the requirements of the total bottom time. This is the safer procedure.

(2) If the delay was near the surface; increase the first stop by the difference between the time consumed in ascent and the time that should have been consumed at 60 feet per minute.

Repetitive Dive Procedure

A dive performed within 12 hours of surfacing from a previous dive is a repetitive dive. The period between dives is the surface interval. Excess nitrogen requires 12 hours to effectively be lost from the body. These tables are designed to protect the diver from the effects of this residual nitrogen. Allow a minimum surface interval of 10 minutes between all dives. Specific instructions are given for the use of each table in the following order:

(1) The "No Decompression Table" or the Navy Standard Air Decompression Table gives the repetitive group designation for all schedules which may preceed a repetitive dive.

(2) The Surface Interval Credit Table gives credit for the desaturation occurring during the surface interval.

(3) The Repetitive Dive Timetable gives the number of minutes or residual nitrogen time to add to the actual bottom time of the repetitive dive in order to obtain decompression for the residual nitrogen.

(4) The "No Decompression Table" or the Navy Standard Air Decompression Table gives the decompression required for the repetitive dive.

U.S. NAVY STANDARD AIR DECOMPRESSION TABLE

INSTRUCTIONS FOR USE

Time of decompression stops in the table is in minutes.

Enter the table at the exact or the next greater depth than the maximum depth attained during the dive. Select the listed bottom time that is exactly equal to or is next greater than the bottom time of the dive. Maintain the diver's chest as close as possible to each decompression depth for the number of minutes listed. The rate of ascent between stops is not critical. Commence timing each stop on arrival at the decompression depth and resume ascent when the specified time has lapsed.

For example – a dive to 82 feet for 36 minutes. To determine the proper decompression procedure: The next greater depth listed in this table is 90 feet. The next greater bottom time listed opposite 90 feet is 40. Stop 7 minutes at 10 feet in accordance with the 90/40 schedule.

For example – a dive to 110 feet for 30 minutes. It is known that the depth did not exceed 110 feet. To determine the proper decompression schedule: The exact depth of 110 feet is listed. The exact bottom time of 30 minutes is listed opposite 110 feet. Decompress according to the 110/30 schedule unless the dive was particularly cold or arduous. In that case, go to the 110/40, the 120/30, or the 120/40 at your own discretion. (Rev. 1958)

TABLE 1-4.—*Decompression procedures.*

DEPTH (ft)	BOTTOM TIME (mins)	TIME TO FIRST STOP	DECOMPRESSION STOPS 50	40	30	20	10	TOTAL ASCENT TIME	REPET. GROUP
40	200						0	0.7	*
	210	0.5					2	2.5	N
	230	0.5					7	7.5	N
	250	0.5					11	11.5	O
	270	0.5					15	15.5	O
	300	0.5					19	19.5	Z
50	100						0	0.8	*
	110	0.7					3	3.7	L
	120	0.7					5	5.7	M
	140	0.7					10	10.7	M
	160	0.7					21	21.7	N
	180	0.7					29	29.7	O
	200	0.7					35	35.7	O
	220	0.7					40	40.7	Z
	240	0.7					47	47.7	Z
60	60						0	1.0	*
	70	0.8					2	2.8	K
	80	0.8					7	7.8	L
	100	0.8					14	14.8	M
	120	0.8					26	26.8	N
	140	0.8					39	39.8	O
	160	0.8					48	48.8	Z
	180	0.8					56	56.8	Z
	200	0.6				1	69	70.6	Z
70	50						0	1.2	*
	60	1.0					8	9.0	K
	70	1.0					14	15.0	L
	80	1.0					18	19.0	M
	90	1.0					23	24.0	N
	100	1.0					33	34.0	N
	110	0.8				2	41	43.8	O
	120	0.8				4	47	51.8	O
	130	0.8				6	52	58.8	O
	140	0.8				8	56	64.8	Z
	150	0.8				9	61	70.8	Z
	160	0.8				13	72	85.8	Z
	170	0.8				19	79	98.8	Z
80	40						0	1.3	*
	50	1.2					10	11.2	K
	60	1.2					17	18.2	L
	70	1.2					23	24.2	M
	80	1.0				2	31	34.0	N
	90	1.0				7	39	47.0	N
	100	1.0				11	46	58.0	O
	110	1.0				13	53	67.0	O
	120	1.0				17	56	74.0	Z
	130	1.0				19	63	83.0	Z
	140	1.0				26	69	96.0	Z
	150	1.0				32	77	110.0	Z
90	30						0	1.5	*
	40	1.3					7	8.3	J
	50	1.3					18	19.3	L
	60	1.3					25	26.3	M
	70	1.2				7	30	38.2	N
	80	1.2				13	40	54.2	N
	90	1.2				18	48	67.2	O
	100	1.2				21	54	76.2	Z
	110	1.2				24	61	86.2	Z
	120	1.2				32	68	101.2	Z
	130	1.0			5	36	74	116.0	Z
100	25						0	1.7	*
	30	1.5					3	4.5	I
	40	1.5					15	16.5	K
	50	1.3				2	24	27.3	L
	60	1.3				9	28	38.3	N
	70	1.3				17	39	57.3	O
	80	1.3				23	48	72.3	O
	90	1.2			3	23	57	84.2	Z
	100	1.2			7	23	66	97.2	Z
	110	1.2			10	34	72	117.2	Z
	120	1.2			12	41	78	132.2	Z
110	20						0	1.8	*
	25	1.7					3	4.7	H
	30	1.7					7	8.7	J
	40	1.5				2	21	24.5	L
	50	1.5				8	26	35.5	M
	60	1.5				18	36	55.5	N
	70	1.3			1	23	48	73.3	O
	80	1.3			7	23	57	88.3	Z
	90	1.3			12	30	64	107.3	Z
	100	1.3			15	37	72	125.3	Z
120	15						0	2.0	*
	20	1.8					2	3.8	H
	25	1.8					6	7.8	I
	30	1.8					14	15.8	J
	40	1.7				5	25	31.7	L
	50	1.7				15	31	47.7	N
	60	1.5			2	22	45	70.5	O
	70	1.5			9	23	55	88.5	O
	80	1.5			15	27	63	106.5	Z
	90	1.5			19	37	74	131.5	Z
	100	1.5			23	45	80	149.5	Z
130	10						0	2.2	*
	15	2.0					1	3.0	F
	20	2.0					4	6.0	H
	25	2.0					10	12.0	J
	30	1.8				3	18	22.8	M
	40	1.8				10	25	36.8	N
	50	1.7			3	21	37	62.7	O
	60	1.7			9	23	52	85.7	Z
	70	1.7			16	24	61	102.7	Z
	80	1.5		3	19	35	72	130.5	Z
	90	1.5		8	19	45	80	153.5	Z
140	10						0	2.3	*
	15	2.2					2	4.2	G
	20	2.2					6	8.2	I
	25	2.0				2	14	18.0	J
	30	2.0				5	21	28.0	K
	40	1.8			2	16	26	45.8	N
	50	1.8			6	24	44	75.8	O
	60	1.8			16	23	56	96.8	Z
	70	1.7		4	19	32	68	124.7	Z
	80	1.7		10	23	41	79	154.7	Z
150	5						0	2.5	C
	10	2.3					1	3.3	E
	15	2.3					3	5.3	G
	20	2.2				2	7	11.2	H
	25	2.2				4	17	23.2	K
	30	2.2				8	24	34.2	L
	40	2.0			5	19	33	59.0	N
	50	2.0			12	23	51	88.0	O
	60	1.8		3	19	26	62	111.8	Z
	70	1.8		11	19	39	75	145.8	Z
	80	1.7	1	17	19	50	84	172.7	Z
160	5						0	2.7	D
	10	2.5					1	3.5	F
	15	2.3				1	4	7.3	H
	20	2.3				3	11	16.3	J
	25	2.3				7	20	29.3	K
	30	2.2			2	11	25	40.2	M
	40	2.2			7	23	39	71.2	N
	50	2.0		2	16	23	55	98.0	Z
	60	2.0		9	19	33	69	132.0	Z
	70	1.8	1	17	22	44	80	165.8	Z
170	5						0	2.8	D
	10	2.7					2	4.7	F
	15	2.5				2	5	9.5	H
	20	2.5				4	15	21.5	J
	25	2.3			2	7	23	34.3	L
	30	2.3			4	13	26	45.3	M
	40	2.2		1	10	23	45	81.2	O
	50	2.2		5	18	23	61	109.2	Z
	60	2.0	2	15	22	37	74	152.0	Z
	70	2.0	8	17	19	51	86	183.0	Z
180	5						0	3.0	D
	10	2.8					3	5.8	F
	15	2.7				3	6	11.7	I
	20	2.5			1	5	17	25.5	K
	25	2.5			3	10	24	39.5	L
	30	2.5			6	17	27	52.5	N
	40	2.3		3	14	23	50	92.3	O
	50	2.2	2	9	19	30	65	127.2	Z
	60	2.2	5	16	19	44	81	167.2	Z
190	5						0	3.2	D
	10	2.8				1	3	6.8	G
	15	2.8				4	7	13.8	I
	20	2.7			2	6	20	30.7	K
	25	2.7			5	11	25	43.7	M
	30	2.5		1	8	19	32	62.5	N
	40	2.5		8	14	23	55	102.5	O
	50	2.3	4	13	22	33	72	146.3	Z
	60	2.3	10	17	19	50	84	182.3	Z

*See table 1-6 for repetitive groups in "no decompression" dives.

(Rev. 1958)

TABLE 1-5.—*U.S. Navy standard air decompression table.*

DEPTH (ft.)	NO DECOMPRESSION LIMITS (Min.)	REPETITIVE GROUPS														
		A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
10	–	60	120	210	300											
15	–	35	70	110	160	225	350									
20	–	25	50	75	100	135	180	240	325							
25	–	20	35	55	75	100	125	160	195	245	315					
30	–	15	30	45	60	75	95	120	145	170	205	250	310			
35	310	5	15	25	40	50	60	80	100	120	140	160	190	220	270	310
40	200	5	15	25	30	40	50	70	80	100	110	130	150	170	200	
50	100	–	10	15	25	30	40	50	60	70	80	90	100			
60	60	–	10	15	20	25	30	40	50	55	60					
70	50	–	5	10	15	20	30	35	40	45	50					
80	40	–	5	10	15	20	25	30	35	40						
90	30	–	5	10	12	15	20	25	30							
100	25	–	5	7	10	15	20	22	25							
110	20	–	–	5	10	13	15	20								
120	15	–	–	5	10	12	15									
130	10	–	–	5	8	10										
140	10	–	–	5	7	10										
150	5	–	–	5												
160	5	–	–	–	5											
170	5	–	–	–	5											
180	5	–	–	–	5											
190	5	–	–	–	5											

(Rev. 1958)

INSTRUCTIONS FOR USE

I. "No decompression" limits

This column shows at various depths greater than 30 feet the allowable diving times (in minutes) which permit surfacing directly at 60 ft. a minute with no decompression stops. Longer exposure times require the use of the Standard Air Decompression Table (Table 1-5).

II. Repetitive group designation table

The tabulated exposure times (or bottom times) are in minutes. The times at the various depths in each vertical column are the maximum exposures during which a diver will remain within the group listed at the head of the column.

To find the repetitive group designation at surfacing for dives involving exposures up to and including the "no decompression limits": Enter the table on the exact or next greater depth than that to which exposed and select the listed exposure time exact or next greater than the actual exposure time. The repetitive group designation is indicated by the letter at the head of the vertical column where the selected exposure time is listed.

For example: A dive was to 32 feet for 45 minutes. Enter the table along the 35 ft. depth line since it is next greater than 32 ft. The table shows that since group "D" is left after 40 minutes exposure and group "E" after 50 minutes, group "E" (at the head of the column where the 50 min. exposure is listed) is the proper selection.

Exposure times for depths less than 40 ft. are listed only up to approximately five hours since this is considered to be beyond field requirements for this table.

TABLE 1–6.—*"No decompression" limits and repetitive group designation table for "no decompression" dives.*

557535 O - 60 - 8

REPETITIVE GROUP AT THE END OF THE SURFACE INTERVAL

REPETITIVE GROUP AT THE BEGINNING OF SURFACE INTERVAL (FROM PREVIOUS DIVE)

	Z	O	N	M	L	K	J	I	H	G	F	E	D	C	B	A
Z	0:10-0:22	0:34	0:48	1:02	1:18	1:36	1:55	2:17	2:42	3:10	3:45	4:29	5:27	6:56	10:05	12:00*
O		0:10-0:23	0:36	0:51	1:07	1:24	1:43	2:04	2:29	2:59	3:33	4:17	5:16	6:44	9:54	12:00*
N			0:10-0:24	0:39	0:54	1:11	1:30	1:53	2:18	2:47	3:22	4:04	5:03	6:32	9:43	12:00*
M				0:10-0:25	0:42	0:59	1:18	1:39	2:05	2:34	3:08	3:52	4:49	6:18	9:28	12:00*
L					0:10-0:26	0:45	1:04	1:25	1:49	2:19	2:53	3:36	4:35	6:02	9:12	12:00*
K						0:10-0:28	0:49	1:11	1:35	2:03	2:38	3:21	4:19	5:48	8:58	12:00*
J							0:10-0:31	0:54	1:19	1:47	2:20	3:04	4:02	5:40	8:40	12:00*
I								0:10-0:33	0:59	1:29	2:02	2:44	3:43	5:12	8:21	12:00*
H									0:10-0:36	1:06	1:41	2:23	3:20	4:49	7:59	12:00*
G										0:10-0:40	1:15	1:59	2:58	4:25	7:35	12:00*
F											0:10-0:45	1:29	2:28	3:57	7:05	12:00*
E												0:10-0:54	1:57	3:22	6:32	12:00*
D													0:10-1:09	2:38	5:48	12:00*
C														0:10-1:39	2:49	12:00*
B															0:10-2:10	12:00*
A																0:10-12:00*

(Rev. 1958)

INSTRUCTIONS FOR USE

Surface interval time in the table is in hours and minutes ("7:59" means 7 hours and 59 minutes). The surface interval must be at least 10 minutes.

Find the repetitive group designation letter (from the previous dive schedule) on the diagonal slope. Enter the table horizontally to select the listed surface interval time that is exactly or next greater than the actual surface interval time. The repetitive group designation for the end of the surface interval is at the head of the vertical column where the selected surface interval time is listed. For example – a previous dive was to 110 ft. for 30 minutes. The diver remains on the surface 1 hour and 30 minutes and wishes to find the new repetitive group designation: The repetitive group from the last column of the 110/30 schedule in the Standard Air Decompression Tables is "J". Enter the surface interval credit table along the horizontal line labeled "J". The 1 hour and 47 min. listed surface interval time is next greater than the actual 1 hour and 30 minutes surface interval time. Therefore, the diver has lost sufficient inert gas to place him in group "G" (at the head of the vertical column selected).

*NOTE: Dives following surface intervals of more than 12 hours are not considered repetitive dives. Actual bottom times in the Standard Air Decompression Tables may be used in computing decompression for such dives.

TABLE 1–7.—*Surface interval credit table.*

REPET. GROUPS	REPETITIVE DIVE DEPTH (Ft.)															
	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180	190
A	7	6	5	4	4	3	3	3	3	3	2	2	2	2	2	2
B	17	13	11	9	8	7	7	6	6	6	5	5	4	4	4	4
C	25	21	17	15	13	11	10	10	9	8	7	7	6	6	6	6
D	37	29	24	20	18	16	14	13	12	11	10	9	9	8	8	8
E	49	38	30	26	23	20	18	16	15	13	12	12	11	10	10	10
F	61	47	36	31	28	24	22	20	18	16	15	14	13	13	12	11
G	73	56	44	37	32	29	26	24	21	19	18	17	16	15	14	13
H	87	66	52	43	38	33	30	27	25	22	20	19	18	17	16	15
I	101	76	61	50	43	38	34	31	28	25	23	22	20	19	18	17
J	116	87	70	57	48	43	38	34	32	28	26	24	23	22	20	19
K	138	99	79	64	54	47	43	38	35	31	29	27	26	24	22	21
L	161	111	88	72	61	53	48	42	39	35	32	30	28	26	25	24
M	187	124	97	80	68	58	52	47	43	38	35	32	31	29	27	26
N	213	142	107	87	73	64	57	51	46	40	38	35	33	31	29	28
O	241	160	117	96	80	70	62	55	50	44	40	38	36	34	31	30
Z	257	169	122	100	84	73	64	57	52	46	42	40	37	35	32	31

(Rev. 1958)

INSTRUCTIONS FOR USE

The bottom times listed in this table are called "residual nitrogen times" and are the times a diver is to consider he has already spent on bottom when he starts a repetitive dive to a specific depth. They are in minutes.

Enter the table horizontally with the repetitive group designation from the Surface Interval Credit Table. The time in each vertical column is the number of minutes that would be required (at the depth listed at the head of the column) to saturate to the particular group.

For example – the final group designation from the Surface Interval Credit Table, on the basis of a previous dive and surface interval, is "H". To plan a dive to 110 feet, determine the "residual nitrogen time" for this depth required by the repetitive group designation: Enter this table along the horizontal line labeled "H". The table shows that one must start a dive to 110 feet as though he had already been on the bottom for 27 minutes. This information can then be applied to the Standard Air Decompression table or "No Decompression" Table in a number of ways:

(1) Assuming a diver is going to finish a job and take whatever decompression is required, he must add 27 minutes to his actual bottom time and be prepared to take decompression according to the 110 foot schedules for the sum or equivalent single dive time.

(2) Assuming one wishes to make a quick inspection dive for the minimum decompression, he will decompress according to the 110/30 schedule for a dive of 3 minutes or less (27 + 3 = 30). For a dive of over 3 minutes but less than 13, he will decompress according to the 110/40 schedule (27 + 13 = 40).

(3) Assuming that one does not want to exceed the 110/50 schedule and the amount of decompression it requires, he will have to start ascent before 23 minutes of actual bottom time (50 - 27 = 23).

(4) Assuming that a diver has air for approximately 45 minutes bottom time and decompression stops, the possible dives can be computed: A dive of 13 minutes will require 23 minutes of decompression (110/40 schedule), for a total submerged time of 36 minutes. A dive of 13 to 23 minutes will require 34 minutes of decompression (110/50 schedule), for a total submerged time of 47 to 57 minutes. Therefore, to be safe, the diver will have to start ascent before 13 minutes or a standby air source will have to be provided.

TABLE 1-8.—*Repetitive dive timetable.*

(14) Other than the above uses to obtain "no decompression" limits, the only purpose of this table is to provide the repetitive group designation for "no decompression" dives. This knowledge is necessary to make repetitive dives after "no decompression" dives.

(15) Details and an example of its use to obtain the repetitive group designations are given directly on the table.

Surface Interval Credit Table

(16) The Surface Interval Credit Table is another requirement of the repetitive diving system. It is the real reason for the success and efficiency of the repetitive dive system.

(17) The diver continues to lose nitrogen while he is on the surface until he is completely desaturated. This requires 12 hours or more. In order to provide efficient decompression instructions, it is necessary to know the amount of nitrogen remaining in the tissues at the time a repetitive dive commences. This table provides that information.

(18) The repetitive groups are the measuring units. In this table, the loss of inert gas with increasing length of surface interval is reflected in the change from one group to another.

(19) Details and an example of its use are given directly on the table.

Repetitive Dive Timetable

(20) The Repetitive Dive Timetable lists the number of minutes at each depth that will build up the nitrogen partial pressure represented by each repetitive group.

(21) Knowing the diver's repetitive group designation, the system gives an arbitrary bottom time (the residual nitrogen time) that he must assume he has already completed when he starts his repetitive dive. This arbitrary bottom time and the actual bottom time of the repetitive dive are added to yield the bottom time of the equivalent single dive mentioned previously.

(22) Details and an example of its use are given directly on the tables.

(23) There is one exception to the table. It occasionally occurs when the repetitive dive is to the same or greater depth than the initial dives and the surface interval is short. Because of the necessity to account for the greatest exposure within a group, the arbitrary bottom time assigned may be greater than the sum of the actual bottom times of the previous dives. In such case, if the repetitive dive is to the same or greater depth than the previous dive or dives, add the actual bottom time of the previous dives to the actual bottom time of the repetitive dive.

Decompression for exceptional exposures

(24) The U.S. Navy Standard Air Decompression Table for Exceptional Exposures (table 1–9) includes only schedules of decompression for exceptional or emergency cases. Schedules are provided for "complete saturation" exposures up to 140 feet, and for extreme exposures up to 300 feet. Great demands are imposed upon the diver's endurance by emergencies which might necessitate use of the table. Therefore complete assurance of success of the schedules is impossible. They have, however, been tested to every practicable limit and found reasonably safe.

(25) Repetitive group designations are not given on the Table for Exceptional Exposures. Never follow a dive covered by that table with a repetitive dive. Make every effort to limit the equivalent single dive schedule of repetitive dives to the Standard Air Decompression Tables. The diving officer must be the one to weigh the need for any dive in the Table for Exceptional Exposures against the increased danger and demands on the diver's physical endurance.

Repetitive dive worksheet

(26) Figure 1–32 is a suggested worksheet for the selection of decompression schedules in repetitive diving. A systematic approach of this kind must *always* be used in applying the repetitive diving tables. (Fig. 1–32A can be removed from the manual and reproduced locally.)

(27) An example using figure 1–32 follows. A diver makes a dive to 105 feet with a bottom time of 24 minutes and decompresses properly according to the Standard Air Decompression Table. After being on the surface for 2 hours,

DEPTH (ft.)	BOTTOM TIME (Min.)	TIME TO FIRST STOP	DECOMPRESSION STOPS 130	120	110	100	90	80	70	60	50	40	30	20	10	TOTAL ASCENT TIME
40	360	0.5													23	24
	480	0.5													41	42
	720	0.5													69	70
60	240	0.7												2	79	82
	360	0.7												20	119	140
	480	0.7												44	148	193
	720	0.7												78	187	266
80	180	1.0												35	85	121
	240	0.8											6	52	120	179
	360	0.8											29	90	160	280
	480	0.8											59	107	187	354
	720	0.7										17	108	142	187	455
100	180	1.0										1	29	53	118	202
	240	1.0										14	42	84	142	283
	360	0.8									2	42	73	111	187	416
	480	0.8									21	61	91	142	187	502
	720	0.8									55	106	122	142	187	613
120	120	1.3										10	19	47	98	176
	180	1.2									5	27	37	76	137	283
	240	1.2									23	35	60	97	179	395
	360	1.0								18	45	64	93	142	187	550
	480	0.8							3	41	64	93	122	142	187	653
	720	0.8							32	74	100	114	122	142	187	772
140	90	1.5									2	14	18	42	88	166
	120	1.5									12	14	36	56	120	240
	180	1.3								10	26	32	54	94	168	386
	240	1.2							8	28	34	50	78	124	187	511
	360	1.0						9	32	42	64	84	122	142	187	683
	480	1.0						31	44	59	100	114	122	142	187	800
	720	0.8					16	56	88	97	100	114	122	142	187	923
170	90	1.8								12	12	14	34	52	120	232
	120	1.5						2	10	12	18	32	42	82	156	356
	180	1.3					4	10	22	28	34	50	78	120	187	535
	240	1.3					18	24	30	42	50	70	116	142	187	681
	360	1.2				22	34	40	52	60	98	114	122	142	187	873
	480	1.0			14	40	42	56	91	97	100	114	122	142	187	1006
200	5	3.2													1	5
	10	3.0												1	4	8
	15	2.8											1	4	10	18
	20	2.8											3	7	27	40
	25	2.8											7	14	25	49
	30	2.7										2	9	22	37	73
	40	2.5									2	8	17	23	59	112
	50	2.5									6	16	22	39	75	161
	60	2.3								2	13	17	24	51	89	199
	90	1.8					1	10	10	12	12	30	38	74	134	323
	120	1.7				6	10	10	10	24	28	40	64	98	180	472
	180	1.3		1	10	10	18	24	24	42	48	70	106	142	187	684
	240	1.3		6	20	24	24	36	42	54	68	114	122	142	187	841
	360	1.2	12	22	36	40	44	56	82	98	100	114	122	142	187	1057
210	5	3.3													1	5
	10	3.2												2	4	10
	15	3.0											1	5	13	22
	20	3.0											4	10	23	40
	25	2.8										2	7	17	27	56
	30	2.8										4	9	24	41	81
	40	2.7									4	9	19	26	63	124
	50	2.5								1	9	17	19	45	80	174
220	5	3.5													2	6
	10	3.3												2	5	11
	15	3.2											2	5	16	27
	20	3.0										1	3	11	24	43
	25	3.0										3	8	19	33	66
	30	2.8									1	7	10	23	47	91
	40	2.8									6	12	22	29	68	140
	50	2.7								3	12	17	18	51	86	190
	5	3.7													2	6
230	10	3.3											1	2	6	13
	15	3.3											3	6	18	31
	20	3.2										2	5	12	26	49
	25	3.2										4	8	22	37	75
	30	3.0									2	8	12	23	51	99
	40	2.8								1	7	15	22	34	74	156
	50	2.8								5	14	16	24	51	89	202
240	5	3.8													2	6
	10	3.5											1	3	6	14
	15	3.5											4	6	21	35
	20	3.3										3	6	15	25	53
	25	3.2									1	4	9	24	40	82
	30	3.2									4	8	15	22	56	109
	40	3.0								3	7	17	22	39	75	166
	50	2.8							1	8	15	16	29	51	94	217
250	5	3.8												1	2	7
	10	3.7											1	4	7	16
	15	3.5										1	4	7	22	38
	20	3.5										4	7	17	27	59
	25	3.3									2	7	10	24	45	92
	30	3.3									6	7	17	23	59	116
	40	3.2								5	9	17	19	45	79	178
	60	2.7					4	10	10	10	12	22	36	64	126	297
	90	2.2		8	10	10	10	10	10	28	28	44	68	98	186	513
	120	(SEE EXTREME EXPOSURES BELOW)														
	180															
	240															
260	5	4.0												1	2	7
	10	3.8											2	4	9	19
	15	3.7										2	4	10	22	42
	20	3.5									1	4	7	20	31	67
	25	3.5									3	8	11	23	50	99
	30	3.3								2	6	8	19	26	61	125
	40	3.2							1	6	11	16	19	49	84	190
270	5	4.2												1	3	9
	10	4.0											2	5	11	22
	15	3.8										3	4	11	24	46
	20	3.7									2	3	9	21	35	74
	25	3.5								2	3	8	13	23	53	106
	30	3.5								3	6	12	22	27	64	138
	40	3.3							5	6	11	17	22	51	88	204
280	5	4.3												2	2	9
	10	4.0										1	2	5	13	25
	15	3.8									1	3	4	11	26	49
	20	3.8									3	4	8	23	39	81
	25	3.7								2	5	7	16	23	56	113
	30	3.5							1	3	7	13	22	30	70	150
	40	3.3						1	6	6	13	17	27	51	93	218
290	5	4.5												2	3	10
	10	4.2										1	3	5	16	30
	15	4.0									1	3	6	12	26	52
	20	4.0									3	7	9	23	43	89
	25	3.8								3	5	8	17	23	60	120
	30	3.7							1	5	6	16	22	36	72	162
	40	3.5						3	5	7	15	16	32	51	95	264
300	5	4.7												3	3	11
	10	4.3										1	3	6	17	32
	15	4.2									2	3	6	15	26	56
	20	4.0								2	3	7	10	23	47	104
	25	3.8							1	3	6	8	19	26	61	128
	30	3.8							2	5	7	17	22	39	75	171
	40	3.7						4	6	9	15	17	34	51	90	234
	60	3.0		4	10	10	10	10	10	14	28	32	50	90	187	458
	90	(SEE EXTREME EXPOSURES BELOW)														
	120															
	180															

(Rev. 1958)

EXTREME EXPOSURES – 250 AND 300 FT.

DEPTH (ft.)	BOTTOM TIME (Min.)	TIME TO FIRST STOP	DECOMPRESSION STOPS 200	190	180	170	160	150	140	130	120	110	100	90	80	70	60	50	40	30	20	10	TOTAL ASCENT TIME
250	120	1.8							5	10	10	10	10	16	24	24	36	48	64	94	142	187	682
	180	1.5					4	8	8	10	22	24	24	32	42	44	60	84	114	122	142	187	929
	240	1.5					9	14	21	22	22	40	40	42	56	76	98	100	114	122	142	187	1107
300	90	2.3					3	8	8	10	10	10	10	16	24	24	34	48	64	90	142	187	691
	120	2.0			4	8	8	8	8	10	14	24	24	24	34	42	58	66	102	122	142	187	887
	180	1.7	6	8	8	8	14	20	21	21	28	40	40	48	56	82	98	100	114	122	142	187	1165

TABLE 1–9.—*U.S. Navy standard air decompression table for exceptional exposures.*

REPETITIVE DIVE WORKSHEET

I. PREVIOUS DIVE:

24 minutes } see table 1-5 or 1-6 for repetitive group designation } Group H
105 feet

II. SURFACE INTERVAL:

2 hours 0 minutes on surface } see table 1-7 for new group } Group E
Group H (from I.)

III. RESIDUAL NITROGEN TIME:

145 feet (depth of repetitive dive) } see table 1-8 } 12 minutes
Group E (from II.)

IV. EQUIVALENT SINGLE DIVE TIME:

12 minutes (residual nitrogen time from III.)

(add) 15 minutes (actual bottom time of repetitive dive)

(sum) 27 minutes

V. DECOMPRESSION FOR REPETITIVE DIVE:

27 minutes (equivalent single dive time from IV.) } see table 1-5 or 1-6
145 feet (depth of repetitive dive)

☐ No decompression required

or

Decompression stops: 20 feet 8 minutes
10 feet 24 minutes
____ feet ____ minutes
____ feet ____ minutes

FIGURE 1-32.—Repetitive dive worksheet (filled in).

REPETITIVE DIVE WORKSHEET

I. PREVIOUS DIVE:

___minutes } see table 1-5 or 1-6 for } Group___
_____feet } repetitive group designation }

II. SURFACE INTERVAL:

__hours__minutes on surface } see table 1-7 } Group___
Group___(from I.) } for new group }

III. RESIDUAL NITROGEN TIME:

_____feet (depth of repetitive dive) } see table } ___minutes
Group___(from II.) } 1-8 }

IV. EQUIVALENT SINGLE DIVE TIME:

____minutes (residual nitrogen time from III.)

(add)____minutes (actual bottom time of repetitive dive)

(sum)____minutes

V. DECOMPRESSION FOR REPETITIVE DIVE:

____minutes (equivalent single dive time from IV.) } see table }
_____feet (depth of repetitive dive) } 1-5 or 1-6 }

☐ No decompression required

or

Decompression stops:_____feet_____minutes
_____feet_____minutes
_____feet_____minutes
_____feet_____minutes

FIGURE 1–32A.—Repetitive dive worksheet (sample for reproduction; see reverse side).

he is required to make a second dive, this time to 145 feet. It is anticipated that 15 minutes bottom time will be required to complete his work. The problem is to determine the proper decompression for this second or *repetitive dive.* Use the time and depth of his first or *previous dive* in worksheet part I. Table 1–5 indicates that he is in repetitive group "H" (according to the 110/25 schedule). During the surface interval of 2 hours he loses sufficient nitrogen to change from group "H" to group "E" according to the Surface Interval Credit Table (table 1–7). His residual nitrogen time may now be determined using the depth of his second or repetitive dive and the *new* group from the end of the surface interval by referring to the Repetitive Dive Timetable (table 1–8). This indicates that the diver's residual nitrogen time is 12 minutes. The 15 minute actual bottom time of the repetitive dive is added to the residual nitrogen time to obtain the *equivalent single dive time* which is 27 minutes. This is used, as indicated in worksheet part V, to select the decompression schedule for the repetitive dive; in this case from table 1–5, the 150/30 schedule.

More than one repetitive dive

(28) When one repetitive dive is to be followed by another, the procedure for selecting the proper decompression schedule for the first repetitive dive is *repeated.* The time and depth of the equivalent single dive of the *first* repetitive dive calculation becomes the time and depth of the "previous dive" of the *second* repetitive dive calculation. That is, the time and depth used in the worksheet part V (fig. 1–32) become the time and depth in part I of the following worksheet.

1.5.3 NITROGEN-OXYGEN DECOMPRESSION TABLES

General

(1) The use of nitrogen-oxygen mixtures in diving is new to the U.S. Navy. At this time there is no specific apparatus in universal use. Therefore, the decompression procedure outlined here and in section 3.6 has not been given extensive field evaluation.

(2) The fundamental principle of decompression from nitrogen-oxygen dives is that an *equivalent air depth* is established for the actual depth of the dive. This equivalent air depth is then combined with the actual bottom time of the dive to determine a schedule to use in the Standard Air Decompression Table.

(3) There is no credit allowed for the fact that high oxygen mixtures are breathed during decompression on the stops established for air decompression.

(4) Definitions of equivalent air depth and other details of nitrogen-oxygen mixture diving are given in section 3.6.

Tables

(5) Use the Equivalent Air Tables (table 1–10) to obtain the equivalent air depth with which to enter the Standard Air Decompression Table.

(6) To apply the tables, use the following procedure:

(*a*) Determine the actual diving depth.

(*b*) Select the table corresponding to the mixture in use for the dive.

(*c*) Enter the column corresponding to the flow setting and diving work condition.

(*d*) Find the next greater value of actual depth tabulated.

(*e*) Read the corresponding equivalent air depth.

(*f*) Decompress according to the Standard Air Decompression Table for the equivalent air depth and the actual bottom time.

(7) Make repetitive dives in accordance with the instructions given in article 1.5.2. Use the equivalent air depth of a repetitive dive as the repetitive dive depth in the Repetitive Dive Timetable.

1.5.4 HELIUM-OXYGEN DECOMPRESSION TABLES

(1) The use of a helium-oxygen mixture as a breathing medium during exposure to pressure requires separate instructions and procedures for decompression. The helium-oxygen decompression tables which follow are different from those used for ordinary compressed air diving. The tables are complicated, but at this time further simplification is impracticable.

Supply oxygen 60 percent			
Nonswimming dive flow setting 4 l. p. m.	Swimming dive flow setting 7 l. p. m.	Nonswimming dive flow setting 7 l. p. m.	**EQUIVALENT AIR DEPTH**
Actual depth up to—	*Actual depth up to—*	*Actual depth up to—*	
51	65	68	**30**
64	80	80	**40**
77	------------	------------	**50**
80	------------	------------	**60**

Supply oxygen 40 percent			
Nonswimming dive flow setting 8 l. p. m.	Swimming dive flow setting 12 l. p. m.	Nonswimming dive flow setting 12 l. p. m.	**EQUIVALENT AIR DEPTH**
Actual depth up to—	*Actual depth up to—*	*Actual depth up to—*	
36	39	40	**30**
47	51	52	**40**
58	62	64	**50**
69	74	76	**60**
80	85	88	**70**
91	97	99	**80**
102	108	111	**90**
113	120	123	**100**
124	131	134	**110**
135	140	140	**120**
140	------------	------------	**130**

Supply oxygen 32.5 percent			
Nonswimming dive flow setting 13 l. p. m.	Swimming dive flow setting 21 l.p.m.	Nonswimming dive flow setting 21 l.p.m.	**EQUIVALENT AIR DEPTH**
Actual depth up to—	*Actual depth up to—*	*Actual depth up to—*	
33	35	36	**30**
44	46	47	**40**
54	57	58	**50**
65	68	69	**60**
75	79	80	**70**
86	89	91	**80**
96	100	102	**90**
107	111	113	**100**
117	122	123	**110**
128	133	134	**120**
138	144	145	**130**
149	155	156	**140**
160	165	167	**150**
170	176	178	**160**
180	180	180	**170**

TABLE 1–10.—*Nitrogen-oxygen equivalent air depth table.*

Further important information about physiological aspects of helium-oxygen mixtures may be found in articles 1.3.9(13) and 1.3.12(5–7). The special methods and equipment applicable are discussed in article 2.6.3.

(2) Helium-oxygen decompression tables differ from the air tables in the following major respects:

(*a*) The partial pressure of the inert gas at depth and not the depth of the dive determine the particular table to use.

(*b*) The rate of ascent from the bottom to the first stop varies and the means to compute it is given in the particular decompression schedule used.

(*c*) The rate of ascent between stops varies and is given for various depths in a separate table.

(*d*) The time of ascent from one stop to the next is included in the time of the subsequent stop.

(*e*) Repetitive diving is not allowed.

(3) The helium-oxygen decompression tables comprise:

(*a*) Partial Pressure Table (table 1–12).

(*b*) Helium-Oxygen Decompression Table (table 1–13).

(*c*) Rate of Ascent Table (table 1–14).

(*d*) Emergency Table (HeO_2) (table 1–15).

(*e*) Emergency Table (Air) (table 1–16).

Oxygen limits in helium-oxygen diving

(4) For exposure times up to 30 minutes, 2.0 atmospheres is the maximum safe oxygen partial pressure (see arts. 1.3.11 and 1.5.7). The maximum allowable oxygen percentage for a gas mixture used in a dive of 30 minutes or less may be determined from the following formula (where D equals depth):

$$\text{Maximum oxygen percentage} = \frac{(2.0 \times 33)}{(D+33)}$$

As exposure time *increases*, the maximum safe oxygen partial pressure *decreases*. (See 1.5.7 (8).) Therefore, in dives longer than 30 minutes bottom time, substitute the *maximum oxygen partial pressure* from table 1–11 for 2.0 in the formula just given (and in art. 2.6.3(21)).

TABLE 1–11.—*Oxygen partial pressure limits*

Exposure time (minutes)	Maximum oxygen partial pressure (atmospheres)
30	2. 0
40	1. 9
60	1. 8
80	1. 7
100	1. 6
120	1. 5
180	1. 4
240	1. 3

Sequence of computations

(5) Specific instructions are given on the use of the various tables. The general sequence of computations after determining the proper oxygen concentrations (2.6.3(21) and 1.5.4(4)) and the use of the tables are:

(*a*) Determine the partial pressure of all other gases (AOG) except oxygen, for the depth of the dive and the percentage of oxygen in the breathing medium. Compute by formula or use the Partial Pressure Table.

(*b*) From knowledge of the partial pressure and the actual bottom time of the dive, select the proper decompression schedule. Use the Helium-Oxygen Decompression Table.

(*c*) Compute the rate of ascent to the first stop. Use the time listed in the "To first stop" column of the proper decompression schedule.

(*d*) Remain at the first stop for the number of minutes specified.

(*e*) Select the rate of ascent between the rest of the stops and stay at the stops the required number of minutes. Include each time of ascent in the subsequent stop. Use the Rate of Ascent Table.

(*f*) Shift to oxygen as the breathing medium at the 50 foot stop. Follow the outlined procedure.

(*g*) Use emergency tables if required.

Partial pressure table

(6) The use of partial pressure of inert gas instead of actual depth of dive is the main difference between the air and helium-oxygen decompression methods. This table provides the partial pressure of inert gas.

TABLE 1-12.—*Helium-oxygen—table of partial pressures—10 feet to 600 feet*

Depth	Percentage of oxygen used													
	13	15	17	19	21	23	25	30	35	40	45	50	55	
10														*ND to 100% O_2.
20														*ND to 100% O_2.
30														*ND to 100% O_2.
40	65	64	62	61	59	58	56							*ND to 100% O_2.
50	74	72	71	69	67	66	64	60	56					*ND to 100% O_2.
60	83	81	79	77	75	73	72	67	62	58	53			*ND to 90% O_2.
70	92	90	88	85	83	81	79	74	69	64	59	54		*ND to 80% O_2.
80	101	98	96	94	92	89	87	81	76	70	64	59	53	*ND to 73% O_2.
90	109	107	105	102	100	97	95	89	82	76	70	64	58	*ND to 67% O_2.
100	118	116	113	110	108	105	102	96	89	82	76	69	63	
110	127	124	122	119	116	113	110	103	96	89	82	74	67	
120	136	133	130	127	124	121	118	110	103	95	87	80	72	
130	145	142	139	135	132	129	126	117	109	101	93	85		
140	154	151	147	144	140	137	133	125	116	107	99			
150	163	159	156	152	148	145	141	132	123	113	104			
160	172	168	164	160	156	152	149	139	129	120				
170	181	177	173	168	164	160	156	146	136	126				
180	190	185	181	177	173	168	164	153	143					
190	198	194	190	185	181	176	172	161	149					
200	207	203	198	193	189	184	179	168	156					
210	216	211	207	202	197	192	187	175						
220	225	220	215	210	205	200	195	182						
230	234	229	224	218	213	208	203	189						
240	243	238	232	227	221	216	210	197						
250	252	246	241	235	229	224	218							
260	261	255	249	243	237	231	226							
270	270	264	258	251	245	239	233							
280	279	272	266	260	254	247	241							
290	287	281	275	268	262	255	249							
300	296	290	283	276	270	263	256							
310	305	298	292	285	278	271								
320	314	307	300	293	286	279								
330	323	316	309	301	294	287								
340	332	325	317	310	302	295								
350	341	333	326	318	310	303								
360	350	342	334	326	318									
370	359	351	343	334	326									
380	368	359	351	343	335									
390	376	368	360	351										
400	385	377	368	359										
410	394	385	377	368										
420	403	394	385	376										
430	412	403	394	384										
440	421	412	402											
450	430	420	411											
460	439	429	419											
470	448	438	428											
480	457	446	436											
490	465	455	445											
500	474	464												
510	483	472												
520	492	481												
530	501	490												
540	510	499												
550	519	507												
560	528	516												
570	537	525												
580	546													
590	554													
600	563													

*(ND)—No Decompression.

NOTE.—The horizontal line in each oxygen percentage column indicates the maximum depth to which that percentage should be used for a dive having a bottom time of 30 minutes or less. (See art. 1.5.4(4).)

(7) The table is based on the formula:

$PP\,(\text{AOG}) = (D+33) \times [1.00 -)O_2 - 0.02)]$

where PP (AOG) = partial pressure in feet of all other gases except oxygen.

D = actual gage depth of water in feet.

O_2 = decimal equivalent of oxygen percentage.

0.02 = an assumed loss of 2 percent of oxygen in the helmet.

(8) Enter the table with the actual depth on the left side of the table. Follow across to the column headed by the average percentage oxygen of the bank in use. The partial pressure is the value tabulated at this point.

(9) Interpolate for depth and percent oxygen as may be necessary. Example: Depth, gage=297 feet, oxygen percentage=20. In the table, the depths of 290 and 300 feet are listed. The partial pressures corresponding to these

depths are listed in increments of 2 percent of oxygen between 13 and 25 percent. Interpolate in either direction as shown below:

	19		*20*		21
290	268		*265*		262
297	*273.6*	—	*270.6*	—	*267.6*
300	273.6		*273*		270

(10) In such cases, it is usually quicker to use the formula:

Example:

$$PP=(297+33)\times(1.00-(O_2-0.02)]$$
$$=330\times[1.00-0.18]$$
$$=330\times.82$$
$$=270.6$$

Helium-Oxygen Decompression Table

(11) Decompression schedules are given for each 10 feet of partial pressure from 60 to 410 and for bottom times of 10 minutes to 240 minutes in increments of about 10 minutes.

(12) The evaluation made to date on the schedules with longer exposures has been inadequate. There is some doubt as to their value. When priorities permit, complete evaluations will be made and necessary corrections issued.

(13) Details on the use of the Helium-Oxygen Decompression Table are:

(*a*) To obtain the decompression schedule, use the partial pressure group that is exactly equal to or is next greater than that you computed. Use the bottom time that is exactly equal to or is next longer than the actual bottom time of the dive. Do not interpolate. Example: Assume the bottom time of the 297 foot dive above was 19 minutes. The partial pressure was 270.6, so the proper decompression schedule is a partial pressure of *280* and a bottom time of *20*.

(*b*) Obtain the rate of ascent to the first stop by dividing the distance in feet from the bottom to the first stop by the number of minutes listed in the "To the first stop" column of the proper decompression schedule. Example: Use the dive and the decompression schedule above. The distance to the first stop is 297–120=177 feet. The "4" listed in the "To first stop" column means that you are to take 4 minutes in ascent. Divide 177 by 4 and obtain a rate of ascent of about 44 feet per minute.

(*c*) Remain at the first stop for the number of minutes specified (usually 7).

(*d*) Obtain the rate of ascent between subsequent stops as instructed below under use of the Rate of Ascent Table. Include the time of ascent and the time spent at the subsequent stop to total with the time specified for the stop. Example: You will find that the rate of ascent between the first and second stops for the 297 foot/19 minute dive is about 35 ft./min. At that rate, you will use about 1 minute ascending from 120 feet to 90 feet. After arrival at the 90 foot stop, stay 1 minute to comply with the 2 minutes specified. The easiest way to do this is to start a stop watch at the time of leaving each stop. Leave the next stop after the specified number of minutes. The note, "Take 1 extra minute from the first stop to next stop," means to add 1 minute to the second stop.

(*e*) The steps to accomplish the shift to oxygen at the 50 foot stop are spelled out in part 2.

(*f*) Surface the diver at a uniform rate during the last minute of decompression time.

TABLE 1–13.—*Helium-oxygen—decompression table*

Time of dive	To first stop	Feet and minutes 40	Total time	Time of dive	To first stop	Feet and minutes 40	Total time
PARTIAL PRESSURE 60							
10	4	0	4	80	2	6	
20	4	0	4	100	2	7	
30	4	0	4	120	2	9	11
40	4	0	4	240	2	13	15
60	4	0	4				
PARTIAL PRESSURE 70							
10	3	6	9	120	3	25	28
20	3	7	10	140	3	27	30
30	3	9	12	160	3	29	32
40	3	10	13	180	3	31	34
60	3	15	18	200	3	31	34
80	3	17	20	220	3	33	36
100	3	22	25	240	3	33	36

TABLE 1-13.—Continued

PARTIAL PRESSURE 80

Time of dive	To first stop	Feet and minutes 40	Total time	Time of dive	To first stop	Feet and minutes 40	Total time
10	3	6	9	120	3	42	45
20	3	10	13	140	3	45	48
30	3	13	16	160	3	47	50
40	3	17	20	180	3	48	51
60	3	24	27	200	3	48	51
80	3	32	35	220	3	48	51
100	3	40	43	240	3	50	53

PARTIAL PRESSURE 90

Time of dive	To first stop	Feet and minutes 40	Total time	Time of dive	To first stop	Feet and minutes 40	Total time
10	3	8	11	120	3	55	58
20	3	15	18	140	3	58	61
30	3	18	21	160	3	60	63
40	3	23	26	180	3	60	63
60	3	35	38	200	3	62	65
80	3	45	48	220	3	62	65
100	3	50	53	240	3	63	66

PARTIAL PRESSURE 100

Time of dive	To first stop	Feet and minutes 40	Total time	Time of dive	To first stop	Feet and minutes 40	Total time
10	3	10	13	120	3	67	70
20	3	17	20	140	3	70	73
30	3	24	27	160	3	72	75
40	3	31	34	180	3	73	76
60	3	47	50	200	3	73	76
80	3	56	59	220	3	73	76
100	3	63	66	240	3	75	78

PARTIAL PRESSURE 110

Time of dive	To first stop	Feet and minutes 40	Total time	Time of dive	To first stop	Feet and minutes 40	Total time
10	3	12	15	120	3	78	81
20	3	21	24	140	3	81	84
30	3	31	34	160	3	83	86
40	3	39	42	180	3	84	87
60	3	56	59	200	3	84	87
80	3	67	70	220	3	85	88
100	3	75	78	240	3	86	89

PARTIAL PRESSURE 120

Time of dive	To first stop	Feet and minutes 40	Total time	Time of dive	To first stop	Feet and minutes 40	Total time
10	3	14	17	120	3	87	90
20	3	25	28	140	3	90	93
30	3	36	39	160	3	92	95
40	3	47	50	180	3	93	96
60	3	66	69	200	3	93	96
80	3	77	80	220	3	95	98
100	3	84	87	240	3	97	100

PARTIAL PRESSURE 130

Time of dive	To first stop	Feet and minutes		Total time	Time of dive	To first stop	Feet and minutes		Total time
		50	40				50	40	
10	3	0	16	19	120	3	0	96	99
20	3	0	29	32	140	3	0	99	102
30	3	0	42	45	160	3	10	92	105
40	3	0	53	56	180	3	10	93	106
60	3	0	73	76	200	3	10	94	107
80	3	0	86	89	220	3	10	95	108
100	3	0	92	95	240	3	10	96	109

PARTIAL PRESSURE 140

Time of dive	To first stop	Feet and minutes 50	Feet and minutes 40	Total time	Time of dive	To first stop	Feet and minutes 50	Feet and minutes 40	Total time
10	3	0	19	22	120	3	10	97	110
20	3	0	34	37	140	3	10	98	111
30	3	0	49	52	160	3	10	99	112
40	3	0	62	65	180	3	12	99	114
60	3	0	82	85	200	3	13	99	115
80	3	0	94	97	220	3	14	99	116
100	3	0	99	102	240	3	15	99	117

TABLE 1–13.—Continued

PARTIAL PRESSURE 150

Time of dive	To first stop	Feet and minutes			Total time	Time of dive	To first stop	Feet and minutes			Total time
		60	50	40				60	50	40	
10	3	0	10	11	24	120	3	7	11	98	119
20	3	0	10	28	41	140	3	7	13	99	122
30	3	0	10	45	58	160	3	8	15	99	125
40	3	7	10	59	79	180	3	9	15	99	126
60	3	7	10	78	98	200	3	10	16	99	128
80	3	7	10	90	110	220	3	11	16	99	129
100	3	7	10	96	116	240	3	12	16	99	130

PARTIAL PRESSURE 160

Time of dive	To first stop	Feet and minutes				Total time	Time of dive	To first stop	Feet and minutes				Total time
		70	60	50	40				70	60	50	40	
10	3	0	0	10	12	25	120	3	0	9	16	99	127
20	3	0	7	10	33	53	140	3	0	15	16	99	133
30	3	0	7	10	50	70	160	3	0	18	16	99	136
40	3	0	7	10	65	85	180	3	0	20	16	99	138
60	3	0	7	10	84	104	200	3	0	22	16	99	140
80	3	0	7	10	96	116	220	3	0	23	16	99	141
100	3	0	7	13	99	122	240	3	7	19	16	99	144

PARTIAL PRESSURE 170

Time of dive	To first stop	Feet and minutes				Total time	Time of dive	To first stop	Feet and minutes				Total time
		70	60	50	40				70	60	50	40	
10	3	0	7	10	15	35	120	3	7	17	16	99	142
20	3	0	7	10	36	56	140	3	8	21	16	99	147
30	3	0	7	10	55	75	160	3	11	22	16	99	151
40	3	0	7	10	70	90	180	3	11	23	16	99	152
60	3	7	6	10	83	109	200	3	12	23	16	99	153
80	3	7	9	10	98	127	220	3	14	23	16	99	155
100	3	7	13	14	98	135	240	3	16	23	16	99	157

PARTIAL PRESSURE 180

Time of dive	To first stop	Feet and minutes					Total time	Time of dive	To first stop	Feet and minutes					Tota time
		80	70	60	50	40				80	70	60	50	40	
10	3	0	7	0	10	17	37	120	3	7	9	21	16	99	155
20	3	0	7	0	10	41	61	140	3	7	11	22	16	99	158
30	3	0	7	1	10	62	83	160	3	7	15	23	16	99	163
40	3	0	7	4	10	77	101	180	3	7	17	23	16	99	165
60	3	0	7	10	10	92	122	200	3	7	19	23	16	99	167
80	3	0	9	14	13	98	137	220	3	7	21	23	16	99	169
100	3	7	5	18	15	99	147	240	3	7	23	23	16	99	171

PARTIAL PRESSURE 190

Time of dive	To first stop	Feet and minutes					Total time	Time of dive	To first stop	Feet and minutes					Total time
		80	70	60	50	40				80	70	60	50	40	
10	4	0	7	0	10	20	41	120	4	7	17	23	16	99	166
20	4	0	7	0	10	44	65	140	4	9	19	23	16	99	170
30	4	0	7	4	10	67	92	160	4	11	20	23	16	99	173
40	4	7	0	8	10	81	110	180	4	13	21	23	16	99	176
60	4	7	5	11	10	96	133	200	4	14	22	23	16	99	178
80	4	7	9	15	15	99	149	220	4	15	23	23	16	99	180
100	4	7	13	19	16	99	158	240	4	17	23	23	16	99	182

PARTIAL PRESSURE 200

Time of dive	To first stop	Feet and minutes						Total time	Time of dive	To first stop	Feet and minutes						Total time
		90	80	70	60	50	40				90	80	70	60	50	40	
10	4	0	0	7	0	10	22	43	120	4	7	8	20	23	16	99	177
20	4	0	7	0	2	10	50	73	140	4	7	11	21	23	16	99	181
30	4	0	7	0	7	10	69	97	160	4	7	15	23	23	16	99	187
40	4	0	7	4	9	10	84	118	180	4	7	17	23	23	16	99	189
60	4	0	7	9	13	12	93	138	200	4	7	18	23	23	16	99	190
80	4	7	3	13	18	15	99	159	220	4	7	20	23	23	16	99	192
100	4	7	6	16	21	16	99	169	240	4	8	20	23	23	16	99	193

Table 1–13.—Continued

PARTIAL PRESSURE 210

Time of dive	To first stop	Feet and minutes						Total time	Time of dive	To first stop	Feet and minutes						Total time
		90	80	70	60	50	40				90	80	70	60	50	40	
10	4	0	7	0	0	10	25	47	120	4	8	15	21	23	16	99	186
20	4	0	7	0	4	10	53	78	140	4	10	17	21	23	16	99	190
30	4	7	0	3	7	10	74	105	160	4	12	17	22	23	16	99	193
40	4	7	0	7	10	10	86	124	180	4	14	18	22	23	16	99	196
60	4	7	4	10	14	13	98	150	200	4	16	18	23	23	16	99	199
80	4	7	8	14	18	16	99	166	220	4	17	19	23	23	16	99	201
100	4	7	12	17	23	16	99	178	240	4	18	20	23	23	16	99	203

PARTIAL PRESSURE 220

Time of dive	To first stop	Feet and minutes							Total time
		100	90	80	70	60	50	40	
10	4	0	0	7	0	0	10	28	50
20	4	0	7	0	1	6	10	57	85
30	4	0	7	0	6	7	10	79	113
40	4	0	7	3	9	10	10	90	133
60	4	7	0	9	11	17	13	98	159
80	4	7	3	11	15	20	13	99	172
100	4	7	6	14	19	23	16	99	188
120	4	7	8	18	23	23	16	99	198
140	4	7	11	18	23	23	16	99	201
160	4	7	14	19	23	23	16	99	205
180	4	7	15	20	23	23	16	99	207
200	4	7	16	20	23	23	16	99	208
220	4	8	17	20	23	23	16	99	210
240	4	9	19	20	23	23	16	99	213

PARTIAL PRESSURE 230

Time of dive	To first stop	Feet and minutes								Total time
		110	100	90	80	70	60	50	40	
*10	4	0	0	0	7	0	1	10	30	53
20	4	0	0	7	0	3	7	10	61	92
30	4	0	0	7	2	6	9	10	81	119
40	4	0	7	0	6	9	11	10	93	140
60	4	0	7	4	9	12	18	14	99	167
80	4	0	7	8	12	17	21	16	99	184
100	4	0	7	12	15	20	23	16	99	196
120	4	0	8	14	19	23	23	16	99	206
140	4	0	10	16	20	23	23	16	99	211
160	4	7	6	18	20	23	23	16	99	216
180	4	7	7	19	20	23	23	16	99	218
200	4	7	9	19	20	23	23	16	99	220
220	4	7	11	19	20	23	23	16	99	222
240	4	7	13	19	20	23	23	16	99	224

*Take 1 extra minute from first stop to next stop.

PARTIAL PRESSURE 240

10	4	0	0	7	0	0	3	10	33	57
20	4	0	7	0	1	4	7	10	65	98
30	4	0	7	0	5	7	10	10	85	128
40	4	7	0	3	7	9	13	11	95	149
60	4	7	0	8	10	14	18	15	99	175
80	4	7	3	10	14	18	23	16	99	194
100	4	7	6	12	17	23	23	16	99	207
120	4	7	7	16	19	23	23	16	99	214
140	4	7	11	16	20	23	23	16	99	219
160	4	7	13	19	20	23	23	16	99	224
180	4	8	15	19	20	23	23	16	99	227
200	4	8	17	19	20	23	23	16	99	229
220	4	9	17	19	20	23	23	16	99	230
240	4	11	17	19	20	23	23	16	99	232

TABLE 1–13.—Continued

PARTIAL PRESSURE 250

Time of dive	To first stop	Feet and minutes									Total time
		120	110	100	90	80	70	60	50	40	
*10	4	0	0	7	0	0	1	4	10	35	62
20	4	0	0	7	0	2	5	7	10	68	103
30	4	0	7	0	2	6	7	10	10	87	133
40	4	0	7	0	5	8	9	14	12	96	155
60	4	0	7	4	8	11	14	19	16	99	182
80	4	0	7	7	11	16	18	23	16	99	201
100	4	0	7	10	14	19	23	23	16	99	215
120	4	7	3	12	17	19	23	23	16	99	223
140	4	7	4	15	18	19	23	23	16	99	228
160	4	7	7	16	19	19	23	23	16	99	233
180	4	7	9	17	19	20	23	23	16	99	237
200	4	7	11	17	19	20	23	23	16	99	239
220	4	7	12	17	19	20	23	23	16	99	240
240	4	7	13	17	19	20	23	23	16	99	241

*Take 1 extra minute from first stop to next stop.

PARTIAL PRESSURE 260

10	4	0	0	7	0	0	2	4	10	37	64
20	4	0	7	0	0	3	7	7	10	70	108
30	4	0	7	0	4	6	8	10	10	89	138
40	4	0	7	2	5	9	9	14	13	96	159
60	4	7	0	7	9	12	16	21	16	99	191
80	4	7	3	9	13	15	21	23	16	99	210
100	4	7	6	11	14	19	23	23	16	99	222
120	4	7	8	13	19	20	23	23	16	99	232
140	4	7	11	15	19	20	23	23	16	99	237
160	4	8	13	17	19	20	23	23	16	99	242
180	4	9	14	17	19	20	23	23	16	99	244
200	4	10	16	17	19	20	23	23	16	99	247
220	4	11	16	17	19	20	23	23	16	99	248
240	4	13	16	17	19	20	23	23	16	99	250

PARTIAL PRESSURE 270

Time of dive	To first stop	Feet and minutes										Total time
		130	120	110	100	90	80	70	60	50	40	
*10	4	0	0	7	0	0	0	3	4	10	40	69
20	4	0	0	7	0	2	4	6	7	10	74	114
30	4	0	7	0	2	5	6	9	10	10	92	145
40	4	0	7	0	3	8	9	10	15	14	96	166
60	4	0	7	3	7	10	14	16	21	16	99	197
80	4	0	7	6	10	13	17	23	23	16	99	218
100	4	7	2	9	13	16	20	23	23	16	99	232
120	4	7	4	11	14	19	20	23	23	16	99	240
140	4	7	5	14	15	19	20	23	23	16	99	245
160	4	7	7	15	17	19	20	23	23	16	99	250
180	4	7	9	16	17	19	20	23	23	16	99	253
200	4	7	11	16	17	19	20	23	23	16	99	255
220	4	7	13	16	17	19	20	23	23	16	99	257
240	4	7	15	16	17	19	20	23	23	16	99	259

*Take 1 extra minute from first stop to next stop.

PARTIAL PRESSURE 280

*10	4	0	0	7	0	0	1	3	4	10	42	72
20	4	0	7	0	0	2	6	6	8	10	78	121
30	4	0	7	0	3	6	6	9	13	10	93	151
40	4	7	0	2	5	8	8	12	16	13	98	173
60	4	7	0	6	8	10	14	19	23	16	99	206
80	4	7	3	8	11	14	17	23	23	16	99	225
100	4	7	5	11	13	16	20	23	23	16	99	237
120	4	7	8	12	16	19	20	23	23	16	99	247
140	4	7	10	16	17	19	20	23	23	16	99	254
160	4	8	13	16	17	19	20	23	23	16	99	258
180	4	9	14	16	17	19	20	23	23	16	99	260
200	4	10	15	16	17	19	20	23	23	16	99	262
220	4	12	15	16	17	19	20	23	23	16	99	264
240	4	14	15	16	17	19	20	23	23	16	99	266

*Take 1 extra minute from first stop to next stop.

Table 1–13.—Continued

PARTIAL PRESSURE 290

Time of dive	To first stop	Feet and minutes											Total time
		140	130	120	110	100	90	80	70	60	50	40	
*10	4	0	0	0	7	0	0	2	3	4	10	46	77
20	4	0	0	7	0	0	4	6	7	7	10	81	126
30	4	0	7	0	1	5	5	9	9	12	10	96	158
40	4	0	7	0	4	6	8	9	12	17	15	98	180
60	4	0	7	4	6	8	12	15	18	23	16	99	212
80	4	7	0	7	9	11	15	17	23	23	16	99	231
100	4	7	2	9	11	15	17	20	23	23	16	99	246
120	4	7	4	11	13	16	19	20	23	23	16	99	255
140	4	7	5	13	16	17	19	20	23	23	16	99	262
160	4	7	8	14	16	17	19	20	23	23	16	99	266
180	4	7	10	15	16	17	19	20	23	23	16	99	269
200	4	7	12	15	16	17	19	20	23	23	16	99	271
220	4	7	13	15	16	17	19	20	23	23	16	99	272
240	4	7	14	15	16	17	19	20	23	23	16	99	273

*Take 1 extra minute from first stop to next stop.

PARTIAL PRESSURE 300

Time of dive	To first stop	Feet and minutes												Total time
		150	140	130	120	110	100	90	80	70	60	50	40	
*10	5	0	0	0	7	0	0	0	3	3	4	10	49	82
*20	5	0	0	7	0	0	1	6	6	6	9	10	83	134
30	5	0	0	7	0	2	5	5	9	9	14	12	94	162
40	5	0	0	7	0	5	7	8	11	13	17	15	98	186
60	5	0	7	0	6	7	9	12	15	20	23	16	99	219
80	5	0	7	2	8	10	12	16	19	23	23	16	99	240
100	5	0	7	5	10	12	15	19	20	23	23	16	99	254
120	5	0	7	8	11	16	17	19	20	23	23	16	99	264
140	5	0	8	9	14	16	17	19	20	23	23	16	99	269
160	5	0	8	13	15	16	17	19	20	23	23	16	99	274
180	5	7	3	13	15	16	17	19	20	23	23	16	99	276
200	5	7	5	14	15	16	17	19	20	23	23	16	99	279
220	5	7	6	14	15	16	17	19	20	23	23	16	99	280
240	5	7	9	14	15	16	17	19	20	23	23	16	99	283

*Take 1 extra minute from first stop to next stop.

PARTIAL PRESSURE 310

*10	5	0	0	0	7	0	0	1	3	3	5	10	52	87
*20	5	0	0	7	0	0	3	5	6	6	11	10	84	137
30	5	0	7	0	0	5	5	7	8	9	14	12	96	168
40	5	0	7	0	3	5	8	8	11	13	18	15	99	192
60	5	0	7	3	6	7	10	12	18	22	23	16	99	228
80	5	7	0	6	9	11	12	16	19	23	23	16	99	246
100	5	7	1	9	10	14	17	19	20	23	23	16	99	263
120	5	7	4	11	12	14	17	19	20	23	23	16	99	270
140	5	7	5	12	15	16	17	19	20	23	23	16	99	277
160	5	7	8	14	15	16	17	19	20	23	23	16	99	282
180	5	7	10	14	15	16	17	19	20	23	23	16	99	284
200	5	7	12	14	15	16	17	19	20	23	23	16	99	286
220	5	8	13	14	15	16	17	19	20	23	23	16	99	288
240	5	9	13	14	15	16	17	19	20	23	23	16	99	289

*Take 1 extra minute from first stop to next stop.

PARTIAL PRESSURE 320

Time of dive	To first stop	Feet and minutes													Total time
		160	150	140	130	120	110	100	90	80	70	60	50	40	
*10	5	0	0	0	7	0	0	0	2	3	3	7	10	54	92
*20	5	0	0	7	0	0	1	4	5	6	7	10	10	85	141
30	5	0	0	7	0	2	4	5	7	8	11	15	13	98	175
40	5	0	7	0	1	4	6	7	8	12	15	19	16	99	199
60	5	0	7	0	5	6	9	11	13	17	20	23	16	99	231
80	5	0	7	3	7	9	11	13	17	20	23	23	16	99	253
100	5	0	7	5	9	11	13	17	19	20	23	23	16	99	267
120	5	0	7	7	12	13	16	17	19	20	23	23	16	99	277
140	5	7	2	9	12	15	16	17	19	20	23	23	16	99	283
160	5	7	3	11	14	15	16	17	19	20	23	23	16	99	288
180	5	7	5	11	14	15	16	17	19	20	23	23	16	99	290
200	5	7	6	13	14	15	16	17	19	20	23	23	16	99	293
220	5	7	7	13	14	15	16	17	19	20	23	23	16	99	294
240	5	7	9	13	14	15	16	17	19	20	23	23	16	99	296

*Take 1 extra minute from first stop to next stop.

557535 O - 60 - 9

Table 1–13.—Continued

PARTIAL PRESSURE 330

Time of dive	To first stop	Feet and minutes													Total time
		160	150	140	130	120	110	100	90	80	70	60	50	40	
*10	5	0	0	0	7	0	0	0	3	3	3	7	10	56	95
*20	5	0	0	7	0	0	2	5	5	6	8	10	10	88	146
30	5	0	7	0	0	4	4	6	7	9	11	17	13	98	181
40	5	0	7	0	4	4	6	7	9	12	16	20	16	99	205
60	5	7	0	2	6	8	9	11	14	17	23	23	16	99	240
80	5	7	0	6	8	8	13	14	19	20	23	23	16	99	261
100	5	7	2	7	10	13	16	17	19	20	23	23	16	99	277
120	5	7	4	9	12	13	16	17	19	20	23	23	16	99	283
140	5	7	6	11	13	15	16	17	19	20	23	23	16	99	290
160	5	7	8	13	14	15	16	17	19	20	23	23	16	99	295
180	5	7	10	13	14	15	16	17	19	20	23	23	16	99	297
200	5	7	12	13	14	15	16	17	19	20	23	23	16	99	299
220	5	9	12	13	14	15	16	17	19	20	23	23	16	99	301
240	5	10	12	13	14	15	16	17	19	20	23	23	16	99	302

*Take 1 extra minute from first stop to next stop.

PARTIAL PRESSURE 340

Time of dive	To first stop	Feet and minutes														Total time
		170	160	150	140	130	120	110	100	90	80	70	60	50	40	
*10	5	0	0	0	7	0	0	0	1	3	3	4	7	10	59	100
*20	5	0	0	7	0	0	1	3	4	6	5	10	10	10	90	152
30	5	0	0	7	0	1	4	5	6	8	8	13	17	14	98	186
40	5	0	7	0	1	4	5	7	7	10	12	17	22	16	99	212
60	5	0	7	0	5	6	8	9	11	15	20	23	23	16	99	247
80	5	0	7	2	7	8	10	13	15	19	20	23	23	16	99	267
100	5	0	7	5	9	9	13	16	17	19	20	23	23	16	99	281
120	5	7	1	7	10	13	15	16	17	19	20	23	23	16	99	291
140	5	7	2	9	12	14	15	16	17	19	20	23	23	16	99	297
160	5	7	4	10	13	14	15	16	17	19	20	23	23	16	99	301
180	5	7	5	12	13	14	15	16	17	19	20	23	23	16	99	304
200	5	7	6	12	13	14	15	16	17	19	20	23	23	16	99	305
220	5	7	8	12	13	14	15	16	17	19	20	23	23	16	99	307
240	5	7	10	12	13	14	15	16	17	19	20	23	23	16	99	309

* Take 1 extra minute from first stop to next stop.

PARTIAL PRESSURE 350

*10	5	0	0	0	7	0	0	0	2	3	3	4	7	10	61	103
*20	5	0	0	7	0	0	1	4	5	7	8	9	10	10	90	157
30	5	0	7	0	0	3	5	5	6	8	9	13	18	14	98	191
40	5	0	7	0	2	4	6	7	8	10	13	16	22	16	99	215
60	5	7	0	3	5	6	9	10	13	16	18	21	23	16	99	251
80	5	7	0	7	7	8	11	13	15	19	20	23	23	16	99	273
100	5	7	2	8	8	12	13	16	17	19	20	23	23	16	99	288
120	5	7	4	9	11	13	15	16	17	19	20	23	23	16	99	297
140	5	7	6	11	13	14	15	16	17	19	20	23	23	16	99	304
160	5	7	9	11	13	14	15	16	17	19	20	23	23	16	99	307
180	5	8	9	12	13	14	15	16	17	19	20	23	23	16	99	309
200	5	8	11	12	13	14	15	16	17	19	20	23	23	16	99	311
220	5	10	11	12	13	14	15	16	17	19	20	23	23	16	99	313
240	5	11	11	12	13	14	15	16	17	19	20	23	23	16	99	314

*Take 1 extra minute from first stop to next stop.

PARTIAL PRESSURE 360

Time of dive	To first stop	Feet and minutes															Total time
		180	170	160	150	140	130	120	110	100	90	80	70	60	50	40	
*10	5	0	0	0	7	0	0	0	1	2	3	3	5	7	10	64	108
*20	5	0	0	7	0	0	0	3	4	5	5	7	9	13	10	94	163
30	5	0	0	7	0	1	4	4	5	7	8	11	13	18	14	99	196
40	5	0	7	0	1	3	5	6	7	8	11	14	17	23	16	99	222
60	5	0	7	0	5	5	8	8	11	12	16	19	23	23	16	99	257
80	5	0	7	2	7	7	10	11	13	17	19	20	23	23	16	99	279
100	5	7	0	6	8	9	11	15	16	17	19	20	23	23	16	99	294
120	5	7	1	7	9	12	14	15	16	17	19	20	23	23	16	99	303
140	5	7	3	9	11	13	14	15	16	17	19	20	23	23	16	99	310
160	5	7	4	10	12	13	14	15	16	17	19	20	23	23	16	99	313
180	5	7	5	11	12	13	14	15	16	17	19	20	23	23	16	99	315
200	5	7	7	11	12	13	14	15	16	17	19	20	23	23	16	99	317
220	5	7	9	11	12	13	14	15	16	17	19	20	23	23	16	99	319
240	5	7	11	11	12	13	14	15	16	17	19	20	23	23	16	99	321

*Take 1 extra minute from first stop to next stop.

Table 1-13.—Continued

PARTIAL PRESSURE 370

Time of dive	To first stop	Feet and minutes																Total time
		190	180	170	160	150	140	130	120	110	100	90	80	70	60	50	40	
*10	5	0	0	0	0	7	0	0	0	1	2	2	3	7	7	10	66	111
*20	5	0	0	0	7	0	0	1	3	4	5	5	8	10	13	10	94	166
30	5	0	0	7	0	0	3	3	5	6	7	8	11	13	19	15	99	201
40	5	0	0	7	0	2	4	5	7	7	9	10	14	20	23	16	99	228
60	5	0	0	7	2	5	6	7	9	11	14	16	19	23	23	16	99	262
80	5	0	7	0	6	6	8	11	12	14	16	19	20	23	23	16	99	285
100	5	0	7	2	7	8	11	13	13	16	17	19	20	23	23	16	99	299
120	5	0	7	4	8	10	12	14	15	16	17	19	20	23	23	16	99	308
140	5	7	0	7	9	12	13	14	15	16	17	19	20	23	23	16	99	315
160	5	7	0	9	10	12	13	14	15	16	17	19	20	23	23	16	99	318
180	5	7	2	9	11	12	13	14	15	16	17	19	20	23	23	16	99	321
200	5	7	2	10	11	12	13	14	15	16	17	19	20	23	23	16	99	323
220	5	7	5	10	11	12	13	14	15	16	17	19	20	23	23	16	99	325
240	5	7	7	10	11	12	13	14	15	16	17	19	20	23	23	16	99	327

*Take 1 extra minute from first stop to next stop.

PARTIAL PRESSURE 380

*10	5	0	0	0	7	0	0	0	0	2	3	3	3	7	7	10	68	116
*20	5	0	0	7	0	0	0	2	0	4	5	5	8	10	13	12	94	170
*30	5	0	7	0	0	1	3	4	4	7	7	8	11	16	19	16	99	208
40	5	0	7	0	0	4	4	5	6	8	10	11	14	20	23	16	99	232
60	5	0	7	0	4	5	7	8	9	11	13	17	20	23	23	16	99	267
80	5	7	0	3	6	7	9	10	12	15	17	19	20	23	23	16	99	291
100	5	7	0	6	7	9	10	14	15	16	17	19	20	23	23	16	99	306
120	5	7	1	7	9	11	13	14	15	16	17	19	20	23	23	16	99	315
140	5	7	2	9	11	12	13	14	15	16	17	19	20	23	23	16	99	321
160	5	7	4	10	11	12	13	14	15	16	17	19	20	23	23	16	99	324
180	5	7	5	10	11	12	13	14	15	16	17	19	20	23	23	16	99	325
200	5	7	7	10	11	12	13	14	15	16	17	19	20	23	23	16	99	327
220	5	7	9	10	11	12	13	14	15	16	17	19	20	23	23	16	99	329
240	5	8	10	10	11	12	13	14	15	16	17	19	20	23	23	16	99	331

*Take 1 extra minute from first stop to next stop.

PARTIAL PRESSURE 390

Time of dive	To first stop	Feet and minutes																	Total time
		200	190	180	170	160	150	140	130	120	110	100	90	80	70	60	50	40	
*10	5	0	0	0	0	7	0	0	0	0	2	3	3	4	7	7	10	68	117
*20	5	0	0	0	7	0	0	1	2	4	5	5	5	9	9	14	12	95	174
*30	5	0	0	7	0	0	2	4	5	6	7	8	10	12	12	19	16	99	212
40	5	0	0	7	0	2	3	5	6	6	8	9	13	14	21	23	16	99	237
60	5	0	7	0	2	5	5	8	8	9	11	15	17	20	23	23	16	99	273
80	5	0	7	0	5	7	8	9	11	12	16	17	19	20	23	23	16	99	297
100	5	0	7	2	7	8	9	11	14	15	16	17	19	20	23	23	16	99	311
120	5	0	7	5	8	9	11	13	14	15	16	17	19	20	23	23	16	99	320
140	5	7	0	7	10	10	12	13	14	15	16	17	19	20	23	23	16	99	326
160	5	7	1	9	10	11	12	13	14	15	16	17	19	20	23	23	16	99	330
180	5	7	3	9	10	11	12	13	14	15	16	17	19	20	23	23	16	99	332
200	5	7	5	10	10	11	12	13	14	15	16	17	19	20	23	23	16	99	335
220	5	7	7	10	10	11	12	13	14	15	16	17	19	20	23	23	16	99	337
240	5	7	8	10	10	11	12	13	14	15	16	17	19	20	23	23	16	99	338

*Take 1 extra minute from first stop to next stop.

PARTIAL PRESSURE 400

Time of dive	To first stop	Feet and minutes																		Total Time
		210	200	190	180	170	160	150	140	130	120	110	100	90	80	70	60	50	40	
*10	5	0	0	0	0	0	7	0	0	0	1	2	3	3	6	9	7	10	69	123
*20	5	0	0	0	7	0	0	0	1	4	4	4	5	8	8	10	14	12	96	179
*30	5	0	0	7	0	0	0	4	4	4	5	7	7	10	11	20	19	16	99	219
40	5	0	0	7	0	1	4	5	6	6	6	7	10	11	16	23	23	16	99	245
60	5	0	7	0	0	5	5	6	7	8	11	13	14	17	20	23	23	16	99	279
80	5	0	7	0	3	6	6	8	10	12	12	15	17	19	20	23	23	16	99	301
100	5	0	7	0	6	7	8	10	13	14	15	16	17	19	20	23	23	16	99	318
120	5	0	7	2	6	9	11	12	13	14	15	16	17	19	20	23	23	16	99	327
140	5	0	7	2	8	10	11	12	13	14	15	16	17	19	20	23	23	16	99	330
160	5	0	7	3	10	10	11	12	13	14	15	16	17	19	20	23	23	16	99	333
180	5	0	7	5	10	10	11	12	13	14	15	16	17	19	20	23	23	16	99	335
200	5	0	7	7	10	10	11	12	13	14	15	16	17	19	20	23	23	16	99	337
220	5	0	7	9	10	10	11	12	13	14	15	16	17	19	20	23	23	16	99	339
240	5	7	1	9	10	10	11	12	13	14	15	16	17	19	20	23	23	16	99	340

*Take 1 extra minute from first stop to next stop.

TABLE 1–13.—Continued

PARTIAL PRESSURE 410

Time of dive	To first stop	Feet and minutes																		Total Time
		210	200	190	180	170	160	150	140	130	120	110	100	90	80	70	60	50	40	
*10	5	0	0	0	0	7	0	0	0	0	2	2	3	3	6	7	7	10	73	126
*20	5	0	0	0	7	0	0	0	2	4	4	4	5	7	9	11	14	13	96	182
*30	5	0	0	7	0	0	2	3	4	4	5	7	8	12	15	15	19	16	99	221
40	5	0	0	7	0	2	3	4	6	6	6	9	11	13	16	22	23	16	99	248
60	5	0	7	0	2	5	5	6	7	10	10	13	15	19	20	23	23	16	99	285
80	5	0	7	0	5	6	8	8	9	12	15	16	17	19	20	23	23	16	99	308
100	5	0	7	3	6	7	8	11	13	14	15	16	17	19	20	23	23	16	99	322
120	5	7	0	5	7	10	10	12	13	14	15	16	17	19	20	23	23	16	99	331
140	5	7	0	7	9	10	11	12	13	14	15	16	17	19	20	23	23	16	99	336
160	5	7	2	8	10	10	11	12	13	14	15	16	17	19	20	23	23	16	99	340
180	5	7	3	9	10	10	11	12	13	14	15	16	17	19	20	23	23	16	99	342
200	5	7	5	9	10	10	11	12	13	14	15	16	17	19	20	23	23	16	99	344
220	5	7	7	9	10	10	11	12	13	14	15	16	17	19	20	23	23	16	99	346
240	5	7	8	9	10	10	11	12	13	14	15	16	17	19	20	23	23	16	99	347

*Take 1 extra minute from first stop to next stop.

Rate of ascent table

(14) The rate of ascent to the first stop is computed from the Helium-Oxygen Decompression Table. Table 1–14 permits the computation of the rate of ascent between the rest of the stops.

TABLE 1–14.—*Rate of ascent table*

Depth	Oxygen percent								
	10	15	20	25	30	35	40	45	50
50	10	10	20	20	30	30	40	50	75
100	10	20	30	40	50	75	--	--	--
150	10	30	40	50	75	--	--	--	--
200	10	40	50	75	--	--	--	--	--
250	20	50	75	--	--	--	--	--	--
300	20	50	75	--	--	--	--	--	--
350	30	75	--	--	--	--	--	--	--
400	30	75	--	Rate, feet per minute					--
450	40	75	--	--	--	--	--	--	--
500	40	75	--	--	--	--	--	--	--
550	50	75	--	--	--	--	--	--	--
600	50	75	--	--	--	--	--	--	--

NOTE.—75 feet per minute is the maximum practical rate.

(15) The depth of the stop and the supply oxygen percentage are the variable factors. Interpolate between the listed oxygen percentages, but use the rates for listed depths without interpolation. Example: Use the 297 foot/9 minute dive. Determine the rate of ascent from the first stop to the second as follows:

From	Distance	Rate of ascent	Time
Ft.	*Ft.*	*Ft./min.*	*Min.*
120–100	20	40	0.5
100–90	10	30	.3
Sum			.8

Emergency table (HeO_2)

(16) In an emergency it may happen that oxygen cannot be used for decompression, owing to failure of the oxygen supply or to symptoms of oxygen poisoning. Either air or helium-oxygen mixtures must be used. The procedure for use of helium-oxygen is immediately available in this table.

TABLE 1–15.—*Emergency table (H_eO_2)*

50 feet	40 feet	30 feet	20 feet	10 feet
Minutes	*Minutes*	*Minutes*	*Minutes*	*Minutes*
26	30	35	42	44

(17) If the impossibility of using oxygen is known in advance, use the regular schedule up to the first oxygen stop, then shift to the Emergency Table (HeO_2). The procedure is obvious. (If development of symptoms requires shift *during* oxygen breathing, use the procedure described in paragraph 21.)

Emergency table (air)

(18) The procedure for use of air in the event of an emergency prohibiting the use of oxygen or helium-oxygen is immediately available in this table.

TABLE 1–16.—*Emergency table (air)*

Stops (feet)	Depth (feet) up to—								
	100 feet	150 feet	200 feet	250 feet	300 feet	350 feet	400 feet	450 feet	500 feet
230	------	------	------	------	------	------	------	------	9
220	------	------	------	------	------	------	------	------	9
210	------	------	------	------	------	------	------	6	10
200	------	------	------	------	------	------	------	10	10
190	------	------	------	------	------	------	3	11	11
180	------	------	------	------	------	------	11	11	11
170	------	------	------	------	------	------	12	12	12
160	------	------	------	------	------	9	12	12	12
150	------	------	------	------	------	13	13	13	13
140	------	------	------	------	4	13	14	14	14
130	------	------	------	------	14	15	15	15	15
120	------	------	------	------	16	16	16	16	16
110	------	------	------	13	16	17	17	17	17
100	------	------	------	18	18	18	18	18	18
90	------	------	7	19	19	20	20	20	20
80	------	------	22	22	22	22	22	22	22
70	------	------	24	24	24	24	24	24	24
60	------	22	26	26	26	27	27	27	27
50	------	30	30	30	30	30	30	30	30
40	14	35	35	35	35	35	35	35	35
30	42	42	42	42	42	42	42	42	42
20	52	52	52	52	52	52	52	52	52
10	68	68	68	68	68	68	68	68	68

(19) The decompression can be calculated for each case. However, since the emergency may occur at any point from the bottom to the last stop, it is impractical to attempt to cover all of the possibilities in tables.

(20) The table is simple. Schedules are provided for each 50 feet. Select the one next deeper than the actual depth unless it is exactly at an even 50-foot figure.

Oxygen poisoning

(21) If the diver reports symptoms of oxygen poisoning during helium-oxygen decompression:

(*a*) If diver is within 5 minutes of completing required water stops for surface decompression (see art. 1.5.5, pars. (17) and (18)).

1. Start ascent at once.
2. Place diver in chamber immediately.
3. Proceed with surface decompression.
4. Double the missed time and add to chamber stop.
5. Use oxygen in chamber but watch carefully for reappearance of symptoms.
6. Keep diver close to chamber following decompression and observe carefully for symptoms of decompression sickness.

(*b*) If prompt ascent for surface decompression is *not* allowable—

1. Bring diver up 10 feet at once.
2. Promptly shift to helium-oxygen (preferably) or air.
3. Have diver open exhaust valve, ventilate, and remain on open circuit.
4. Be alert for possible blow up.
5. Complete decompression according to the proper Emergency Table. (See pars. (16) to (20).) (If using HeO_2, return to "circulate" after 10 minutes on open circuit.)
6. Bring up for surface decompression following completion of 30-foot stop on Emergency Table if desired. Take to 40 feet in chamber and complete decompression with oxygen as if oxygen had been used throughout.

(*c*) If symptoms proceed to convulsion in spite of measures taken,

1. Bring diver to surface at moderate rate.
2. Place in recompression chamber at once.
3. Take to 165 feet. (See table 1–21.)
4. Follow TREATMENT TABLE 3 OR 4 depending on condition at end of 30 minutes at 165 feet.

(NOTE.—Danger of causing air embolism by bringing diver up during convulsion is outweighed by other dangers of failing to do so. Since the possibility that air embolism has occurred cannot be ruled out in these cases, they require treatment.)

1.5.5 SURFACE DECOMPRESSION

(1) In surface decompression procedures, stage decompression in the water is reduced to a minimum or eliminated and the major part of decompression is accomplished in a recompression chamber on the surface. Oxygen is the standard breathing medium during the decompression period on the surface. Air or gas mixtures are alternate breathing mediums. There are separate decompression tables and procedures which apply specifically to the breathing medium used.

(2) At present in the U.S. Navy, surface decompression procedures expose the diver to

atmospheric pressure for a *brief surface interval* between leaving the water and attaining the scheduled decompression stop depth in the recompression chamber. The interval *must* be as short as possible.

(3) The principal advantages of surface decompression are the comfort and security of the diver in situations of extremely cold or rough sea, physical exhaustion, and the like. In certain dives, surface decompression with pure oxygen has the additional advantage of saving an appreciable amount of the total decompression time required for straight air decompression.

(4) Surface decompression schedules may be applied to emergencies where a surface interval *must* come between the dive and the major part of the decompression. Such cases may be emergencies forcing unscheduled surfacing (see 1.5.6), or in scuba diving, when the diver *must* surface to obtain a new air supply (see 1.5.5(9)). Although it is possible when air is the breathing medium for the decompression period following the surface interval to be in the water, *recompression in a chamber if available is always to be preferred.*

Oxygen following an air dive

(5) If a recompression chamber is available and is equipped with proper oxygen-breathing equipment (see 1.6.21(17)), the procedure outlined in Surface Decompression Table Using Oxygen (table 1–17) may be used in a routine manner. Follow the instructions accurately and take all precautions to insure that only pure oxygen is breathed. Maintain breathing equipment in perfect working condition to insure successful results from this table.

(6) In the event of oxygen toxicity symptoms, or failure of the oxygen supply, give decompression in accordance with table 1–18, disregarding time spent on oxygen.

(7) Table 1–17 has not been recomputed in accordance with the concepts established in the calculation of the Standard Air Decompression Tables. There are some discrepancies in limits of allowable exposures. However, this table is considered to be safe in its present form. Note that ascent at the rate of 25 feet per minute is required for the initial ascent when using this table.

Air following an air dive

(8) The Surface Decompression Table Using Air (table 1–18) may be used in any situation requiring surface decompression when breathing oxygen in a chamber is impossible. Since there is no saving of time over ordinary decompression methods, the comfort and security of the diver are the only advantages for the use of this surface decompression method.

(9) In self contained diving it may be impossible for the diver to carry sufficient air supply for the duration of the entire dive and standard decompression. When this is the case, the diver may (according to either table 1–17 or 1–18) surface, and receive the major part of his decompression in a recompression chamber. If no chamber is available, he may (according to table 1–18) take the "water stops" in the water, surface, obtain new air supply, and return in the water to the scheduled stop depths. However, providing surface-supplied air extra air cylinders for use at the decompression stop depth, with decompression according to standard tables, is a safer and more reasonable procedure.

(10) Table 1–18 requires repetition of one stop and increases the total decompression time required by the same schedule in the Standard Air Decompression Table by that amount. At the moment, there is no procedure outlined for surface decompression following a dive on the Standard Air Decompression Table for Exceptional Exposures.

(11) Ascend from the last water stop to the surface at the rate of 60 feet per minute. Maintain the time on the surface to the absolute minimum. Do not exceed the 3½ minute limit. Descend to the first chamber stop at the normal rate.

Oxygen following a nitrogen-oxygen dive

(12) Table 1–17 may be used in a routine manner for decompression from dives using nitrogen-oxygen mixtures as the breathing medium.

(13) After the "corresponding equivalent air depth" is determined in accordance with

1**	2**	3**				4**	5**	6**	7**
Depth in feet	Time	Time (min.) at water stops breathing air at					Time (min.) at 40' chamber stop oxygen		Approximate total decompression time (min.)
		60'	50'	40'	30'				
70	52	0	0	0	0	SURFACE INTERVAL NOT TO EXCEED 5 MINUTES	0	2 MINUTE ASCENT FROM 40 FEET IN CHAMBER TO SURFACE WHILE BREATHING OXYGEN	3
	90	0	0	0	0		15		24
	*120	0	0	0	0		23		32
	150	0	0	0	0		31		40
	180	0	0	0	0		39		48
80	40	0	0	0	0		0		3
	70	0	0	0	0		14		23
	85	0	0	0	0		20		29
	100	0	0	0	0		26		35
	*115	0	0	0	0		31		40
	130	0	0	0	0		37		46
	150	0	0	0	0		44		53
90	32	0	0	0	0		0		4
	60	0	0	0	0		14		24
	70	0	0	0	0		20		30
	80	0	0	0	0		25		35
	*90	0	0	0	0		30		40
	100	0	0	0	0		34		44
	110	0	0	0	0		39		49
	120	0	0	0	0		43		53
	130	0	0	0	0		48		58
100	26	0	0	0	0		0		4
	50	0	0	0	0		14		24
	60	0	0	0	0		20		30
	70	0	0	0	0		26		36
	*80	0	0	0	0		32		42
	90	0	0	0	0		38		48
	100	0	0	0	0		44		54
	110	0	0	0	0		49		59
	120	0	0	0	3		53		66
110	22	0	0	0	0		0		5
	40	0	0	0	0		12		23
	50	0	0	0	0		19		30
	60	0	0	0	0		26		37
	*70	0	0	0	0		33		44
	80	0	0	0	1		40		52
	90	0	0	0	2		46		59
	100	0	0	0	5		51		67
	110	0	0	0	12		54		77
120	18	0	0	0	0		0		5
	30	0	0	0	0		9		20
	40	0	0	0	0		16		27
	50	0	0	0	0		24		35
	*60	0	0	0	2		32		45

1**	2**	3**				4**	5**	6**	7**
Depth in feet	Time	Time (min.) at water stops breathing air at					Time (min.) at 40' chamber stop oxygen		Approximate total decompression time (min.)
		60'	50'	40'	30'				
120	70	0	0	0	4	SURFACE INTERVAL NOT TO EXCEED 5 MINUTES	39	2 MINUTE ASCENT FROM 40 FEET IN CHAMBER TO SURFACE WHILE BREATHING OXYGEN	54
	80	0	0	0	5		46		62
	90	0	0	3	7		51		72
	100	0	0	6	15		54		86
130	15	0	0	0	0		0		5
	30	0	0	0	0		12		23
	40	0	0	0	0		21		32
	50	0	0	0	3		29		43
	*60	0	0	0	5		37		53
	70	0	0	0	7		45		63
	80	0	0	6	7		51		76
	90	0	0	10	12		56		90
140	13	0	0	0	0		0		6
	25	0	0	0	0		11		23
	30	0	0	0	0		15		27
	35	0	0	0	0		20		32
	40	0	0	0	2		24		38
	45	0	0	0	4		29		45
	50	0	0	0	6		33		51
	*55	0	0	0	7		38		57
	60	0	0	0	8		43		63
	65	0	0	3	7		48		70
	70	0	2	7	7		51		80
150	11	0	0	0	0		0		6
	25	0	0	0	0		13		25
	30	0	0	0	0		18		30
	35	0	0	0	4		23		39
	40	0	0	3	6		27		49
	45	0	0	5	7		33		58
	*50	0	2	5	8		38		66
	55	2	5	9	4		44		78
160	9	0	0	0	0		0		7
	20	0	0	0	0		11		24
	25	0	0	0	0		16		29
	30	0	0	0	2		21		35
	35	0	0	4	6		26		49
	40	0	3	5	8		32		62
	*45	3	4	8	6		38		73
170	7	0	0	0	0		0		7
	20	0	0	0	0		13		26
	25	0	0	0	0		19		32
	30	0	0	3	5		23		44
	35	0	4	4	7		29		58
	*40	4	4	8	6		36		73

*These are the optimum exposure times for each depth which represent the best balance between length of work period, safety and amount of useful work for the average diver. Exposure beyond these times is permitted only under special conditions.

**Notes on columns.

Column 1. Depth–In feet, gage.

Column 2. Time–Interval from leaving the surface to leaving the bottom.

Column 3. Water stops–Time spent at tabulated stops using air. If no water stops are required use a 25 foot per minute rate of ascent to the surface. When water stops are required use a 25 foot per minute rate of ascent to first stop. Take an additional minute between stops. Use one minute for the ascent from 30 feet to the surface.

Column 4. Surface interval–The surface interval shall not exceed 5 minutes and is composed of the following elements:

(a) Time of ascent from the 30-foot water stop, or from 30 feet if no water stops are necessary, to the surface (1 minute).

(b) Time on surface for landing the diver on deck and undressing (not to exceed 3½ minutes).

(c) Time of descent in the recompression chamber from the surface to 40 feet (about ½ minute).

Column 5. During the period while breathing oxygen the chamber shall be ventilated.

Column 6. Surfacing–Oxygen breathing during this 2-minute period shall follow the period of oxygen breathing tabulated in Column 5 without interruption.

Column 7. Total decompression time–This includes

(a) Time of ascent from bottom to first stop, or to 30 feet if no water stop is required, at 25 feet per minute.

(b) Sum of tabulated water stops, column 2.

(c) One minute between water stops.

(d) Surface interval.

(e) Time at 40 feet in recompression chamber, column 4.

(f) Time of ascent, an additional 2 minutes, from 40 feet in the recompression chamber to the surface, column 5.

The Approximate Total Decompression Time may be shortened only by decreasing the time required to undress the diver on deck.

TABLE 1–17.—*Surface decompression table using oxygen.*

DEPTH (ft.)	BOTTOM TIME (Min.)	TIME TO FIRST STOP	TIME AT WATER STOPS			TIME ON SURFACE NOT TO EXCEED 3.5 MINUTES	CHAMBER STOPS (AIR)			TOTAL ASCENT TIME
			30	20	10		30	20	10	
40	230	0.5			3				7	10.5
	250	0.5			3				11	14.5
	270	0.5			3				15	18.5
	300	0.5			3				19	22.5
50	120	0.7			3				5	8.7
	140	0.7			3				10	13.7
	160	0.7			3				21	24.7
	180	0.7			3				29	32.7
	200	0.7			3				35	38.7
	220	0.7			3				40	43.7
	240	0.7			3				47	50.7
60	80	0.8			3				7	10.8
	100	0.8			3				14	17.8
	120	0.8			3				26	29.8
	140	0.8			3				39	42.8
	160	0.8			3				48	51.8
	180	0.8			3				56	59.8
	200	0.7		3				3	69	75.7
70	60	1.0			3				8	12.0
	70	1.0			3				14	18.0
	80	1.0			3				18	22.0
	90	1.0			3				23	27.0
	100	1.0			3				33	37.0
	110	0.8		3				3	41	47.8
	120	0.8		3				4	47	54.8
	130	0.8		3				6	52	61.8
	140	0.8		3				8	56	67.8
	150	0.8		3				9	61	73.8
	160	0.8		3				13	72	88.8
	170	0.8		3				19	79	101.8
80	50	1.2			3				10	14.2
	60	1.2			3				17	21.2
	70	1.2			3				23	27.2
	80	1.0		3				3	31	38.0
	90	1.0		3				7	39	50.0
	100	1.0		3				11	46	61.0
	110	1.0		3				13	53	70.0
	120	1.0		3				17	56	77.0
	130	1.0		3				19	63	86.0
	140	1.0		26				26	69	122.0
	150	1.0		32				32	77	142.0
90	40	1.3			3				7	11.3
	50	1.3			3				18	22.3
	60	1.3			3				25	29.3
	70	1.2		3				7	30	41.2
	80	1.2		13				13	40	67.2
	90	1.2		18				18	48	85.2
	100	1.2		21				21	54	97.2
	110	1.2		24				24	61	110.2
	120	1.2		32				32	68	133.2
	130	1.0	5	36				36	74	152.0
100	40	1.5			3				15	19.5
	50	1.3		3				3	24	31.3
	60	1.3		3				9	28	41.3
	70	1.3		3				17	39	60.3
	80	1.3		23				23	48	95.3
	90	1.2	3	23				23	57	107.2
	100	1.2	7	23				23	66	120.2
	110	1.2	10	34				34	72	151.2
	120	1.2	12	41				41	78	173.2
110	30	1.7			3				7	11.7
	40	1.5		3				3	21	28.5
	50	1.5		3				8	26	38.5
	60	1.5		18				18	36	73.5
	70	1.5	1	23				23	48	96.5
	80	1.3	7	23				23	57	111.3
	90	1.3	12	30				30	64	137.3
	100	1.3	15	37				37	72	162.3

DEPTH (ft.)	BOTTOM TIME (Min.)	TIME TO FIRST STOP	TIME AT WATER STOPS					TIME ON SURFACE NOT TO EXCEED 3.5 MINUTES	CHAMBER STOPS (AIR)			TOTAL ASCENT TIME
			50	40	30	20	10		30	20	10	
120	25	1.8					3				6	10.8
	30	1.8					3				14	18.8
	40	1.7				3				5	25	34.7
	50	1.7				15				15	31	62.7
	60	1.5			2	22				22	45	92.5
	70	1.5			9	23				23	55	111.5
	80	1.5			15	27				27	63	133.5
	90	1.5			19	37				37	74	168.5
	100	1.5			23	45				45	80	194.5
130	25	2.0					3				10	15.0
	30	1.8				3				3	18	25.8
	40	1.8				10				10	25	46.8
	50	1.7			3	21				21	37	83.7
	60	1.7			9	23				23	52	108.7
	70	1.7			16	24				24	61	126.7
	80	1.5		3	19	35				35	72	165.5
	90	1.5		8	19	45				45	80	198.5
140	20	2.2					3				6	11.2
	25	2.0				3				3	14	22.0
	30	2.0				5				5	21	33.0
	40	1.8			2	16				16	26	61.8
	50	1.8			6	24				24	44	99.8
	60	1.8			16	23				23	56	119.8
	70	1.7		4	19	32				32	68	156.7
	80	1.7		10	23	41				41	79	195.7
150	20	2.2				3				3	7	15.2
	25	2.2				4				4	17	27.2
	30	2.2				8				8	24	42.2
	40	2.0			5	19				19	33	78.0
	50	2.0			12	23				23	51	111.0
	60	1.8		3	19	26				26	62	137.8
	70	1.8		11	19	39				39	75	184.8
	80	1.7	1	17	19	50				50	84	222.7
160	20	2.3				3				3	11	19.3
	25	2.3				7				7	20	36.3
	30	2.2			2	11				11	25	51.2
	40	2.2			7	23				23	39	94.2
	50	2.0		2	16	23				23	55	121.0
	60	2.0		9	19	33				33	69	165.0
	70	1.8	1	17	22	44				44	80	209.8
170	15	2.5				3				3	5	13.5
	20	2.5				4				4	15	25.5
	25	2.3			2	7				7	23	41.3
	30	2.3			4	13				13	26	58.3
	40	2.2		1	10	23				23	45	104.2
	50	2.2		5	18	23				23	61	132.2
	60	2.0	2	15	22	37				37	74	187.0
	70	2.0	8	17	19	51				51	86	234.0
180	15	2.7				3				3	6	14.7
	20	2.5			1	5				5	17	30.5
	25	2.5			3	10				10	24	49.5
	30	2.5			6	17				17	27	69.5
	40	2.3		3	14	23				23	50	115.3
	50	2.2	2	9	19	30				30	65	155.2
	60	2.2	5	16	19	44				44	81	211.2
190	15	2.8				4				4	7	17.8
	20	2.7			2	6				6	20	36.7
	25	2.7			5	11				11	25	54.7
	30	2.5		1	8	19				19	32	81.5
	40	2.5		8	14	23				23	55	125.5
	50	2.3	4	13	22	33				33	72	179.3
	60	2.3	10	17	19	50				50	84	232.3

TABLE 1–18.—*Surface decompression table using air.*

the procedure outlined in article 3.6.8(17), use table 1–17 in the standard manner.

Air following a nitrogen-oxygen dive

(14) All of the previous statements relative to the use of air in surface decompression apply to mixed gas diving.

(15) A high oxygen percentage mixture of nitrogen-oxygen is more efficient than air as a breathing medium for surface decompression. Use it if available, but the same restrictions and precautions applicable to air apply to mixtures as well.

Oxygen following a helium-oxygen dive

(16) Recompression chambers equipped with oxygen are available at any helium-oxygen diving operation. Surface decompression may be used as a routine procedure, as described in the following paragraphs.

(17) In tables where the first stop is 40 feet, bring diver to 40 feet, shift to oxygen, and stay 10 minutes. Surface the diver in 1 minute and return him to 40 feet in the recompression chamber on oxygen for the full time of the 40-foot stop. Not more than 4 minutes should elapse from the time of leaving the water stop to reaching the chamber stop. During the last 5 minutes of decompression time, surface the diver at a uniform rate.

Example:

Partial pressure	100
Time of dive (minutes)	40
Time (minutes):	
Leave bottom	0
Reach 40	3
Ventilate 25 cubic feet of oxygen.	
Leave 40	13
Reach surface	14
Leave surface	16
Reach 40	16½
Leave 40	42½
Reach surface	47½

(18) In tables where the first stop is other than 40 feet, give decompression as listed until the diver reaches the 40-foot stop. Remain at 40 feet for a length of time equal to the 50-foot stop. Surface the diver in 1 minute and return him to 40 feet in the recompression chamber on oxygen for the full time of the 40-foot stop. Not more than 4 minutes should elapse from leaving the water stop to reaching the chamber stop. During the last 5 minutes of decompression time, surface the diver at a uniform rate.

Example:

Partial pressure	160
Time of dive (minutes)	40
Leave bottom	0
Reach 60	3
Leave 60	10
Reach 50	10½
Ventilate 25 cubic feet of oxygen.	
Leave 50	20
Reach 40	20½
Leave 40	30
Reach surface	31
Leave surface	32½
Reach 40	33
Leave 40	93
Reach surface	98

Air or helium-oxygen following a helium-oxygen dive

(19) The use of air or helium-oxygen mixtures during surface decompression from a helium-oxygen dive is strictly an emergency procedure. The instructions in article 1.5.4 on emergency shifts to air or helium-oxygen mixtures apply to surface decompression.

1.5.6 OMITTED DECOMPRESSION IN EMERGENCIES

(1) Certain emergencies may interrupt or prevent specified decompression. Blowup, complete loss of communication without a standby diver, exhausted air supply, bodily injury, and the like are among such emergencies. If there are symptoms of decompression sickness or air embolism, immediate treatment by recompression (see table 1–21) is essential. Even without evidence of any ill effects, omitted decompression must be made up in some manner to avert later difficulty.

Use of surface decompression tables

(2) It may *appear* that surface decompression schedules offer an immediate solution to this problem since they provide for a surface interval. Such schedules should *only* be used, however, *if the emergency surface interval occurs at such a time that "water stops" are not required or have already been completed* according to whichever surface decompression table is considered most appropriate.

Surface decompression tables not applicable

(3) When the conditions in paragraph (2) are *not* fulfilled, the diver's decompression has been compromised. Special care should be taken to detect signs of decompression sickness regardless of what action is initiated. The diver must be returned to pressure as soon as possible. Use of a recompression chamber, if available, is always preferable to water decompression.

When a recompression chamber is available

(4) Even if the diver shows no ill effects from his omitted decompression, he needs immediate recompression. Take him to 100 feet in the chamber and keep him at that depth for 30 minutes. If he is still all right after that time, bring him out according to TREATMENT TABLE 1 OR 1A. (See table 1–21.) Consider decompression sickness developing during or after this as a recurrence. (See table 1–22.)

When no chamber is available

(5) Recompress the diver in the water, following the procedure in paragraph (4) as nearly as possible. Keep the diver at rest, provide a standby diver, and maintain good communication and depth control.

(6) When the course of action outlined in paragraph (5) is impossible, use the following procedure which is based on the Standard Air Decompression Table:

(*a*) Repeat any stops deeper than 40 feet.

(*b*) At 40 feet, remain for 1/4 of the 10-foot stop time.

(*c*) At 30 feet, remain for 1/3 of the 10-foot stop time.

(*d*) At 20 feet, remain for 1/2 of the 10-foot stop time.

(*e*) At 10 feet, remain for 1 1/2 times the scheduled 10-foot stop time.

1.5.7 OXYGEN LIMITS

(1) Exposure to oxygen for 30 minutes at 60 feet is used as the routine oxygen tolerance test, and exposures of this depth and duration are used in treatment of decompression sickness. (See art. 1.6.2.) In decompression from helium-oxygen dives, oxygen is breathed as deep as 50 feet. *Such exposures are safe only if the diver is at rest.* (See art. 1.3.11, pars. 5–8.) This section concerns exposure limits for *working dives* in which oxygen is the breathing medium. The limits established to provide safety from oxygen poisoning anticipate exceptional operational requirements and emergencies as well as normal requirements.

(2) The system is three-phased. The first limit is based on normal, uncomplicated daily requirements. The second limit is considered sufficiently safe for exceptional operational requirements, and the third limit is a summary of experience at the higher oxygen tensions. It is actually a warning of the results to expect and to prepare for.

(3) These limits are applicable mainly to diving with pure oxygen. The depth limits for diving with nitrogen-oxygen and helium-oxygen mixtures are discussed in parts 2 and 3 and establish the oxygen limits during use of those mixtures.

(4) The potential results from oxygen poisoning at depth are so serious, and so many uncontrolled variables are present, that a relatively safe limit is necessary for normal operations. The importance of the amount of physical exertion and of excess carbon dioxide is explained in section 1.3.11 along with other physiological factors. Review all of that article before diving with a high partial pressure of oxygen.

Normal oxygen limit

(5) The normal limit is straightforward. When using oxygen as the breathing medium, DO NOT DIVE DEEPER THAN 25 FEET (Stay within the time limits in table 1–19)

Limits for exceptional operations ("important operation limit")

(6) Provided all other variables are optimum, tests indicate that short exposures at depths greater than 25 feet are safe. The diving officer may authorize use of the depth-time limits given in table 1–19 for depths greater than 25 feet when he has weighed his operational objectives against the increased hazards and has taken all precautions possible.

TABLE 1–19

OXYGEN DEPTH–TIME LIMITS

(Depth and time limits of exposure when breathing pure oxygen during working dives.)

1. NORMAL OXYGEN LIMITS

DO NOT DIVE DEEPER THAN 25 FEET

Observe these time limits:

Depth (feet)	Time (minutes)
10	240
15	150
20	110
25	75

2. LIMITS FOR EXCEPTIONAL OPERATIONS

Depth (feet)	Time (minutes)
30	45
35	25
40	10

3. EMERGENCY LIMITS

See article 1.5.7, paragraph (7), and figure 1–33.

Emergency limit

(7) Extraordinary situations, such as the requirement for an extremely important mission when oxygen is the only breathing medium that can be used, might dictate that an attempt be made to exceed the limits of table 1–19. These paragraphs present the odds for and against success.

(8) Figure 1–33 presents the results of experimental exposures to pure oxygen at various depths for various times. The proximity of possible warning symptoms and even convulsions to the Important Operation Limit Curve is apparent. Less apparent is the contrast between the perfect conditions that existed during these exposures and the conditions that would probably exist in the field. The experiments were conducted in a pressure tank. The work rates were moderate and uniform. The inspired gas was free of carbon dioxide. Two tenders were standing by each subject. It is likely that exposure to oxygen at these depths for the same times under operating conditions would produce a much larger proportion of unfavorable effects.

(9) The necessity to exceed the limits of table A in order to accomplish a mission must be brought to the attention of the officer assigning the mission who accepts the responsibility for the increased hazard to personnel.

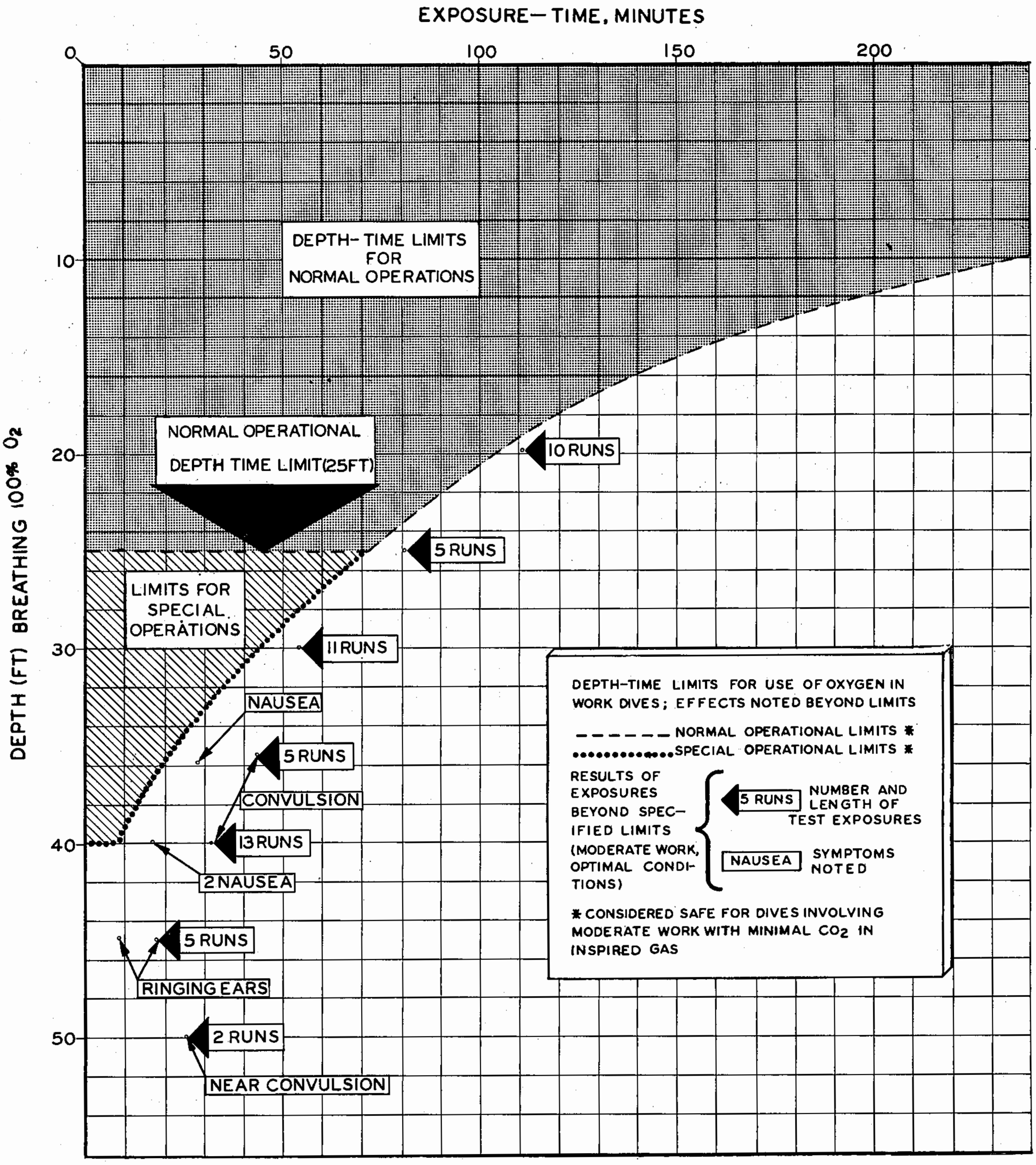


FIGURE 1–33.—Oxygen depth-time limits.

SECTION 1.6 DIVING HAZARDS

1.6.1 INTRODUCTION

General problem

(1) Diving confronts man with forces and physiological effects which are not encountered in his normal environment. These impose definite limits and can cause serious accidents. The diver's safety depends upon his knowledge of these factors and his ability to recognize and handle them.

Recognition and management of hazards

(2) The discussions on physics and physiology (see sections 1.2 and 1.3) have made you aware of most of the potential hazards of diving. The purpose of this chapter is to give you knowledge which will help you to avoid hazards when you can, to cope with hazards which cannot be avoided, and to recognize and treat accidents when they occur. It permits you to evaluate factors of environment, of specific equipment, and of your own condition in relation to each job. *Ignorance is the diver's worst enemy.* Many potential dangers can almost completely be avoided if they are recognized. To cite just one example, many dead amateur divers would be alive today if they had known that holding their breath on ascent would cause air embolism. Even after such an accident had occurred, many of these lives could have been saved if anyone nearby had recognized the condition and had been able to provide proper treatment.

(3) You will meet with many unavoidable hazards, but awareness and understanding will permit you to face them with a minimum of risk. Under combat conditions, some of these hazards are likely to be increased and diving must be performed under conditions which would be otherwise unacceptable.

(4) When a dangerous condition is developing in yourself, your buddy, or the man you are tending or supervising, active *awareness* promotes early recognition of danger and prompts you to take immediate corrective action. As a diver, you must know the *causes*, *symptoms*, and *signs* of diving accidents so that proper actions or treatment can be commenced without delay.

(5) In the following discussions of accidents, the words *symptom* and *sign* will be used frequently. This explanation is given to clarify their meanings as used in this manual: *Symptom* refers to those sensations experienced by the diver. *Sign* refers to those changes which can be observed by another person. A symptom can also be a sign. For example, a diver may complain of inability to move his leg. This is a symptom. The observer would see limping or the inability to lift that leg. These are signs. Pain is purely a symptom since the observer cannot feel or see it. He may see evidence of it, such as wincing or grimacing, but the observer cannot determine the existence of a symptom like pain other than by what the patient reports. This differentiation of signs and symptoms adds to the awareness of the diver. This becomes particularly important in the use of scuba where the individual and his buddy must protect not only themselves but each other. The diver must be able to recognize *symptoms* in himself and also be able to recognize *signs* of early stages of accidents in his buddy so that early corrective action may be taken.

(6) When a hazard is encountered or an accident occurs, you must take all possible action to prevent further development of the condition. You must know the proper treatment of a condition which has already developed. In order to accomplish treatment, you must be familiar with the proper operation of specialized equipment like recompression chambers and resuscitators. In addition, knowledge of manual artificial respiration methods and of the principles of first aid must be a part of your ability to cope with diving accidents. You must know how to transport casualties properly, taking into consideration problems of pressure and good first aid technique.

(7) Articles 1.6.2. to 1.6.20 are discussions of various hazards and accidents. General material on treatment, equipment needed for

treatment, and the problem of transporting casualties is provided in article 1.6.21.

1.6.2 DECOMPRESSION SICKNESS

(1) Decompression sickness is the result of formation of gas bubbles in the blood or tissues. Depending on their number, size, and location, these bubbles may cause a wide variety of symptoms including pain, paralysis, unconsciousness, and possibly death. Decompression sickness can occur only when decompression (a reduction in the pressure surrounding the body) has taken place—as when a diver comes up from depth or when an aviator goes up to high altitude. It will not occur unless there is an excessive amount of inert gas dissolved in the blood or tissues at the time. (See art. 1.3.9.) NOTE.—Other terms applied to decompression sickness include the bends, compressed-air illness, and caisson disease. Aviators' bends are sometimes called aero-embolism; do not confuse this with *air embolism*—a different condition.

(2) When a diver speaks of *decompression*, he means not only the reduction of pressure that takes place on ascent but also the systematic procedure used to eliminate the excess of dissolved gas safely (making decompression stops on ascent according to the decompression table).

Cause

(3) Decompression sickness is caused by *inadequate decompression* following a dive, but this does not necessarily mean that the decompression table has not been followed properly. An excessive amount of gas in the tissues can result from any condition (in the man or in the surroundings) that causes an unexpectedly large amount of inert gas to be taken up at depth or that results in abnormally slow elimination of gas during the decompression procedure. In such situations, following the table to the letter would not always assure adequate decompression. However, the decompression tables are designed to cover all but exceptional cases of this sort, so the actual risk of decompression sickness is small if the right table is properly employed.

Prevention

(4) The prevention of decompression sickness is best accomplished by the observing of these rules:

(*a*) *Careful selection of personnel.*—For example, old injuries or diseases which result in poor circulation would be cause for rejection.

(*b*) *Observation and evaluation of each man before he makes any dive.*—Alcohol intoxication or "hangover," excessive fatigue, or a general rundown condition should be sufficient cause to restrict a man from diving. It is the duty of the diving officer and the diving supervisor to keep any man from diving on a day when his physical condition is not satisfactory. If any doubt exists as to the diver's physical fitness, the medical officer's recommendation will normally be the deciding factor. Divers have a responsibility for keeping themselves fit to the best of their ability.

(*c*) *Careful attention to the details of the dive.*—Accurate determination of the depth and time of the dive and of the decompression time must be made. (See art. 1.4.7, par. 15.) All data concerning these details must be accurately and completely recorded and kept readily available. They are important in the diagnosis and treatment of decompression sickness.

(*d*) *Strict observance of the decompression tables, with due consideration of modifying factors.*—Follow the tables at all times unless there is reason to question the accuracy of depth or time. In this event, decompress the diver for a dive of greater depth or longer duration. When in doubt, always act in the diver's favor by adding to decompression. Never shorten a decompression table merely for convenience.

(*e*) *Report all symptoms or signs immediately to the medical or diving officer.*—Serious cases of decompression sickness often begin with a slight itch or pain. When men fail to report early symptoms, their chance of suffering permanent damage is greatly increased, and their treatment is likely to be much more prolonged.

Diagnosis

(5) Diagnosis of decompression sickness depends upon the evaluation of the history of the dive, the symptoms and signs of the patient, and your ability to do a simple physical examination.

History

(6) A man cannot have decompression sickness unless he has been diving; and if the dive was as much as 24 hours before symptoms appeared, it is not at all likely that decompression sickness accounts for the symptoms. The fact that a dive was of short duration, at a relatively shallow depth, or that the decompression table was followed does not necessarily rule out the possibility of decompression sickness. As a general rule, however, as the depth, time, and severity of work increase, the frequency of decompression sickness increases also. The likelihood increases very much when a diver does not receive proper decompression.

Symptoms and signs

(7) Decompression sickness usually causes symptoms within a short period of time following a dive. If a diver comes to the surface quickly without stops when they are required, or if he makes stops of greatly insuffficient duration, he may be suffering from decompression sickness when he reaches the surface. Most cases develop after a short period of time on the surface and almost always before 12 hours. A review of data concerning onset of symptoms following decompression revealed that:

50 percent occurred within 30 minutes
85 percent occurred within 1 hour
95 percent occurred within 3 hours
1 percent delayed over 6 hours.

(8) Various symptoms of decompression sickness have been found to occur with the following frequency:

	Percent
Local pain	89
Leg	70
Arm	30
Dizziness (the "staggers")	5.3
Paralysis	2.3
Shortness of breath (the "chokes")	1.6
Extreme fatigue and pain	1.3
Collapse with unconsciousness	0.5

(9) Occasionally, the skin may show a blotchy and mottled rash. There may be small red spots which vary in size from a pinhead to the size of a dime. Sometimes mottling is so pronounced that the skin takes on an appearance like pink marble, and the term "marbling" is applied.

(10) A typical case of decompression sickness may begin with itching or burning of a localized area of the body. This may spread and then finally become localized again. There may be a feeling of tingling or numbness of the skin. In rare cases, the man may have a sensation of ants crawling all over him.

(11) Pain, which is the most frequent and predominating symptom, is of a deep and boring character. Divers describe it as being felt in the bone or in the joint. Usually the pain is slight when first noticed and then becomes progressively worse until it is unbearable. The pain usually is not affected by motion of the area, but it may be temporarily relieved by vigorous rubbing or hot applications. The most frequently confused situation is when a diver suffers a muscle strain or a joint sprain during a dive. However, this can usually be distinguished by the fact that strains and sprains are painful to touch and motion while pain in a joint from decompression sickness is generally not. Swelling and discoloration usually occur with a sprain but are rare in uncomplicated cases of decompression sickness. A diver who has pain that might be a symptom of decompression deserves treatment by recompression even though it may turn out to have been a strain or sprain. WHEN IN DOUBT, TREAT BY RECOMPRESSION. Failure to treat doubtful cases is the most frequent cause of lasting injury.

(12) When dizziness occurs, the diver feels that the world is revolving around him and that he is falling to one side. Frequently, he will have ringing in the ears at the same time that dizziness occurs. History and physical examination become important when these symptoms occur because they also can follow middle ear damage, as from squeeze. (See art. 1.6.8(2).)

(13) Serious symptoms are those caused by bubbles in the brain, spinal cord, or lungs.

These require longer treatment (see table 1–20 and 1–21) than the "pain only" type; and it is very important not to overlook them when they are present. Many of the serious symptoms are so clean-cut that the diver is certain to notice and report the symptoms, or the signs are so obvious that his tenders could not miss them. However, it is quite possible to miss some of the less obvious signs and symptoms or to fail to recognize the milder disorders like simple weakness, partial paralysis, or a defect in vision. Do not let a serious case be treated inadequately just because no one bothered to check! For example, every now and then a diver who complains only of pain in an arm or a leg will also be found to have weakness or partial paralysis when he is examined thoroughly. It is also important to know *all* that is wrong with the patient so that you can be sure when he is really relieved of all his symptoms during treatment.

(14) If a medical officer is present, it is his responsibility to examine the man. (See fig. 1–34.) If there is no medical officer, this becomes the responsibility of the corpsman, diving officer, or diving supervisor.

(*a*) If the diver reports only pain and is not suffering severely, examine him thoroughly at the surface.

(*b*) If it is clear that serious symptoms are present, do not take time for complete examination at the surface. You know the man needs treatment on TABLE 3 or TABLE 4 (see table 1–20 and 1–21), and the best procedure

TABLE 1–20

TREATMENT OF AN UNCONSCIOUS DIVER

(*Loss of consciousness during or within 24 hours after a dive. See art. 1.6.4*)

1. IF NOT BREATHING, *start manual artificial respiration at once.* (See tables 1–23, 1–24, and 1–25.)

2. RECOMPRESS PROMPTLY. (See note (d).)

3. Examine for injuries and other abnormalities; apply first aid and other measures as required. (Secure the help of a medical officer as soon as possible.)

NOTES

Artificial respiration

(*a*) Shift to a mechanical resuscitator if one is available and working properly, but never wait for it. Always start a manual method first.

(*b*) Continue artificial respiration by some method without interruption until normal breathing resumes or victim is pronounced dead. Continue on way to chamber and during recompression. (Do not use oxygen deeper than 60 feet in chamber.)

Recompression

(*c*) Remember that an unconscious diver may have air embolism or serious decompression sickness even though some other accident *seems* to explain his condition.

(*d*) Recompress unless—

(1) Victim regains consciousness and is free of nervous system symptoms before recompression can be started.

(2) Possibility of air embolism or decompression sickness can be ruled out without question.

(3) Another lifesaving measure is absolutely required and makes recompression impossible.

(*e*) Try to reach a recompression chamber no matter how far it is.

(*f*) Treat according to treatment TABLE 3 or 4 (see table 1–21), depending on response. Remember that early recovery under pressure never rules out the need for adequate treatment.

Table 1-21. Treatment of Decompression Sickness and Air Embolism.

<table>
<tr><th>Stops</th><th colspan="2">Bends—Pain only</th><th colspan="2">Serious Symptoms</th></tr>
<tr><td rowspan="2">Rate of descent—25 ft. per min.
Rate of ascent—1 minute between stops.</td><td rowspan="2">Pain relieved at depths less than 66 ft.
Use table 1—A if O_2 is not available.</td><td rowspan="2">Pain relieved at depths greater than 66 ft.
Use table 2—A if O_2 is not available.
If pain does not improve within 30 min. at 165 ft. the case is probably not bends. Decompress on table 2 or 2—A.</td><td colspan="2">Serious symptoms include any one of the following:
1. Unconsciousness.
2. Convulsions.
3. Weakness or inability to use arms or legs.
4. Air embolism.
5. Any visual disturbances.
6. Dizziness.
7. Loss of speech or hearing.
8. Severe shortness of breath or chokes.
9. Bends occurring while still under pressure.</td></tr>
<tr><td>Symptoms relieved within 30 minutes at 165 ft.
Use table 3</td><td>Symptoms not relieved within 30 minutes at 165 ft.
Use table 4</td></tr>
</table>

<table>
<tr><th>Pounds</th><th>Feet</th><th>Table 1</th><th>Table 1-A</th><th>Table 2</th><th>Table 2-A</th><th>Table 3</th><th>Table 4</th></tr>
<tr><td>73.4</td><td>165</td><td>----------</td><td>----------</td><td>30 (air)</td><td>30 (air)</td><td>30 (air)</td><td>30 to 120 (air)</td></tr>
<tr><td>62.3</td><td>140</td><td>----------</td><td>----------</td><td>12 (air)</td><td>12 (air)</td><td>12 (air)</td><td>30 (air)</td></tr>
<tr><td>53.4</td><td>120</td><td>----------</td><td>----------</td><td>12 (air)</td><td>12 (air)</td><td>12 (air)</td><td>30 (air)</td></tr>
<tr><td>44.5</td><td>100</td><td>30 (air)</td><td>30 (air)</td><td>12 (air)</td><td>12 (air)</td><td>12 (air)</td><td>30 (air)</td></tr>
<tr><td>35.6</td><td>80</td><td>12 (air)</td><td>12 (air)</td><td>12 (air)</td><td>12 (air)</td><td>12 (air)</td><td>30 (air)</td></tr>
<tr><td>26.7</td><td>60</td><td>30 (O_2)</td><td>30 (air)</td><td>30 (O_2)</td><td>30 (air)</td><td>30 (O_2) or (air)</td><td>6 hrs. (air)</td></tr>
<tr><td>22.3</td><td>50</td><td>30 (O_2)</td><td>30 (air)</td><td>30 (O_2)</td><td>30 (air)</td><td>30 (O_2) or (air)</td><td>6 hrs. (air)</td></tr>
<tr><td>17.8</td><td>40</td><td>30 (O_2)</td><td>30 (air)</td><td>30 (O_2)</td><td>30 (air)</td><td>30 (O_2) or (air)</td><td>6 hrs. (air)</td></tr>
<tr><td>13.4</td><td>30</td><td rowspan="4">5 (O_2) ↓</td><td>60 (air)</td><td>60 (O_2)</td><td>2 hrs. (air)</td><td>12 hrs. (air)</td><td>First 11 hrs. (air) Then 1 hr. (O_2) or (air)</td></tr>
<tr><td>8.9</td><td>20</td><td>60 (air)</td><td rowspan="3">5 (O_2) ↓</td><td>2 hrs. (air)</td><td>2 hrs. (air)</td><td>First 1 hr. (air) Then 1 hr. (O_2) or (air)</td></tr>
<tr><td>4.5</td><td>10</td><td>2 hrs. (air)</td><td>4 hrs. (air)</td><td>2 hrs. (air)</td><td>First 1 hr. (air) Then 1 hr. (O_2) or (air)</td></tr>
<tr><td colspan="2">Surface</td><td>1 min. (air)</td><td>1 min. (air)</td><td>1 min. (air)</td><td>1 min. (O_2)</td></tr>
</table>

Time at all stops in minutes unless otherwise indicated.

557535 O - 60 - 10

FIGURE 1–34.—Medical officer examining diver in recompression chamber. It is extremely important to detect any abnormal sign or symptom a diver may have as a result of decompression sickness. Abnormalities that indicate bubbles in nervous system call for treatment shown in table 3 or table 4.

is to take him to 165 feet in the chamber without delay. Once that depth is reached, go ahead with the best examination you know how to perform. (See fig. 1–34.)

(15) These are the most important things to check when examining a man prior to treatment or when trying to determine whether all symptoms have been relieved:

(*a*) **How does he feel–** (Ask him).

FIGURE 1–35.—Diver breathing oxygen during treatment of decompression sickness. Use of oxygen hastens elimination of nitrogen and greatly shortens treatment. Since there is a slight chance that patient may develop oxygen poisoning, he must be tended carefully while breathing oxygen.

1. Pain—where and how severe? Changed by motion? Sore to touch or pressure? Bruise marks in the area?
2. Mentally clear?
3. Weakness, numbness, or peculiar sensations anywhere?
4. Can he see and hear clearly?
5. Can he walk, talk, and use his hands normally?
6. Any dizziness?

(*b*) **Does he look and act normal?** (Don't just take his word for it if he says that he is all right.)

1. Can he walk normally? Any limping or staggering?
2. Is his speech clear and sensible?
3. Is he clumsy or seem to be having difficulty with any act of movement?
4. Can he keep his balance when standing with his eyes closed?

(*c*) **Does he have normal strength?** (Check his strength against your own and compare his right side with his left.)

1. Normal handgrip?
2. Able to push and pull strongly with both arms and legs?
3. Able to do deep knee bends and other exercises?

(*d*) **Are his sensations normal?**

1. Can he hear clearly?
2. Can he see clearly both close (reading) and distant objects? Normal vision in all directions?
3. Can he feel pin pricks and light touches with a wisp of cotton all over his body? (Note that some areas are normally less sensitive than others—compare with yourself if in doubt.)

(*e*) **Look at his eyes:**

1. Are the pupils normal size and equal?
2. Do they close down when you shine a light in his eyes?
3. Can he follow an object around normally with his eyes?

(*f*) **Check his reflexes** if you know how

(16) Note that it should not take a great deal of time to examine a man reasonably well. Especially when you are under pressure in the chamber, there is seldom time to waste; but

do not shortchange the patient. If there is real need for haste, having him walk and do a few exercises will usually show (or call to his attention) the more serious defects.

(17) In all cases where there is any doubt, treat the diver as though he is suffering from decompression sickness. If you are not sure that he is completely free from *serious* symptoms, use the longer table. Remember that time and air are much cheaper than joints and brain tissue.

1.6.3 AIR EMBOLISM AND RELATED ACCIDENTS (See also art. 1.3.8.)

Definitions

(1) *Air embolism* refers to the plugging of a blood vessel by a bubble of air (or whatever the diver has been breathing) that entered the circulatory system directly from the lungs. It is similar to a vapor lock in a gasoline line. When this condition occurs in a diver, arteries in the brain are usually affected. Since the brain cannot function without a constant flow of blood, the consequences are rapid in onset and extremely serious in effect.

(2) *Emphysema* refers to a swelling or inflation due to abnormal presence of air in the tissues. *Subcutaneous emphysema* is the presence of air in the tissues just under the skin. When seen in diving, it usually involves the skin of the neck and nearby areas. *Mediastinal emphysema* is the presence of air in the tissues in the vicinity of the heart and large blood vessels in the middle of the chest. Unless extreme, neither of these conditions is likely to cause serious difficulty. If emphysema is extreme, air embolism will usually be present also.

(3) *Pneumothorax* indicates presence of air between the lungs and the chest wall. When air enters this space, the lung on the affected side collapses. This results in varying degrees of difficulty in breathing depending on the volume of air and the extent of resulting collapse. If pressure builds up in the space, severe difficulty in breathing and interference with the circulation can follow.

Cause

(4) In diving, the same basic process produces air embolism and the related conditions: excessive pressure in the lungs sufficient to produce leakage of air. In diving, this comes about because of the expansion of air retained in the lungs during ascent. For example, if a man holds his breath on ascent, the lung air will expand as the surrounding pressure decreases (Boyle's Law. See art. 1.2.4, par. (15).) If it expands enough to fill the lungs completely, and the man still continues to hold his breath, the pressure in the lungs will become higher than that in the rest of the body. The lungs will be overexpanded, and at some point they will start to leak air—either into the blood vessels that go through the lungs or into the surrounding tissues or both. Actual tears in the lung tissue usually occur in the process of overexpansion. If air enters the mediastinum in sufficient amounts and under enough pressure, it will make its way up toward the neck and appear under the skin as subcutaneous emphysema.

(5) Trapping of air in the lungs may result from several causes. The most common, in diving, is the voluntary holding of breath. Among amateur divers this is usually the result of a lack of understanding of the physics and physiology of diving. Breath holding may also come about as the result of panic. When panic occurs it is instinctive to hold your breath. Diseases of the lungs may produce pockets of air, which do not empty on ascent, or cause restriction of flow of air from areas of the lungs. The disease may be of recent origin, such as pneumonia, or it may be one which occurred earlier in life and caused permanent changes such as scarring.

(6) Pressure changes in extremely shallow depths may be sufficient to cause air embolism. Cases have occurred in depths as shallow as 12 feet. In theory, it can occur in even shallower depths. Air embolism and its related conditions most frequently occur in what is usually termed shallow water diving. It has also become a problem of primary importance in the use of self-contained breathing apparatus.

Prevention

(7) Air embolism and its related conditions are best prevented by observing the following procedures or rules:

(*a*) *Careful selection of personnel.*—As in the prevention of decompression sickness, careful evaluation of each candidate must be done. Those men who show evidence of old lung disease or have a past history of asthma must be carefully evaluated by the medical officer.

(*b*) *Careful observation and evaluation of each man before he makes any dive.*—Any evidence of acute lung conditions must be reported by each diver to the medical officer. Colds, bronchitis, coughing, pain in the chest, or the like should be reported and then carefully evaluated by the medical officer prior to making a dive.

(*c*) *Proper, intensive training of every diver in the physics and physiology involved in diving.*—Every diver should be familiar with the sections of this manual concerning physics, physiology, and diving accidents. Many cases of air embolism have occurred, especially among civilians, simply because Boyle's Law and its application to diving had never been explained.

(*d*) *Proper, intensive training of every diver in the use of any diving equipment which he may be required to use.*—This is especially important concerning the use of scuba. Training and proper indoctrination give the individual confidence which is so important during times of danger so that intelligent action will be taken and panic will not result.

(*e*) *Never hold your breath during ascent from a dive in which a breathing apparatus was used and is being used while making the ascent.*—Breathe regularly during ascent. (A skin diver who is not using a breathing apparatus cannot develop air embolism simply because the volume of air in his lungs can never exceed that volume which he was able to hold while breathing at the surface.)

(*f*) *Exhale continuously while making an ascent from a dive in which air supply failed.*—When air supply fails or runs out, an emergency ascent becomes necessary. The ideal method for making an emergency ascent is accomplished by floating to the surface by means of natural buoyancy or assisted buoyancy from a lifejacket. While ascending with no lifejacket, air is exhaled continuously at such a rate that buoyancy is maintained, but the exhalation is sufficient to prevent overexpansion of the lungs. Free ascent, as this procedure is termed, is difficult for the untrained individual and must never be taught at facilities which do not have the proper equipment and personnel to provide adequate supervision of ascents and treatment of accidents that may result. *The immediate presence of a recompression chamber is absolutely necessary to carry out any free ascent training or buoyant ascent training.* Ascent assisted by an external source of buoyancy (now termed *buoyant ascent*) requires a slightly different technique. A fully inflated lifejacket will cause a much more rapid ascent through the water. The rate of ascent may be as much as 400 feet per minute. With this method, exhalation should start before ascent begins and must be rapid and continuous in order to prevent overexpansion of the lungs. (It is not within the scope of this manual to give the details of these ascent methods, and it is not feasible to attempt to teach such methods without actual training in the water under proper conditions.)

Diagnosis

(8) Air embolism is an extreme emergency. When it is present, the victim may die or suffer permanent brain damage unless he receives proper treatment (recompression) very promptly. **If a diver who has had any source of air (or other breathing medium) at depth surfaces unconscious or loses consciousness shortly after surfacing, you must assume that he has air embolism and act accordingly at once.** If the diver regains consciousness *before* recompression, and shows no sign of brain injury, then this rules out air embolism; but you must never wait hoping that this will happen. (The conditions related to air embolism, if they appear in the absence of air embolism, are seldom acute emergencies.)

History

(9) In order to develop air embolism or any of the related conditions there must have been an ascent from a depth greater than a few feet after using any source of air under pressure. This need not be compressed air in the way we usually think of it. A case occurred in a small boy who had taken an ordinary bucket down in the water to a depth of 11 feet. He breathed in the bucket until the air became foul. After this, he surfaced holding his breath. He was pronounced dead several hours later as the result of air embolism.

(10) The arteries of the brain are almost always involved immediately; and since the brain is extremely sensitive to reduced circulation of blood, there is rarely a delay of more than a minute or so before the development of signs and symptoms. Certainly, any symptoms other than unconsciousness developing more than 5 minutes following the ascent should *not* be considered air embolism. Other possible causes should be investigated.

Symptoms

(11) Symptoms developing from *air embolism* are dramatic and sudden in onset. In the usual case they will occur within seconds of the time of surfacing. In a case in which the leakage of air from lung tissue took place at a relatively deep depth, the symptoms may have started long before reaching the surface. Many cases will occur without the development of any symptoms prior to unconsciousness.

(12) Symptoms, if they do develop prior to unconsciousness, are primarily those of involvement of the brain. For example, the diver will experience weakness, dizziness, paralysis or weakness of extremities, visual disturbances such as blurring, all of which indicate involvement of the brain. Any symptoms that develop will then rapidly become more severe and be joined by others until unconsciousness occurs, usually within a matter of seconds.

(13) The diver may or may not have experienced discomfort or pain in the chest prior to or during the rupture of the lungs. Sometimes a victim will report that he felt a blow to the chest.

(14) When actual tearing of lung tissue has taken place, the victim of an embolism will often have bloody froth at the mouth. When this is seen in a diver who loses consciousness on or before surfacing, it is a strong indication of air embolism. However, it is by no means always seen when this accident has occurred. Never assume that an unconscious diver *does not* have air embolism simply because there is no bloody froth. (On the other hand, bloody froth can also appear after a lung squeeze; and blood from an ear or sinus squeeze or a bitten tongue can sometimes be mistaken for bloody froth.)

(15) The symptoms of *mediastinal emphysema* are pain under the breast bone and in extreme cases, shortness of breath or faintness due to interference with circulation as the result of direct pressure on the heart and large blood vessels.

(16) Unless it is extreme, there are no symptoms with *subcutaneous emphysema* except perhaps a feeling of fullness in the neck and a change in the sound of the voice.

(17) The symptoms of *pneumothorax* are:

(*a*) Sharp pain in the chest usually made worse by deep breathing.

(*b*) Shortness of breath.

Signs

(18) The signs which may be observed in a diver suffering from *air embolism* are, from less serious to more serious:

(*a*) Bloody frothy sputum.
(*b*) Staggering.
(*c*) Evidence of confusion or difficulty in seeing (for example, moving in the wrong direction or bumping into objects.)
(*d*) Paralysis or weakness of extremities.
(*e*) Collapse.
(*f*) Unconsciousness.
(*g*) Convulsions.
(*h*) Cessation of breathing.

(Note that onset may be so sudden that none but the more serious signs can be seen.)

(19) With *mediastinal emphysema* the following signs may be seen:

TABLE 1–22

NOTES ON RECOMPRESSION

Explanation: All references to TABLES *indicate parts of table 1–21 "Treatment of Decompression Sickness and Air Embolism."*

1. *General Considerations*
   a. Follow TREATMENT TABLES (table 1–21) accurately.
   b. Permit no shortening or other alteration of tables except on advice of trained *diving medical officer* or in extreme emergency.

2. *Rate of Descent in Chamber*
   a. Normal rate is 25 feet per minute.
   b. Serious symptoms: rapid descent is desirable.
   c. If pain increases on descent: stop, resume at a rate tolerated by patient.

3. *Treatment Depth*
   a. Go to full depth indicated by table required.
   b. Do not go beyond 165 feet except on decision of medical officer.

4. *Examination of Patient* (see article 1.6.2(14))
   a. If no serious symptoms are evident and pain is not severe, examine thoroughly before treatment.
   b. If any serious symptom is noted, do not delay descent for examination or for determining depth of relief.
   c. In "pain only" cases where relief is reported before reaching 66 feet, make sure it is complete before deciding on TABLE 1.
   d. On reaching maximum depth of treatment, examine as completely as possible to detect
      1) Incomplete relief
      2) Any symptoms overlooked
      NOTE.—At the very least, have patient stand and walk length of chamber.
   e. Recheck before leaving bottom.
   f. Ask patient how he feels before and after coming to each stop and periodically during long stops.
   g. Do not let patient sleep through changes of depth or for more than an hour at a time at any stop. (Symptoms can develop or recur during sleep.)
   h. Recheck patient before leaving last stop.

5. *Patient Getting Worse*
   a. Never continue bringing a patient up if his condition is worsening.
   b. Treat as a *recurrence during treatment* (see 6).
   c. Consider use of helium-oxygen as breathing medium for patient (see 8).

6. *Recurrence of Symptoms*
   a. *During* treatment:
      1) Take patient to depth of relief (but never to less than 30 feet; and not deeper than 165 feet except on decision of medical officer).
      (If recurrence involves serious symptom not previously present, take patient to 165 feet.)

MOST FREQUENT ERRORS RELATED TO TREATMENT

1. Diver's failure to report symptoms early.
2. Failure to treat doubtful cases.
3. Failure to treat promptly.
4. Failure to recognize serious symptoms.
5. Failure to treat adequately.
6. Failure to keep patient near chamber after treatment.

6. *Recurrence of Symptoms*—Continued
   a. *During* treatment—Continued
      2) Complete the treatment according to TABLE 4.
   b. *Following* treatment:
      1) Recompress to depth giving relief.
      2) If depth of relief is less than 30 feet,
         a) Take to 30 feet.
         b) Decompress from 30-foot stop according to TABLE 3.
      3) If relief occurs deeper than 30 feet,
         a) Keep patient at depth of relief for 30 minutes.
         b) Complete remaining stops of TABLE 3.
         NOTE.—If original treatment was on TABLE 3, use TABLE 4.
      4) Examine carefully to be sure no serious symptom is present. If the original treatment was on TABLE 1 or TABLE 2, appearance of a serious symptom requires full treatment on TABLE 3 or TABLE 4.

ALWAYS KEEP DIVER CLOSE TO CHAMBER FOR AT LEAST 6 HOURS AFTER TREATMENT. (Keep him for 24 hours unless very prompt return can be assured.)

7. *Use of Oxygen*
   a. Use oxygen wherever permitted by tables unless
      1) Patient has not had oxygen tolerance test, or
      2) Is known to tolerate oxygen poorly.
   b. Be sure mask fits snugly.
   c. Take all precautions against fire (see table 1–29).
   d. Tend carefully, being alert for symptoms of oxygen poisoning such as
      1) Twitching 3) Nausea
      2) Dizziness 4) Blurring of vision
   e. Know what to do in event of convulsion. Have mouth-bit available.
   f. If symptoms appear, remove mask at once.
   g. If oxygen breathing must be interrupted—
      1) On TABLE 1, proceed on TABLE 1–A.
      2) On TABLE 2, proceed on TABLE 2–A.
      3) On TABLE 3, continue on TABLE 3 using air.
   h. At medical officer's discretion, oxygen breathing may be resumed at 40-foot stop. If this is done, complete treatment as follows:
      1) Resuming from TABLE 1–A: breathe oxygen:
         at 40 feet for 30 minutes
         at 30 feet for 1 hour
      2) Resuming from TABLE 2–A: breathe oxygen:
         at 40 feet for 30 minutes
         at 30 feet for 2 hours
      3) In both cases, then surface in 5 minutes still breathing oxygen.
      4) Resuming from TABLE 3: breathe oxygen:
         at 40 feet for 30 minutes
         at 30 feet for first hour
         (then finish treatment with air)

TABLE 1–22.—Continued

NOTES ON RECOMPRESSION

Explanation: All references to TABLES *indicate parts of table 1–21 "Treatment of Decompression Sickness and Air Embolism."*—Continued

8. *Use of Helium-Oxygen*
   a. Helium-oxygen mixtures (ratio about 80:20) can be used *instead of air* (not in place of oxygen) in all types of treatment and at any depth.
   b. Use of helium-oxygen is especially desirable in any patient who
      1) Has serious symptoms that fail to clear within a short time at 165 feet.
      2) Has recurrence or otherwise becomes worse at any stage of treatment.
      3) Has any difficulty in breathing.

9. *Tenders*
   a. A qualified tender must be in chamber
      1) If patient has had any serious symptom.
      2) Whenever patient is breathing oxygen.
      3) When patient needs unusual observation or care for any reason.
   b. Tender must be alert for any change in patient, especially during oxygen breathing. (See 7, d–f.)
   c. *Tender must breathe oxygen* if he has been with patient throughout TABLE 1 or TABLE 2
      TABLE 1: Breathe oxygen—
      at 40 feet for 30 minutes
      TABLE 2: Breathe oxygen—
      at 30 feet for 1 hour
   d. Tender in chamber only through oxygen breathing part of TABLE 1 or 2 gains safety-factor by breathing oxygen for 30 minutes of last stop, but this is not essential. Tender may breathe oxygen during use of TABLE 3 or 4 at 40 feet or less.
   e. Anyone entering chamber and leaving before completion of treatment must be decompressed according to standard diving tables.
   f. Personnel outside must specify and control decompression of anyone leaving chamber and must review all decisions concerning treatment or decompression made by personnel (including medical officer) inside chamber.

10. *Ventilation of Chamber*
    (See art. 1.6.21, par. 18)
    Rule 1. Volume of air required (volume as measured at chamber pressure—applies at any depth):
    a. Basic requirement:
       1) Allow 2 cubic feet per minute per man.
       2) *Add* 2 cubic feet per minute for each man *not at rest* (as tender actively taking care of patient).
    b. When using oxygen:
       Allow 4 cubic feet of air *per man breathing oxygen* if this yields larger figure than basic requirement. (Do not add to basic requirement.)

    Rule 2. Maximum interval between ventilations:
    a. Not using oxygen:
       $$\text{Interval (min.)} = \frac{\text{Chamber (or lock) volume (cu. ft.)}}{\text{Basic vent. req. (cu. ft./min.) (from rule 1)}}$$
    b. Using oxygen:
       $$\text{Interval (min.)} = \frac{\text{Chamber (or lock) vol. (cu. ft.)}}{\text{No. of men br. } O_2 \times 10}$$
    a. Timing of ventilation:
       1) Use any convenient interval shorter than maximum from rule 2.
       2) (Continuous steady-rate ventilation is also satisfactory.)
    b. Volume used at each ventilation:
       1) Multiply volume requirement (cu. ft./min.) from rule 1 by number of minutes since start of last ventilation.
    c. Use predetermined exhaust valve settings to obtain required volume of ventilation. (See article 1.6.21 (18), (b).)

11. *First Aid*
    a. First aid measures may be required in addition to recompression. Do not neglect them.
    b. See table 1–26 and *Standard First Aid Training Course,* NAVPERS 1–0081.

12. *Recompression in the Water*
    a. Recompression without a chamber is difficult and hazardous. Except in grave emergency, seek nearest chamber even if at considerable distance.
    b. If water recompression must be used and diver is conscious and able to care for himself:
       1) Use deep sea diving rig if available.
       2) Follow treatment tables as closely as possible.
       3) Maintain constant communication.
       4) Have standby diver ready.
    c. If diver is unconscious or incapacitated, send another diver with him to control his valves and otherwise assist him.
    d. If lightweight diving outfit or scuba must be used, keep at least one diver with patient at all times. Plan carefully for shifting rigs or cylinders. Have ample number of tenders topside and at intermediate depths.
    e. If depth is inadequate for full treatment according to tables:
       1) Take patient to maximum available depth.
       2) Keep him there 30 minutes.
       3) Bring him up according to TABLE 3 if he can tolerate exposure. (If patient has been taken beyond 100 feet, do not use stops shorter than those of TABLE 2–A.)

(*a*) Blueness or cyanosis of the skin, lips, or fingernails.

(*b*) Difficulty in breathing.

(*c*) Shock.

(20) With *subcutaneous emphysema*, the following signs may be seen:

(*a*) Swelling or inflation of the neck even to the extent of resembling a bull frog.

(*b*) A crackling sensation (crepitation) when the skin is moved slightly.

(*c*) Change in sound of the voice.

(*d*) Difficulty in breathing or swallowing.

(21) With *pneumothorax*, the person may show any or all of the following:

(*a*) Blueness (cyanosis) of the skin, lips, or fingernails.

(*b*) Evidence of pain such as grimacing or clutching the side of the chest involved.

(*c*) Tendency to bend chest towards the side involved.

(*d*) Rapid shallow breathing.

Treatment

(22) The treatment of air embolism consists of *recompression* in a recompression chamber. This reduces the size of the bubble and may permit the resumption of normal circulation of blood in the brain. Recompress the patient without delay to a depth of 165 feet. Descend at the maximum rate possible within the capability of the tender or tenders to equalize. (The normal descent rate of 25 feet per minute does not apply to the treatment of air embolism.) If the tenders have difficulty equalizing, descent must continue regardless. After reaching 165 feet, follow either TABLE 3 or TABLE 4, whichever is indicated by the response of the patient: If he *completely* recovers within 30 minutes, use TABLE 3. If he does not completely recover within 30 minutes, use TABLE 4. (Both of these tables are given in table 1–21.) Be extremely watchful for any evidence of recurrence of symptoms during ascent.

NOTE.—Having a case of air embolism when no recompression chamber is nearby presents very serious problems. The delay involved in getting the victim to a chamber may result in death or permanent injury. However, attempting to treat such a patient in the water presents so many difficulties and risks (especially if only scuba equipment is available) that this can seldom be recommended except where the nearest chamber is at great distance.

(23) Use oxygen where permitted by the treatment table, but discontinue it if there is evidence that oxygen-breathing is producing lung irritation (pain or coughing) or difficulty in breathing. Note that a helium-oxygen mixture can be used at any time during treatment with TABLE 3 or 4. (See table 1–21 and 1–22.)

(24) In a simple, uncomplicated case of mediastinal or subcutaneous emphysema where air embolism is not present, recompression is seldom desirable unless there is marked difficulty in breathing or evidence of impairment of circulation of blood due to pressure about the heart. If recompression is used, then TABLE 3 or TABLE 4 must be used for decompression.

(25) In a case of pneumothorax uncomplicated by air embolism, do not use recompression. If it is severe and causes marked difficulty in breathing, the treatment required is direct removal of the air trapped between the lung and chest wall. This should be done by a medical officer. It is accomplished by careful insertion of a long hypodermic needle into the air-filled space and withdrawing the air by means of a syringe. The needle must be inserted no farther than necessary to reach the air. Care must be taken not to admit additional air during this procedure. This can best be avoided by using a two-way petcock between the needle and the syringe so that a direct free airway never exists into the chest cavity. Another emergency means of accomplishing this consists of constructing a simple one-way flutter valve using a condom slit at one end and tying the normally open end securely about the end of the needle. This then permits the air to escape; but no air can enter the chest cavity, and the lung will then expand.

(26) In any case of air embolism or its related accidents, breathing may cease. In this case, artificial respiration must be started in addition to immediate recompression. Stimulants are indicated to help restore respiration. Shock must also be treated when it exists.

1.6.4 LOSS OF CONSCIOUSNESS

Causes

(1) Loss of consciousness during or after a dive is an acute emergency, and it may result from many different accidents. Air embolism and serious forms of decompression sickness have been discussed and should always be considered when a diver loses consciousness. Simple fainting occurs occasionally. Any mishap that stops breathing or seriously interferes with any part of the respiratory process will also lead to unconsciousness. Especially when a diver "passes out" underwater, more than one accident may have happened by the time he can be rescued. For example, loss of consciousness due to oxygen poisoning or some other initial accident might then lead to drowning, air embolism, or even a head injury —or conceivably all three. It is often very difficult to determine exactly what has happened to the victim, and it is far more important to start treating him at once than to try to figure out the cause. Actually, the supposed nature of the accident seldom will change the steps that should be followed in treatment.

Essentials of Treatment

(Table 1–20 presents the most important steps in treatment.)

(2) *Artificial respiration* must obviously be started without delay whenever a man is not breathing. *Recompression* should be given in almost every case of unconsciousness simply because it is seldom possible to be *certain* that it is not essential. Air embolism can result from only a few feet of ascent with breath-holding or respiratory obstruction. Decompression sickness has been known to follow dives that were well within the "no decompression" limits, and its symptoms may appear many hours after surfacing.

(3) Although the steps given in table 1–20 provide a sound basis for treating almost any case of unconsciousness, several problems can arise. Common sense and good judgment must always be used.

(*a*) If transporting the victim to a chamber and recompressing him will make some other lifesaving procedure difficult or impossible, then it may be best to concentrate on the other measure instead, especially if it seems extremely remote that the victim has a condition requiring recompression. In general, it is safer to assume that recompression is essential and make every effort to provide it, plus all other necessary measures as well. For example, it should almost always be possible to continue artificial respiration by some means while transporting the patient and recompressing him. Also, there are very few tests, treatments, or even surgical procedures that could not be performed in a chamber of usual size in a real emergency. Recompression can seldom do harm. Failure to recompress can lose a life needlessly.

(*b*) If the chamber is at a considerable distance, the likelihood that recompression will be beneficial is naturally reduced. But even in air embolism, recompression is worthwhile as long as the victim remains alive. Distance is never a sufficient excuse for not trying to reach a chamber as rapidly as possible. Attempting to recompress an unconscious man in the water (see table 1–22) involves great difficulty and risk even when the conditions and available gear are ideal. It can seldom be recommended if any other course of action is possible.

(*c*) Where unconsciousness results from a less serious condition like fainting, mild anoxia, or carbon dioxide excess, consciousness will frequently return before the man can be recompressed. In such a case, recompression is unnecessary unless some abnormality like paralysis or some other neurological sign remains and fails to show definite spontaneous improvement. In the milder conditions, recovery may occur very shortly after recompression is started. In some of these, the fact that recovery occurred under pressure may seem only a coincidence. However, it is *never* safe to assume that this was true. Any patient who regains consciousness during recompression deserves full proper treatment (no less than TABLE 3).

(*d*) While following the steps of table 1–20, bear in mind that unconsciousness may have been caused by some medical emergency not directly related to diving. The more time since surfacing from a dive, the more likely this is to be the case. Do not fail to examine the patient for signs of injury or other abnormalities and see that he is examined completely by a medical officer at the earliest opportunity. Recompression should not be delayed for this, and even positive findings of another condition will seldom veto recompression; but it is important to be fully aware of all that is wrong with the patient so appropriate action can be taken.

1.6.5 RESPIRATORY ACCIDENTS

(1) Some of the most important hazards of diving, especially in the use of scuba, are those that can *stop or seriously interfere with breathing* or with some other phase of the respiratory process. (See art. 1.3.5.) These can all result in unconsciousness even though in some cases breathing itself may continue for some time. In all of them, the proper initial treatment is the same as specified for unconsciousness. (See table 1–20 and art. 1.6.4.) Any special considerations are indicated in the discussions of the individual accidents. In most instances, these accidents are discussed more fully in the section on Underwater Physiology, and references to that section are supplied.

Drowning

(2) *Circumstances*

(*a*) Drowning is extremely unlikely with *deep sea rig* but could occur in event of:

1. Loss of helmet.
2. Being in *head-down position* with spit cock open or when leaning on chin button, or with torn or ruptured suit.

(*b*) Normally, as long as he remains upright and has air supply, a deep sea diver can keep water out of his helmet even though his suit is badly torn.

(*c*) With lightweight gear, drowning can follow loss or ditching of mask. (Interruption of air supply may necessitate ditching.)

(*d*) Numerous possibilities of drowning with self contained breathing equipment include:

1. Loss or flooding of mask or mouthpiece.
2. Failure of gear or gas supply.
3. Surface exposure in rough water.
4. Overexertion, exhaustion.
5. Almost any mishap followed by failure of emergency procedures or panic.
6. Any accident causing unconsciousness.

(3) *Treatment*

(*a*) See tables 1–20, 1–23, 1–24, and 1–25.

(4) *Prevention*

(*a*) Adequate training and drill in emergency procedures.

(*b*) Proper equipment in good condition.

(*c*) Use of lifejacket with scuba; lifeline with lightweight outfit.

(*d*) Good diving practices; adequate preparations.

(*e*) Appropriate boats, floats, etc.; readiness for going to aid of diver in distress.

Anoxia (oxygen deficiency) (See art. 1.3.5, pars. 2–7.)

(5) Usual causes of anoxia in diving are:

(*a*) *Loss or inadequacy of air supply.* (This also causes carbon dioxide excess (see art. 1.3.5, pars. 9–13), thus represents asphyxia (see art. 1.3.5, pars. 14–17). *Diver generally knows he is in trouble.*)

(*b*) Using up available oxygen in rebreathing-type apparatus (closed or semiclosed circuit.) *This seldom gives warning.*

In *closed circuit* apparatus:

1. Poor initial purge.
2. Use of gas other than pure oxygen.

In *Semiclosed "mixed gas"* apparatus:

1. Use of too-low oxygen concentration in mixture.
2. Too-low flow setting.
3. Accidental reduction or cessation of flow.

(6) *Symptoms:*

(*a*) Diver frequently notices nothing; loses consciousness without warning.

(*b*) May note mental changes similar to those of alcohol intoxication.

(7) *Signs:*

(*a*) Slowing up of responses, confusion, clumsiness, foolish behavior, and the like.

(*b*) Unconsciousness.

(*c*) Cyanosis (blueness).

(*d*) Cessation of breathing in severe anoxia; death if not treated promptly.

(8) *Treatment:*

(*a*) If underwater with rebreathing apparatus, add oxygen to breathing bag immediately if possible. Otherwise, get to surface and give fresh air.

(*b*) If still breathing and not suffering from another accident, fresh air will cause rapid recovery. Use oxygen if available.

(*c*) If unconscious, treat according to table 1–20.

(9) *Prevention:*

(*a*) Training, good equipment, etc. (See part 3.)

(*b*) Special attention to proper purge in using closed-circuit apparatus.

(*c*) With mixed gas apparatus, extreme care in maintenance and preparation; attention to any sign of flow reduction or other malfunction during dive.

Carbon dioxide excess (including *shallow water blackout*) (See art. 1.3.5, pars. 8–14.)

(10) *Usual causes:*

(*a*) Loss or inadequacy of air supply. Using too little air in deep sea rig.

(*b*) Failure of carbon dioxide absorption in rebreathing scuba.

1. Canister too small or poorly designed.
2. Exhausted absorbent or poor filling.
3. Exceeding duration of canister.
4. Water leakage into canister.

(*c*) Overexertion.

(*d*) Excessive "controlled breathing."

(11) *Symptoms:*

(*a*) *Sometimes none*, as in anoxia. (See par. 5.)

(*b*) Usually notice labored breathing, air-hunger.

(*c*) May have headache, dizziness, weakness, unusual sweating, nausea.

(*d*) May note mental changes: inability to think clearly, confusion.

(12) *Signs:*

(*a*) Slowing up of responses, confusion, clumsiness, foolish actions, and the like.

(*b*) Unconsciousness; may have muscular twitching in extreme case.

(*c*) (Breathing usually continues.)

(13) *Action:*

(*a*) Diver should stop, rest, ventilate. Surface if practical.

(*b*) Bring diver up and provide fresh air. (Effects usually subside rapidly.)

(*c*) If unconscious, treat according to table 1–20.

(14) *Prevention:*

(*a*) Avoid causes.

(*b*) Rest when breathing becomes labored.

(*c*) Discontinue dive if breathing continues to be excessive or if mental changes are noted.

Asphyxia (See art. 1.3.5, par. 15.)

(15) Asphyxia involves *both* anoxia and carbon dioxide excess.

Usual causes:

(*a*) Loss or inadequacy of air supply.

(*b*) Obstructed breathing (strangulation).

(16) *Signs and Symptoms:*

(*a*) Usually have labored breathing.

(*b*) May have headache, weakness, dizziness.

(*c*) Mental changes as in anoxia and carbon dioxide excess.

(*d*) Cyanosis (blueness).

(*e*) Unconsciousness if severe.

(*f*) May have violent increase in breathing followed by cessation of breathing.

(17) *Action:*

(*a*) Diver should stop, rest, ventilate. Surface if practical.

(*b*) Bring diver up and give fresh air.

(*c*) If unconscious, follow steps of table 1–20.

(18) *Prevention:*

(*a*) Same as for anoxia and carbon dioxide excess.

Strangulation (See art. 1.3.5, par. 16.)

(19) Strangulation refers to *obstruction* of breathing. It will produce asphyxia if severe. Inhalation of foreign material such as chewing gum, a false tooth, or vomitus is the *most likely cause* of strangulation in diving. The diver may have spasm of the larynx due to inhalation of water. Strangulation may be a complication of drowning and other conditions requiring artificial respiration.

(20) *Signs and symptoms:*

(*a*) Extremely difficult (usually noisy) breathing; choking.

(*b*) Unconsciousness if severe or prolonged.

(*c*) Struggle to breathe eventually ceases.

(21) *Treatment:*

(*a*) Relieve cause if possible. If he is conscious, encourage victim to cough, pound him on back, hold inverted.

(*b*) Attempt removal with finger or forceps if obstructing object is within reach, but take care not to push it farther down the throat.

(*c*) Consider emergency tracheotomy if other measures fail. (See art. 1.3.5, par. 16.)

(22) *Prevention:*

(*a*) Remove dentures; do not chew gum during a dive.

(*b*) Guard against strangulation in unconscious victims of any accident.

Carbon monoxide poisoning (See art. 1.3.5, pars. 17–23.)

(23) Carbon monoxide combines with hemoglobin in blood and keeps it from carrying oxygen. Basic difficulty, as a result, is that insufficient oxygen reaches the tissues (tissue anoxia).

(24) *Usual cause* of carbon monoxide poisoning in diving is contamination of diver's air from:

(*a*) Compressor intake too close to exhaust.

(*b*) Flashing of lubricating oil in compressor.

(25) *Symptoms:*

(*a*) Frequently no symptoms noted; unconsciousness without warning.

(*b*) Occasionally have tightness across forehead, headache, dizziness, nausea, weakness.

(*c*) Confusion and other mental changes similar to those of anoxia.

(26) *Signs:*

(*a*) Failure to respond, clumsiness, bad judgment, and the like may be noted by tender or buddy.

(*b*) Unconsciousness.

(*c*) Breathing ceases in severe cases.

(*d*) Abnormal redness of lips, nailbeds, or skin may help make diagnosis.

(27) *Treatment:*

(*a*) Get victim into fresh air. Give oxygen if available.

(*b*) If unconscious, treat according to table 1–20.

(*c*) Continue use of oxygen in chamber (but not deeper than 60 feet or longer than 30 minutes at that depth).

(28) *Prevention:*

(*a*) Place exhaust downwind and as far from compressor intake as possible.

(*b*) Assure adequate maintenance and proper operation of compressors.

(*c*) Where any doubt exists, test air periodically for carbon monoxide. (See arts. 1.10.9 and 1.10.10.)

Other respiratory accidents

(29) *Electrocution* can cause abrupt cessation of breathing.

(*a*) *Causes.*—Rare in diving but can occur through—

1. Accidents with underwater cutting and welding procedures.
2. Careless handling of lights, power tools, and other electrical equipment.
3. Allowing use of electrical gear in bad condition.

(*b*) *Prevention.*

1. Comply with instructions in the Underwater Cutting and Welding Manual, NAVSHIPS 250–692–9.
2. Exercise special care and attention at all times when electrical appliances are in use around the diving station.
3. Repair or replace defective equipment promptly.

(*c*) *Action.* Free victim from source of current promptly, but exercise extreme caution to avoid electrocution of rescuer. Cut power first if at all possible.

(*d*) *Treatment.*

1. Give artificial respiration. (See tables 1–23 to 1–25.)
2. Get medical assistance at once.

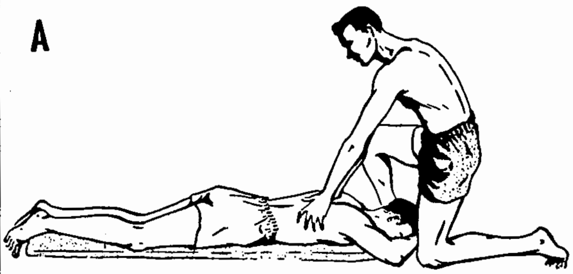
NOTE.—Electrocution frequently stops heart action as well as breathing. (See par. 31 of this article.)

3. Continue artificial respiration until victim revives or is pronounced dead.
4. When a victim of electrocution revives, keep him strictly at rest for 24 hours even though consciousness and heart action (pulse) have returned to normal.

TABLE 1–23

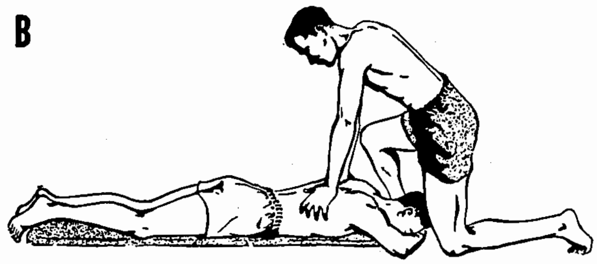
BACK-PRESSURE, ARM-LIFT METHOD OF ARTIFICIAL RESPIRATION

A



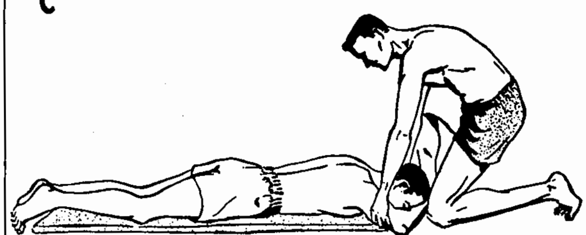
INITIAL POSITION.

B



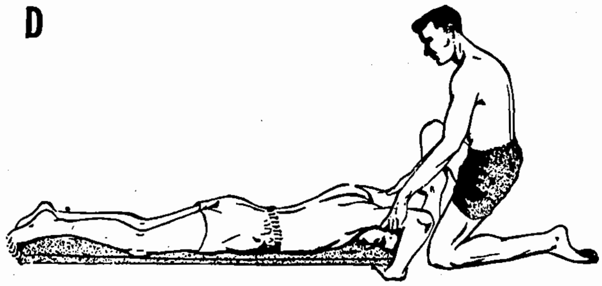
PRESSURE PHASE. NOTE THAT THE OPERATOR'S ARMS ARE STRAIGHT AND NEARLY VERTICAL.

C



POSITIONING THE HANDS ON THE VICTIM'S ARMS NEAR HIS ELBOWS.

D



LIFT PHASE. NOTE THAT THE OPERATOR IS LEANING BACK WITH HIS ARMS NEARLY STRAIGHT AND THAT THE VICTIM'S ARMS ARE RAISED ENOUGH TO ARCH HIS BACK AND PARTIALLY RAISE HIS CHEST FROM THE GROUND.

INSTRUCTIONS

1. Act immediately.
2. Complete necessary preparations *rapidly:*
   - (*a*) Loosen any tight clothing about neck.
   - (*b*) Get victim in proper position (see diagrams).
   - (*c*) *Quickly* sweep fingers through mouth to clear it out and be sure throat is open. (Take care not to push anything farther down throat.)
3. Get yourself into position (A) and apply pressure (B).
   - (*a*) Kneel at head (one or both knees).
   - (*b*) Hands on back just below shoulder blades, fingers spread, thumbs pointed toward spine with tips barely touching.
   - (*c*) Rock forward, pressing almost straight downward (arms straight and almost vertical).
   - (*d*) Make pressure slow, steady, equal on both hands; not sudden or jerky.
   - (*e*) Do not apply too much pressure.
4. Start to rock backwards; grasp arms (C).
   - (*a*) Slide hands up victim's back.
   - (*b*) Cup them under arms just above elbows.
5. Continue to rock backwards, drawing arms upward and toward you (D).
   - (*a*) Let his arms lift naturally as you rock back.
   - (*b*) Do not pull; raise arms only until you feel resistance at shoulder blades.
6. Lower arms gently; resume "press" position (A).
7. Repeat whole cycle again. *Keep it up.*
   - (*a*) Be regular and rhythmical.
   - (*b*) Make 10 to 12 cycles per minute.
8. Get another person to do other things required. (See table 1–24.)

TABLE 1–24

NOTES ON ARTIFICIAL RESPIRATION

1. Start artificial respiration immediately whenever a man is *not breathing* due to drowning or any other cause.
   (*a*) Never wait for mechanical resuscitator.
   (*b*) Delay *only* to stop serious bleeding (if possible have another person tend to such measures while you start artificial respiration).
   (*c*) Send *another person* for a medical officer or other competent aid.
2. Before starting, remove victim from the cause of his trouble; but do not waste time moving him any farther than necessary.
3. *Get on with artificial respiration.* Leave details to others or try to get them done quickly between cycles.
   (*a*) Recheck position of victim:
      1) On stomach.
      2) Head slightly lower than feet if possible, especially in drowning.
      3) Head turned to side, chin pulled toward operator.
      4) Hands under head.
   (*b*) Recheck airway:
      1) Remove froth, debris, or other material.
      2) See that tongue stays forward; have someone hold it if it draws back (you can run a safety pin through tongue if necessary).
      3) *If artificial respiration does not move any air, there is an obstruction.* Strangulation must be overcome. (See art. 1.3.5, par. 16.)
   (*c*) Loosen any tight clothing—collar, belt, etc.
   (*d*) Keep victim warm.
   (*e*) Check pulse. Combat shock.
4. Continue artificial respiration without interruption. (Minimum time is 4 hours unless victim revives or is pronounced dead by medical officer.)
   (*a*) Do not apply *too much* back pressure. (A strong operator can crack ribs of a small victim.)
   (*b*) If you become tired, let another operator take over. Do not break rhythm during shift.
   (*c*) Watch carefully for signs of return of natural breathing movements. If they appear, time your movements to assist them.
   (*d*) Shift to a mechanical resuscitator if one is available, ready, and operating properly.
   (*e*) If victim starts breathing for himself, watch him carefully. Resume artificial respiration if he stops or if movements become too feeble.
5. If victim revives, continue care.
   (*a*) Keep him lying down.
   (*b*) Remove wet clothes; keep warm.
   (*c*) Give nothing by mouth until fully conscious.
   (*d*) Attend to any injuries.
   (*e*) Be sure he is seen promptly by medical officer.

NOTE

If victim has been underwater with any kind of breathing apparatus, he *may have air embolism.* This can seldom be ruled out in an unconscious diver whether he is breathing or not, and recompression should be given if any doubt exists.

Do not delay artificial respiration. Give it by some method on way to chamber and during recompression.

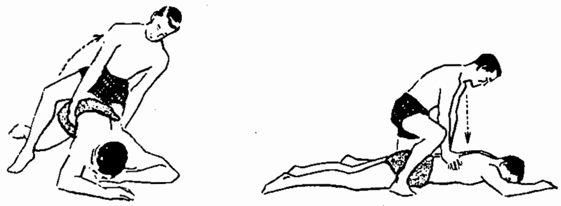
TABLE 1–25

ALTERNATIVE METHODS OF ARTIFICIAL RESPIRATION

The back-pressure, arm-lift method is generally considered best for most purposes. If it cannot be used because of lack of space, injuries to the victim, or having to transport him, use one of the methods described here. All are effective. Use hip-roll (A) if possible, since there is less danger of airway obstruction and better blood flow to the brain than in the sitting-up methods.

All procedures should be performed at 10–12 cycles per minute. Most of the notes and precautions given for the back-pressure, arm-lift method apply: (Clear mouth first, etc. See tables 1–23 and 1–24.)

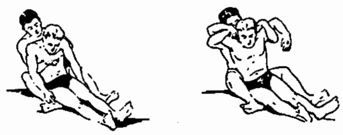
HIP-ROLL, BACK-PRESSURE



Excellent method. Not too tiring if properly done. Especially valuable in cramped space or if victim's arms are injured.

Position: Face victim's head. Kneel on one knee—knee well forward of victim's hip and close in to operator's forearm. Grip hip bones with both hands.
Roll: Sway toward kneeling side. Keep arms straight. Roll victim's hip up on thigh to elevate *both* hips off ground. Sway back and let down.
Back pressure: Shift hands from hips to back just below shoulder blades. Rock forward and press almost straight down.

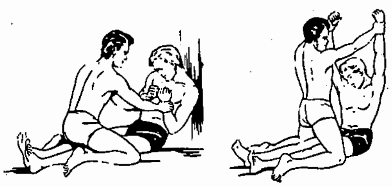
BEAR-HUG, ARM-LIFT



Highly effective where victim cannot be placed flat. Could be used even in water (with flotation gear).

Position: (See diagrams.) Sit behind victim, arms around chest under his arms.
Pressure: Squeeze chest with both arms.
Arm-lift: Raise both arms, lifting victim's arms.
Caution: Do everything possible to prevent obstruction; keep tongue forward.

CHEST-PRESSURE, ARM-LIFT



Effective; usable in very cramped space; permits facing victim.

Position: (See diagrams.) Victim seated, operator kneels straddling his legs. Grasps both wrists.
Pressure: Place victim's hands side-by-side on chest. Push.
Arm-lift: Raise victim's arms over his head.
Caution: Try to prevent obstruction.

MOUTH-TO-MOUTH

One of most effective methods. Can be performed almost anywhere and in any position. Method of choice for infants and young children. Especially valuable in chest injury cases.

Position: Having cleared mouth, hold victim's jaw in "jutting-out" position with one hand. Close nostrils with other hand. Place your mouth over his, making good seal. Keep his head tilted back.
Inflation: Breathe into victim with smooth steady action, until definite expansion of chest is noted, *but do not exert much pressure.* If he does not inflate readily, airway is obstructed.
Deflation: Remove mouth and allow victim to exhale. If he fails to do so, apply gentle pressure on chest. Check for obstruction. (Operator inhales during this phase.)

OTHER PROCEDURES

There will be few situations where one of these methods cannot be used, but remember that almost any procedure that involves squeezing the chest or abdomen will move some air and is worth trying if nothing better can be done.

(30) *Poisonous gases* other than carbon monoxide are unlikely to be met with in diving itself, but a variety of them may be encountered in salvage operations.

(*a*) *Prevention* requires exercise of great caution and use of approved procedures in opening, ventilating, and entering holds and closed spaces of all kinds.

(*b*) *Action.*—Be extremely careful that attempts to rescue victim do not result in similar accident to rescuers.

(*c*) *Treatment.*

1. Give artificial respiration.
2. Get medical assistance.
3. Use other measures as required by nature of poisoning.

Heart stopping

(31) Electrocution frequently causes cessation of heart action (cardiac arrest) as well as cessation of breathing. The heart may also stop in the course of other respiratory accidents. If this occurs, artificial respiration alone cannot revive the victim, and there is no time to be lost. *Sometimes, a vigorous blow or series of blows with the fist on the chest over the heart will restart the heart.* If this fails, there are other measures that can be applied; but they must be attempted only by a medical officer and are useless unless performed almost immediately following cardiac arrest. These include opening the chest to perform cardiac massage (squeezing the heart by hand to produce pumping action) and application of an electrical device to restore normal heart action. In any case, even if cardiac arrest is thought to have occurred, artificial respiration must be continued until the victim either revives or is pronounced dead. Artificial respiration must also be continued throughout any other procedure like cardiac massage; and if the chest has been opened, only a method that inflates the lungs with positive pressure will be effective. A mechanical resuscitator or the mouth-to-mouth method (see table 1–25) can be used.

1.6.6 OXYGEN POISONING (See art. 1.3.11.)

(1) Oxygen poisoning in diving can result from any exposure to increased oxygen partial pressures beyond acceptable limits. This can come about through:

(*a*) Use of closed-circuit oxygen (or any other type of apparatus supplied with oxygen) for working dives beyond specified depth-time limits. (See art. 1.5.7.)

(*b*) Use of excessively high oxygen concentrations in breathing media for helium-oxygen or nitrogen-oxygen diving, or exceeding proper depths and times for mixtures and flows used.

(*c*) Failing to remain at rest during oxygen phase of helium-oxygen decompression or therapeutic use of oxygen in chamber.

(*d*) Accumulation of carbon dioxide in self contained apparatus with increased oxygen partial pressure.

(*e*) Unusual susceptibility to oxygen poisoning.

Symptoms

(2) The main consequence of oxygen poisoning is *convulsion.* Less serious symptoms sometimes precede convulsion. If one of these symptoms appears and is recognized in time, the diver may be able to lower the partial pressure of oxygen (as by coming up) and avert convulsion. The most common "warning symptoms" are:

(*a*) Muscular twitching (usually appearing first in the face).

(*b*) Nausea.

(*c*) Dizziness.

(*d*) Abnormalities of vision or hearing.

(*e*) Difficulty in breathing.

(*f*) Anxiety and confusion.

(*g*) Unusual fatigue.

(*h*) Incoordination (clumsiness, etc.).

Signs

(3) Prior to convulsion, the only *sign* likely to be observed is twitching. Once convulsion occurs, the sequence of events and signs is usually about the same:

(*a*) Consciousness is lost at the onset of convulsion. Breathing stops during "stiff phase."

(*b*) Violent convulsive movements may continue for a minute or two.

(*c*) Biting the tongue, various physical injuries due to striking hard objects, and drowning may occur during convulsion. Air embolism is possible with ascent during convulsion.

(*d*) Breathing generally resumes spontaneously after convulsion.

(*e*) Victim remains unconscious for several minutes after relaxing from convulsion.

(*f*) A period of semiconsciousness follows, with irrational behavior, great restlessness, and intermittent sleep. This phase usually lasts from 30 minutes to an hour.

Treatment

(4) Convulsions almost invariably stop before any active treatment can or needs to be applied. Concentrate on preventing drowning and injury. Action depends largely on circumstances:

(*a*) In self contained diving:

1. Buddy should bring diver up promptly despite danger of air embolism from ascent during convulsion. (Drowning is a greater hazard.)
2. At surface, inflate victim's lifejacket and keep his face out of water.

(*b*) In helium-oxygen decompression, follow procedure given in article 1.5.4, paragraph (21).

(*c*) In recompression chamber (surface decompression using oxygen, oxygen tolerance tests, treatment):

1. Hold chamber at same depth until breathing resumes.
2. Use padded mouth-bit to prevent tongue-biting.
3. Prevent injury by falling or hitting objects, but do not try to oppose convulsive movements.
4. Turn on stomach with face to side to prevent inhalation of secretions or "swallowing tongue."

(*d*) In all cases:

1. Start artificial respiration if normal breathing fails to resume. Check for airway obstruction.
2. Watch carefully. Obtain medical assistance.
3. *Recompress if diver was brought up during convulsion* or if there is any other reason to suspect air embolism.

Prevention

(5) The seriousness of oxygen poisoning in diving makes prevention extremely important. Therefore:

(*a*) Be sure that all divers have had the oxygen tolerance test. (See art. 1.8.2., par. 2 (c).)

(*b*) Carefully observe specified depth-time limits for use of oxygen apparatus for working dives (see article 1.5.7).

(*c*) Follow instructions carefully in use of semiclosed-circuit scuba. (See sec. 3.6.)

(*d*) Avoid exertion when using oxygen for decompression or in treatment. Avoid overexertion when using self contained equipment.

(*e*) Assure efficient absorption in rebreathing apparatus to prevent carbon dioxide buildup.

(*f*) Be alert for warning symptoms when oxygen poisoning is possible. Come to shallower depth (if possible, surface and breathe air) if such a symptom develops. Never *depend* upon the appearance of warning symptoms. Observe the limits!

(*g*) *Never charge demand apparatus with oxygen.*

(6) If warning symptoms appear during helium-oxygen decompression, follow the procedure given in article 1.5.4, paragraph (21).

1.6.7 NITROGEN NARCOSIS (See art. 1.3.10.)

Cause

(1) The nitrogen in the air begins to have intoxicating effects at about 100 feet. At depths much over 200 feet, most divers are too narcotized to work effectively or safely.

Symptoms and signs

(2) The effects of nitrogen narcosis are similar to those of alcohol intoxication. Individuals differ not only in susceptibility but also in the nature of their reactions. Effects usually include:

(*a*) Loss of judgment and skill.

(*b*) False feeling of well-being.

(*c*) Lack of concern for job and own safety.

(*d*) Difficulty accomplishing even simple jobs.

(*e*) Foolish behavior and inappropriate actions.

(*f*) Near-unconsciousness in highly susceptible men at great depth.

Treatment

(3) No treatment is required. The effects disappear rapidly with ascent to shallower depths. There are no aftereffects.

Prevention

(4) Nitrogen narcosis can be *prevented* only by avoiding exceptionally deep dives with air. Where such dives must be made:

(*a*) Use only mature, stable, experienced divers.

(*b*) Make sure the diver understands the effects and will act accordingly.

1.6.8 SQUEEZE (See art. 1.2.4 (21–23) and art. 1.3.7.)

(1) The term *squeeze* (or barotrauma) refers to any injury that comes about because of inability to equalize pressure between a closed air space and outside water pressure. If an air space within the body (or attached to it) has rigid or semirigid walls, it must be equalized by free entry of air. (Nonrigid air spaces equalize simply by compression.)

Middle Ear Squeeze

(2) *Cause:*

(*a*) Diving with blocked eustachian tube.

(*b*) Failure to "pop ears" on descent.

(3) *Symptoms:*

(*a*) Pain in ear during descent.

(*b*) Sudden relief of pain if eardrum ruptures.

(4) *Signs* (depend on extent of damage):

(*a*) Redness and swelling of eardrum.

(*b*) Bleeding into drum or middle ear space.

(*c*) Rupture of drum with bleeding.

(*d*) Spitting up blood.

(*e*) Bleeding to outside if drum is ruptured.

(5) *Treatment:*

(*a*) Report to medical officer or corpsman.

(*b*) Mild case without rupture: avoid pressure until

1. Damage heals.

2. Ears can be cleared readily.

(*c*) Ruptured eardrum:

1. No diving until healed (usually about 2 weeks).

2. Keep water and all objects and materials (including "medications") out of ear. (*Hands off!*)

3. Return to medical officer at once if pain increases or drainage appears. (These signs may indicate infection requiring antibiotic treatment.)

(6) *Prevention:*

(*a*) Do not accept men who cannot pass pressure test.

(*b*) "Pop ears" properly during descent:

1. Swallow or yawn.

2. Move jaw.

3. Blow gently against closed nostrils.

(*c*) Do not dive with head cold or infection that blocks eustachian tubes.

(*d*) Use nose drops, spray, or inhaler for mild difficulty.

NOTE.—If eardrum ruptures when diver is bareheaded in cold water, severe dizziness (sometimes with nausea and vomiting) can result. The diver may be so completely confused that he may be unable to find his way to surface. (This is another example of the value of the buddy system and the lifejacket in self contained diving.) Dizziness passes when water in the ear warms to body temperature.

External Ear Squeeze

(7) *Cause:*

(*a*) "Suit squeeze"—paragraph 31 of this article.

(*b*) Hood sealing over external ear.

(*c*) Use of ear plugs.

(8) *Symptoms:*

(*a*) Pain on descent even though able to "pop ears."

(*b*) Feels almost same as middle ear squeeze; pain stops if eardrum ruptures.

(9) *Signs:*

(*a*) Drum may have same appearance as in middle ear squeeze.

(*b*) Often see blood-blisters on or around drum or in canal.

(*c*) Drum may be ruptured, but bleeding to outside *does not* necessarily mean rupture.

(10) *Treatment:*

(*a*) Same as in middle ear squeeze. (See par. 5 of this article.) (Hands off!)

(*b*) Report any sign of infection.

(11) *Prevention:*

(*a*) If using closed rubber swim suit, be sure to admit air for equalization during descent. (Pinch face seal at junction with mask to make a channel.)

(*b*) Line hood (ear area) with flannel or porous rubber to prevent "sealing."

(*c*) Never use ear plugs!

Sinus Squeeze

(12) *Cause:*

(*a*) Blockage of opening leading from nose to sinuses.

(*b*) Most likely during colds and other infections.

(13) *Symptoms:*

(*a*) Increasing pain in face (above, below, between, or behind the eyes) during descent.

(*b*) Pain relieved by ascent.

(14) *Signs:*

(*a*) Blood and mucus discharge from nose on surfacing.

(*b*) Tenderness over sinus areas.

(15) *Treatment:*

(*a*) Avoid diving until cause subsides.

(*b*) Use nose drops, spray, or inhaler to promote drainage.

(*c*) Report to the medical officer; return promptly in case of pain, pus drainage, or other signs of possible infection.

(*d*) Use antibiotics for treatment of infection only under the medical officer's direction.

(16) *Prevention:*

(*a*) Avoid diving with head colds and the like.

(*b*) Use nose drops, spray, or inhaler for mild difficulty.

(*c*) Discontinue dive promptly if sinus pain develops.

Lung (thoracic) squeeze

(17) *Cause:*

(*a*) Too-deep descent during skindive.

(*b*) Holding breath during descent with diving equipment.

(*c*) Failure of self contained gear or gas supply during descent.

(*d*) (Will occur also in generalized squeeze with deep sea rig (see par. 20) and occasionally with mask squeeze (see par. 26).

(18) *Symptoms and signs:*

(*a*) Sensation of chest compression during descent.

(*b*) Pain in chest (sometimes).

(*c*) Difficulty breathing on return to surface.

(*d*) Bloody, frothy sputum.

(19) *Treatment:*

(*a*) Bring diver to surface.

(*b*) Place in "drainage" position; try to clear blood from mouth.

(*c*) Give artificial respiration if not breathing.

(*d*) Use oxygen if breathing is labored or anoxia appears to be present.

(*e*) Secure help of medical officer promptly. (Most cases should be hospitalized at least for observation.)

(*f*) Prevent and treat shock.

(*g*) Give antibiotics to prevent infection.

Body squeeze (with deep sea rig)

(20) The helmet is a closed, rigid airspace applied to the body. Normally, proper control of air supply and exhaust prevent the helmet from producing squeeze; but certain conditions can cause it to squeeze the diver's head and shoulders (and thus, in effect, his whole body). This is one of the most serious of all diving accidents.

(21) *Causes:*

(*a*) Falling while submerged. (Note that a fall in shallow water is more serious than falling the same distance in deep water.) (See art. 1.2.4.)

(*b*) Failure to open air control valve enough to keep pace with rate of descent.

(*c*) Loss of pressure in air hose (as due to rupture of hose or failure of supply) with absence or failure of nonreturn valve.

(*d*) Loss of air from suit when inflow is small and exhaust valve is open too far.

(22) *Symptoms:*

(*a*) If mild, diver may note only tightness of suit about chest and difficulty inhaling.

(*b*) Can proceed to body being forced into helmet.

(23) *Signs:*

(*a*) If mild, observer may note nothing.

(*b*) If more severe, signs may include:

1. Bleeding from nose, lungs or eyes.
2. Swelling of tissues of head, neck, and shoulders; bleeding into the skin and membranes.
3. Unconsciousness.
4. Actual "molding" of diver into helmet.

(24) *Treatment:*

(*a*) Onset of squeeze is corrected by increasing air pressure in suit.

(*b*) Measures required depend on severity.

1. Treatment as for lung squeeze. (See art. 1.6.8, par. 17.)
2. Use cold packs on areas of skin bleeding.
3. Secure medical help at once; hospitalize unless squeeze is mild or unless recompression is required.

(*c*) As in every case where a diver must be pulled up before normal end of dive, consider need for decompression and provide it in chamber if necessary.

(25) *Prevention:*

(*a*) Always check nonreturn valve properly before every dive.

(*b*) Use volume tank on compressor; avoid using over-age hose.

(*c*) Always descend "under control":

1. Diver must be able to stop own descent by hanging onto descending line.
2. Tender must never let lifeline and airhose "run" through his hands.

(*d*) Always open air control valve sufficiently during descent.

(*e*) Take great care to avoid falling from the ship or stage, from what you are working on underwater, or off ledges, etc. on the bottom.

(*f*) If falling, open air control valve as rapidly as possible and tell tender to pull in slack and hold on, but take care to avoid blowup following the fall. (Blowup is generally a less serious accident than a bad squeeze.)

Facemask squeeze

(26) *Cause:*

(*a*) With self contained apparatus and eye-nose mask: Too rapid descent with failure to equalize by letting air out through nose. (Never wear goggles!)

(*b*) With full-faced mask of lightweight rig: Same causes as with Body Squeeze. (See par. 20 of this article.)

(*c*) With full-face mask as part of scuba rig: Failure of gas supply or demand valve, or failure to add gas to rebreathing unit on descent.

(*d*) Causes of lung squeeze (see par. 17) can sometimes also produce facemask squeeze.

(27) *Symptoms:*

(*a*) Sensation of suction applied to face.

(*b*) Pain and squeezing sensation.

(*c*) Inability to breathe.

(28) *Signs* may include:

(*a*) Face swollen and bruised, whites of eyes are bright red.

(*b*) Bleeding from nose, lungs, eyes.

(*c*) Protrusion of eyes with hemorrhage in eyeball, behind it, and in membranes lining lids.

(*d*) Signs of lung squeeze if this has also occurred.

(*e*) Signs of suffocation in severe cases.

(29) *Treatment:*

(*a*) Administer artificial respiration if diver is not breathing.

(*b*) Provide treatment as for lung squeeze if required. (See par. 19 of this article.)

(*c*) Apply cold packs to bruised or bleeding areas.

(*d*) Give sedatives and pain-relieving drugs if required.

(30) *Prevention:*

(*a*) "Descend under control" in any dive—even with self contained equipment or in skin diving; do not use excessive weight to descend rapidly.

(*b*) Always use nonreturn valve with lightweight rig; test it before each dive. Be sure that your air supply is reliable and that your hose is good.

(*c*) Be positive that cylinders are turned on and that equipment (or bypass) is functioning properly.

(*d*) If pressure in mask of lightweight-rig starts to drop (squeeze sensation begins), ditch mask promptly; then ditch belt and make free ascent exhaling all the way.

Suit squeeze

(31) *Cause:*
Closed "dry type" swim suits generally have airspaces in the folds, and these will not compress completely on descent. External ear canals also form closed, rigid space within hood. Unless air is admitted to suit to equalize these spaces, descent beyond a certain depth will produce "suit squeeze," which generally includes external ear squeeze. (See par. 7.)

(32) *Symptoms:*

(*a*) Pinching sensation of skin in area of folds in suit material or of fittings inside a suit.

(*b*) Symptoms of external ear squeeze. (See par. (7).)

(33) *Signs:*

(*a*) Raised welts with skin bleeding in areas of squeeze.

(*b*) Signs of external ear squeeze. (See par. 8.)

(34) *Treatment:*

(*a*) Skin usually requires no treatment. Cold applications are useful where there is bleeding.

(*b*) See treatment of external ear squeeze (par. 9).

(35) *Prevention:*

(*a*) Provide a means of admitting air to equalize suit.

(*b*) Stop descent when pinching or ear pain develops.

(*c*) Equalize by getting air from facemask to go past face seal into hood.

1.6.9 GAS EXPANSION (See art. 1.3.8.)

(1) Most of the air-containing structures of the body vent expanding gas readily on ascent. Even a middle ear or sinus that equalized with difficulty on descent rarely gives trouble on ascent. However, there are a few exceptions to this rule, and they should be kept in mind.

Air embolism

(2) Air embolism and related accidents have been discussed fully in article 1.6.3. They result from gas expansion in the lungs during ascent but rarely happen, except when the diver makes the mistake of holding his breath.

Ears and sinuses

(3) On very rare occasions, air becomes trapped in a middle ear or sinus during ascent. Such an event will cause considerable pain, and it is conceivably possible for rupture of an eardrum to occur. A sinus that has been "squeezed" going down will frequently contain free blood or fluid, and this will sometimes be expelled by the expansion of gas on ascent. Slowing the rate of ascent is usually all that is necessary to allow trapped gas to escape without causing harm.

Gut

(4) *Cause:* Gas pockets in the gastrointestinal tract do not cause difficulty on descent because the nonrigid walls of the tract allow free compression. If no gas is added during the dive, ascent will cause only reexpansion to the original volume. However, if a diver swallows air while under pressure, or if his intestines form an exceptional amount of gas during the dive, the added amount will have to be expelled during ascent. Familiar maneuvers generally accomplish this without difficulty. However, gas that happens to be too far from either end of the tract to escape readily can occasionally cause trouble.

(5) *Symptoms:*

(*a*) Mild: Sensation of abdominal fullness.

(*b*) Moderate: Abdominal pain and cramping.

(*c*) Severe: Severe pain; fainting.

(NOTE.—Fainting is due to reflexes and is not necessarily a result of pain.)

(6) *Treatment:*

(*a*) Stop ascent before pain becomes severe.

(*b*) Redescend sufficiently to relieve pain.

(*c*) Attempt to belch and break wind; *but note that overzealous attempts to belch may result in swallowing more air.*

(*d*) Resume ascent cautiously.

(*e*) Be sure topside (or buddy) realizes difficulty.

(7) *Prevention:*

(*a*) Reject men with history of many stomach and bowel disorders.

(*b*) Do not dive if stomach or bowel is upset.

(*c*) Watch diet before diving. (Avoid foods you have found likely to produce intestinal gas.)

(*d*) Avoid swallowing air during dive. Avoid chewing gum during dive (causes air swallowing, and men have strangled on "inhaled" gum).

(*e*) Do not continue ascent if abdominal pain develops. (See par. 6.)

1.6.10 BLOWUP

(1) Blowup is one of the most serious accidents associated with diving in suit and helmet. It is extremely rare in self contained diving but could occur in several ways.

Cause

(2) In deep sea or helium-oxygen rig:

(*a*) Any mishap or error that causes overinflation of dress; poor adjustment of air control and exhaust valves, or plugging of exhaust openings.

(*b*) Loss of shoe or weights.

(*c*) Allowing legs to be higher than body—if legs are not properly laced or shoes too light.

(*d*) Too strong or rapid a pull by tenders; being stuck in mud with sudden break free.

(*e*) Strong tide causing diver to lose hold on bottom or descending line, thus sweeping him to surface.

(3) In self contained diving:

(*a*) Unintentional dropping of weights.

(*b*) Accidental overinflation of breathing bag.

(*c*) Excess air in closed dry suit as result of efforts to equalize suit squeeze; failure of vent-valves on suit during ascent.

(*d*) Unintentional inflation of lifejackets.

Consequences

(4) Accidental "blowing up" may be injurious in ways such as:

(*a*) Air embolism, if breath is held during blowup even from extremely shallow depth (i.e. 7 feet above diver's head).

(*b*) Decompression sickness, if dive required decompression stops or was close to nondecompression limits. (The rapid ascent of blowup may cause trouble even in a dive that did not require stops.)

(*c*) Mechanical injury due to striking bottom of boat or other object at surface.

(*d*) Squeeze may result from falling back into deeper water after reaching surface and exhausting air from dress.

(*e*) Drowning not unlikely if suit ruptures at surface.

Prevention

(5) In addition to guarding against the causes listed in paragraphs 2 and 3 give attention to these points:

(*a*) Prohibit use of "controlled blowup" as a means of ascent.

(*b*) *Exhale* continuously if blowup occurs.

(*c*) Tenders: take in all slack in diver's lines at once when diver reaches surface upon blowing up.

(*d*) Diver: avoid exhausting air from suit until tenders have taken in slack. (Be alert to adjust air control valve so as to avoid further inflation and possible rupture of suit.)

Treatment

(6) Think of all the mishaps that may have occurred in the course of the blowup and act accordingly.

(*a*) If diver is unconscious, recompress immediately (probable air embolism).

(*b*) If dive did not require decompression and diver appears all right, watch closely and keep near recompression chamber. If symptoms of decompression sickness develop, treat according to treatment tables (table 1–21).

(*c*) If dive did require decompression, follow procedure specified in article 1.5.6.

(*d*) Apply first aid and other measures as required for injuries, if any.

1.6.11 FOULING

(1) Accidents that prevent a diver's ascent are more common in surface-supplied diving

than with scuba, but while the diver with lifeline and airhose may be more likely to become fouled, he at least has an ample air supply to use while the difficulty is being corrected. The scuba diver may be able to escape by ditching his equipment but then faces some additional risk in making a "free ascent."

Causes

(2) Possible causes of fouling include:

(*a*) Entanglement of lifeline, airhose, cylinders, other equipment, or the body itself with some underwater obstruction. (Stray lines and kelp are a particular hazard to the scuba diver.)

(*b*) Cavein of tunnel or shifting of heavy objects near diver or in route of exit from wreck.

Consequences

(3) Assuming that he is eventually released, the surface-supplied diver generally suffers from no more than:

(*a*) Fatigue, exhaustion, exposure, and their possible consequences.

(*b*) Need for prolonged decompression; decompression sickness if this is not provided.

(*c*) Possible physical injury from cause of entrapment.

(4) The scuba diver is susceptible to the same consequences. In addition, he must be concerned about:

(*a*) Using up gas supply with consequent asphyxia.

(*b*) Air embolism in improperly executed free ascent.

Action

(5) Whether a diver emerges safely from fouling depends very much on his own actions even though the help of another diver is often required to free him. The diver must:

(*a*) Remain calm; think.

(*b*) Describe situation to tender or call buddy's attention to it.

(*c*) Carefully and systematically attempt to determine cause of fouling and clear self. Use knife cautiously to avoid cutting airhose or breathing apparatus.

(*d*) In fouling with self contained apparatus, regard ditching and free ascent as a last resort; but make preparations for doing this in case it proves necessary.

(*e*) If efforts to clear prove futile, be quiet and wait for aid.

(*f*) Remember that frantic, ill-planned efforts not only usually fail but can make the situation worse. Futile struggling and panic can result in death from exhaustion and shock.

Prevention

(6) Being aware of possible causes of fouling and using proper precautions can usually avert fouling.

(*a*) Always inspect area as well as possible to detect obstructions on which lines or other equipment might foul.

(*b*) Note and remember on which side of an obstruction you pass and return the same way. Go over, rather than under or around, when possible.

(*c*) Have another diver tend lines outside when entering a space in which fouling could occur. If using self contained apparatus, use a snap on buddy line if you must proceed into a space alone and outside of your buddy's visual range.

(7) Ability to go to the aid of a fouled diver is the main reason for having a standby diver ready in surface-supplied diving and one of the many reasons for insisting on the "buddy system" in self contained diving.

Treatment

(8) When a fouled diver is freed, give careful attention to the decompression he requires and be ready to treat him for exposure or any injuries.

1.6.12 PHYSICAL INJURY

Mechanical injury

(1) Divers sometimes sustain a variety of mechanical injuries from external violence both underwater and in the surface phases of diving operations.

(*a*) When injury occurs underwater, bring the diver to the surface as soon as is deemed safe.

(*b*) Apply first aid as required.

(*c*) Obtain medical assistance unless injury is trivial.

(2) *General first aid* is beyond the scope of this manual. All hands should be familiar at least with its basic principles. (See table 1–26.) Keep at hand a good first-aid manual such as *Standard First Aid Training Course*, NAVPERS 1–0081.

Burns

(3) *Chemical burns* (such as might result from contact with the shell natron used in helium-oxygen diving) deserve special comment. Shell natron is extremely caustic (alkaline, like lye). Even small particles, or water that has been in contact with the material, can cause serious burns. In the event of such burns:

(*a*) Flush the affected area immediately with large quantities of water. Make sure that any adhering particles of material are washed off or otherwise removed at once.

(*b*) Use only *weak acids* like vinegar in attempts to neutralize the material. (Vinegar is preferable to boric acid solution because it is not poisonous if taken by mouth. The best neutralizing agent to have at hand is diluted vinegar, 1 part vinegar to 1 part water, or the equivalent strength of dilute acetic acid: 2 percent.)

(*c*) *Use only large quantities of water for burns involving the eye.*

(*d*) Follow thorough washing with application of dressing of sterile dry or vaseline-impregnated gauze. (Boric acid ointment should be used only on small areas.) Use sterile mineral oil in the eye.

(*e*) Notify medical officer at once.

NOTE.—*Acid* burns are rare in diving. If they occur, follow the same treatment, relying mainly on flushing with large quantities of water and avoiding use of strong neutralizing agents. (For acid burns, only *weak bases* like baking soda should ever be used.)

1.6.13 BLEEDING

Causes

(1) Bleeding from mouth, nose, or an ear is a sign of some minor or major accident rather than a condition in its own right. Conditions causing it are discussed elsewhere. The following are conditions to consider in the situations indicated, but they are not invariable diagnoses.

(2) Bleeding from mouth:

(*a*) Unconscious diver, blood not frothy:

1. Convulsion with bitten tongue (inspect tongue for injury). Oxygen poisoning is most common cause, but convulsion can also occur in other conditions.

(*b*) Unconscious diver, frothy blood:

1. Lung rupture and air embolism.

2. Severe thoracic squeeze (most likely in deep skin diving).

(*c*) Frothy blood, diver otherwise in good condition except possible difficulty breathing:

1. Mild lung squeeze in deep skin diving.

2. Possible lung damage due to breathholding on ascent but *without* air embolism.

(*d*) Diver in good condition, non-frothy blood:

1. Usually, drainage from eustachian tube following middle ear squeeze.

2. Condition related to bleeding from nose.

(3) Bleeding from nose is usually associated with bleeding from mouth (see preceding paragraph) or comes from:

(*a*) Drainage from eustachian tube after middle ear squeeze.

(*b*) Drainage from sinus following sinus squeeze.

(*c*) *Nosebleed* from too vigorous blowing in an attempt to pop ears on descent, or unrelated cause.

(4) External bleeding from ear usually signifies:

(*a*) Rupture of eardrum due to inability to equalize during descent, or

(*b*) Ear canal damage due to external ear squeeze if diver was wearing hooded suit. (Rupture may be, but is not necessarily, present also in these cases.)

Treatment

(5) Treatment depends on cause and on the condition of diver. Frequently, no treatment is needed. Inform medical officer promptly if serious condition is suspected or if bleeding is profuse or shows no sign of stopping.

NOTE.—Bleeding from any open wound should be stopped promptly. (See table 1–26.)

TABLE 1–26

FIRST AID

Proper first aid can make the difference between life and death. Every diver should have a good knowledge of first aid, and *Standard First Aid Training Course*, NAVPERS 1–0081 should be kept handy wherever diving is done. This table is only a reminder of some vital points.

1. If nature of injury is not certain, check victim over quickly but carefully.
   a. Is he breathing?
   b. Is he bleeding?
   c. Any broken bones?
   d. Any sign of head injury?
2. Start artificial respiration if breathing has stopped. (See tables 1–23, 1–24, and 1–25.)
3. Stop bleeding. (If bleeding is very heavy, do this before *anything* else.)
   a. Try direct pressure with snug bandage.
   b. Use "pressure points."
   c. Apply tourniquet only as last resort.
4. If victim is a diver, consider possible need for immediate recompression. (See table 1–20.)
5. Combat shock.
   a. Know its signs:
      1) Paleness
      2) Skin cold and moist
      3) Weak, rapid pulse
      4) Fainting
   b. Remember that shock is a serious danger in almost any injury or severe illness. Take steps to prevent or treat it:
      1) Keep victim flat (head slightly lower than rest of body—except with head injury or if this causes trouble breathing).
      2) Keep warm by covering.
      3) Try to calm him; do what you can to lessen pain.
      4) If conscious, able to swallow, not vomiting, and with no abdominal injury, give as much *shock solution* as victim will take. (1 teaspoonful table salt and ½ teaspoonful baking soda per quart of water.)
   c. If shock is present, give plasma or plasma-substitute intravenously if possible.
6. Take immediate action in *poisoning* or *chemical burns*.
   a. In poisoning.
      1) If victim is conscious and poison is not a corrosive one, get him to vomit.
      2) Dilute poison in stomach (but give nothing by mouth if unconscious), and repeat vomiting.
      3) Determine nature of poison, give proper antidote.
   b. In chemical burns.
      1) Flush with large quantities of water.
      2) Avoid strong "neutralizers."
7. Send for medical help, or get victim to hospital or dispensary, in anything but most minor conditions.
   a. If another person is present, send him at once for medical assistance.
   b. Do not move victim unless you can do it properly. (See 8.)
8. Handle any injured person with care.
   a. If victim must be moved, use stretcher (or improvise one). Transfer him to it with as little movement as possible. Use special precautions with possible back or neck injuries.
   b. Splint broken bones temporarily on the spot.
9. Cover wounds and burns.
   a. Avoid handling; do not try to clean or disinfect (let the doctor do this).
   b. Use sterile dressing (or cleanest cloth available) and apply bandage over it.
10. In head injuries.
   a. Keep patient lying down and quiet.
   b. Secure medical attention even if injury seems slight.
11. In convulsions:
   a. Put something soft between teeth.
   b. Try to prevent injury, but do not restrain movements.
12. In collapse in hot surroundings:
   a. Check for signs of heatstroke.
      1) Skin hot, dry.
      2) Pulse rapid but full.
      3) High body temperature.
   b. If signs are present,
      1) Get medical assistance.
      2) Take immediate steps to lower body temperature.

1.6.14 OVEREXERTION AND EXHAUSTION (See art. 1.3.5, pars. 31 to 34.)

Causes

(1) Every man's ability to do hard work has definite limits even under the best conditions. Many different situations can lead a man to try to exceed these limits. They include:

(*a*) Working against strong currents or on unusually muddy bottom.

(*b*) Diving job requiring heavy exertion or unusually prolonged task.

(*c*) Wasting effort early in dive.

(*d*) Efforts to free himself when fouled, particularly if efforts are ill planned and ineffectual.

(2) Several conditions can reduce a man's ability to do hard work, for example:

(*a*) Excessive breathing resistance in self-contained breathing apparatus.

(*b*) Carbon dioxide buildup due to:

1. Inadequate helmet ventilation.
2. Failure of absorption system in scuba.
3. Excessive dead space.
4. Excessive use of "controlled breathing."

(*c*) Bad air, breathing mixture too low in oxygen, carbon monoxide poisoning.

(*d*) Excessive cold or inadequate protection.

Symptoms

(3) Symptoms of overexertion and exhaustion include:

(*a*) Extreme fatigue.

(*b*) Increasing weakness.

(*c*) Labored breathing.

(*d*) Anxiety and tendency towards panic.

Treatment

(4) Diver should:

(*a*) Stop and rest if possible.

(*b*) Inform buddy or tender.

(*c*) Terminate dive if resting fails to help.

(*d*) Surface when practical, observing proper rate of ascent and decompression stops if required.

(5) Buddy should:

(*a*) Render all possible assistance.

(*b*) Get diver to surface properly; support him at surface.

(6) Surface personnel should:

(*a*) Give ample help in getting diver aboard.

(*b*) Provide rest, warmth, and nourishment.

Prevention

(7) Prevention is the most important aspect and should almost always be possible.

(*a*) Know your own limits and stay within them.

(*b*) Discontinue dive if it exceeds your powers.

(*c*) Use good gear in good condition.

(*d*) Concentrate on training and experience to help eliminate panic.

(*e*) Employ weights and line when working in strong current.

(*f*) Stop to rest and ventilate before becoming overfatigued.

(*g*) Wear adequate cold-water protection.

1.6.15 SYNCOPE (FAINTING) (See art. 1.3.3, par. 15.)

1.6.16 LOSS OF COMMUNICATION

(1) Loss of contact either between a self contained diver and his buddy or between a surface-supplied diver and his tender is a potentially serious matter. It can be the first sign of a hazardous mishap, or can sometimes in itself lead to a serious accident.

Causes

(2) In self contained diving, loss of visual or other means of contact between swim buddies may mean:

(*a*) Simple inattention has resulted in separation, and both divers are all right.

(*b*) One diver has had to surface for some reason and was unable to communicate this to the other.

(*c*) One diver is in trouble underwater.

(3) In surface-supplied diving, similarly, loss of communication can mean either that the diver has suffered some disabling mishap or merely that the *means* of communication have failed. However, if it cannot be shown clearly that it is only a failure of the means of communication, loss of contact must be presumed to mean that the diver has lost con-

sciousness; and appropriate action must be taken. In this case, it is extremely important that the actions should involve minimal risk of harming the diver.

Action

(4) If swim buddies lose contact, they must immediately make an attempt to locate each other so that the worst possibilities can be ruled out or necessary action can be taken as soon as possible. Unless you will lose an immediate opportunity to locate and assist your buddy, surface and notify the diving supervisor of the situation. If both divers are all right and do this, he will orient them. If one diver is in trouble, the diving supervisor will be able to muster all available assistance.

(5) In diving with deep sea rig, if *telephone communication* is lost:

(*a*) Try *hand signals* at once. (Remember, however, that these can also fail for reasons other than disability of diver.)

(*b*) Note whether normal amount of air is coming up from diver. If circumstances would normally permit his bubbles to be seen and they are not, or if they are not in normal quantity, this is a strong indication that diver is in trouble.

(*c*) Listen for sounds from helmet.

1. If none are heard and bubbles are visible, this is near proof that diver-tender circuit is dead. *Diver may be all right.*

2. If sounds are heard, this does not necessarily mean that diver can hear tender's requests for reply, but it strongly increases suspicion that diver is in trouble.

(6) If you have indicated that the telephone circuit is dead and know a likely reason for temporary failure of hand signals, and if diver's bubbles indicate normal ventilation, some delay to wait for spontaneous communication from diver may be justifiable. Be sure that standby diver is ready. Have recompression chamber ready if one is available.

(7) It is usually safer to assume that diver is unconscious or otherwise rendered helpless and to take proper action without delay.

(*a*) In most cases, the safest procedure is to *send the standby diver down to investigate.*

(*b*) Where use of a standby diver is impossible or is considered unwise, follow this procedure:

1. If depth and time of exposure are such that *decompression is not required*, bring diver directly to surface at a speed not in excess of the normal rate. Be prepared for the possibility that this may cause blowup.

2. If exposure permits *surface decompression* without water stops, bring diver up at normal rate and place him in chamber at once.

3. If depth and duration of exposure requires decompression in the water, bring diver up at normal rate to *first decompression stop required* and repeat efforts to communicate with him. (If possible, have standby diver meet him at this stop and evaluate his condition.) If communication remains impossible (and if standby has not ascertained that diver is all right), bring diver to surface at normal rate regardless of his need for decompression and place him in recompression chamber immediately. Treat from this point as a case of blowup. (See art. 1.5.6.)

4. If no chamber is available, use standby diver to tend man at stops until decompression is completed.

(*c*) From the outset, the standby diver has the advantage of controlling the victim's air and thus reducing the danger of blowup. In many cases, as where the diver is also fouled, the standby will be essential. In cases like simple asphyxia or carbon dioxide blackout, having the standby ventilate the victim's helmet may be all that is required to remedy the situation.

Treatment

(8) Treatment of the diver in situations like those described in preceding paragraphs depends primarily upon his condition when he is brought to the surface. If he remains unconscious, follow the steps given in table 1–20.

Prevention

(9) One of the best means of avoiding loss of contact is to communicate frequently and regularly during the dive. In self-contained diving, this clearly applies to whatever means of communication is being used by swim bud-

dies. In surface-supplied diving, both hand signals and telephone communication should be used at frequent intervals wherever possible. This serves to keep the tender informed of the diver's progress and condition, makes failure of the means of communication or an accident to the diver apparent promptly, and often permits the possible causes of loss of contact to be identified and rectified before a difficult problem develops.

1.6.17 ENVIRONMENTAL HAZARDS

Exposure to climate

(1) *Planning.*—In planning diving operations, a study must be made of weather conditions in the area of operations, particularly:

(*a*) Air temperature.

(*b*) Water temperature.

(*c*) Currents, surface winds, and storm frequency.

This information can be obtained from Fleet Intelligence Centers and Fleet Weather Centers. Based on this information, preparations must be made to care for the diver in any region from polar to equatorial. The range of temperatures in which a diver may operate without protection of some kind is very limited.

(2) *Diving craft.*—Ships or craft must be fitted to give the diver protection from cold, rain and snow, spray, and sun. Diving craft must be seaworthy enough to maintain station under moderate weather conditions when operating in rivers, bays, or the open sea. First aid and recompression equipment should be installed. In recent years, requirements for diving operations have ranged from mountain lakes at 10,000 feet altitude, remote areas in desert regions, to reef-bound sections of coast line inaccessible to surface craft. In such instances, an inflatable rubber boat may be the only craft usable by divers. Seaplanes have frequently been used in the transport of Underwater Demolition Team (UDT) divers in the Arctic, and have also been used to support diving operations in tropical waters. A seaplane fitted with a portable recompression chamber, resuscitator, and inflatable boats could be an excellent craft for the transport and support of divers.

Exposure to cold (See art. 1.3.13.)

(3) Excessive cold can impair the performance of a diver and his ability to remain underwater more readily than almost any other factor. The self contained diver is unusually susceptible to cold because the bulk and buoyancy of insulating material limits the protective clothing he can wear. Any diver in cold water has a particular problem in maintaining the sense of touch and ability to work with his hands. Loss of body heat causes an increase in metabolism and breathing. If a scuba diver is uncomfortably cold, especially if shivering, he will consume his gas supply more rapidly than if he were comfortable.

(4) *Tolerance.*—Chilling may be experienced in water as warm as 80° F. if prolonged immersion without vigorous exercise is involved. Ordinarily, 68° F. may be tolerable for a reasonable period without protection if the diver is active. Down to about 60° F. just a suit of woolen underwear may suffice for a working diver. Below this temperature, or at rest, more extensive protection is required. Article 1.3.13 and figure 1–31 present some approximate relationships. Individuals vary considerably in their tolerance. As indicated, the work rate makes a large difference in ability to stand cold water.

(5) *Prevention.*—Adequate clothing, underwear, and specially designed swim suits are the best protection. A diver should leave the water as soon as he feels chilled. Hard work or exercise will increase blood circulation and warm the diver temporarily. The extremities, head, hands, and feet should be kept as warm as possible. A diver with cold hands feels cold all over.

(6) *Treatment.*—When a diver emerges from a chilling dive, make it possible for him to dry himself and put on warm, dry clothes at once. Use hot soup or coffee as warming agents. Avoid alcohol until the diver starts to warm up. Then, a small amount is unobjectionable and has a favorable morale effect. If shivering persists, try a brief period of vigorous exercise after donning dry clothes.

Exposure to heat

(7) *Cause.*—Excessively warm water is not often encountered, but it can present a serious problem. Exercise in water warmer than 86° F. will cause overheating, and 96° F. is the maximum tolerable for any length of time at rest. Water temperatures in this range do occur, and they impose serious limitations on diving.

(8) *Prevention.*—In tropical climates with water temperatures above 86° F., diving should be planned to commence in the early morning hours (0400–0900) or be conducted in the evenings or at night.

Sunburn (See art. 1.3.16.)

(9) *Cause.*—Sunburn is caused by exposure to the direct or reflected rays of the sun. Sunburn can occur even when light clouds or fog partially obscure the sun. It can be aggravated by wind, which causes chapping of the skin. Sun glare can harm eyesight.

(10) *Prevention.*—If possible, divers should be gradually exposed to the sun until tanned. Protective clothing and ointments will prevent serious burns. Sunglasses should be worn to prevent glare damage to the eyes. It is the responsibility of each individual and those in charge of an operation to guard against sunburn. Avoid excessive exposure in any case.

(11) *Treatment.*—Sunburn may be treated by application of ointments or as directed by the corpsman or medical officer. Severe cases may require hospitalization.

Wave motion—seasickness

(12) *Cause.*—The sea is constantly in motion. Divers are frequently obliged to spend extended periods of time embarked in small craft in the open sea. Prolonged exposure to the motion of the sea can cause severe cases of seasickness. In addition, scuba divers at times will have to remain at or close to the surface during dives, and in some operations there may be significant wave motion at the diving depth. Working beneath smaller ships in rough water can be a problem, as can spending a period of decompression in similar circumstances. Even mild seasickness can produce great loss of efficiency. Vomiting during the use of scuba is a serious matter.

(13) *Prevention.*—Men who are unusually susceptible to seasickness will generally eliminate themselves from diving. This is a factor that demands consideration in the selection process. Use of preventive medication may be essential in some situations. The usual side effects of such drugs should be considered. Divers should control their diet rigidly prior to a dive and be sure to chew their food thoroughly.

Surf, surge, currents, and tides

(14) Tides and currents can interfere with the diver's work, produce unusual fatigue, or even carry him away. Surges and surf may cause physical injury by dashing him against rocks. Rough water at the surface may put him in danger especially if his breathing apparatus is not functioning.

(15) Any situation is unfavorable if the diver must cover a considerable distance on the surface before reaching safety in case of an emergency. This is particularly true in rough water, heavy surf, or strong currents. Such circumstances must, of course, often be accepted in combat situations. Self contained diving is impractical, if not impossible, in currents in excess of 1½ knots without propulsive or stabilizing aid for the diver. However, self contained divers can work in stronger currents if holding to a descending or search line. Strong currents also affect the surface-supplied diver's ability to perform his tasks.

Bottom conditions

(16) On reaching the bottom or the working depth, divers frequently encounter conditions that reduce their effectiveness or increase the hazards of diving. Decreased water visibility due to turbidity or lack of light is one of the most frequent difficulties. The character of the bottom itself is important (see art. 1.4.6). Presence of obstructions or other possible causes of fouling (see art. 1.6.11) requires particular caution especially when visibility is poor.

1.6.18 MARINE LIFE

(1) Despite the thousands of forms of animal and plant life to be found in the ocean, relatively few constitute a real hazard to the diver. However, some species are dangerous; and these may in some instances inflict serious wounds, poisoning, or violent death. Fortunately, most difficulties can be prevented if the diver is made sufficiently aware of the problem. Marine life hazards of concern to the diver consist of two general kinds: those that produce wounds and those that inflict stings.

Sharks

(2) Among the marine animals that produce wounds, the most generally feared are sharks. There are more than 225 species of sharks, but only a score or more are believed to attack men. Information concerning the more important of these is summarized in tables 1–27 and 1–28 and the more readily recognized types are pictured in figures 1–36A and 1–36B.

(3) It is difficult to make specific statements concerning the actual risk of attacks by sharks. As a whole, the experience of divers indicates that the risk is almost negligible; but the possibility does exist. A number of general statements about the problem can be made:

(*a*) The danger of shark attacks is greatest in tropical and subtropical seas, between 30° north and 30° south of the Equator. Particularly dangerous areas are Queensland, Australia, and South Africa. Most attacks have occurred when the temperature of the water was greater than 70° F. The peak month of attacks is January, and the hour of greatest risk is between 1500 and 1600. However, sharks feed at all hours, and particularly so at night.

(b) Sharks are attracted by blood, carrion, flashing of light, colored materials, thrashing about, explosions, or unusual noises. When they are hunting in packs and food or blood is present, sharks become highly excited and may radically alter their usual habits. It is at times like this that the greatest danger is encountered, and shark repellents are useless. Sharks will frequently single out an individual in a crowd and will ignore others who may attempt to rescue him. Several men together, however, are in a better position to ward off sharks than a lone swimmer.

(*e*) Various suggested methods of chasing sharks away, like banging rocks together, blowing bubbles, shouting, splashing, and such are of questionable value when the shark really means business. They may even attract the shark. Movement should be slow and purposeful. It has been demonstrated that if the individual is not wounded, the sharks may leave if he remains perfectly still. It may be necessary actually to shove the shark away with the use of a "shark billy"—a large stick that is carried for this purpose—or some other object. Attempts to wound the shark are usually useless and may even aggravate the situation; but if such action appears necessary, hit the shark on the snout, eyes, or gills.

(*d*) In general, dark colored clothing and equipment are preferable to light-colored articles. The use of explosives can usually be expected to attract sharks in large numbers.

(*e*) The fatality rate from actual shark attacks has been estimated at more than 80 percent. Bites are severe, and death is due to massive bleeding and shock.

(*f*) When sharks are present, divers should not dangle arms or legs in the water from the surface. They should get in or out of boats quickly. An injured swimmer should not remain in the water.

Barracudas

(4) There are about 20 species of barracuda. The great barracuda (see fig. 1–37) is one of the most dangerous. These are widely distributed throughout the tropical and subtropical waters of the world. The great barracuda is found in the West Indies and Brazil, north to Florida, and in the Indo-Pacific from the Red Sea to the Hawaiian Islands.

(*a*) Great barracudas can attain a length of 6 to 8 feet. They have large mouths filled with enormous knifelike canine teeth, are swift swimmers and strike rapidly and fiercely. In some areas they are more feared than sharks. They are attracted by anything which enters the water, particularly bright colored objects. They will follow divers by the hour but have seldom been known to attack.

TABLE 1–27.—*Marine life—sharks*

Name	Danger [1]	Maximum size	Appearance [2]	Behavior	Where found
White shark	4+	30 feet	Slaty brown to black on back.	Savage, aggressive	Oceanic; tropical, subtropical, warm temperate belts, especially in Australian waters.
Mako shark	4+	30 feet	Slender form, deep blue gray on back.	Savage	Oceanic, tropical, and warm temperate belts.
Porbeagle shark	2+	12 feet	Dark bluish gray on back.	Sluggish except when pursuing prey.	Continental waters of Northern Atlantic. Allied forms in North Pacific, Australia and New Zealand.
Tiger shark	2+	30 feet	Short snout, sharply pointed tail.	Can be vigorous and powerful.	Tropical and subtropical belts of all oceans, inshore and offshore.
Lemon shark	2+	11 feet	Yellowish brown on back, broadly rounded snout.	Found in salt water creeks, bays, and sounds.	Inshore western Atlantic, northern Brazil to North Carolina, tropical West Africa.
Lake Nicaragua shark.	2+	10 feet	Dark gray on back.	Found in shallow water.	Fresh water species of Lake Nicaragua.
Dusky shark	1+	14 feet	Bluish or leaden gray on back.	Found in shallow water.	Tropical and warm temperate waters on both sides of Atlantic.
White-tipped shark.	3+	13 feet	Light gray to slaty blue on back.	Indifferent, fearless.	Tropical and subtropical Atlantic and Mediterranean. Deep offshore waters.
Sand shark	2+	10 feet	Bright gray-brown on back.	Stays close to bottom.	Indo-Pacific, Mediterranean, tropical West Africa, South Africa, Gulf of Maine to Florida, Brazil, Argentina.
Gray nurse shark.	3+	10 feet	Pale gray on back	Swift and savage	Australia.
Ganges River shark.	4+	7 feet	Gray on back	Ferocious, attacks bathers.	Indian Ocean to Japan, ascends fresh water rivers.
Hammerhead shark.	4+	15 feet	Ashy-gray on back, flat, wide head.	Powerful swimmers.	Warm temperate zone of all oceans including Mediterranean Sea, out at sea or close inshore.

[1] 1+ means minimum danger, 4+ means maximum danger.
[2] All sharks listed are some shade of white on lower half.

TABLE 1–28.—*marine life—other forms*

Name	Danger	Maximum size	Appearance	Behavior	Where found
Great barracuda	4+	6–8 feet	Long, slender, large mouths.	Swift, fierce, attracted easily.	Tropical and subtropical waters, West Indies, Brazil, northern Florida, In the Indo-Pacific from Red Sea to Hawaiian Islands.
Groupers	2+	12 feet, 700 lbs.	Bulky type of body.	Curious, bold, voracious feeders.	Around rocks. caverns, old wrecks.
Moray eels	1+	10 feet	Long, narrow, snakelike.	Attack when provoked.	Tropical and subtropical, bottom dwellers.
Killer whales	4+		Jet black head and back, white under parts.	Ruthless, ferocious.	All oceans and seas, tropical to polar. *Caution*—leave water immediately if sighted.
Sea lions	1+		Resemble seals but larger.	Curious, fast swimmers.	Northern waters.
Sea urchins	2+		Small spiny animals.	Spines, needle sharp, small venomous pincers.	Tropical and temperate zones, ocean floor on rocks and coral reefs.
Corals	1+			Extremely sharp	Tropical and subtropical waters.
Barnacles, mussels.	1+			Deep cuts	Rocks, pilings, wrecks.
Giant clams	2+	Several hundred pounds.		Traps legs and arms between shells.	Abound in tropical waters.
Portuguese man-o-war.	3+	6 in. in diameter.	Tentacles up to 50 feet long.	Stings with cells on tentacles.	Tropical waters.
Sea wasp	4+		Tentacles up to 50 feet long.	Stings with cells on tentacles.	Northern Australia, Philippines, Indian Ocean.
Octopuses	2+	25 feet	Arms radiating from head.	Hold with tentacles, bite also.	Underwater caves.
Cone shells	2+		Colorful shells	Penetrates skin with venom filled teeth on proboscis (trunk).	Widespread.
Horned sharks	1+		Spines anterior to back fins.		
Stingrays	1+	Several feet	Spine on top of tail, flat body.	Drives spine into leg when stepped on.	Tropical to temperate waters.
Catfish	1+		Venomous dorsal and pectoral spines.		Tropical and temperate, mostly fresh water, some marine.
Weeverfish	1+		Venomous dorsal and pectoral spines.	Toxic to the nervous system and blood, extremely painful.	Eastern Atlantic and Mediterranean.
Scorpionfish	1+		Venomous back anal, and pelvic spines.	Toxic to the nervous system and blood.	Tropical and temperate.
Sea snakes	3+	9 feet	Resembles snakes, venomous fangs.	Boldness varies	Tropical Pacific and Indian Ocean. River mouths to far at sea.

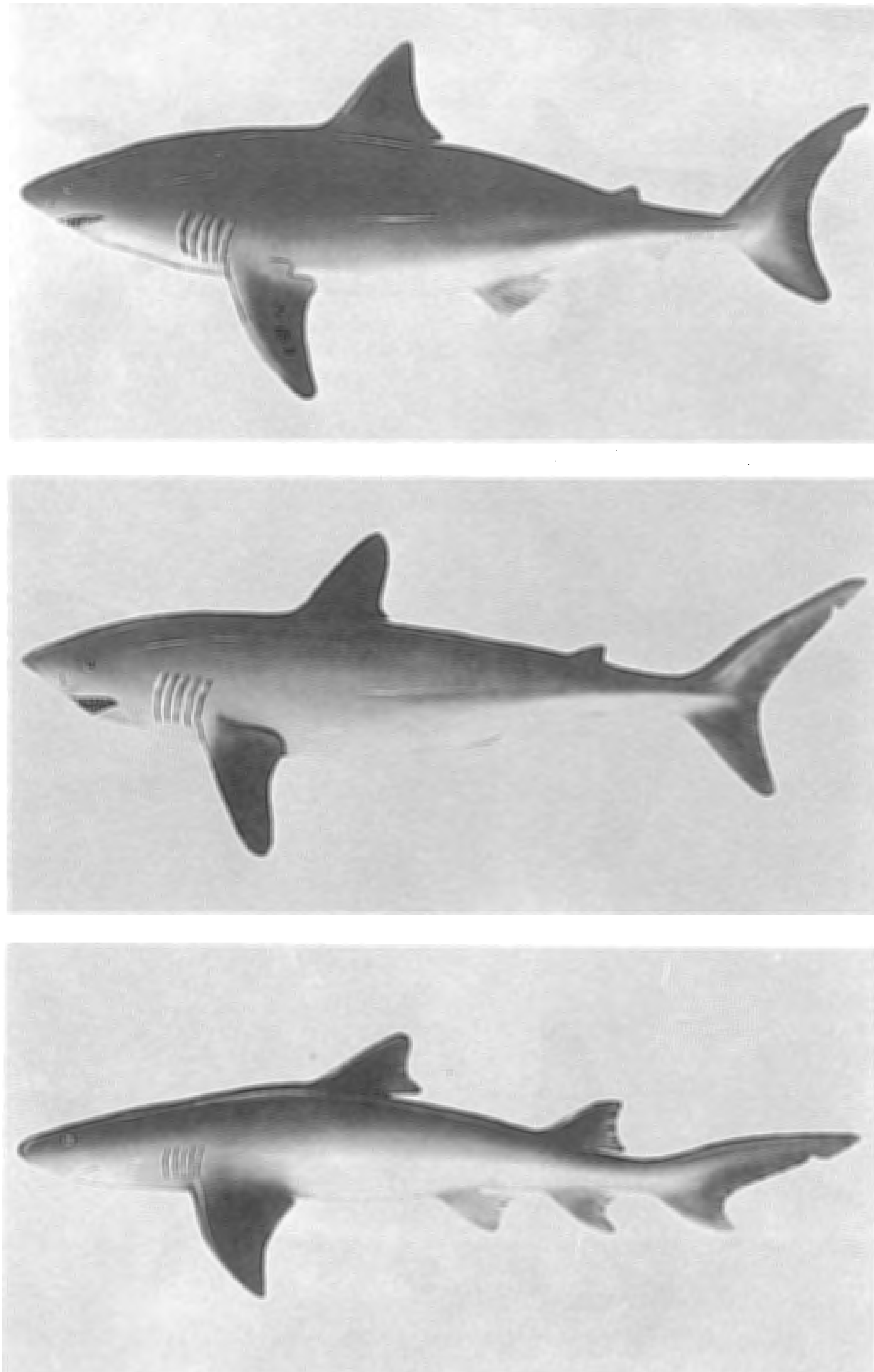


FIGURE 1-36A.—White shark, mako shark, tiger shark.

557535 O - 60 - 12

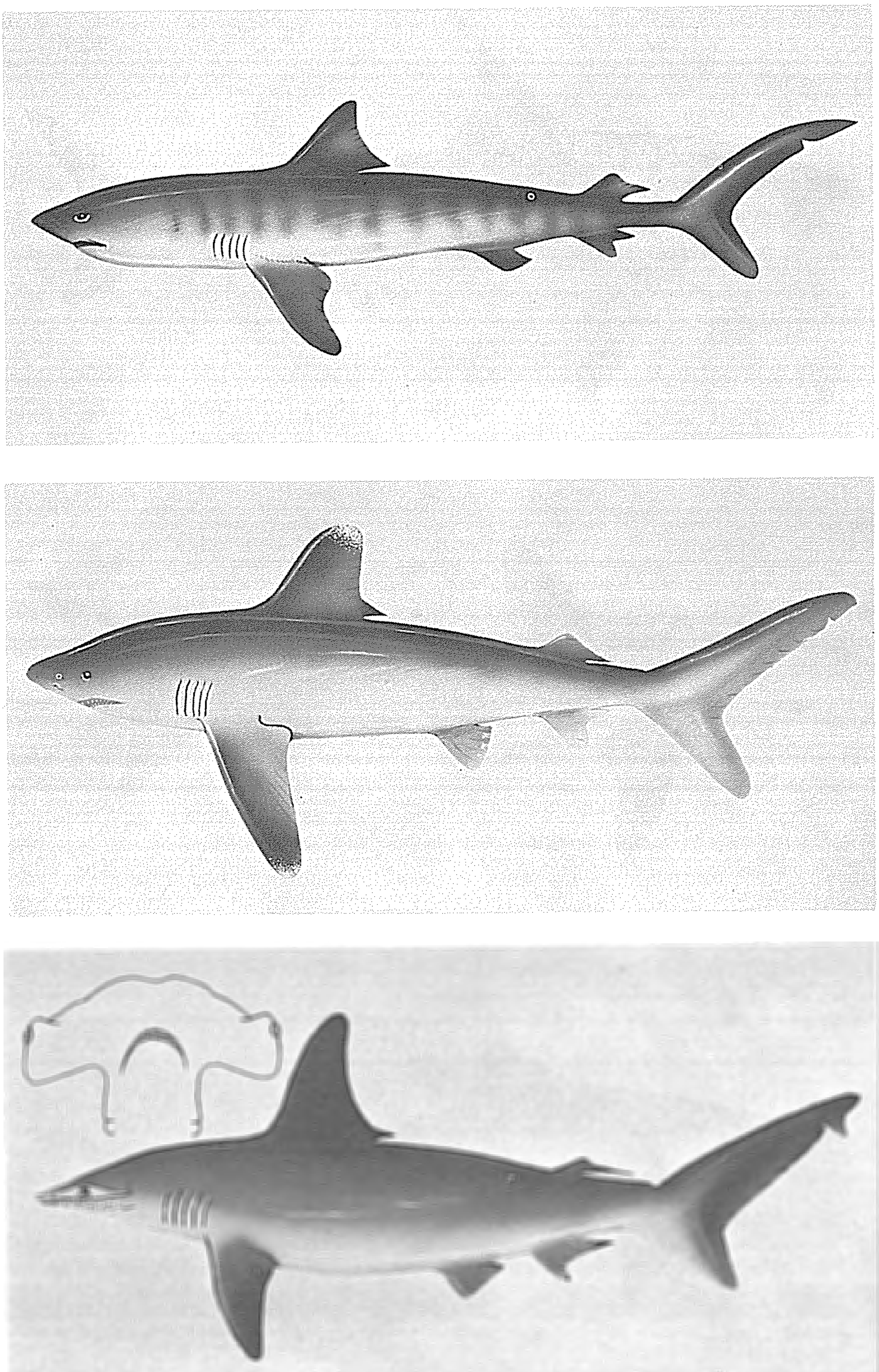


FIGURE 1–36B.—Lemon shark, white-tipped shark, hammerhead shark.

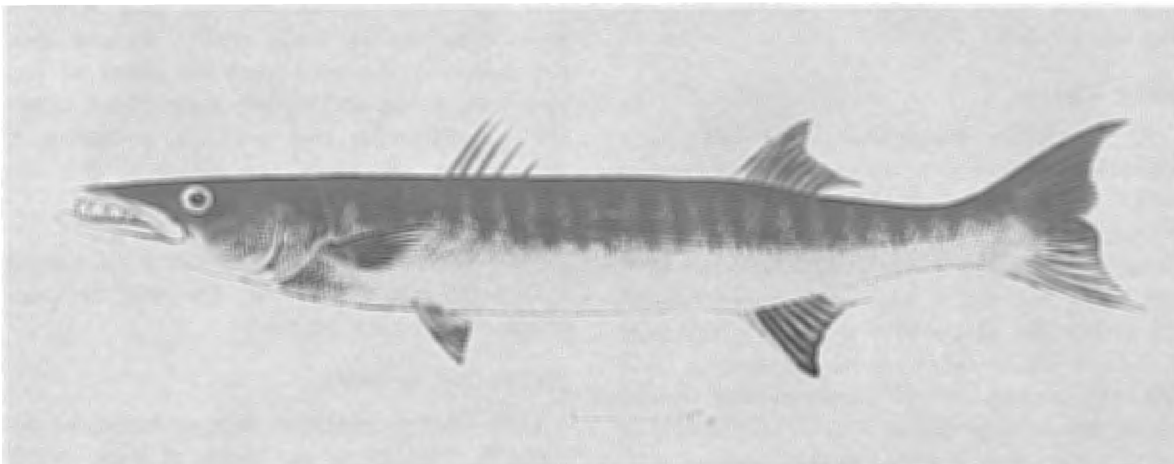


FIGURE 1–37.—Great barracuda.

(*b*) Barracuda wounds can be differentiated from those of a shark since the former are straight cuts, where as those made by the shark are curved like the shape of their jaws. The barracuda will strike at any speared fish that a diver may be carrying. They should be treated with respect.

Groupers

(5) Some of the giant groupers attain a length of 12 feet and a weight of more than 700 pounds. They are frequently found lurking around rocks, caverns, old wrecks, etc. They are curious, bold, and ravenous feeders. Their feeding characteristics coupled with their large size make them a potential danger to the skin diver. Several fatal attacks have been reported.

Moray eels

(6) Moray eels (see fig. 1–38) are seldom found except in tropical and subtropical seas. They may attain a length of 10 feet. Morays are bottom dwellers, commonly found lurking in holes and writhing through crevices under rocks and corals. They seldom attack unless provoked, but provoking them is not difficult. When encroaching upon their habitat by reaching into dark holes and crevices, one should move with great caution. The moray's narrow jaws are armed with strong knifelike or crushing teeth which can inflict severe lacera-

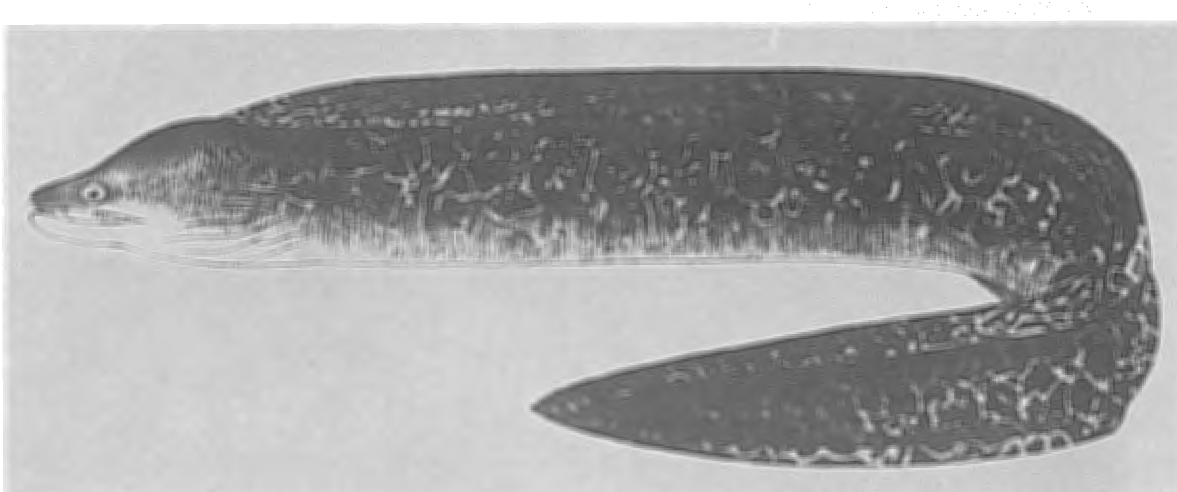


FIGURE 1–38.—Moray eel.

tions. The jaws frequently maintain their grip until death.

Killer whales

(7) The killer whale (see fig. 1–39) has a reputation of being a ruthless and ferocious beast. It is found in all oceans and seas, tropical and polar alike. The killer whale is characterized by a bluntly rounded snout, a high black top fin, a white patch just behind and above the eye, and the striking contrast of the jet black color of the head and back with the snowy white underparts. Killer whales hunt in packs of 3 to 40 individuals, preying on other warm blooded marine animals. They are fast swimmers, will attack anything that swims, and have been known to come up under ice flows and knock seals and people into the water. If a killer whale is seen in the area, the diver should get out of the water immediately.

Sea lions

(8) Sea lions are curious, fast swimmers, and have been known to nip at skin divers. Keep away from sea lions especially during breeding time or when young are in the water.

Sea urchins

(9) Sea urchins (see fig. 1–40) abound on the ocean floor and cling to rocks in tropical and temperate zones; they are also found in great numbers in coral reefs. Injury from the spines is the most common effect of contact with a sea urchin, but some types have a venom apparatus and produce poisoning as well. (See par. 18 of this article.)

Corals

(10) Corals can also produce both wounds and poisoning. They are discussed in paragraph 15 of this article.

Barnacles, mussels

(11) Certain shellfish, such as barnacles and mussels, that grow on rocks, pilings, wrecks and the like, are sharp and can cause deep cuts when a diver is forced against them.

Giant clams

(12) Tridachna, or so-called giant or killer clams, abound in tropical waters. Some of them attain huge proportions, weighing several hundred pounds. Although accidents from them are rare, one should learn to recognize them and avoid catching a foot or hand between the two valves. Drownings have occurred from divers accidentally stepping into the open shells and becoming trapped. In order to release the victim, a knife must be inserted between the shells to sever the clam's adductor muscle.

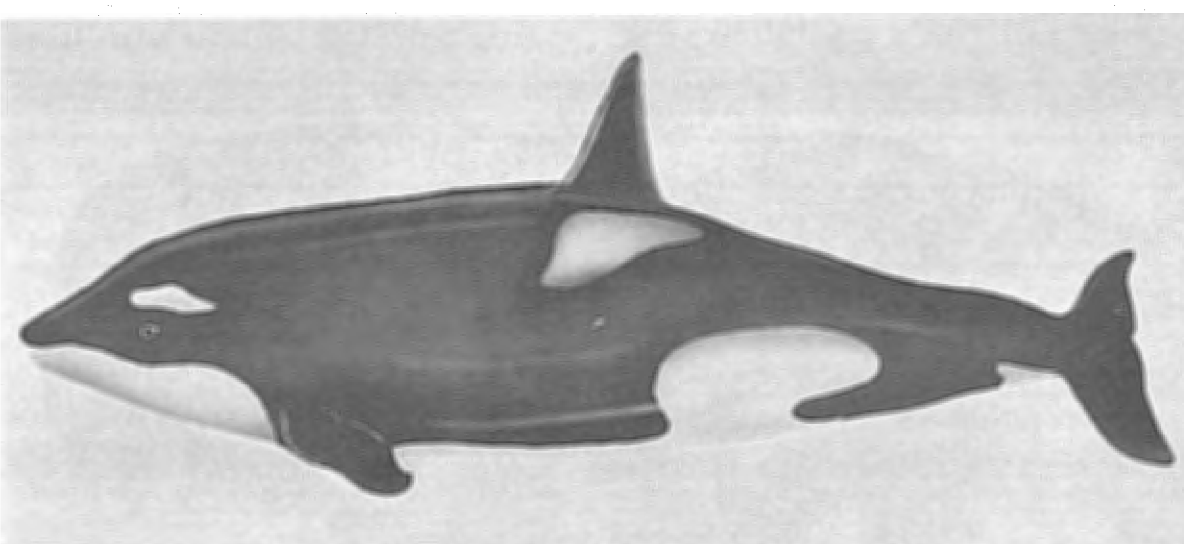


FIGURE 1–39.—Killer whale.

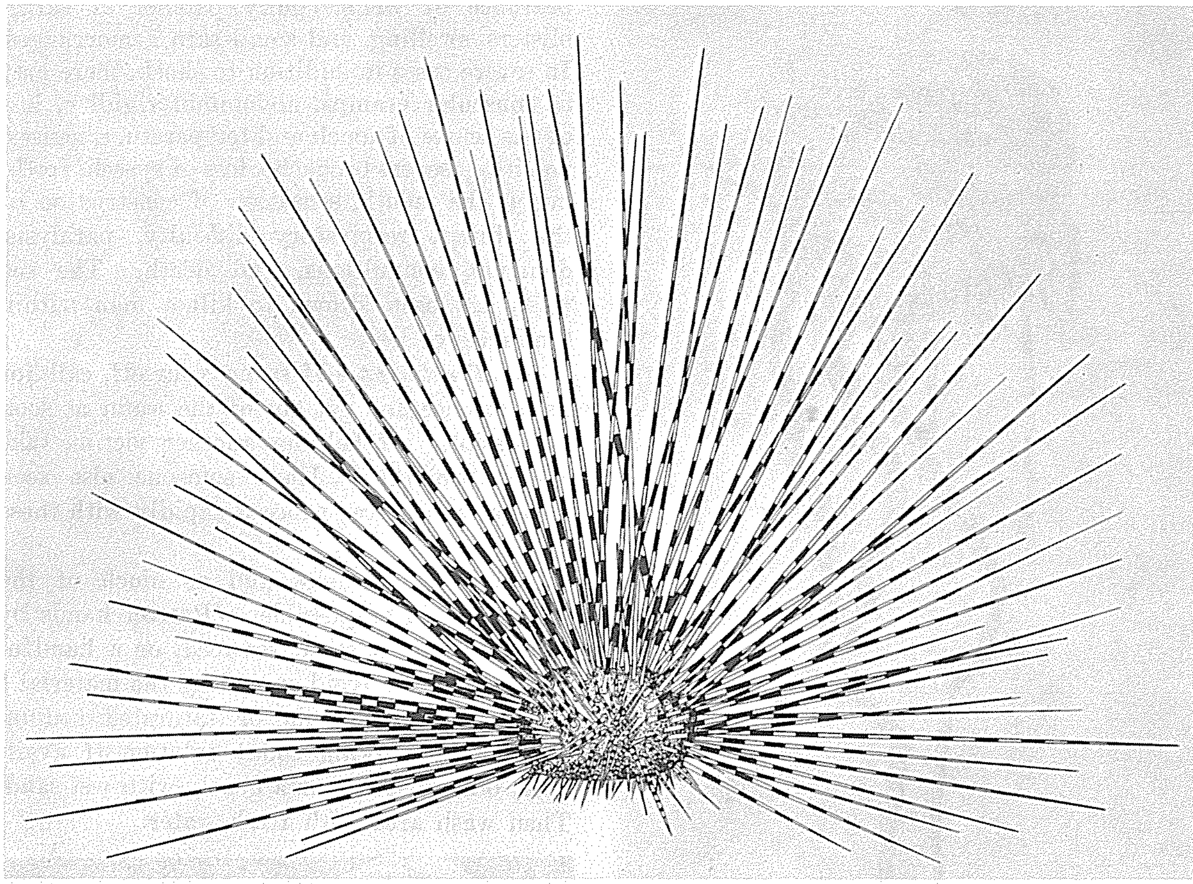


FIGURE 1-40.—Sea urchin (long-spined).

Animals that inject venom

(13) Venomous marine animals are for the most part slow moving or tend to remain in one spot. In some instances, as with stonefish, scorpionfish, and stingrays, they are well-camouflaged and exceedingly difficult to distinguish from their surroundings. In other instances they are spectacularly colored and attract attention, as in the case of zebrafish and some jellyfish. Favorite colors of many venomous creatures are combinations of black and orange.

Jellyfish

(14) Forms of marine life commonly clumped under the term "jellyfish" are found in large numbers in all oceans, in bays, and in the tidal portions of rivers. At times, they concentrate to such a degree that contact by a swimmer is almost inevitable.

(*a*) The stings of the most dangerous types, the Portuguese man-of-war (see fig. 1-41) and the sea wasp (see fig. 1-42) can have extremely serious effects. Both of these organisms are rather small in size, seldom exceeding 6 inches in diameter of the central portion. The tentacles may reach a length of 50 feet. The Portuguese man-of-war is largely an inhabitant of tropical waters. The sea wasp is found in the waters about northern Australia and the Philippines and in the Indian Ocean. The sea wasp is considered the most dangerous type.

(*b*) *Method of stinging.*—Stinging is produced by a series of specialized cells which are located largely on the tentacles. Contact with these cells sets off a trigger-like mechanism which ejects a tiny thread tube from a venom filled cell. Many thousands of these micro-

FIGURE 1–41.—Portuguese man-of-war.

scopic cells are to be found on the tentacles of a single jelly fish.

(*e*) *Symptoms.*—The symptoms of jellyfish stings vary according to the species of jellyfish, the extent and duration of contact, the site of the sting, and the health of the victim. Symptoms vary from an immediate mild prickly or stinging sensation like that of a nettle sting to an intense burning, throbbing or shooting pain which may render the victim unconscious. The area coming in contact with the tentacles usually becomes red followed by the appearance of welts (puffy patches of skin), blisters, swelling, and small skin hemorrhages. In severe cases in addition to shock, there may be muscular cramps, abdominal rigidity, loss of the senses of touch and temperature, nausea, vomiting, severe backache, loss of speech, frothing at the mouth, sensation of constriction of the throat, respiratory difficulty, paralysis, delirium, convulsions, and death. The sea wasp has been known to kill a man within 5 minutes or less.

(*d*) *Treatment.*—If stung yourself, call for help at once and get out of the water as soon as possible. If helping another victim, take action promptly. Have someone else seek medical assistance; proceed rapidly with these steps;

1. Remove tentacles and as much of the stinging fluid as possible. (Protect hands by using a cloth, a stick, seaweed, or a handful of sand; try to avoid spreading the material.) Apply weak ammonia or saturated sodium bicarbonate (baking soda) solution if available; otherwise rub area gently with wet sand. Then wash area with fresh water.

FIGURE 1–42.—Sea wasp.

2. Attempt to reduce local reaction. Use cortisone ointment, antihistamine cream, or local anesthetic ointment if available. Otherwise, try olive oil, sugar, soothing lotions, or ethyl alcohol. Apply cold compresses.

3. Try to check general reaction and shock. Keep victim lying down; elevate feet. Give artificial respiration if needed. Give oral antihistamine preparation if victim is conscious.

4. Medical personnel may use the following if considered necessary: epinephrine for "allergic shock," adrenocortical preparations for local and general reaction, morphine for pain (unless respiration is depressed), careful intravenous injection of calcium gluconate for muscular cramps, and respiratory and cardiac stimulants. Intravenous fluids for shock. (Note that there is no specific antidote.)

(*e*) *Prevention.*

1. Be alert to avoid contact when possible.

2. Wear well-fitting underwear or a rubber suit especially for night operations or when jellyfish are thickly congregated.

3. Remember that tentacles of some forms stream considerable distance from "body" and that stings can be inflicted even by detached and broken tentacles or "dead" jellyfish washed up on the beach.

Corals

(15) Divers who must work about reefs frequently sustain cuts and abrasions from contact with coral formations. The injuries are generally superficial, but they are usually very slow in healing and can cause loss of much manpower in operations. While some forms of coral inflict only a dirty wound, others produce additional injury and reaction by means of stinging cells similar to those of jellyfish.

(*a*) *Symptoms.*—Even without the stinging effect, a coral wound can be unusually painful and troublesome. Especially under unfavorable living conditions, even a simple scratch, left untreated, can become a pus-forming ulcer surrounded by a painful reddened area. The initial effect of a coral sting "coral poisoning" is a violent reaction with pain and itching in and around the wound and reddening and welt-formation in the surrounding skin. Severe general reactions, like those seen with some jellyfish stings, are not frequent.

(*b*) *Treatment.*

1. Rinse area with baking soda solution or weak ammonia if available, otherwise with clean water.

2. Use cortisone ointment or antihistamine cream on the wound and give antihistamine by mouth to help reduce initial pain and reaction.

3. As soon as pain begins to subside, cleanse wound thoroughly with soap and water to remove all foreign material. Apply an antiseptic and cover wound with a sterile dressing.

4. In a severe case, give patient bed rest with elevation of affected limb. Apply kaolin poultices or wet dressings of magnesium sulfate solution in glycerine.

(*c*) *Prevention.*—Wear gloves, shoes, and other appropriate protective gear when working around coral.

Octopus

(16) While large specimens of octopus may exceed 25 feet in span, those found at usual diving depths are generally much smaller. They tend to be inquisitive rather than vicious. (See fig. 1–43.)

FIGURE 1–43.—Octopus.

(*a*) One possible danger of contact with an octopus lies in the fact that even a relatively small one might trap a diver underwater if it could get a good grip on him and a rock at the same time. Clothing like wool underwear will hinder attachment of the suction cups. Since underwater caves, crevices and wrecks are favorite haunts of the octopus, these are best avoided when possible.

(*b*) The octopus has a well-developed venom apparatus associated with its beak and produces injurious effects by biting. Symptoms include a stinging sensation with swelling, redness, and heat in the area about the wound. Death has been reported. There is no specific treatment.

(*c*) Stabbing deep between the eyes is the best method of killing an octopus.

Cone shells

(17) Cone shells. (See fig. 1–44.) Cone shells are a favorite of shell collectors because of their attractive patterns. There are more than 400 species and all of them contain a highly-developed venom apparatus. Several of the tropical species have caused human deaths. The living shell contains a slug-like animal which may crawl out. If the animal is disturbed, microscopic venom filled teeth may be suddenly moved from the inside of the animal to the proboscis (trunk), where they can be utilized as a stinging apparatus. Avoid coming in contact with the soft parts of the animal.

(*a*) *Symptoms.*—The stings are of the puncture variety. Localized ischemia (shutting-down of blood supply), cyanosis (blueness), or a sharp stinging or burning sensation, are usually the initial symptoms. Numbness and paresthesias (abnormal sensations) begin at the wound site and may spread rapidly, involving the entire body particularly about the lips and mouth. In severe cases paralysis may follow. Respiratory distress is usually absent. Coma may ensue and death is said to be due to heart failure.

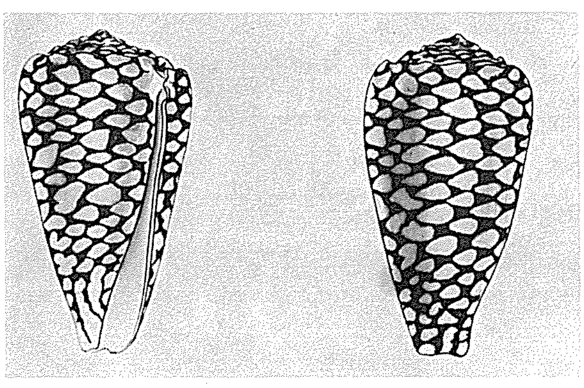


FIGURE 1–44.—Cone shell.

(*b*) *Treatment.*—There is no specific treatment. Cases of cone shell stings should be managed like venomous fish stings. (See par. 22 of this article.)

Sea urchins

(18) Sea urchins (see fig. 1–40) exist in numerous species and vary in characteristics such as length and shape of the spines. In most cases, the spines are solid, have blunt rounded tips, and do not inject venom. A few have long, slender, hollow spines that are sharp and dangerous. The sharp tips permit easy penetration, but small barbs and extreme brittleness cause the spines to break off when removal is attempted. Some sea urchins also have small, venom-carrying pincers. These are generally spread over the surface of the shell and may appear buried near the base of the spines. They are on stalks and can be extended. The pincers consist of sharp, stonelike jaws enclosed within a venom gland.

(*a*) *Symptoms.*—Penetration with the spines may result in an immediate and intense burning sensation followed by redness, swelling, and aching. Weakness of the legs, anesthesia (loss of body sensation), swelling of the face, and irregularities in the pulse have been noted. Secondary infection may result. Severe cases may produce an intense radiating pain, faintness, numbness, generalized paralysis, loss of voice, respiratory distress, and even death.

(*b*) *Treatment.*—When sea urchin spines are broken off in the skin, remove as many as possible with forceps, then cleanse the area, and cushion it with a large, loose dressing. If any evidence of infection appears, seek medical attention promptly. Spines of some types will be absorbed within 24 to 48 hours; otherwise, surgical removal will be required. When a venomous type of sea urchin is involved, remove the pincers from the wound promptly since they remain active for several hours and continue to inject venom into the wound. Management of the case is otherwise like that for venomous stings in general. (See par. 22 of this article.)

(*c*) *Prevention.*—Do not touch or handle sea urchins that have long, needle like spines. Be cautious in contacts with the short-spined variety because of the venomous pincers. Since shoes, gloves, suits, and the like afford little protection against the sharp spines, contact must simply be avoided whenever possible.

Sting rays

(19) There are many varieties of rays, and many of them are venomous. One example is the round stingray which is shown in figure 1–45. Varieties usually encountered can sometimes reach a length of 3 or 4 feet.

(*a*) The exact nature of the venom apparatus varies from species to species, but it usually consists of a spine covered by a skin-like sheath. The spine is located on the upper side of the tail at a variable distance from the base of the tail.

(*b*) Stingrays are generally found lying on the bottom in shallow water. They are usually well camouflaged and are often partly covered by sand. The main danger to a swimmer or diver is that of stepping on one. When stepped-on, the ray strikes upward with its tail and drives the spine deeply into the foot or leg. This usually produces a ragged, dirty wound. Often all or part of the sheath of the spine remains in the wound. The venom produces severe pain, and if present in large quantities can cause generalized effects.

(*c*) *Symptoms.*

1. Local pain develops within four to ten minutes.

2. Fainting and weakness are common.

3. Within 30 minutes, the pain increases in intensity and may affect the entire lower leg.

4. In about 90 minutes, the pain reaches its maximum, is extremely severe, and may involve the whole limb.

(*d*) *Recognition* is aided by these observations:

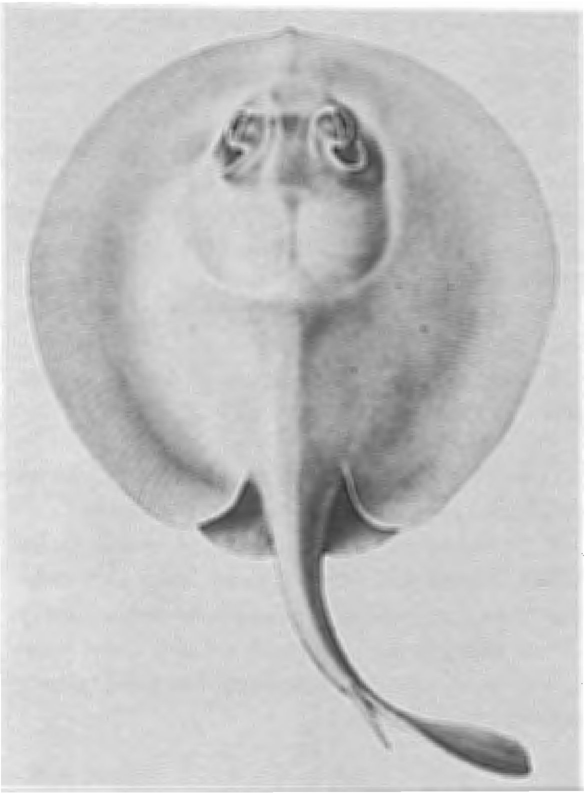


FIGURE 1–45.—Round stingray.

1. A puncture or lacerated wound on the upper portion of the foot or ankle. (Victim may recall that he stepped on something soft and slippery.)

2. Pain within a few minutes, increasing in intensity and finally affecting the entire limb.

3. Shock symptoms, with fainting, nausea, and weakness.

4. Muscular spasms of the affected limb.

(*e*) *Treatment.*—Since fainting is common, get victim out of the water promptly. Commence treatment at once.

1. Wash wound with sterile saline solution if this is available, otherwise cold, clean water.

2. Try to remove any remaining portions of the stinger sheath.

3. Soak in plain water, as hot as can be tolerated, for at least 30 minutes. Use hot compresses on areas that cannot be immersed. (Heat is believed to destroy the venom.)

4. If pain is severe and fails to respond to heat treatment, local injection of 0.5 to 2 percent procaine can be tried. If local measures

fail to relieve pain, intramuscular or intravenous demerol is usually effective.

5. When pain has subsided, cover the wound and elevate the limb.

6. Obtain medical assistance for further treatment of wound. (Most, if treated early and properly, can be sutured. If the wound is large, a drain should be left in place for a day or two.)

(7) Give a booster injection of tetanus toxoid.

8. Use antibiotics if signs of infection appear.

(*f*) *Special considerations.*

1. If victim is wounded in the chest or abdomen, get him to a hospital at once.

2. If signs of shock (fainting, weak pulse, falling blood pressure) appear, keep victim lying down and obtain medical help immediately. (Treatment is the same as for shock from other causes with special emphasis on maintaining cardiovascular tone.)

Venomous fishes

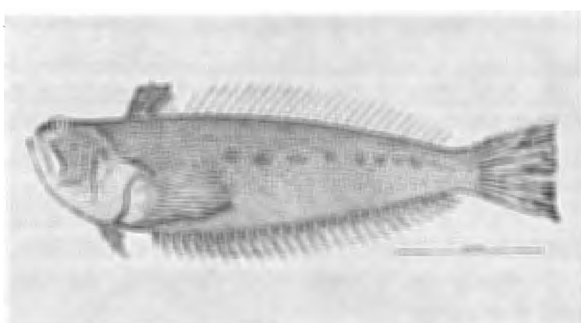
(20) Fishes that inflict poisonous stings are found throughout the world but are most common in tropical waters. They tend to be quiet in their habits. Injury is produced by contact with poison-bearing spines. A diver should learn to recognize the most important venomous fish groups mentioned here. (Symptoms and treatment of stings from these species are discussed in paragraph 22 of this article.)

(*a*) *Horned sharks.*—These include bullhead sharks, the spiny dogfish, and some less common species. The venom organs consist of two spines on the each one in front of each back fin.

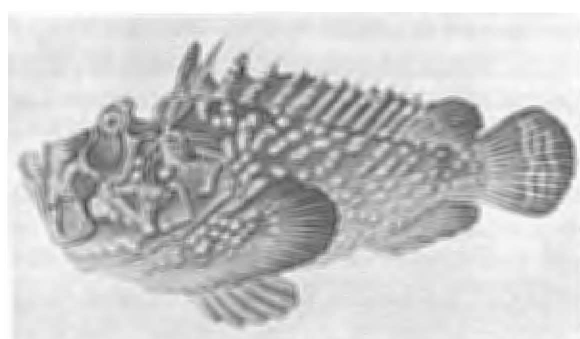
(*b*) *Catfish.*—Are largely found in fresh water. Their venom apparatus consists of spines on the back and behind the gills. The venom is believed to have effects on the nerves and the blood.

(*c*) *Weeverfish.*—(See fig. 1–46) are small and found only along the eastern Atlantic and

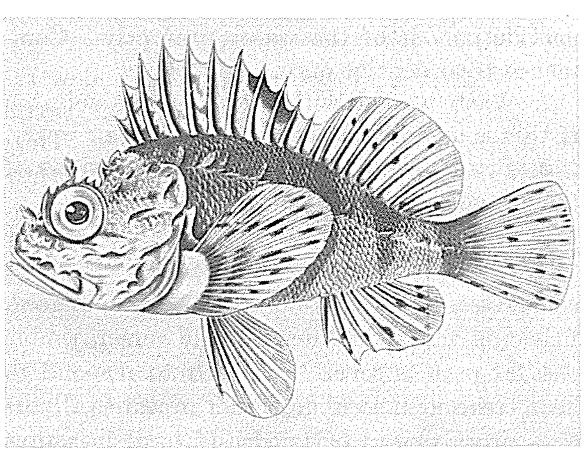
FIGURE 1–46.—Venomous fishes.



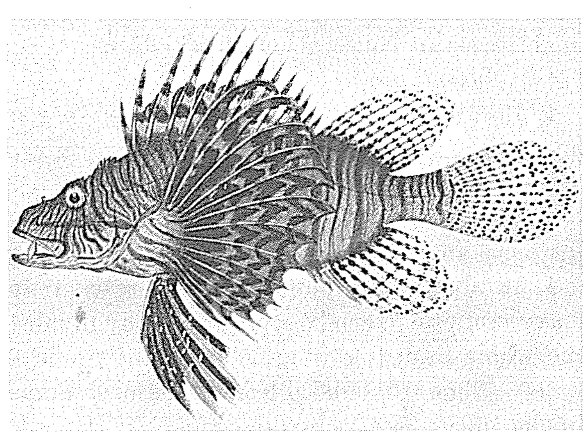
Weeverfish



Stonefish



Scorpionfish



Zebrafish

Mediterranean coasts. They have poison-bearing spines on the back and head. The venom is powerful and resembles that of certain snakes. It affects both nerves and blood. The stings are extremely painful.

(*d*) *Scorpionfish.*—Poisonous scorpionfish can be found in all tropical and temperate seas. The most dangerous species under this classification are:

1. Scorpionfish, proper. (See fig. 1–46.)
2. Zebrafish. (See fig. 1–46.)
3. Stonefish. (See fig. 1–46.)
4. Tropical scorpionfish.

Most of these carry venomous spines on the back and about the tail. The venom resembles that of the weeverfish.

(*e*) *Other venomous fish.*—Numerous other kinds of fish are capable of inflicting stings. In many cases, rather little is known about them. Several that deserve mention, and the areas where they may be found, are:

1. *Ratfish.*—One type is found in European waters, another along the Pacific coast of North America. They carry a single spine on the back.
2. *Toadfish.*—These are found in the warmer waters along the coasts of America, Europe, Africa, and India. They have hollow spines on the back and head.
3. *Surgeonfish.*—These are found along reefs in warm seas. They have a sharp, lance-like movable spine near the tail.
4. *Rabbitfish.*—These abound about rocks and reefs from the Red Sea to Polynesia. Their venom apparatus includes spines on the back and belly and near the tail.

(*f*) *General comment.*—When diving in an unfamiliar area, it is wise to consult local divers or appropriate authorities for information concerning particular marine-life hazards of the region. This is particularly true of venomous fish, since they present a particularly difficult problem in recognition.

(21) *Symptoms.*—The effects of venomous fish stings vary with the species, the extent of contact, and other factors. In general, they resemble those of stingray injury although most produce less sizable wounds and some produce more serious local and general reactions. Some of the effects have points in common with those of snakebite. Pain results from the actual injury produced by the spine, from the effects of the venom, and from the irritation of slime and other foreign substances introduced into the wound.

(22) *Treatment.*—Get the victim out of the water as soon as possible because of the likelihood of fainting and serious general reactions. Keep him lying down and watch for signs of shock. Secure medical assistance.

(*a*) Proceed with the measures indicated for stingray injuries, (see par. 19 (*e*)) with this exception: If the injury is of the small, puncture-wound type, make a small incision at the site to encourage bleeding and make flushing possible. Flush with sterile saline or clean, cold water. Remove any visible foreign material. Use suction if a method of applying it without using the mouth is available.

(*b*) Some authorities recommend the following treatment for stings of the hand or foot:

1. Immediately after being stung, place a tourniquet between the site of the sting and the rest of the body at the closest possible point to the injury.
2. Immerse the hand or foot, including the tourniquet, in iced *fresh* water. (Iced sea water will produce a dangerously low temperature.)
3. After not less than 5 or more than 10 minutes of soaking in the ice water, remove the tourniquet.
4. Keep the part in ice water for not less than 2 hours.
5. Carry out other necessary measures, including treatment for shock, later care of wound, and the like.

Sea snakes (See fig. 1–47.)

(23) In general appearance, sea snakes resemble the land varieties. Coloration varies considerably among about 50 species. They rarely exceed 3 or 4 feet in length, but a few species may attain a length of 9 feet or more. The body is compressed at the rear to form a paddle-shaped tail. The forward part of the upper jaw carries one or two hollow, venom-injecting fangs on each side. These resemble the fangs of a cobra but are smaller.

(*a*) Sea snakes remain in the water all the time, only one species lives in fresh water.

FIGURE 1–47.—Sea snake.

They are found mainly in the tropical Indian and Pacific oceans, and most of the species prefer sheltered coastal waters and river mouths. Sea snakes have been seen swimming together or breaking the surface in large numbers. They are able to float on the surface for long periods; and although they are air-breathers, they can remain submerged for long periods of time.

(*b*) While unprovoked attacks are very rare, the species vary in disposition. Since the venom is extremely potent, it pays to treat *all* sea snakes with respect and distance.

(24) *Symptoms.*—Sea snake bites are unusual in that there is a considerable delay between the injection of venom and the reaction. (The delay varies from 20 minutes to several hours; average about 1 hour.) Also, there is no pain or reaction at the site. Some victims fail to realize the connection between the bite and the illness.

(*a*) The beginning symptoms usually include the following:

1. A general "unwell" feeling and anxiety in some cases; a mild euphoria (false sense of well-being) in others.
2. A sensation of thickening of the tongue.
3. Generalized feeling of muscular stiffness.
4. Aching, or pain on movement.

(*b*) Somewhat later symptoms include:

1. Weakness that progresses to actual inability to move, to include the whole body within an hour or two, beginning with the legs and moving upward. (This paralysis is usually of the flaccid or flexible type, but the spastic or rigid form is sometimes seen.)
2. Drooping of the eyelids.
3. Tightening of the jaw muscles, not unlike that seen in tetanus (lockjaw).
4. Increasing difficulty speaking and swallowing.
5. Thirst, burning, or dryness of the throat.

(*c*) *Shock* very frequently develops. Symptoms that may also occur include:

1. Muscular spasms.
2. Paralysis of face and eye muscles.
3. Respiratory difficulty.
4. Convulsions.
5. Unconsciousness.

(*d*) Death occurs in an average of about 25 percent of cases of sea snake bite. The final cause of death varies; but shock, respiratory difficulty, and convulsions are probably most often responsible. If recovery occurs, it is complete. Late effects do not occur.

(25) *Diagnosis* of sea snake bite can be difficult especially if the bite was slight and the victim did not happen to see the snake. Prompt diagnosis is important because of the

treatment required. The following points can be helpful in distinguishing it from other types of marine-life injury:

(*a*) Victim has usually been in the water or working with nets or other equipment in a coastal area or near a river mouth.

(*b*) Pain was absent after the initial prick.

(*c*) Fang marks (2 circular dots or 2 pairs of dots half an inch or so apart) should be visible at the site of pain. There is no swelling, bruise, bleeding, or tenderness in the area. (Sometimes a fang will be found embedded in the skin.)

(*d*) Symptoms generally develop as discussed previously.

(26) *Treatment.*—Immediate steps should include the following:

(*a*) Keep the affected part quiet, avoid exertion.

(*b*) If bitten on a leg or arm, apply a tourniquet above the bite. Release it every 30 minutes for 5 minutes.

(*c*) Get help promptly.

(*d*) Transport victim quietly to nearest medical facility. (Medical assistance is essential, and hospitalization should be provided if at all possible.)

(*e*) If possible, capture and kill the snake and have it identified. (It may prove to be a harmless type.)

(*f*) Give *antivenin treatment* at the earliest possible moment.

1. Give cortisone first to prevent serum reaction. Have epinephrine ready in case reaction occurs.

2. Use a polyvalent antiserum containing a Krait (Elapidae) fraction. (There is no serum specifically made for sea snake bites.)

3. Give 20 milliliters of antiserium by slow, cautious intravenous injection.

4. Be prepared to give additional amounts if required.

(*g*) Recovery of the patient may depend on a great many factors. Medical personnel should keep the following in mind.

1. Take all necessary steps to prevent or treat shock.

2. Provide constant reassurance to the patient.

3. Maintain fluid intake and electrolyte balance.

4. Watch for respiratory difficulty or inadequacy. Treat as a case of bulbar poliomyelitis or tetanus if necessary.

5. Provide sedation and anticonvulsant therapy if needed. Avoid morphine because of respiratory depression.

6. Use antibiotics in the event of wound infection or pneumonia.

(27) *Prevention.*—If working near coasts and river mouths, around rocky crevices, piers, old tree roots, and other places likely to be inhabited by sea snakes, be aware of the danger. If snakes are seen, avoid them carefully.

1.6.19 POLLUTED WATER

(1) The water of most rivers and harbors is heavily polluted with sewage. Diving in such water is frequently necessary and represents a potential hazard to divers. Even deliberately drinking such water would not always cause illness, but this would certainly be unwise; and even being in polluted water in a full deep-sea diving rig warrants some precautions:

(*a*) If using suit and helmet or lightweight rig:

1. Avoid taking in water through the spit cock or by other means.

2. Hose the diver off when he surfaces to remove any clinging filth.

3. Avoid putting hands in mouth or handling food after tending or working with diving equipment.

4. Wash hands thoroughly and bathe as soon as possible when the job is completed.

(*b*) If using scuba:

1. Use equipment with full face mask if at all possible.

2. If using mouthpiece, try to avoid getting water in mouth.

3. Wear full dry type rubber swimsuit if available—particularly if any skin abrasions are present or are likely to occur during the dive.

4. Bathe as soon as possible after surfacing; use alcohol drops in ears if they were exposed.

5. Tenders and other personnel take same precautions indicated in (a).

(*c*) General:

1. If injury occurs in polluted water, surface promptly and cleanse wound thoroughly with soap and water. Secure tetanus booster.

2. Make sure that all inoculations are up to date.

3. Report any signs of illness promptly.

1.6.20 MEDICAL CONDITIONS

(1) Although they are not specifically caused by diving, several medical conditions deserve discussion because of their prevalence in divers, their possible consequences in diving, or both.

Respiratory infections

(2) Infections like colds, sore throat, and sinusitis are particularly important in diving for several reasons:

(*a*) They can interfere seriously with equalization of pressure in the middle ear and sinuses.

(*b*) Diving with such an infection can be made worse by causing spread of infection or further damage to tissues involved.

(*c*) A diver with a respiratory infection is seldom close to peak efficiency either mentally or physically.

(*d*) The exposure, cold, and fatigue often involved in diving not only may favor the development of such infections but may not provide ideal conditions for recovery.

(3) It is frequently impossible to excuse a man from diving every time he has a slight cold. As long as he feels reasonably well and can equalize pressure without much difficulty (aided if necessary by nose drops or the like), no great harm is likely to result. However, fewer man-hours will generally be lost in the long run if a man does not dive until he has recovered.

(4) Chest colds, bronchitis, and the like have additional implications in diving.

(*a*) Coughing is a problem in scuba diving.

(*b*) Breathing resistance in a man's airways may be abnormally high especially at depth, and his ability to work will be reduced.

(*c*) The risk of air embolism due to temporary obstruction of an air passage may be increased considerably.

(5) Except in an emergency situation, do not dive a man with fever or other signs of a marked respiratory infection or with more than a slight cold that involves the chest. Consult the medical officer in every case where there is any doubt. Make sure that men excused from diving for respiratory infections receive proper treatment, take care of themselves, and do not abuse the exemption. Try to encourage the reporting of these conditions without letting them become too easy an excuse for avoiding unpleasant jobs. Disqualify men who have exceptionally frequent infections or who have similar symptoms due to hay fever or asthma.

External ear infections

(6) Infections of the external ear canal are particularly prevalent and troublesome in scuba divers operating in warm climates. They can cause great discomfort and loss of many man-hours. The difficulty can be reduced markedly if steps like these are followed:

(*a*) Routine examination of ears by the medical officer at regular intervals.

(*b*) Removal of excessive ear wax when found.

(*c*) Good personal cleanliness; keep fingers and implements out of ears.

(*d*) A prophylactic routine such as use of alcohol drops to promote drying ears after each dive.

(*e*) Prompt reporting to the medical officer when symptoms appear (itching, pain, or crusting of the canal).

(*f*) Adequate treatment with avoidance of diving until the condition has cleared.

(*g*) Frequent re-examination of men who have had the condition in order to detect recurrences promptly.

Skin conditions

(7) Fungus infections like athlete's foot and "jock itch," and other skin disorders, are among the most frequent and annoying conditions in diving. Warm climate and frequent and prolonged wetness favor their development. If neglected, they can become disabling.

Usually, serious difficulty can be avoided:

(*a*) Dry thoroughly as soon as possible after a dive.

(*b*) Avoid unnecessarily prolonged wearing of rubber suits, wet clothing, supporters, and snug-fitting trunks. Keep these articles clean.

(*c*) Pay attention to keeping the feet clean and drying between the toes.

(*d*) Report to the medical officer or corpsman for treatment without delay when signs of infection develop.

(*e*) Avoid diving until healed if infection becomes severe or fails to respond to treatment.

Other medical problems

(8) This discussion covers by no means all the diseases and illnesses that can be important in diving. A good working relationship between diving officers and supervisors, the divers, and their medical officer or corpsman is important to assure that any physical or psychological difficulties are reported or otherwise noted at an early stage. A medical officer or corpsman who knows the divers well and enjoys their confidence can contribute much to both morale and safe diving, and his recommendations deserve respect.

1.6.21 TREATMENT OF DIVING ACCIDENTS

Principles

(1) There are very few diving accidents that cannot be treated successfully if the *facilities* and *skill* are available for:

(*a*) Recompression.

(*b*) Artificial respiration.

(*c*) First aid.

(2) Management of the victim of a diving accident seldom requires difficult decisions as to what to do. The foregoing articles have indicated the treatment for specific accidents, but frequently it is impossible to be sure at once of the nature of an accident; and often the exact sequence of events will never be known. Fortunately, satisfactory treatment usually does not require knowing these things or making an exact diagnosis. It is far more important to take appropriate action than to debate what has happened. The proper action for almost all diving casualties is summed up by four simple statements:

(*a*) If the diver is not breathing, give him artificial respiration.

(*b*) If there is *any chance* that he needs recompression, see that he gets it.

(*c*) If he is injured, give him first aid.

(*d*) Send for a medical officer at once (unless it is a very mild or simple condition).

(3) Remember that a victim of an accident might need all three forms of treatment. The fact that a man is not breathing never proves that he does not need recompression, and the same man might also be bleeding severely from an injury. Think of these things and try to provide all the needed forms of treatment as rapidly as possible. If everything cannot be done at once, use your judgment and do your best. Recall that artificial respiration will be useless if the diver bleeds to death from a wound, and recompression will become useless in a few minutes if no air is getting into his lungs.

(4) Once the proper course of action has been taken, most accident victims will be on their way to recovery if the damage is not too great or the treatment too late to permit saving them. During the course of treatment, more difficult decisions or more specialized procedures may be needed; so, a medical officer's help may be needed urgently even in a case that appeared simple at first. It is therefore advisable to secure medical assistance promptly wherever possible. However, there are few situations where you should delay action until a medical officer arrives at the scene, unless he is already close at hand.

(5) *Transportation of an accident victim* may be required if the casualty requires recompression or other treatment that is not available at the scene. Observe these rules wherever possible.

(*a*) If a victim requires artificial respiration alone, do not move him any farther than is essential until normal breathing resumes. Continue artificial respiration by some means during any necessary move. Keep victim flat for some time even after he regains consciousness. (Sitting or standing too soon may produce fainting, heart failure, or shock.)

(*b*) If a victim requires *both* artificial respiration and recompression, start artificial respiration and keep it up continuously by some method while transporting him to a recompression chamber. If this is impossible or extremely difficult, concentrate on artificial respiration; but try not to omit or delay either procedure. (See the following paragraph for one possible exception to this rule.)

(*c*) If air embolism appears the most probable cause of cessation of breathing and a chamber is *immediately* available, recompress at once and start artificial respiration as soon as the victim is in the chamber.

(*d*) Do not transport a casualty by air except at low altitude especially if he is, or may be, suffering from decompression sickness or air embolism. (The reduced pressure of altitude will not only enlarge any bubbles that may be present but will aggravate *any* condition where anoxia is a factor.)

(*e*) If oxygen is available, administer it to the patient during transportation. This is especially important when using air transportation. (Oxygen administration will assist in maintaining tissue oxygen levels in almost all conditions and may produce some reduction in the size of bubbles in decompression sickness and air embolism.)

(*f*) Keep any unconscious victim lying down during transportation and guard against airway obstruction. In cases of shock and suspected air embolism, keep the victim's legs elevated.

(6) The following paragraphs present useful information concerning the facilities and skills required for forms of treatment most likely to be needed. Much of the essential information is provided in the form of convenient tables. (See tables 1–22 through 1–26 and 29.)

Recompression Chamber

(7) Prompt recompression is the only treatment for air embolism and decompression sickness, and recompression in the water is at best a hazardous and difficult procedure—almost always too difficult and too dangerous even to attempt with self-contained equipment. Therefore, a recompression chamber should be close by the scene of any diving operation if this can possibly be arranged. Prior to diving, make sure that the chamber is ready for use. If at all possible, obtain a portable chamber when conducting operations in remote areas. If a chamber cannot be provided at the scene, know the location of the nearest one, provide fast means of reaching it, and be sure that it is ready for use.

(8) Recompression chambers are regularly furnished to ships and activities that do either very deep diving, a large amount of relatively shallow diving, or both. They are required not only for treatment of decompression sickness and air embolism but also for use in surface decompression and for administering pressure and oxygen tolerance tests.

(9) Two types of chambers are most commonly provided. One is a two-lock chamber having a working pressure of 200 p.s.i. (See fig. 1–48.) The other is a one-lock chamber having a working pressure of 100 p.s.i. Both of these types are intended for permanent installation. A less common type, more readily moved, is constructed of aluminum and has two locks despite being of much smaller size than the usual two-lock chamber. The working pressure of all these chambers is adequate for recompression in accordance with the treatment tables.

(10) The large recompression chamber has a total volume of about 500 cubic feet—inner lock 370 cubic feet, outer lock 130 cubic feet. Such chambers are provided for activities that are required to dive to extreme depths and where resultant cases of decompression sickness are more likely to require prolonged treatment and the assistance of medical personnel. For example, they are found aboard submarine rescue vessels and submarine tenders. The one-lock chamber has a volume of about 250 cubic feet.

(11) The principal advantage of a two-lock chamber is the ability of personnel to enter and leave during the course of treatment. With a one-lock chamber, the patient's attendant must obviously remain with him throughout treatment and cannot be relieved or assisted. All regular chambers are provided with a means of sending food, medical supplies, and other small articles in and out.

(12) Readily portable chambers are not in common use in the Navy but would be of

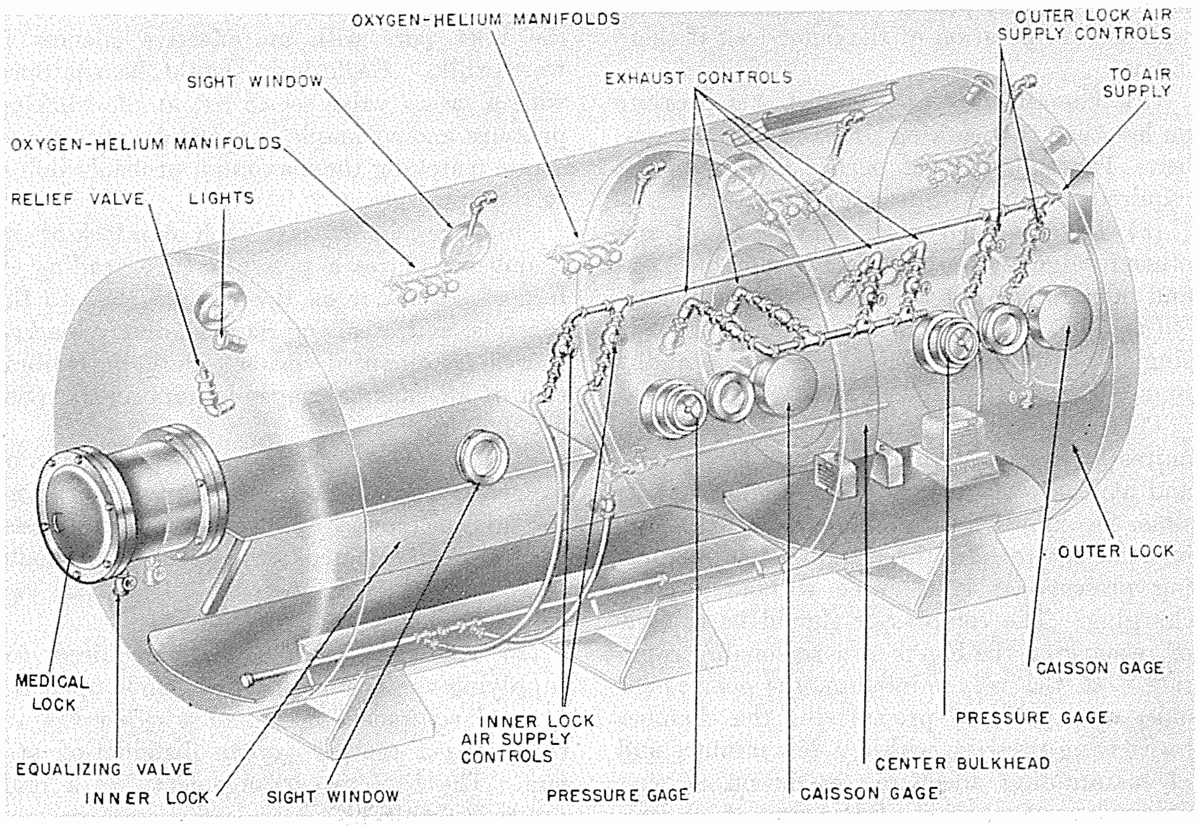


FIGURE 1-48.—Diagram of recompression chamber. Recompression chamber shown is of the type having an inner lock (left) and an outer lock (right). Diver and attendant occupy inner lock. When necessary for personnel to enter or leave inner lock, pressure is built up in outer lock so inner chamber door can be opened. Attendant leaving inner lock is given proper decompression during ascent in outer lock. Small medical lock at opposite (left) end of chamber is equipped with valves for equalization of pressure and can be used to permit food, medical supplies, and other small articles to be sent into chamber or removed from it. (Recompression chambers are also shown in figs. 1-4, 1-5, 1-34, and 1-35.)

value to any diving activity that must operate at a distance from a permanent installation. Even a chamber so small that it can hold only the patient is far better than none. It could provide adequate treatment for the majority of cases of decompression sickness and permits transporting the victim rapidly by air without risking further injury. (See par. 5.) The value of a portable chamber is increased if it allows the patient to be transferred to a larger chamber. (The French Navy uses a one-man chamber designed for direct attachment to a chamber of usual size. One model of portable chamber telescopes into a relatively compact unit and could, with some difficulty, be carried into a larger chamber and removed from the patient after pressure had been built up.)

(13) *Air supply for the recompression chamber.* Satisfactory operation of a chamber requires a large and reliable supply of suitable compressed air.

(*a*) The *volume* of air needed, in terms of free air measured at one atmosphere, is equal to the internal volume of the chamber times the number of atmospheres of *increase* in pressure required. For example, it will take $500 \times 5 = 2{,}500$ cubic feet of free air to take the usual two-lock chamber from surface to a "treatment depth" of 165 feet (6 atmospheres absolute). The supply should permit taking the chamber to its working pressure, and a generous safety factor should be provided. The supply must also be adequate for ventilation of the chamber for an indefinite period after the desired pressure has been reached as well as for operation of the outer lock if there is one.

(*b*) The air must be provided at a pressure no less than the working pressure of the chamber. The supply must permit delivering the required volume within a few minutes.

(*c*) The air itself must be free of oil and other foreign matter and of objectionable gases and odors. It must be as cool as possible.

(*d*) The chamber must not depend upon a single source of air. There must be a standby source that can be used in an emergency.

(14) A satisfactory air supply generally requires a bank of cylinders of ample capacity and at least one reliable compressor. If possible, the supply available in the banks should be sufficient to take the chamber to its working pressure at least twice without further charging. The compressor should be capable of recharging the banks at a reasonably rapid rate. At the very minimum, the compressor must be capable of pressurizing the chamber to working pressure within a few minutes and of maintaining adequate ventilation at that pressure. (Note that *direct* use of a compressor is highly undesirable because of the problem of temperature. It is much more satisfactory to use banks or some type of accumulator in which the air can be cooled before it enters the chamber.)

(15) *Piping and valves* should be arranged to permit control of air supply and exhaust from either the outside or the inside of both locks. However, the system must permit control from the inside to be overridden by control from the outside. The usual arrangement provides one supply and one exhaust line, each fitted with a single valve outside of the chamber. A second set of supply and exhaust lines is provided with double valves, one on the inside and one on the outside. With this arrangement, the tender inside the chamber can regulate descent or ascent but is subject to final control by the outside tenders. In addition, it is desirable to provide an extra stop valve on each main supply and exhaust line to be used in the event of failure of one of the others. Optimum chamber ventilation requires maximum separation of the inlet and exhaust ports within the chamber. Providing the inlet port with an effective silencer is worthwhile. Each lock should be equipped with a safety valve set to lift at the working pressure and of ample capacity to vent air at a rate matching the maximum probable inflow at that pressure.

(16) *Pressure gages.*—Each man lock of the chamber requires a pressure gage reading in feet of sea water on the outside close to the controls, and a caisson gage similarly marked should be mounted inside. Periodic calibration of all chamber gages is important. (See art. 1.10.12.)

(17) *Oxygen equipment.* To permit use of oxygen during recompression treatment (and for administration of oxygen tolerance tests, if this is anticipated), the inner lock should be equipped with connections for at least two demand-type oxygen inhalators.

(*a*) The exact arrangement required for supplying these connections depends upon the type of equipment used and whether the activity has a central oxygen distribution system. The simplest arrangement has a high pressure manifold for at least two large oxygen cylinders just outside the chamber with stop valves, gage, and a high pressure line to the inside. Inside, a high pressure manifold is provided, with at least two valves and connections like those on standard oxygen cylinders. The usual inhalator (see sub-par. (*d*)) is equipped with its own pressure regulator and operates best when connected directly to a high pressure source without intermediate pressure reduction. Since the regulator is inside of the chamber, this automatically provides the demand unit with the proper over bottom pressure for optimum operation; and replacing oxygen cylinders is the only thing that requires special attention during use of the system. The high-pressure system must be constructed properly, hydrostatically tested, and properly cleaned. (See art. 1.10.11.)

(*b*) Provision of a similar system in the outer lock is not required but would occasionally be desirable, as in using oxygen decompression for tenders leaving the chamber.

(*c*) The desirability of having helium-oxygen mixtures available for use in treatment (table 1–22) warrants making provisions whereby the oxygen inhalation system can be supplied with helium-oxygen instead. Provision of a separate system complete with its own manifold and inhalators inside of the chamber is not necessary.

(*d*) The demand inhalators used for administration of oxygen or helium-oxygen mixtures should be of the standard type: *Inhalator, Divers', Federal Standard Stock Catalog, G4220–240–7150.* Oxygen breathing devices that involve the possibility of rebreathing exhaled gas or of drawing air into the system present serious hazards. They must not be used in the chamber for any purpose.

(18) *Ventilation of the recompression chamber* during use is necessary not only for the comfort of the occupants (mainly a matter of temperature and humidity) but also to keep the levels of carbon dioxide and oxygen within safe limits. When the air supply is ample, the occupants' demands for ventilation for the sake of comfort are likely to exceed what is needed to keep the gases under control. However, it is always desirable to be certain that ventilation is adequate; and when the air supply is limited or the number of men in the chamber is unusually large, proper ventilation may become critical. It is necessary to know two things: (1) how much ventilation is needed and (2) how to provide the right amount—how much to open the valves and how often to do it.

(*a*) *Rules for ventilation* are presented in table 1–22. These permit you to compute very rapidly how many cubic feet of air per minute (*as measured at chamber pressure*) are required under different conditions. They also provide a means of determining how often the chamber must be ventilated—the maximum safe interval between ventilations. (The rules are designed to assure that the *effective* concentration of carbon dioxide will not exceed 1.5 percent and that when oxygen is being used, the true percentage of oxygen in the chamber will not exceed 30 percent.) As long as the interval does not exceed the maximum, it makes very little difference what method of ventilation is used if the necessary amount of air is put through the chamber over a certain period of time. For example, if the rules call for 4 cubic feet per minute, the chamber can be flushed continuously at a steady rate of 4 cubic feet per minute. Or, usually more convenient, it can be ventilated once in each 15 minutes with $4 \times 15 = 60$ cubic feet, or once each 30 minutes with $4 \times 30 = 120$ cubic feet of air, if 30 minutes does not exceed the safe interval.

(*b*) *Setting the valves.*—Knowing how much air must be used does not solve the problem unless there is some way of determining the volume of air actually being used for ventilation. One such means would be provided if you knew that opening the exhaust valve a certain number of turns (or fractions of a turn) would give a certain number of cubic feet of ventilation per minute at a certain chamber pressure. It would then be simple to open the exhaust that far and use the control valve to keep the chamber pressure up while you ventilated for the necessary period of time. Determining what valve settings are required for different amounts of ventilation at different depths is not difficult:

1. Mark the valve handle so that it is possible to determine the number of turns and fractions of turns fairly accurately.

2. Check the rules in table 1–22 against probable situations to determine what rates of ventilation at what depths (chamber pressures) are likely to be needed. If the air supply is ample, making the determination for a few depths (like 30, 100, and 165 feet) may be sufficient, since the valve opening specified for a given rate of flow at one depth is sure to provide at least that much at a deeper depth. It will be most convenient to know the valve settings for rates like 30, 60, or 120 cubic feet per minute because these give a simple relationship between volume and time (60 cubic feet per minute = 1 cubic foot per second, etc.).

3. Determine the necessary valve settings for the selected flows and depths by using the chamber itself as a measuring vessel with the help of a stop watch.

(*a*) Calculate how long it would take to bring the chamber up 10 feet if the exhaust valve were letting air escape at the desired rate close to the depth in question. Use this formula:

$$T=\frac{V\times 20}{R\times\left(\frac{P+33}{33}\right)}$$

Where:

T=time in seconds for chamber to come up 10 feet.

V=internal volume of chamber (or of lock being used for test) in cubic feet.

R=rate of ventilation desired, in cubic feet per minute as measured at chamber pressure.

P=chamber pressure (gage) in feet of sea water.

Example: How long will it take pressure to drop from 170 to 160 feet in a 500 cubic foot chamber if the exhaust valve is releasing 60 cubic feet of air per minute (as measured at chamber pressure of 165 feet)?

T=?

V=500 cubic feet

R=60 cubic feet per minute

P=165 feet

Insert values in formula:

$$T=\frac{20\times 500}{60\times\frac{(165+33)}{33}}=\frac{10{,}000}{60\times 6}=27.8 \text{ seconds}$$

(Round to the nearest whole second, here 28.)

(*b*) Take chamber down (with no one inside) to 5 feet beyond the depth in question. Then open exhaust valve a certain amount and determine how long it takes to come up 10 feet. (For example, if checking for a depth of 165 feet, take chamber to 170 and clock the time to 160 feet.) Try opening the valve different amounts until you know what setting will give close to the desired time. Write down what the setting is. Calculate times for other rates and depths and determine settings for these in the same way. Make a chart or table of the valve settings found and prepare a ventilation bill using this information and the rules (table 1–22).

(*c*) *Sample ventilation problem:* Chamber is at 30 feet with one patient breathing oxygen, one tender also breathing oxygen, and another tender actively taking care of the patient. Chamber volume = 500 cubic feet.

1. Basic requirement (rule 1) is three men × 2 = 6 cubic feet per minute, plus two for working tender = 8 cubic feet.

2. Oxygen is being used by two men, so must ventilate with at least 2×4=8 cubic feet—which happens to be the same as basic requirement in this case.

3. Maximum interval between ventilations (rule 2) is 500/(2×10)=500/20=25 minutes.

4. It is decided to ventilate once each 20 minutes. This will require 8×20=160 cubic feet of air per ventilation.

5. Previous determination showed that opening exhaust valve 1½ turns would produce 60 cubic feet per minute (1 cu. ft. per sec.) of ventilation with chamber at 30 feet.

6. Therefore, exhaust valve is opened 1½ turns for 160 seconds, while pressure is maintained with supply valve. Ventilation is repeated every 20 minutes.

(*d*) *Notes on chamber ventilation.*

1. The rules given (table 1–22) are not intended to *limit* ventilation. If air is reasonably plentiful, more should generally be used for the sake of comfort. This is desirable because it also lowers the concentrations of carbon dioxide and oxygen further.

2. There is seldom any danger of too little oxygen in the chamber. Even with no ventilation and a high carbon dioxide level, the oxygen present would be ample for a long time.

3. The rules given assume that circulation of air in the chamber during ventilation is reasonably good. If it is poor, the rules may be inadequate. Having the inlet near one end of the chamber and the outlet near the other will promote good ventilation.

4. Coming up to the next stop helps reduce the gas levels, and proper ventilation requires a smaller actual quantity of air as depth decreases. Therefore, if a ventilation comes near the end of one stop, waiting until you come up to the next will save air.

5. When longer intervals between ventilations do not produce discomfort, they are less

disturbing to the patient especially if he is trying to rest. Continuous ventilation has the disadvantage of exposing the men in the chamber to a constant source of noise. Unless its intensity is low, this noise may not only be objectionable but may produce hearing fatigue and interfere with communications.

6. Note that the size of the chamber does not influence the amount of air required for ventilation—only the allowable intervals.

7. Note also that increasing depth increases the actual mass of air required for ventilation, but that when expressed in volumes as measured at chamber pressure, the number of cubic feet required does not change with depth.

(19) *Communication equipment.*—It is extremely important to assure good voice communication between the inside and outside of both locks of the chamber. The primary system should be an "intercom" with speakers that double as microphones, arranged so that personnel inside the chamber can hear and be heard in normal voice without interrupting their activities. This type of system can be provided by means of the standard divers' amplifier. It is also extremely desirable to have a second system of some kind as a standby for emergency use. The simplest and most infallible standby is provided by a set of sound-powered telephones. All voice communication gear should be maintained carefully and checked at weekly intervals.

(20) *Electrical equipment.*—The wiring of a recompression chamber must be of an approved heavy duty type, armored or in conduit. All electrical switches should be located outside. All lighting fixtures should be permanently installed; and if not of the pressure-proof type, at least provided with heavy glass covers for the bulbs. (Fluorescent fixtures must not be used.) If appliance receptacles are provided, these must be of a type assuring positive contact and no chance of accidental removal of the appliance plug. Household type electrical outlets and connections and jury-rigs of any kind must absolutely never be used.

(*a*) It is a good policy to prohibit all electrical equipment other than lights. Heaters and fans may be considered essential in some installations, but it is better if they are avoided entirely. If heat is required, it would be more safely provided by a small steam line and radiator. Fans are rarely effective in any case because of the high moisture content and density of the air. If a fan is used, the motor must be of the induction type (no brushes and no starter relay). Heater and fan switches must be removed to permit control only from the outside.

(*b*) If the wiring provides the necessary separate circuit, one desirable addition is a low-intensity light that can be used to relieve the patient of the heat and glare of the regular lights, yet permit him to be observed continuously during long treatment. (This can also be provided by a portable light placed outside of one of the ports.)

(*c*) All electrical wiring and equipment must be checked at regular intervals and kept in perfect condition.

Precautions in use of chamber

(21) The chamber itself must be kept in an optimum state of repair and subjected to periodic test. (See table 1–29.) Periodic training runs should be made to assure proper operation and readiness of the chamber and all its accessory equipment as well as to keep personnel familiar with its use. Appropriate periodic checks and preventive maintenance routines should be applied to the air supply, oxygen and helium-oxygen systems, and the communication and electrical equipment. The chamber must never be used for stowage of gear, as a locker, or for sleeping quarters.

(22) Certain features of operation deserve special comment:

(*a*) Unless doors are sprung or gaskets improperly fitted, only enough force to make an initial seal is required on hatch dogs. As pressure builds up in the chamber, the seal automatically becomes tighter and tighter. Dogs should be released routinely as soon as pressure is adequate to hold. They should be re-checked before pressure is reduced to make sure they have been released.

(*b*) *Explosive fire* is the most serious danger in operation of a recompression chamber. The danger is ever present and is increased at pressure and when pure oxygen enters the chamber in the course of oxygen breathing in treatment. In both cases, the effective concentration (partial pressure) of oxygen is increased. In order to reduce the possibility of fire, take the following precautions:

1. Replace all wooden deck gratings, benches, shelving, etc. with metal or other fireproof material.

2. Use only fire-retarding paint similar to that listed in the Federal Standard Stock Catalog (GF8010–290–2875) and keep painting to the absolute minimum—one coat preservative and one white coat. If it is not known that the chamber has been painted in this manner, remove all old paint and repaint as indicated. Assure that thorough drying of paint and removal of all volatile vapors by ventilation is accomplished before using the chamber.

3. Be certain that the electrical system complies with paragraph 20 of this article.

4. Keep the interior of the chamber free of all dirt and refuse and of any oily deposits or volatile materials of any kind. If for any reason inflammable liquids such as ether, alcohol, gasoline, or volatile oils, or their vapors, have been present, thorough ventilation must precede use of the chamber. No oils should be in or on high pressure lines or apparatus of the oxygen-breathing installation. Allow no oils or volatile materials to collect or soak into any absorbent material in the chamber or in the well under the deck plates. All air filters and accumulators in lines leading to the chamber must be cleaned regularly to keep oil and vapors from being carried in.

5. If a mattress is used, be sure it is covered by fire-resistant sheeting on all sides. Keep blankets and other bedding to the minimum required for the patient's comfort. Do not use wool or synthetic fiber blankets because of the possibility of sparks from static electricity. Flame-proof bedding material can be obtained from the Naval Supply Center, Oakland, or the Naval Supply Depot, Bayonne, under Stock No. GF–7210–243–8863 or GF–7210–243–8864. Clothing worn by personnel in the chamber must be free from grease or oil.

6. No open flames, matches, cigarette lighters, lighted cigarettes, cigars, or pipes are to be taken in or used in the chamber at any time.

7. When oxygen is being used, the chamber must be ventilated *at least* to the extent specified in table 1–22. Have water and sand buckets on hand in the chamber during use of oxygen. (CO_2 or carbon tetrachloride fire extinguishers must never be used!)

8. Use no electrical appliance of any kind (other than lights) in the chamber during oxygen-breathing. Ventilate thoroughly following oxygen breathing before any appliance is turned on.

9. Post a warning like that in table 1–29 prominently inside and outside of the chamber.

10. If the above precautions are taken, the possibility of fire within the chamber will be reduced to an absolute minimum.

Treatment by recompression

(23) Actual use of the recompression chamber for treatment of decompression sickness and air embolism is covered in the Treatment Tables (table 1–21) and in the additional table of Notes on Recompression (table 1–22). Only medical officers trained in the management of diving accidents are permitted to modify the procedures specified, except in case of acute emergency or obvious necessity.

(24) Conduct of treatment requires accurate timekeeping and recording of all significant events and other information as well as competent operation of the chamber and provision of tenders. Do not neglect to fill in form NAVMED 816 promptly for each patient treated. (See art. 1.9.8.)

Preparedness

(25) The personnel and facilities of all diving activities must be prepared at all times to provide treatment of decompression sickness or air embolism at a moment's notice. Because of the possibility of being called upon to treat a commercial or sport diver, this is true even if the activity itself has not made dives recently. The state of readiness should be such that the minimum number of personnel aboard

at any time can at least begin treatment without assistance and without delay.

(*a*) Keep the chamber itself ready for immediate use.

(*b*) If air banks are available, keep them charged sufficiently to take the chamber to 165 feet. Keep the compressor ready to operate.

(*c*) Be sure that oxygen equipment is ready —demand inhalators operable and supply cylinders full.

(*d*) Keep communication equipment ready to turn on and use.

(*e*) Be sure stopwatches are at hand and that all items which may be required in the chamber are either in it or immediately available. Such items include:

1. Emergency medical kit and related equipment. (See par. 30 of this article.)
2. Slate and grease pencil.
3. Wingnut wrench.
4. Fire-resistant mattress and blankets.
5. Bucket for body wastes.
6. Water and sand buckets.

(*f*) Assure that all personnel have been thoroughly instructed in the use of the chamber and its auxiliary equipment and that any man can take any station required in its operation. Maintain readiness through periodic training runs directed by the medical or diving officer.

(*g*) Have a casualty bill in force that defines stations and assigns specific tasks to all personnel required in the operation of the chamber. These include, for example:

1. Two "outside tenders" to operate supply and exhaust valves of inner and outer locks.
2. Timekeeper.
3. Talker.
4. Recorder.
5. Personnel required to operate air banks and compressor. (Note that some jobs can be combined if necessary but that the duties of each must be defined clearly.)

(26) Preparedness for handling casualties extends also to the ability to provide artificial respiration, first aid, and other measures that may be required in addition to—or instead of —recompression. The more important considerations in preparedness are summarized in table 1–29.

Artificial respiration

(27) Tables 1–23, 1–24, and 1–25 provide necessary information concerning *manual artificial respiration* in ready reference form. All hands should be instructed in the back-pressure-arm lift method and should be given an opportunity to practice it on simulated "victims." All should at least be aware of the alternative methods and, if the circumstances of their work make the necessity of using them likely, should be trained in them also. Drills with the mechanical resuscitator should also be provided.

Emergency medical supplies

(28) The number and variety of emergencies that can arise in diving require that a considerable number of items of medical equipment and supplies be available for prompt use by the medical officer or corpsman. What must be kept immediately at hand for first aid and subsequent treatment depends somewhat on the availability of such items from the ship's regular sickbay or from a dispensary or hospital close to a shore-based diving activity. The possible needs and means of filling them should be considered carefully and appropriate steps taken by the medical officer or corpsman responsible.

(29) One question of particular importance concerns items that must be immediately available at the scene of a diving accident or *in the recompression chamber*. Every diving activity should maintain an emergency bag or box of convenient size to carry into the chamber at a moment's notice. It should contain *at least* those items that will be needed routinely or that may be needed so urgently that passing them in through the medical lock is impractical. Other desirable items may be included as space permits. The following list of suggested items is based on the actual contents of the emergency kits maintained at the Experimental Diving Unit and Deep Sea Diving School. Local needs and conditions will probably vary the contents desired elsewhere.

(30) *Suggested Contents of Emergency Kit*

(*a*) Diagnostic equipment.

1. Flashlight.
2. Stethoscope.

3. Reflex hammer.
4. Tongue depressors.
5. Clinical thermometer (designed for either oral or rectal use).
6. Pin, camels hair brush, etc. for sensory testing.

(*b*) Surgical instruments, etc.

1. Scalpel (handle and assortment of blades).
2. Hemostats, medium curved (2).
3. Suture material.
4. Suture needles (assorted).
5. Scissors.
6. 5 cc. syringe } sterile pack.
7. 18, 20, 22 gage needles } sterile pack.
8. 30 cc. syringe.
9. Thoracentesis needle (13 gage, 4″ long).

(*c*) Dressing materials, etc.

1. Gauze sponges, 4″ by 4″ (100).
2. Gauze roller bandage, 1″ and 2″.
3. Adhesive tape, rolls 1″ and 2″.
4. Band-aids.
5. Cotton-tipped applicators.

(*d*) Solutions, etc.

1. Diluted vinegar (8 oz. bottle).
2. Distilled water (8 oz. bottle).
3. Tr. merthiolate (2 oz. bottle).
4. Sterile water for injection (50 cc. vial).
5. Boric acid ointment (tube).

(*e*) Drugs.

1. Pentothal sodium, 0.5 gm. ampule.
2. Amobarbital sodium, 0.5 gm. ampule.
3. Morphine tartrate, ¼ grain syrettes (2).
4. Epinephrine HCl, 1:1000, ampules (2).
5. Caffeine sodium benzoate, 0.5 gm. ampules (2).
6. Nikethamide, 25 percent solution, 1½ cc. ampules (2).
7. Procaine HCl with epinephrine 1:1000, ampules (4).
8. Spirits of ammonia, ampules (2).

(*f*) Miscellaneous items.

1. Padded mouth bit.
2. Pharyngeal airway.
3. Tongue forceps.
4. Endotracheal catheter (24 Fr.).
5. Rubber tubes equiv. to sizes 4 and 6 (for temporary use in tracheotomy). (Safety pin through end of each.)
6. Rubber tourniquet.
7. Pencils and paper.

(31) Comment on contents of emergency kit:

(*a*) Having to take the kit under pressure complicates matters in several ways: Not all drug ampules will withstand pressure. Some vials will have their stoppers pushed in. Bottles of solutions must either be filled completely to eliminate air space or capped loosely —which favors spilling and evaporation. (In some cases, plastic bottles could be used.) Sterile goods will be contaminated by air compressed into their wrappings and should be resterilized after each time in the chamber whether used or not.

(*b*) In the Experimental Diving Unit and Deep Diving School Kits, many valuable items were omitted, or included only in small quantities, because they are available close by or could be obtained and sent in ample time to meet most possible requirements. Several items included (like the unsterile surgical instruments) are intended only for use in a very unusual emergency when there would not be time to send in more appropriate equipment—like having to do an emergency tracheotomy or apply ligatures to stop bleeding. Several items were intended for more than one purpose. For example, the 30 cc. syringe could be used with the endotracheal catheter for aspiration of secretions from the throat until a more effective aspirator could be provided; or it could be used with the thoracentesis needle for aspirating air from the chest in a massive pneumothorax requiring immediate relief.

(*c*) Items available promptly from the sickbay or nearby dispensary and thus not provided in the kit include:

1. Sphygmomanometer } at hand outside chamber.
2. Otoscope-Opthalmoscope } at hand outside chamber.
3. Drugs (including more of those in the kit, and others not likely to be needed as urgently).
4. Intravenous solutions and kits for administration.
5. Sterile trays for—
   a. Minor surgery

b. Tracheotomy
c. Thoracentesis
d. Catheterization.

6. Splints, etc.
7. Aspirator (type safe for use in chamber).

(32) The emergency kit should be *sealed* in such a way that it can be opened readily when needed but will not be opened and plundered for no good cause. A broken seal will indicate that it has been opened. The kit should contain a list of contents, and each time it is opened (or at monthly intervals in any case), it should be checked for presence and condition of all items. Sterile supplies should be provided in duplicate so that one set can be autoclaved in the meantime.

(33) By and large, use of the emergency kit should be reserved to the medical officer or a well-trained corpsman. Concise instructions for administration of each drug should be provided in the kit. In untrained hands, many of the items can be dangerous. Remember that, as in all types of treatment, YOUR FIRST DUTY IS NOT TO DO HARM.

SECTION 1.7 GENERAL SAFETY PRECAUTIONS

1.7.1 GENERAL

(1) Each type of diving equipment and operation gives rise to unique demands for safety precautions. The safety precautions presented in this section are those common to all diving. This part of the manual is intended to be used as a check-off list by those responsible for safety in diving.

1.7.2 ADMINISTRATION AND PLANNING

(1) Have you notified all interested activities that diving operations are in progress?

(2) Is the type of gear you have chosen to use adequate and safe for the job?

(3) Is the recompression chamber ready for use or have you notified the nearest command having one that you may need it?

(4) Have you made provision to obtain medical assistance in case of emergency?

(5) Has a competent diving supervisor been designated to be in charge of the job?

(6) Has a timekeeper been detailed and does he understand his duties and responsibilities?

(7) Do you have a copy of the decompression tables available?

(8) Have the divers been thoroughly briefed and understand what is to be accomplished and how?

(9) Has a lead line or pneumofathometer measurement of the depth of water been made?

(10) If conducting a search; have you exhausted all other means before putting the divers down?

(11) If diving on the propeller of a ship, have you informed the duty engineer and received an acknowledgment?

(12) If diving around the hull of a submarine, have you notified the duty officer not to operate bow planes, stern planes, vents, sound heads, or propellers?

1.7.3 PERSONNEL

(1) Have you determined that all of the divers you intend to use have been examined and found to meet the physical standards for deep sea diving within the current calendar year?

(2) Have all of your men been trained to use the equipment you have selected?

(3) Do you have reason to suspect the physical condition of any of your men? Consider the following:

(*a*) Do not dive a man if he is suffering from a severe cold, sinusitis, or ear trouble.

(*b*) Do not dive a man who is fatigued from lack of sleep or previous physical or emotional strain.

(*c*) Do not dive a man who shows evidence of alcoholic intoxication or its after effects.

(*d*) If you question the physical condition of any man, have him report to the medical officer and be guided by his advice.

(4) Have all the divers been qualified to the depth of the job?

(5) Do not force or urge a man to dive if he honestly desires to be excused. If his reasons for wishing to be excused do not appear to be sufficient or appropriate, it is best to take administrative action.

1.7.4 EQUIPMENT

(1) Has the equipment you intend to use been tested and adopted for Navy use?

(2) Have you inspected the equipment to determine that it is in usable condition?

(3) Do you have an adequate supply of compressed gas available?

1.7.5 SAFETY DURING DIVING OPERATIONS

(1) Have all efforts been made to prevent the divers from becoming fouled on the bottom?

(2) Have divers been instructed not to cut any lines until they have made certain of the purpose for which they are being used?

(3) Is the diving boat moored in the most advantageous position to minimize effort by the divers to reach their work?

(4) Are you displaying the proper signal?

(*a*) SEVEN flag is used in areas where traffic is principally Navy craft.

(*b*) If diving in international waters, either of the following hoists are correct:

1. "Underwater task" shapes—red ball, white diamond, red ball, spaced 6 feet apart.

2. International diving hoist: code pennant, Foxtrot-Charley-Zulu.

(5) Has a standby diver been designated and is he ready to enter the water in a minimum time?

(6) If working inside a wreck, have you made arrangements for one diver to tend the lines of the diver working inside from the point of entry?

(7) If using explosives, Have you taken measures to prevent a charge being set off when a diver is in the water?

(8) Use the full deep sea diving outfit when using electric power for underwater welding or cutting.

(9) REMEMBER: In all cases the depth of the water and the condition of the diver, especially in regards to fatigue, rather than the amount of work to be done, shall determine the amount of time the diver is to spend on the bottom.

(10) Have you made provisions for decompressing the divers should this be necessary?

1.7.6. RECOMPRESSION CHAMBERS

(1) The following general safety precautions must be observed with regard to recompression chambers. (See also art. 1.6.21, pars. 7–22, and table 1–29.)

(*a*) The recompression chamber must never be used for a storage space. Keep it clear, clean, and ready for use at all times.

(*b*) Medical supplies as outlined in section 1.6.21, paragraph 30, must be available at all times.

(*c*) Use only fire-retarding paint inside the chamber.

(*d*) Do not take open flames, cigarette lighters, matches, lighted cigarettes, or pipes into the chamber while it is being used.

(*e*) Decompression tables and treatment tables must be located both on the inside and outside of the chamber.

(*f*) Use fire-resistant non-static blankets.

(*g*) Insure that the wrench for the medical lock is inside the chamber.

1.7.7 GENERAL SAFETY RULES GOVERNING THE USE OF COMPRESSED GAS CYLINDERS AND GASES

(1) In diving, the following compressed gases are commonly used: Compressed Air, Helium, Oxygen, and mixtures of these gases. The safety rules contained in this section have been abstracted from Chapter 23 of the Bureau of Ships Manual.

(2) *Handling of cylinders.* The following are general safety rules for working with compressed gas cylinders:

(*a*) Never drop cylinders, nor permit them to strike each other violently.

(*b*) Never use a lifting magnet or sling when handling cylinders.

(*c*) Securely close valves and replace valve cover caps before moving, storing, or returning cylinders.

(*d*) Be sure that all cylinders used are approved under Interstate Commerce Commission regulations.

(*e*) Do not fill any cylinder with a gas other than that for which the cylinder was designated.

(*f*) Never use cylinders for rollers, supports, or any other purpose other than to carry gas.

(*g*) Do not tamper with the safety devices or valves on cylinders.

(*h*) Never hammer or strike the valve wheel in attempting to open or close valves. Use only wrenches or tools provided and approved for this purpose.

(*i*) Be sure that the threads on regulators or other auxiliary equipment are the same as those on cylinder valve outlets. Never force connections which do not fit.

(*j*) Do not subject compressed gas cylinders either in storage or service to a temperature in excess of 130° F.

(*k*) Protect cylinders from objects that will produce a cut or other abrasion on the surface of the metal.

(*l*) Do not use any cylinder which is improperly marked.

TABLE 1–29

PRECAUTIONS IN USE OF RECOMPRESSION CHAMBER

(See art. 1.6.21)

PREPAREDNESS

The personnel and facilities of every Navy diving activity must be ready to treat decompression sickness or air embolism at a moment's notice at any time.

1. The chamber and its auxiliary equipment must be in working order and ready for use. Check the following:
   a. The chamber itself—free of extraneous gear, equipped and ready.
   b. The air supply—banks charged, compressor ready to operate.
   c. Communication gear—functioning properly.
   d. Oxygen installation—cylinders full, demand valves operative.
   e. Medical kit—stocked and at hand.

   Follow routine of periodic tests and preventive maintenance.
2. Personnel must be trained in operation of equipment and be able to do any job required in treatment; definite assignment of responsibilities is required.
   a. Hold periodic training runs with rotation of personnel.
   b. Provide emergency bill listing jobs and duties.

GENERAL PRECAUTIONS IN USE

1. Avoid damage to doors and dogs. Use minimum force required in "dogging-down"; be sure dogs are released before pressure is reduced.
2. Provide ample chamber ventilation especially when oxygen is being used.
3. Assure accurate timekeeping and recording.
4. Keep tender with patient especially when breathing oxygen.
5. Assure proper decompression of all persons entering chamber.

PREVENTION OF FIRE

1. Remove all combustible materials and replace with metal or fireproof construction (deck gratings, benches, etc.).
2. Use only fire-retarding paint, keep painting to minimum.
3. Keep chamber clean and free from all oily deposits and volatile materials of any kind. Keep all air filters clean.
4. Ventilate thoroughly after painting or unavoidable presence of any inflammable substance.
5. Use no oil on any oxygen fitting or equipment.
6. Keep bedding and clothing to minimum. Be sure mattress, if used, is covered with fire-resistant material. Use flameproof bedding material. Be sure that clothing is free of grease and oil.
7. Locate all electrical switches outside chamber. Keep electrical system in perfect condition. Prohibit use of any electrical appliance in chamber during oxygen breathing.
8. Let no flame, matches, cigarette lighter, lighted cigarette, cigar, or pipe be carried into the chamber at any time.
9. Assure ample ventilation of chamber during use of oxygen and before any appliance is used.
10. Provide water and sand buckets.
11. Display the following warning prominently inside and outside the chamber:

> **WARNING**
>
> **Danger of fire and explosion is much greater in oxygen or under pressure than in normal atmosphere. Do not admit flames, sparks, volatile or inflammable substances, or unnecessary combustibles of any kind. Provide ample ventilation and use no electrical appliances during oxygen breathing.**

(*m*) Keep compartments where compressed gases are stored (or in use) well ventilated. Prohibit smoking in such compartments.

(*n*) In the event that valve outlets become clogged with ice use warm water, not boiling water, to thaw them out. The use of boiling water will melt the fusible plugs (if present) and vent the cylinder.

(*o*) Never use cylinders which show evidence of damage, for example, severely dented or gouged, bulged from internal pressure, or corroded.

Oxygen and compressed air

(3) The following are safety rules for working with high concentrations of oxygen:

(*a*) Never permit oil, grease, or other readily combustible substance to come in contact with oxygen cylinders, valves, regulators, gages, and fittings.

(*b*) Never lubricate oxygen or compressed-air valves, regulators, gages or fittings with oil or other inflammable substances.

(*c*) Be sure that all oxygen distribution systems have been *cleaned for oxygen service* in accordance with the Bureau of Ships approved method (see art. 1.10.11) to remove all dirt, filings, grease, oil and other foreign materials. Repeat the cleaning process whenever contamination of the system (as by oily compressed air, for example) is known to have occurred or is suspected.

(*d*) Never use oxygen from a cylinder without reducing the pressure through a suitable regulator.

(*e*) Use only approved regulators, hose, and other appliances.

(*f*) Never use compressed gases for cooling the body or for blowing dust from clothing. The danger of combustion is great.

(*g*) Do not smoke where oxygen is stored or in use.

Nitrogen—oxygen mixtures

(4) Never mix oil-contaminated air with oxygen to obtain a specific nitrogen-oxygen mixture. Handle nitrogen-oxygen and helium-oxygen mixtures according to the same rules applied to oxygen.

SECTION 1.8 SELECTION, QUALIFICATION, AND TRAINING

NOTE.—Several of the official directives governing the subject matter of this section were under revision at the time of publication. The omitted articles will be supplied at a later date.

1.8.2 SELECTION OF PERSONNEL

(1) In the selection of personnel for diving training, commanding officers and examining boards shall be guided strictly by the Bureau of Naval Personnel Manual, the Manual of the Medical Department, Catalog of U. S. Naval Training Activities and Courses (Nav Pers 91769–B) and other current instructions.

Physical and psychological

(2) Commands must insure that applicants for all types of diving duty are properly screened prior to being ordered to diving instruction. To effect such screening, order applicants to the nearest activity having facilities to conduct the following:

(*a*) Physical examinations by a medical officer in accordance with the Manual of the Medical Department Article 15–30 to determine fitness for diving training.

(*b*) Recompression Chamber pressure test (50 lbs.)

(*c*) Oxygen tolerance test—At the time of his initial examination, each candidate for diving training must demonstrate his ability to tolerate breathing pure oxygen at a simulated depth of 60 feet for 30 minutes at rest. The purpose of this test is to eliminate from diving duty those individuals who are susceptible to oxygen intoxication to a degree that they are a hazard to themselves and others. To maintain uniform standards certain procedures must be followed. The oxygen must be supplied through a demand valve. (See art. 1.6.21, par. 17(d).) Oxygen masks and systems employing a rebreathing bag must not be used. If a man has a convulsion or demonstrates definite preconvulsive signs (i.e. twitching of lips or limbs) during the test, he has failed. The test must not be repeated. If in the course of the test the candidate complains of questionable symptoms such as nausea, tingling, dizziness or other, the test may be terminated and repeated at a later date at the discretion of the medical officer.

(*d*) A test dive in a diving suit under the guidance of a qualified officer. In this connection, it has been repeatedly demonstrated that a man showing any reluctance or timidity in making his initial dive seldom becomes an acceptable diver.

(*e*) Interview by a qualified diving officer to ascertain insofar as possible, the attitude and motivation of the applicant—Because of the nature of the duties and responsibilities of each officer and man engaged in diving, the psychological fitness of each officer and man for diving training should be carefully appraised. (All diving candidates must be volunteers.) The individual should have arrived at his decision for diving training after mature deliberation and should be motivated by a real desire for this duty. Emotional maturity and stability, dependability, and at least normal intelligence are necessary. Psychiatric conditions or personality traits which might tend to prevent satisfactory adjustment while engaged in this duty are disqualifying.

Physical standards

(3) *Manual of the Medical Department, U.S. Navy*, Article 15–30. Diving Duty:

1. All accepted candidates for duty which involves diving (master, first class, second class, salvage, underwater demolition team, explosive ordnance disposal team, underwater swimmers) shall conform to the following standards:

(*a*) *History of disease.*—Any of the following shall be disqualifying: (1) tuberculosis, asthma, chronic pulmonary disease; (2) chronic or recurrent sinusitis, otitis media, otitis externa; (3) chronic or recurrent orthopedic pathology; (4) chronic or recurrent gastrointestinal disorder; (5) chronic alcoholism; (6) no candidate shall be accepted with a history of syphilis, unless there has been adequate treatment and no signs of activity or organic involvement are discovered.

(*b*) *Age.*—Candidates beyond the age of 30 years shall not be considered for initial training in diving, the most favorable age being 20 to 30. All divers upon reaching the age of 40 shall be examined in accordance with subarticle 15–30 (3), MMD. For officers undergoing training in deep sea diving for the specific purpose of becoming diving supervisors or salvage officers, the upper age limit shall be 39 years. In cases where the candidate's age is 40 or more, the provisions of subarticle 15–30 (3) shall apply.

(*c*) *Weight.*—Diving candidates should be rugged individuals without tendency toward obesity. Fat absorbs about five times the volume of nitrogen as does lean tissue and, due to the low circulatory rate of fatty tissue, the nitrogen is eliminated very slowly, thus acting to increase the incidence of bends. It is considered in general that candidates should present no greater than 10 percent variation from standard age-height-weight tables. Consideration will be given, however, to applicants whose overweight is believed to be due to heavy bone and muscular structure.

(*d*) *Vision.*—A minimum of 20/30 vision bilateral, corrected to 20/20, shall be required. This requirement is not made for underwater work but for the retention of relatively high physical standards for hazardous work in connection with diving and salvage operations. Ophthalmoscopic examinations shall be normal.

(*e*) *Color vision.*—Normal color perception is required of all candidates. Candidates are required to qualify in accordance with the provisions of article 15–11. (NOTE.—This requires ability to pass the Farnsworth Lantern test.)

(*f*) *Teeth.*—A complete dental examination shall be conducted by a dental officer. Definite oral disease and generally unserviceable teeth shall be cause for rejection. Vincent's infection shall disqualify until the infection and such conditions which may contribute to recurrence are eradicated. A high standard of oral hygiene is mandatory. Teeth replaced by satisfactory bridges and dentures are not to be considered disqualifying. Applicants with moderate overbite, underbite, or extensive restorations and replacements by bridges or dentures may be accepted if such do not interfere with effective gripping of the mouthpiece of certain types of self-contained underwater breathing apparatus (SCUBA).

(*g*) *Ears.*—Acute or chronic disease of the auditory canal, membrana tympani, middle or internal ear shall be disqualifying. Perforation or marked scarring and/or thickening of the drum shall be disqualifying. The eustachian tubes must be freely patent for equalization of pressure changes. Hearing of each ear shall be normal.

(*h*) *Nose and throat.*—Obstruction to breathing or chronic hypertrophic or atrophic rhinitis shall disqualify. Septal deviation is not disqualifying in the presence of adequate ventilation. Chronically diseased tonsils shall be disqualifying pending tonsillectomy. Presence or history of chronic or recurrent sinusitis is cause for rejection.

(*i*) *Respiratory system.*—The lungs shall be normal as determined by physical and X-ray examination.

(*j*) *Cardiovascular system.*—The cardiovascular system shall be without significant abnormality in all respects as determined by physical examination and tests as may be indicated. The blood pressure shall not exceed 145 mm., systolic or 90 mm., diastolic. In cases of apparent hypertension repeated daily blood pressure determinations should be made before final decision, bearing in mind that a valuable indication of undesirable excitable temperament is often revealed by vasomotor manifestations (see (*n*) below). Persistent tachycardia and arrhythmia except of sinus type, evidence of arteriolosclerosis (an ophthalmoscopic examination of the retinal vessels shall be included in the examination), varicose veins, marked or symptomatic hemorrhoids, shall be disqualifying.

(*k*) *Gastrointestinal system.* — Candidates subject to gastrointestinal disease shall be disqualified.

(*l*) *Genitourinary system.*—The following shall be disqualifying:

1. Chronic or recurrent genitourinary disease or complaints (normal urinalysis required).

2. Active venereal disease or repeated venereal infection.

3. History of clinical or serological evidence of active or latent syphilis within the past 5 years, or of cardiovascular or central nervous system involvement at any time. An applicant who has had syphilis more than 5 years before must have negative blood and spinal fluid serology.

(*m*) *Skin.*—There shall be no active acute or chronic disease of the skin on the basis of infectiveness and/or offensiveness in close working conditions and interchange of diving apparel.

(*n*) *Temperament.*—The special nature of diving duties requires a careful appraisal of the candidate's emotional, temperamental, and intellectual fitness. Past or recurrent symptoms of neuropsychiatric disorder or organic disease of the nervous system shall be disqualifying. No individual with a history of any form of epilepsy, or head injury with sequelae, or personality disorder shall be accepted. Neurotic trends, emotional immaturity or instability and asocial traits, if of sufficient degree to militate against satisfactory adjustment shall be disqualifying. Stammering or other speech impediment which might become manifest under excitement is disqualifying. Intelligence must be at least normal.

(*o*) *Ability to equalize pressure.*—All candidates shall be subjected in a recompression chamber to a pressure of 50 pounds per square inch to determine their ability to clear their ears effectively and otherwise to withstand the effects of pressure. Due consideration must be given to the presence of an upper respiratory infection which temporarily may impair the ability to equalize, owing to congestion of the eustachian tube.

(*p*) Individual susceptibility to oxygen shall be tested by determining candidate's ability to breathe oxygen without untoward effects at a pressure of 60 feet (27 pounds) for a period of 30 minutes.

(2) Annual physical examination of all divers shall be conducted in accordance with standards set forth above.

(3) Qualified divers who desire to continue in that specialty and are about to reach the age of 40 shall be examined by a board of medical officers appointed by the senior officer present. At least one member of the board shall be qualified as a deep sea diver or in submarine medicine. The report of the examination on Standard Form 88 with the recommendation of the board as to whether the individual is or is not physically qualified to continue as a diver shall be forwarded to the Bureau of Medicine and Surgery for final decision and in time to reach the Bureau before the man attains the age of 40. A certain latitude may be allowed for a diver of long experience and a high degree of efficiency in diving. He must be free from any diseases of the cardiovascular, respiratory, genitourinary, and gastrointestinal systems, and of the ear. His ability to equalize air pressure must be maintained. A moderate degree of overweight may be disregarded if the diver is otherwise vigorous and active.

SECTION 1.9 REPORTS

1.9.1 INTRODUCTION

(1) The reports and records outlined herein are designed to overcome certain inadequacies in the method of logging diving operations. On the assumption that the diver is the most immediately concerned with his own career, the responsibility for preparation and retention of most of the records is placed on him. The responsibility for a high overall standard of completeness and accuracy rests progressively on the diving supervisor, the diving officer and the personnel and commanding officers.

1.9.2 DIVING RECORD SYSTEM

(1) There are four objectives to be attained in the establishment of an adequate diving record system. These four objectives are:

(*a*) Establish a satisfactory command and operational record.

(*b*) Authorize disbursements of special and incentive pay.

(*c*) Establish a personal record.

(*d*) Provide data for analysis.

(2) The command record of the first objective may be described as a standardized record prepared in accordance with established military practice. Such a record is the normal minimum required when life is risked. It tends to insure proper operational procedures. It promotes safety and safe practices. By recording the objectives of dives and the work accomplished along with details of the dives, the command has a ready justification for any special or incentive pay authorized.

(3) The authorization of disbursements in the second objective is the normal requirement that the disbursing officer be furnished adequate instructions to permit proper disbursements. There is a tangible and distinct difference between the responsibility of the disbursing officer for the disbursement of funds and that of the commanding officer for the justification of disbursement authorizations. The disbursing officer is responsible for insuring that the disbursement authorizations presented to him contain certifications required by law. The commanding officer is responsible that the operations in fact are correct as certified.

(4) The establishment of a personal record in the third objective is an effort to promote esprit de corps and personal pride. By imposing a certain responsibility on the individual, he becomes more aware of the existence of the record and of the benefit of a good record. The long, arduous, unrewarded dives amass an experience level that is, in itself, rewarding. The diving supervisor and diving officer are provided with an assessment factor to assist in the assignment of difficult diving jobs.

(5) The fourth objective, to provide data for analysis, is the least tangible of the four objectives. The expense of diver training and the mission of the Experimental Diving Unit to develop diving equipment and techniques do merit a measure of surveillance effort. The procedure designed to meet this objective requires a minimum effort.

1.9.3 COMPONENTS OF THE SYSTEM

(1) The components established to meet the objectives outlined in 1.9.2 (1) are:

(*a*) Diving Log Book, NAVSHIPS 1000 (Rev. 11–57) (figure 49 is a sample page).

(*b*) Record of Dive form (figure 50).

(*c*) Diving Duty Summary form (figure 51).

(*d*) Report of Decompression Sickness and all Diving Accidents: (NAVMED–816 (Rev. 2–56) (figure 52)).

(2) In general, these components satisfy the parallel objectives. There is some overlap in that the Record of Dive becomes part of the command and personal record as well as the disbursing authorization. Also, the Activity Diving Logs and the accident report form ultimately provide data for analysis.

1.9.4 DIVING LOG BOOK

(1) The Diving Log Book, NAVSHIPS 1000 (Rev. 11–57) is a bound book of individual dive sheets. In use, it is similar to the Quartermaster's Notebook and the Rough Deck

(Name, last, first, middle) | (Service No.)

RANK/RATE	CLASS OF DIVER	GEOGRAPHICAL LOCATION

1. DIVE	DATE	DEPTH FT.	BOTTOM TIME MIN.		
2. DIVING COND.	WATER DEPTH FT.	WATER TEMP. °F.	CURRENT KTS.	TYPE BOTTOM	BOTTOM VISIBILITY FT.
3. TYPE WORK (None, mild, moderate, heavy)	4. EQUIPMENT	☐ DEEP SEA	☐ HEL.-OXYGEN	☐ MASK	
		☐ SCUBA (Open)	☐ SCUBA (Closed)	☐ OTHER:	
5. BR. MED.	AIR	HELIUM %	OXYGEN %	NITROGEN %	6. SOURCE OF BREATH. MEDIUM: ☐ AIR BANKS ☐ HEO₂ BANKS ☐ COMP.

7. REPETITIVE NO-DECOMP. DIVES

	1	2	3	4
TIME OUT				
TIME IN				
TIME (Min.)				
DISTANCE (Yards)				
AIR OUT (PSI)				
AIR IN (PSI)				
AIR USED (Cu. feet)				
MAX. DEPTH (Feet)				
☐ SUIT USED	BOT. VOL. (Cu. ft.)	TOT. TIME (Min.)	TOT. DIST. (Yds.)	
10. TOTAL TIME OF DIVE(S)	THIS/THESE MIN.	CUMULATIVE HRS. MIN.		

8. DECOMP. TABLE

STD.	SURFACE AIR	SURFACE OXYG.	HEO₂	SCHEDULE FT./PP.	SCHEDULE MIN.
LEFT SURF.	REACH'D BOT.	LEFT BOT.	SURF'D	ASC. TO 1st STOP (Ft./Min.)	
If surface decomp. used, time from last water to first chamber stop.				MIN.	

9. DECOMPRESSION STOPS (Record additional stops in 12)

DEPTH	WATER MIN.	WATER BR. MED.	CHAMBER MIN.	CHAMBER BR. MED.
50				
40				
30				
20				
10				

11. WORK SCHEDULED AND ACCOMPLISHED

12. REMARKS

DIVING SUPERVISOR (Rank/rate) | DIVING OFFICER

U. S. GOVERNMENT PRINTING OFFICE : 1958 O-F—455420

FIGURE 1-49.—Diving log book (sample page).

Log combined. It provides a continuous and permanent official record and its maintenance by naval commands authorized to conduct diving operations is mandatory.

Purpose

(2) The purpose of the *Diving Log Book* is primarily to establish a satisfactory and permanent command record of diving operations and secondarily to provide data for subsequent analysis.

The first purpose tends to insure proper and safe operational practices as well as to aid in administration and disbursing of diving in the command.

The second purpose enables the Experimental Diving Unit to maintain a final and overall survey of naval diving in order to better carry out its mission of development and improvement of diving procedures.

Maintenance

(3) To obtain full benefit from this log and to maintain it properly, the diving supervisor must record entries as they occur at the scene of diving operations. These entries should be printed legibly and without erasure. If required by the number of diving locations, by clerical requirements, or other valid reason, more than one log may be used. If this is done, give each a suitable designation.

Entries

(4) Most entries are self-explanatory. Amplifying remarks for others are listed below:

Block 1.—"Bottom time" is the elapsed time between leaving the surface in descent and leaving the bottom in ascent. It is used only to select the proper decompression schedule. The time of dive for pay and other purposes includes bottom, ascent time, decompression time, and time required to return to the surface and to the surface crew's care.

Block 5.—If breathing air, so indicate. If breathing other gases indicate percentages.

Block 7.—This block is printed for convenience in scuba diving but it can be used equally well with surface-supplied equipment. Use it when a diver makes one or more "no decompression" dives within a 12 hour period. Buddy pairs may be recorded on the same sheet if they make the same dive or the same series of repetitive dives. "Time out" and "time in" refer to times of entering and leaving the water. Entries for "distance," "air used," "bottle volume," and "total distance" are not mandatory but are included for convenience in certain self contained diving operations.

Block 8.—Do not record more than one dive requiring decompression on the same sheet.

Block 9.—Record any decompression stops deeper than 50 feet in spaces provided and on back of form as necessary.

Block 11.—Specify the purpose of the dive and whether or not the job was completed.

Block 12.—This section may be used to amplify any information listed elsewhere on the page and to record any unusual features of the dive. Computations for repetitive dives requiring decompression may also be made in this section. Include all pertinent information needed to substantiate special or incentive pay. (Note Art. A–4202, BuPers Manual.)

Distribution

(5) Diving Log Book is distributed by:

Officer in Charge
U.S. Navy Experimental Diving Unit
U.S. Naval Gun Factory
Washington 25, D.C.

(6) One initial copy is distributed to each *nondiving* activity and two to each *diving* activity. (See latest revision of OPNAV Instruction 9940.1.) One initial copy is also distributed to each shore activity having a diving capability.

Disposition

(7) Retain completed Diving Log Books in the command's files for four years from the date of the last entry involving special or incentive pay. At that time forward the log to the Experimental Diving Unit.

1.9.5 RECORD OF DIVE FORM

(1) The Record of Dive form is the pay voucher, the personal log entry, and the record in the CO order file.

(2) The format is designed to permit transcription direct from the Diving Log Book. Have the yeoman type all of the data from the Diving Log Book sheet to the corresponding blocks in the Record of Dive form. Have him check the applicable areas in the pay voucher, (SUBSTANTIATION) section in accordance with the instructions in the "Remarks" block of the log. Diving officer and commanding officer sign in the proper blocks with the carbon inserted. Then, distribute copies as indicated.

(3) A majority of dives made within the fleet involve additional pay of some type. Two copies of the Record of Dive form must be submitted to the disbursing officer. In order to give the diver his personal record, prepare those that do not involve pay in the same manner as those that do. The one copy for the diver is all that is required. Only the signature of the diving officer is required.

(4) The initial assignment of a diver to diving duty is one time that a Record of Dive form might be prepared solely for pay purposes. If no diving is conducted within the month following assignment of a qualified diver to diving duty, use a Record of Dive form to initiate the monthly basic special diving pay. In the Special Pay section, check the blocks labeled "Diving Duty" and "Assigned." Enter the date assigned to diving duty in the block labeled "Effective Date" and enter the diver's qualification and lapsing date in the blocks following. Over the commanding officer's signature, this is the necessary authorization to commence payment of the proper monthly basic diving pay.

(5) To assign a qualified diver to diving duty involving incentive pay at the U.S. Naval School, Deep Sea Divers, The U.S. Navy Experimental Diving Unit or a submarine escape training tank, use the blocks in the Incentive Pay Section in the same manner. No further substantiation of these duties is required to justify continued payment of incentive pay. A diver receiving incentive pay must be currently qualified.

(6) The blocks labeled "Qualified as" and "Lapsing date" under the special pay section are for recording the diver's qualification and the date that the particular qualification will lapse if the required dives are not completed. Except for the duty listed in (5) above, submit a Record of Dive form each time a diver requalifies. This form may also be submitted as a salvage special pay voucher, a footage or diving time special pay voucher or a helium-oxygen incentive pay voucher.

(7) The basic responsibility to know the status of current qualification dives rests on the diver himself. Each activity will naturally initiate machinery proportional to the size of the diving crew to insure routine completion of qualification dives. Insure that each Record of Dive form submitted to the disbursing officer contains the proper qualification date and that it is current. If, in spite of efforts of the diver and the command, the

Approved by
Comptroller General, U. S.
Dec. 17, 1957

RECORD OF DIVE

NAME (*Last, first, middle*)	SERVICE NO.	RANK/RATE	CLASS OF DIVER
SHIP OR STATION	GEOGRAPHICAL LOCATION		

1. DIVE

DATE	DEPTH	BOTTOM TIME
	FT.	MIN.

2. DIVING CONDITIONS

WATER DEPTH	WATER TEMP.	CURRENT	TYPE OF BOTTOM	BOTTOM VISIBILITY
FT.	°F.	KTS.		FT.

3. TYPE OF WORK

☐ NONE ☐ MILD ☐ MOD-ERATE ☐ HEAVY

4. TYPE OF EQUIPMENT

DEEP SEA	HEL.-OXYGEN	MASK	SCUBA (*Type circuit*)	OTHER

5. BREATHING MEDIUM

AIR	HELIUM	OXYGEN	NITROGEN
	%	%	%

6. SOURCE OF BREATHING MEDIUM

☐ AIR BANKS ☐ HEO2 BANKS ☐ COMPRESSOR

7. REPETITIVE NO-DECOMPRESSION DIVES

NO.	TIME OUT	TIME IN	TIME (MIN.)	DISTANCE (YDS.)	AIR OUT (PSI)	AIR IN (PSI)	AIR USED (CU. FT.)	MAXIMUM DEPTH (FT.)
1								
2								
3								
4								

SUIT USED

BOTTLE VOLUME — CU. FT.

TOTAL TIME — MIN.

TOTAL DISTANCE — YDS.

IF SURFACE DECOMPRESSION USED, TIME FROM LAST WATER STOP TO FIRST CHAMBER STOP. — MIN.

8. DECOMPRESSION TABLE

STANDARD	SURFACE		HEO2	SCHEDULE		LEFT SURFACE	REACHED BOTTOM	LEFT BOTTOM	SURFACED	RATE OF ASCENT TO FIRST STOP
	AIR	OXYGEN		FT.OR P.P.	MIN.					FT/MIN

9. DECOMPRESSION STOPS

DEPTH OF STOP	WATER		CHAMBER	
	MIN. AT STOP	BREATH'G. MED.	MIN. AT STOP	BREATH'G. MED.
50				
40				
30				
20				
10				

11. BRIEF OF WORK PERFORMED

12. REMARKS

10. TOTAL TIME OF DIVES

THIS/THESE DIVE(S)	CUMULATIVE		SIGNATURE OF DIVING OFFICER
MIN.	HRS.	MIN.	USN

SUBSTANTIATION

TO DISBURSING OFFICER: As provided by law and regulations, the disbursing officer is authorized and directed to adjust the pay record of the above named individual for the reason and the period indicated.

SPECIAL PAY

FOR ☐ DIVING DUTY — DUTY IS ☐ ASSIGNED ☐ TERMINATED — EFFECTIVE DATE — QUALIFIED AS — LAPSING DATE

☐ DIVING TIME ☐ DIVES OF MORE THAN 120 FEET ☐ ACTUAL SALVAGE OR REPAIR OPERATIONS — (BUPERS MANUAL ART.) 4202* — *If less than 90 ft., indicate the extraordinary hazardous conditions that existed by inserting (3)* or (2) (a), (b), etc.*

INCENTIVE PAY

DUTY INVOLVING TRAINING

☐ OF DIVERS AT NAVSCOL DEEP SEA DIVERS OR AT USN EXPERIMENTAL DIVING UNIT

☐ IN METHODS OF ESCAPE FROM SUBMERGED SUBMARINE (Training Tank)

DUTY INVOLVING

☐ BREATHING HELIUM-OXYGEN MIXTURES DURING DEEP SEA DIVING

DUTY IS ☐ ASSIGNED ☐ TERMINATED ☐ SUSPENDED ☐ RESTORED — EFFECTIVE DATE

☐ DIVE PERFORMANCE REQUIREMENTS IN CONNECTION WITH HELIUM-OXYGEN INCENTIVE PAY COMPLETED FOR PERIOD— TO

COMMANDING OFFICER* (*Signature, rank, title*)	C. O. ORDER NO.	D. O. SYMBOL NO.	DATE

NAVPERS 2540/NAVCOMPT 2039 (New 10-57)

PART 1 — DIVER'S LOG

**When pay is for dives of less than 90 feet and Art. 4202(3) is cited, the personal signature of the commanding officer is required.*

FIGURE 1-50.—Record of dive (form).

required dives are not performed and the qualification lapses, it is then a command responsibility to see that a Record of Dive form is prepared on the date the qualification lapses. In that form, check the applicable "Diving Duty" and the "Terminated" blocks. In both the "Effective Date" and "Lapsing Date" blocks enter the date that the qualification lapsed. The comanding officer is primarily responsible to see that this action is unnecessary except under unusual circumstances. When the action is necessary, sign the form and transmit it to the disbursing officer immediately along with all of the man's earlier Record of Dive forms for the month.

(8) Assignment to diving duty involving the breathing of helium-oxygen mixtures requires a special procedure for the submission of pay vouchers. The first pay voucher assigning a qualified diver to helium-oxygen duty must record a helium-oxygen dive. A 3-month period is allowed after initial assignment to perform that dive. In the block "Performed——," enter the month of assignment and the third month following, i.e. 3/57–5/57 for example. In the "Effective" block enter the date assigned to duty, i.e. 13 March 1957 for the example above. Subsequent dives reported for pay purposes may cover any 3-month period that includes the month in which the dive was performed. Repeat the original effective date as long as the assignment to duty is continuous. If military operations prevent completion of the required minimum of one dive in any 3 month period, two dives may be performed within the following 3 months in order to comply with the required minimum for the 6 months. Report the first dive in the normal manner; that is, use it to cover the month in which the dive was performed and the 2 months preceding. Report the second dive as covering the entire 6 months and note that military operations prevented completion of the required dive during the specific 1, 2 or 3 months ahead of the last voucher. Continue this system throughout the period the man is assigned to helium-oxygen diving duty. On termination, check the duty is "Terminated" block and enter the effective date in the "Effective" block.

(9) Forward Record of Dive forms to the disbursing officer only once each month except for personnel being transferred. Arrange the sheets for each diver in chronological sequence with the latest date on top.

1.9.6 THE DIVER'S LOG BINDER

(1) A Diver's Log binder is issued to each graduate of the U.S. Naval School, Deep Sea Divers. It is his personal property. The binder serves as a depository for his personal copies of the Record of Dive forms and the Diving Duty Summary forms. (See art. 1.9.7.)

(2) Training activities other than the Diving School should present suitable binders to divers of any designation qualified by them. Divers already qualified on promulgation of this article may use a file folder to hold their forms.

(3) The binder and its contents are available to the diving supervisor to assist him in the detailing of divers. Each diver is responsible for maintaining his own records and for presenting his binder on each new assignment to diving duty. Each command may establish its own system for assisting the divers in keeping their records current and for providing proper stowage.

(4) The Diver's Log is an official record and may be used for such purposes as determining the experience of divers and for comparing the relative experience of several divers. Ultimately the Log will be valuable when considering recommendation of a diver, first class for advancement to master diver.

1.9.7 DIVING DUTY SUMMARY FORM

(1) Along with the log binder, each graduate of the Diving School is presented with two copies of a Diving Duty Summary Form. The initial entries recording qualification and the issuance of the log binder are completed and signed prior to presentation. The original is placed in the Diver's Log binder and the duplicate copy is placed in his service record.

(2) Training activities other than the Diving School should prepare similar forms for presentation to divers of any designation qualified by them. Commands having divers assigned should prepare forms for those divers

DIVING DUTY SUMMARY

QUALIFICATIONS	DATE	CERTIFYING OFFICER	DIVER'S LOG BINDER ISSUED
SCUBA DIVER			ACTIVITY
DIVER SECOND CLASS			DATE
SALVAGE DIVER			DUPLICATE BINDER ISSUED
DEEP SEA DIVER			ACTIVITY
DIVER FIRST CLASS			DATE
MASTER DIVER		AUTHORITY BUPERS LTR. SERIAL OF	REASON

ASSIGNED TO DIVING DUTY		TOTAL DIVES							DETACHED	
		DEEP SEA		LIGHT-WEIGHT	SCUBA					
SHIP OR STATION	DATE	AIR	HEO2		AIR	O2	N_2O_2	HEO2	DATE	CERT. OFFICER

FORM COMPLETED AND FORWARD TO US NAVAL SCHOOL DEEP SEA DIVERS

C.O. SIGNATURE ______ DATE ______

☐ ON SEPARATION FROM SERVICE

☐ QUALIFICATION REVOKED (GIVE REASON)

DIVER'S NAME (LAST, FIRST, MIDDLE)	SERVICE NO	RANK OR RATE	BRANCH & CLASS

FIGURE 1-51.—Diving duty summary (form).

already qualified on promulgation of this article. Those divers should estimate, to the best of their abilities from available records, prior diving experience and enter that information on the form for each former duty station. These entries may be certified by the diver's signature.

(3) It is then the diver's responsibility to insure that both copies of the form are maintained current with each permanent assignment to diving duty or with each assignment to requalification diving. Just prior to detachment, he must sum up in his copy all of the diving he has performed. It must then be turned in to the ship's office for transcription in the duplicate copy. Both copies must then be signed by the commanding officer or his authorized representative before the diver is transferred. The signature on the diver's copy signifies that the command approves his record and that it has been transcribed to the official copy.

(4) This form, when properly filled out, represents a complete record of the diver's diving career. Each line entry represents a permanent assignment to diving duty. It includes all temporary additional duty assignments made within the permanent assignment period. One line may thus represent several years' service on board one command.

(5) On failure to retain diving qualification, or on final separation from active duty, the form must be completed and the duplicate forwarded to the Officer in Charge, U.S. Naval School, Deep Sea Divers, Naval Gun Factory, Washington 25, D.C.

(6) Primarily, this record is for the benefit of the Diving School and the Experimental Diving Unit. It provides a source of data to compare against the Reports of Decompression Sickness and all Diving Accidents (NAVMED 816). The knowledge of the amount of diving performed by various units of the fleet, gained by analysis of this record, enables EDU to improve its support of the diving field. It is also a method to keep interested persons in the Navy Department informed of the use and disposition of trained divers. As a final summary, it becomes the record of the individual's diving career.

(7) Duplicate Diving Duty Summaries and Divers Log binders may be requested from the Diving School when the original is verified lost or destroyed or when the individual reenlists after broken service.

(8) An individual who is retrained and redesignated at the Diving School after his previous qualification has lapsed is issued a new Diving Duty Summary. It must be the objective of all concerned to reduce to an absolute minimum the occasions requiring this retraining and redesignation.

1.9.8 REPORT OF DECOMPRESSION SICKNESS AND ALL DIVING ACCIDENTS

(1) The Report of Decompression Sickness and all Diving Accidents (NAVMED–816) rounds out the system of diving reports. It provides data for analysis concerning the safety of decompression tables and the effectiveness of treatment procedures. It also supplies much valuable information concerning diving hazards of all kinds. Analysis of the reports plays an important role in the continual effort to improve diving practices and increase the safety of diving as a whole.

Accidents to be reported

(2) Reporting of the following types of accident is considered mandatory:

(*a*) Cases of decompression sickness requiring treatment; all cases of air embolism.

(*b*) All episodes of convulsion or serious impairment of consciousness during or after a dive, regardless of cause or outcome.

(*c*) Every accident that occurs during the course of a diving operation and results in death, serious injury, or more than brief incapacitation of the victim.

(*d*) Any serious mishap during the course of a dive (i.e. blowup, squeeze, fouling of more than brief duration, failure of scuba requiring free ascent from significant depth) even though the diver escapes actual injury.

(*e*) Any event or aftermath of a dive which requires medical treatment beyond simple first-aid or routine measures.

(3) Since the basic purpose of NAVMED–816 is to increase the overall safety of all

REPORT OF DECOMPRESSION SICKNESS AND ALL DIVING ACCIDENTS
NAVMED-816 (REV. 2-56)

ORIGINAL – TO BUMED, WASHINGTON, D. C.
COPY – TO EXP. DIVING UNIT, NAVAL GUN FACTORY, WASH., D. C.

REPORTS SYMBOL: MED-6420-1

NAME AND ADDRESS OF REPORTING STATION	DATE
NAME OF PATIENT *(Surname first)*	IDENTIFICATION NUMBER

AGE	WEIGHT	HEIGHT	BUILD *(Check one)*				DIVING QUALIFICATIONS *(Check one)*									
			SLENDER	MED.	HEAVY	OBESE	MAST	1/c	SAL.	D. S.	2/c	UDT	EOD	UWS	STU	(OTHER)
YRS.	LBS.	INS.														

RECORD OF ALL DIVES MADE DURING THE TWELVE HOURS PRECEDING THE ACCIDENT
(If more than three dives were made, record additional under "REMARKS" on reverse.)

FIRST DIVE				SECOND DIVE				THIRD DIVE			
TYPE OF DIVE		DEPTH OF DIVE	BOTTOM TIME	TYPE OF DIVE		DEPTH OF DIVE	BOTTOM TIME	TYPE OF DIVE		DEPTH OF DIVE	BOTTOM TIME
WET	DRY	feet	min.	WET	DRY	feet	min.	WET	DRY	feet	min.

TYPE OF EQUIPMENT

First dive						Second dive						Third dive					
DEEP SEA	DEEP SEA HELIUM	OPEN CIRCUIT SCUBA	CLOSED CIRCUIT SCUBA	SHALLOW WATER MASK	OTHER	DEEP SEA	DEEP SEA HELIUM	OPEN CIRCUIT SCUBA	CLOSED CIRCUIT SCUBA	SHALLOW WATER MASK	OTHER	DEEP SEA	DEEP SEA HELIUM	OPEN CIRCUIT SCUBA	CLOSED CIRCUIT SCUBA	SHALLOW WATER MASK	OTHER

TYPE OF WORK

First dive				Second dive				Third dive			
NONE	MILD	MODERATE	HEAVY	NONE	MILD	MODERATE	HEAVY	NONE	MILD	MODERATE	HEAVY

BREATHING MEDIUM

First dive				Second dive				Third dive			
AIR	HELIUM % OXYGEN %	OXYGEN	OTHER *(Specify)*	AIR	HELIUM % OXYGEN %	OXYGEN	OTHER *(Specify)*	AIR	HELIUM % OXYGEN %	OXYGEN	OTHER *(Specify)*

SOURCE OF BREATHING MEDIUM

First dive				Second dive				Third dive			
AIR BANKS	HELIUM–OXYGEN BANKS	GASOLINE COMPRESSOR	OTHER	AIR BANKS	HELIUM–OXYGEN BANKS	GASOLINE COMPRESSOR	OTHER	AIR BANKS	HELIUM–OXYGEN BANKS	GASOLINE COMPRESSOR	OTHER

DECOMPRESSION SCHEDULE

First dive					Second dive					Third dive				
STANDARD	SURFACE USING		HE. DECOMPR.	TABLE USED	STANDARD	SURFACE USING		HE. DECOMPR.	TABLE USED	STANDARD	SURFACE USING		HE. DECOMPR.	TABLE USED
	AIR	OXYGEN	P.P.	MIN.		AIR	OXYGEN	P.P.	MIN.		AIR	OXYGEN	P.P.	MIN.

First dive				Second dive				Third dive			
TIME LEFT SURFACE	TIME REACHED BOTTOM	RATE OF ASCENT TO FIRST STOP	TIME REACHED SURFACE	TIME LEFT SURFACE	TIME REACHED BOTTOM	RATE OF ASCENT TO FIRST STOP	TIME REACHED SURFACE	TIME LEFT SURFACE	TIME REACHED BOTTOM	RATE OF ASCENT TO FIRST STOP	TIME REACHED SURFACE
		FT/MIN				FT/MIN				FT/MIN	

If surface decompression used, time from last water stop to 1st chamber stop. MIN. | *If surface decompression used, time from last water stop to 1st chamber stop.* MIN. | *If surface decompression used, time from last water stop to 1st chamber stop.* MIN.

DEPTH OF STOP *(feet)*	WATER		CHAMBER		DEPTH OF STOP *(feet)*	WATER		CHAMBER		DEPTH OF STOP *(feet)*	WATER		CHAMBER	
	MINUTES AT STOP	BREATHING MEDIUM	MINUTES AT STOP	BREATHING MEDIUM		MINUTES AT STOP	BREATHING MEDIUM	MINUTES AT STOP	BREATHING MEDIUM		MINUTES AT STOP	BREATHING MEDIUM	MINUTES AT STOP	BREATHING MEDIUM
210					210					210				
200					200					200				
190					190					190				
180					180					180				
170					170					170				
160					160					160				
150					150					150				
140					140					140				
130					130					130				
120					120					120				
110					110					110				
100					100					100				
90					90					90				
80					80					80				
70					70					70				
60					60					60				
50					50					50				
40					40					40				
30					30					30				
20					20					20				
10					10					10				

(over)

Figure 1–52.—Report of decompression sickness and all diving accidents (form).

SIGNS AND SYMPTONS BEFORE TREATMENT

	ONSET		ANATOMICAL LOCATION	INTENSITY (MILD, MOD., SEVERE)
	DATE	TIME		
LOCALIZED PAIN				
RASH				
MUSCULAR WEAKNESS				
NUMBNESS				
DIZZINESS			XXXX	
VISUAL DISTURBANCES				
PARALYSIS				
UNCONSCIOUSNESS			XXXX	XXXX
DYSPNEA (CHOKES)			XXXX	
NAUSEA OR VOMITING			XXXX	
MUSCULAR TWITCHING				
RESTLESSNESS			XXXX	
CONVULSIONS				
ACOUSTIC AURA				
PARESTHESIA				

REMARKS: *(other signs and symptoms before, during and following treatment)*

TREATMENT SCHEDULE

LEFT SURFACE		RELIEF		TIME REACHED BOTTOM
DATE	TIME	TIME	DEPTH	
TIME ON BOTTOM		REACHED SURFACE		TREATMENT TABLE USED
MIN.		DATE	TIME	

DEPTH OF STOP		CHAMBER *(Stops filled in only when treatment table 3 or 4 is used or when other treatment tables are altered)*	
FEET	LBS	MINUTES AT STOP	BREATHING MEDIUM
165	73.4		
140	62.3		
120	53.4		
100	44.5		
80	35.6		
60	26.7		
50	22.3		
40	17.8		
30	13.4		
20	8.9		
10	4.5		
TO SURFACE			

RECURRENCE TREATMENT SCHEDULE

LEFT SURFACE		RELIEF		TIME REACHED BOTTOM
DATE	TIME	TIME	DEPTH	
TIME ON BOTTOM		REACHED SURFACE		TREATMENT TABLE USED
MIN.		DATE	TIME	

DEPTH OF STOP		CHAMBER *(Stops filled in only when treatment table 3 or 4 is used or when other treatment tables are altered)*	
FEET	LBS	MINUTES AT STOP	BREATHING MEDIUM
165	73.4		
140	62.3		
120	53.4		
100	44.5		
80	35.6		
60	26.7		
50	22.3		
40	17.8		
30	13.4		
20	8.9		
10	4.5		
TO SURFACE			

REMARKS: *(Include sequence of events preceding the accident and subsequent result of treatment, noting any unusual contributing factors – Use continuation sheet if needed)*

SIGNATURE OF MEDICAL DEPARTMENT REPRESENTATIVE

B-48320

aspects of diving operations, it is considered highly desirable to report *any* happening or observation that calls attention to a potential hazard or can otherwise contribute to safe practices. In this sense, for example, the report of a narrow escape from a serious accident under unusual circumstances would be of as much value as a report of a fatal accident of the same nature. It is also extremely desirable to report such observations as, for example, an unusual number of cases of a particular type of respiratory infection among a group of divers or some peculiar set of symptoms appearing frequently with a certain type of equipment. It is only through such reporting that a new problem can be recognized early and steps taken to deal with it. (In some instances, as for example when a similar condition has been observed in a number of individuals, it may be more convenient to prepare a letter-report than to utilize NAVMED–816 itself; but the same basic instructions and distribution should be observed.)

Preparation

(4) The cognizant medical officer (normally the medical officer who treats the victim of the accident concerned) is responsible for preparing the report. If no medical officer is attached to the activity or present at the time of the accident or treatment, the medical department representative (hospital corpsman) concerned must prepare and sign it. In this case, the report should also bear the signature of the cognizant medical officer, if any, with indication of his approval and/or comments. Where no medical officer or corpsman is present or directly concerned, preparation of NAVMED–816 becomes the responsibility of the diving officer.

(5) The report-form itself is largely self-explanatory. Any information not adequately covered by the spaces provided should be detailed under "remarks." Enough information should be provided to permit anyone reading the report to obtain a clear picture of the accident, circumstances, treatment, and outcome.

(6) Prepare and submit NAVMED–816 at once unless the victim has residual symptoms and the final outcome remains in doubt. In such a case, prepare the body of the report immediately but delay completion and submission (*not longer than 30 days*) to permit the actual or probable end-result to be specified with reasonable accuracy. Where submission is delayed, be sure that the report is not neglected. If the outcome remains uncertain as long as 30 days following the accident, submit the report with appropriate notations including the patient's condition at that time, medical opinion concerning probable course, and hospital to which patient was transferred (or other disposition). In such cases, supply a follow-up letter-report at a later date whenever possible.

Distribution

(7) Send the original of NAVMED–816 to the Bureau of Medicine and Surgery (Attn: Code 75), Navy Department, Washington 25, D.C. Send a legible copy to the Experimental Diving Unit, Naval Gun Factory, Washington 25, D.C. (Retention of a copy in the files of the diving activity is recommended.)

SECTION 1.10 TECHNICAL INFORMATION

1.10.1 GAS MIXING

(1) Mixtures of nitrogen and oxygen and of helium and oxygen are required for various purposes in diving. Article 1.3.12 provides a discussion of physiological reasons for their employment. Further details concerning methods of use and determination of percentages required are presented in the sections on helium-oxygen diving (pt. 2) and semiclosed-circuit scuba (for use of nitrogen-oxygen mixtures) in article 3.6.5. The following paragraphs describe the preparation of mixtures and provide necessary related information.

Methods—General

(2) There are two basic methods of preparing compressed gas mixtures. One involves mixing the component gases by volume in a large gas holder at normal barometric pressure and then compressing the mixture into cylinders. Considerable accuracy is possible with this method because analysis and adjustment of percentage can be accomplished before compression. Since it involves special equipment, this procedure is not feasible except in commercial processes or by a central plant supplying mixtures to a number of operational units.

(3) The only practical methods for field use are those in which the mixing is done with the gases under pressure in cylinders. Here, pressure provides the usual basis for proportioning. For example, if a mixture with 50 percent oxygen is desired, half of the intended final pressure must be provided by oxygen. The type of mixture and other circumstances governs the details of the mixing procedures, and several of these are discussed below. Because of difficulties in exact measurement of pressure, temperature effects, and other factors, "mixing by pressure" is usually not very precise. The resulting mixtures must always be sampled and analyzed, and adjustment of percentage by addition of more of one of the components is often necessary. (A procedure in which one of the gases is added by accurate measurement of *weight* is sometimes used and has the advantage of reducing temperature effects.)

Booster pumps

(4) Obtaining full pressure in the process of mixing gases or charging scuba cylinders from large cylinders of prepared mixtures presents problems. One solution is to employ a *cascade* arrangement (described in art. 1.10.10 par. (10)). Another is to employ a booster pump designed for use with oxygen. The oxygen booster pump currently available (fig. 1–53) is suitable for pumping oxygen or mixtures from a cylinder with large volume and relatively low pressure to a smaller cylinder at higher pressure. This pump is hand-operated, and its use is practical for charging scuba cylinders up to 2,200 p.s.i. (its rated pressure) but not for mixing purposes involving large cylinders. It is anticipated that a unit designed for higher pressures (some scuba units can utilize pressures up to 3,000 p.s.i.) and possibly for larger volumes will be made available. For detailed operating and maintenance instructions, refer to the manual supplied with each pump.

Safety precautions

(5) In dealing with gases under high pressure, it is extremely important to observe all applicable safety precautions (article 1.7.7). Those concerning contact between oil and oxygen are particularly important. For example, gages and fittings that are not specifically intended for use with oxygen often contain oil; and when oxygen under high pressure is applied, a violent explosion can occur. Be sure gages for use on oxygen and other mixing equipment are tested with *water*, not oil. A first class diver was preparing to mix helium and oxygen. He put a new gage, which had been tested with oil, on an oxygen cylinder. Result: loss of one eye and multiple lacerations. Do not transfer gages from one place to another, i.e. a gage previously used on a compressor to a mixing rack.

(6) Precautions regarding oil extend even to the oil deposited by fingers in handling

FIGURE 1–53.—MSA booster pump.

parts of regulators and the like that will be exposed to oxygen under high pressure or to high-pressure streams of oxygen. Use of an oily wrench on an oxygen fitting can start a serious fire. Where removal of oily materials from equipment is required, employ only approved cleaning procedures (art. 1.10) or, when a solvent must be employed, use only non-inflammable ones like trichlorethylene and assure complete drying before reassembly.

(7) *Never attempt to mix compressed air that may contain oil vapor with oxygen.*—Fittings used with air from an oil-lubricated compressor (or any oil-pumped gas) must never be used with oxygen. If an oxygen gage or regulator has been used in this way, it should be painted a distinctive color and marked "AIR ONLY."

(8) In the use of oxygen cylinders, exercise great care to prevent contamination with foreign material or other gases. Leave at least 25 p.s.i. of oxygen in the cylinder. In particular, never charge an oxygen cylinder with air and then return it for refilling with oxygen. In this case, a residual of oil vapor or an oily film in the cylinder could cause explosion on recharging unless the cylinder was cleaned first by a special (and expensive) procedure. When contamination of any kind has occurred or is suspected, withdraw the cylinder from oxygen service and mark it "Contaminated" *using paint* (tags or labels are not adequate). If the cylinder is subsequently returned, call the nature of the contamination specifically to the attention of the supplier.

(9) Gas under pressure in cylinders, valves, gages, lines, and fittings can be dangerous and should be handled with extreme care. Failure

of any part can suddenly release the gas with a blast effect similar to a high explosive.

(10) In handling cylinders, use a suitable truck equipped with a steadying device to keep cylinders from falling while being moved. Always close valves securely and replace valve cover caps before moving or storing cylinders.

(11) Do not use a wrench or hammer to open or close cylinder valves. If a valve is too tight to open by hand, a slight steady pressure with an extension tool may be applied to the handwheel, taking care not to break the interior parts.

(12) Do not tamper with the safety plug. The plug is designed to relieve excess pressure in the cylinder, and it fractures at a pressure in excess of the maximum filling pressure.

(13) If the safety plug fractures or blows, it must be replaced only by a plug designed for that particular type of cylinder. Cylinders in storage, whether empty or charged, should have the threaded protection cap screwed on the threaded connection. The protection cap has the dual purpose of protecting the valve and of preventing any of the fusible metal of the safety plug (if it fractures or blows) from striking and injuring personnel. The valve cover cap should be placed on the cylinders so fitted.

(14) Store cylinders in a dry, cool place away from the direct rays of the sun. Do not store near highly combustible material, especially oil, grease or any substance likely to cause or accelerate fire. Store well away from cylinders containing another gas. Avoid smoking near oxygen cylinders.

(15) Inspect all valves, gages, fittings, and lines periodically for signs of weakening. Replace all defective or suspected parts. Clean any corrosion or dirt from fittings and valves. When repacking valve stems, do not use any packing that has been treated with oil. If the packing recommended by the valve manufacturer is not available, use clean, dry, new lamp wicking soaked in pure, clean glycerine.

Helium—oxygen mixing

(16) Methods of preparing helium-oxygen mixtures are discussed in detail in article 1.10.2, herein.

1.10.2 HELIUM—OXYGEN MIXING

Single cylinder method

(1) The first step in one method of preparing helium-oxygen mixtures is splitting. A full cylinder of helium is connected by means of a mixing "T" (see fig. 1–54) to one which is empty or nearly so. Open the stop valve on the full cylinder and read the pressure gage on the "T" fitting. Open the valve on the empty cylinder and allow the pressure in the cylinders to equalize slowly. The gage reading should then be half its original value. Close the valves on the cylinders.

Figure 1–54.—Helium-oxygen splitting "T."

(2) In mixing a single cylinder, a fully charged oxygen cylinder is bled into a helium cylinder which contains helium at the reduced pressure previously mentioned. This requires a "T" fitting like that mentioned in the preceding paragraph but with an oxygen connection at one end. Using the "T" fitting, connect a split helium cylinder (about 900 p.s.i.) to a full oxygen cylinder (about 1,800 p.s.i.). Open the stop valve on the helium cylinder, read the pressure on the gage on the "T", then close the valve. Open the stop valve on the oxygen cylinder and read the gage.

(3) Compute the pressure which the helium cylinder will contain when enough oxygen has flowed into it to give the desired percentage:

(*a*) Assume that an 80 percent helium-20 percent oxygen mixture is required. The total pressure in the cylinder, after mixing the two gases, is obtained by dividing the pressure in

the split helium cylinder by the percentage (expressed in decimals) of helium in the final mixture.
For example:

Final pressure in mixed gas cylinder=

$$\frac{\text{Pressure in split helium cylinder}}{\text{Percentage of helium in final mixture}} = \frac{900}{0.80} = 1{,}125 \text{ p.s.i.}$$

(Pressure exerted by oxygen=1,125=900 =225 p.s.i.=pressure drop in oxygen cylinder.)

(*b*) If an 84 percent helium-16 percent oxygen mixture is desired and the split helium cylinder pressure is 860 p.s.i., then: Final pressure in the cylinder will be$=\frac{860}{0.84}=1{,}024.$ (Pressure drop in oxygen cylinder will be 1,024−860=164 p.s.i.)

(4) In the process of mixing, the helium cylinder heats up and the oxygen cylinder cools. This influences the pressures. (Charles' Law: See Article 1.2.4(19).) More accurate results are obtained if the oxygen is allowed to enter the helium cylinder slowly (not over 70 p.s.i. per minute). Even when this slow rate is maintained, it will be found that when the flow between the two cylinders is stopped and the temperatures are allowed to equalize, the pressure in the oxygen cylinder will have increased slightly and the pressure in the helium cylinder will have dropped. There is no practical way of controlling the temperature of the gases during mixing, so this temperature effect must be compensated for by running over a slight excess of oxygen pressure or by adjusting the pressures two or three times at intervals after the cylinders have been allowed to return to approximately the same temperature.

(5) To determine whether an oxygen cylinder has enough pressure to permit its use in mixing for a desired percentage of oxygen when helium pressure is known, subtract helium cylinder pressure from final cylinder pressure (a handy aid is a "Final Pressure Disk" obtainable from the Experimental Diving Unit) and add the remainder to the final pressure plus 50 pounds safety factor.

(*a*)
 1, 250 (final pressure)
 −1, 000 (helium cylinder pressure)
 ———
 250 (lbs. oxygen added)

(*b*)
 1, 250 (final pressure)
 +250 (lbs. oxygen added)
 ———
 1, 500
 +50 (safety factor)
 ———
 1, 550 (pressure needed in O_2 cylinder)

In other words, the oxygen cylinder must have a pressure equal to the final helium-oxygen pressure *plus* the oxygen pressure of the mixture—and 50 p.s.i. to spare.

Multiple cylinder method

(6) Where large quantities of a given mixture must be prepared, much time can be saved by use of a multiple-cylinder mixing and splitting rack. An example of one arrangement is diagrammed in figure 1–55. The basic principle of mixing with a rack is the same as that of the single cylinder method, and the calculations are also the same.

(7) The usual steps in using a mixing and splitting rack like that shown in figure 1–55 are as follows:

(*a*) Connect 10 full oxygen cylinders to one side of the rack.

(b) Close valves A, C, and D.

(*c*) Open all cylinder valves; then crack valve A to permit pressures to equalize in all the oxygen cylinders.

(*d*) On the other side of the rack, connect five full helium cylinders in positions 1 to 5 and five that are empty or nearly so in positions 6 to 10.

(*e*) Close valve B and open all cylinder valves; then crack valve B to let all ten cylinders equalize (splitting).

(*f*) Allow temperatures to stabilize.

(*g*) By cracking valve C or D (or both, if two operators are used) bleed oxygen into the helium cylinders to the desired pressure.

(*h*) Adjust pressure as described in the single cylinder method.

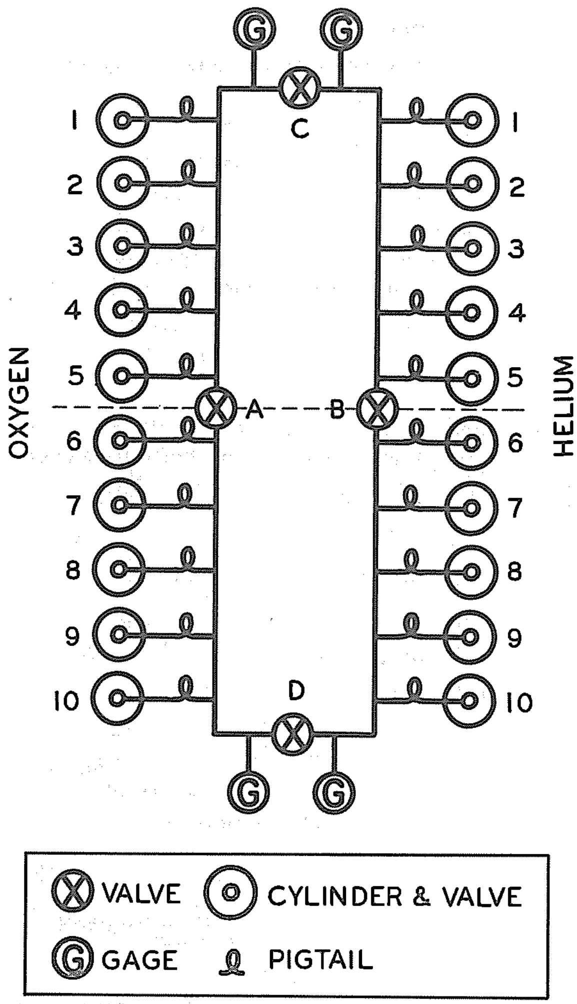


FIGURE 1–55.—Helium-oxygen multiple cylinder mixing manifold.

Adjustment of percentage

(8) If it is necessary to increase the oxygen percentage of a previously mixed cylinder, follow these steps:

(*a*) Subtract the known percentage of oxygen from 100 to obtain the existing percentage of helium.

(*b*) Multiply the helium percentage by the cylinder pressure to obtain the pressure of helium in the cylinder.

(*c*) Subtract the desired oxygen percentage from 100 to obtain the desired percentage of helium.

(*d*) Divide the existing helium *pressure* (step b) by the desired helium *percentage* (step c) in decimal form. (This step yields the cylinder pressure that will exist when enough oxygen has been added to yield the desired percentage.)

(*e*) Add oxygen until this pressure is reached. (Allow temperature and pressure to stabilize and add more oxygen if necessary.)

(*f*) The following formula sums up the computation:

$$F=\frac{P\times(1.00-Oo)}{(1.00-Of)}$$

Where:

F=final cylinder pressure
P=original cylinder pressure
Oo=original oxygen percentage (decimal form)
Of=final oxygen percentage (decimal form).

(*g*) Example:

Cylinder containing 1,000 p.s.i. of 16 percent oxygen; 20 percent oxygen desired.

$$F=\frac{1000\times(1.00-0.16)}{(1.00-0.20)}=\frac{1000\times0.84}{0.80}=\frac{840}{0.80}=1050 \text{ p.s.i.}$$

Therefore, add 50 p.s.i. of oxygen to obtain a cylinder pressure of 1,050 p.s.i.

(9) To reduce the oxygen percentage, use this procedure:

(*a*) Multiply oxygen percentage (decimal form) by cylinder pressure to obtain p.s.i. of oxygen pressure.

(*b*) Divide this figure by the desired oxygen percentage (decimal form). This yields the final pressure to be obtained by adding helium.

(*c*) Formula (symbols as in (8), above):

$$F=\frac{P\times Oo}{Of}$$

(*d*) Example:

Cylinder containing 1000 p.s.i of 20 percent oxygen; 16 percent oxygen desired.

$$F=\frac{1,000\times0.20}{0.16}=\frac{200}{0.16}=1,250 \text{ p.s.i.}$$

Therefore, add 250 p.s.i. of helium to obtain a cylinder pressure of 1,250 p.s.i.

1.10.3 GAS ANALYSIS

(1) When gas mixtures are used for diving, an accurate determination of oxygen concentration (percentage) is necessary. *Any significant deviation from the planned or assumed oxygen content can produce serious difficulties.* Personnel responsible for mixing and analyzing gases must be extremely careful and accurate in their procedures. They must have comprehensive knowledge of gas mixing and analyzing. They must maintain complete records of mixing and analysis operations, and they must check the accuracy of the work and eliminate any errors in procedure and technique.

Methods

(2) Every gas has certain chemical and physical properties that distinguish it from other gases and permit it to be identified and measured. For example, carbon dioxide is absorbed by alkaline solutions. Other gases likely to be present in breathing media are not, so this reaction provides a means of analyzing for carbon dioxide. Similarly, oxygen is absorbed by a pyrogallol solution. This also absorbs carbon dioxide; but if CO_2 is absent or is absorbed separately first, the oxygen content of a sample can be determined. These reactions form the usual basis for chemical gas analysis in diving. For years, *chemical* methods like use of the Haldane analyzer (art. 1.10.4) were the only practical field procedures.

(3) In more recent years, many instruments for analysis based on *physical* properties have been developed. Some of these have advantages like the ability to analyze almost instantaneously and to provide a record of the concentration of a gas in a continuously flowing sample. Such instruments have found many applications in industry and research. One, the Beckman Oxygen Analyzer (articles 1.10.6 & 7), has greatly simplified gas analysis in diving. However, it is a delicate instrument easily broken, or put out of adjustment by mishandling and requires periodic calibration. Therefore, it has not completely replaced older methods; and technicians must be familiar with both.

Gas sampling

(4) The accuracy of a gas analyzer or method means nothing unless the sample of gas analyzed represents what the operator thinks it does. For example, allowing air to mix with a sample, when it is drawn or later, will completely invalidate the results. Regardless of the method of analysis employed, appropriate sampling devices must be used, and careful attention must be given to both sampling and transfer procedures.

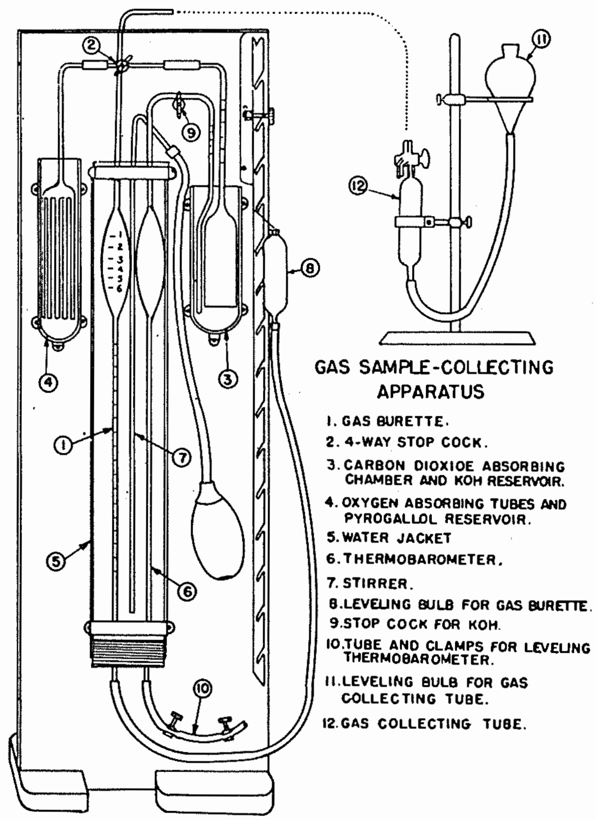


FIGURE 1–56.—Haldane-Henderson gas analysis apparatus.

1.10.4 THE HALDANE GAS ANALYZER

(1) Accurate chemical analysis of gas samples for carbon dioxide and oxygen content is usually done with gas analyzers of the type originated by Haldane, the same man who contributed much to decompression (art. 1.3.9 (7)). The specific apparatus most often used is the Haldane-Henderson analyzer (fig. 1–56). Several models of this instrument are avail-

able, varying in minor details of construction but having the same principle and method of operation.

(2) When properly assembled and used by an experienced operator, this instrument will determine the oxygen and carbon dioxide concentration of a sample with an accuracy of plus or minus 0.02 volumes percent.

(3) The gas burette in which the measurements are made (by volume) holds 10 cc. of gas. The elongated lower portion of the burette (from 7 to 10 cc.) is marked off to 0.01 cc., but it may be read to 0.001 cc. by estimating between the lines. Samples in which the combined oxygen and CO_2 concentration much exceeds 20 percent will leave less than 7 cc. of residual nitrogen in the burette and thus prevent taking readings in the finely calibrated portion. When this is the case, a procedure for storing nitrogen and diluting the sample must be employed; and the analysis becomes less accurate and more laborious. Therefore, the usual Haldane analyzer is not well-adapted to analyzing high-oxygen mixtures.

Procurement

(4) The Haldane-Henderson analyzer and replacement parts currently must be obtained on open purchase from laboratory apparatus supply houses. Since the models produced by various manufacturers generally do not have interchangeable parts, obtain an ample supply of "spares" at the same time.

Location

(5) Maintain a convenient place ashore to house the apparatus. (It is impossible to operate the apparatus aboard ship even in calm water alongside the dock because the slightest motion produces erroneous readings.) Provide a sturdy bench in an area as free from vibration, motion, drafts, and temperature changes as possible.

Assembly

(6) The apparatus is shipped unassembled. Most of the working parts are glass to be mounted on the wood or metal panel. They are fragile and require great care in unpacking and assembly. Where glass parts are connected to each other by tubing, the joints should be made glass-to-glass with sulfur-free rubber tubing over the connection. Place the short pieces of small glass tubing in the oxygen absorbing chamber and secure them with a small wooden wedge, being careful not to use too much force. Lubricate and seal the stopcocks with a minimum amount of a lubricant designed for this purpose. A properly lubricated stopcock turns freely, looks clear, and does not show air tracks between the stationary and rotating parts when it is turned. The holes should show no accumulation of lubricant. (Clean and relubricate any stopcock that becomes difficult to turn or shows signs of dirt, excess grease, or leakage.) Push gently on stopcock when turning to keep rotating part firmly in place.

(7) The stirring tube (No. 7 in fig. 1–56) may be connected to a rubber bulb, as shown, or to a well-controlled source of compressed air. A small stream of bubbles will keep the water in the water bath stirred sufficiently to keep the temperature uniform throughout, while an excess of bubbling may produce inaccuracies. If the bulb is used, squeeze it once or twice about every 3 minutes during the course of an analysis. Do not agitate the water enough to make it splash.

Absorbent solutions

(8) The carbon dioxide absorbent is 20 percent potassium hydroxide (KOH). It must be entirely clear and free of precipitate. The oxygen absorbent is potassium pyrogallol. It is prepared by adding 200 cc. of water to 300 gms. of potassium hydroxide sticks (not purified by alcohol). Place solution in a bottle with a greased stopper. To each 100 cc. of the solution, add 15 gms. of pyrogallic acid (Merck). Both reagents must be kept from contact with air to prevent them from absorbing carbon dioxide and oxygen and thus losing their strength. Both are very caustic and require careful handling.

Preparing for use

(9) Follow these steps in preparing the Haldane-Henderson apparatus for use:

(*a*) Fill the water jacket (5) with water to just above the enlarged portion of the thermobarometer (6).

(*b*) Attach to the bottom of the thermobarometer a piece of rubber tubing about 4 inches long. At the extreme end of this tubing place a clamp and screw down tightly. With a 10 cc. hypodermic syringe, inject about 4 or 5 cc. of water into the tubing in order to reach the level of the bottom of the enlarged section of the thermobarometer. Now inject enough mercury into the tubing to force the water up through the enlarged section. If bubbles form in the thermobarometer, force water up by injecting more mercury into the tubing, until bubbles escape out through the one-way stopcock. Then draw mercury back into the syringe until the level of water is about half way up the enlarged section of the thermobarometer. Now withdraw the needle and place a second clamp about halfway between the end of the tube and the thermobarometer.

(*c*) Pour potassium hydroxide into its reservoir.

(*d*) Close one-way stopcock and squeeze tubing at bottom of thermobarometer, thus forcing air out the thermobarometer outlet tube into the KOH reservoir. Release pressure on tubing causing the KOH solution to rise to the graduated position of the thermobarometer outlet.

(*e*) Set the four-way cock (2) to connect the burette (1) to the carbon dioxide chamber (3).

(*f*) Raise the mercury almost to the top of the burette by elevating the mercury bulb (8), then lower the mercury bulb to draw the KOH solution up into the carbon dioxide absorbing chamber.

(*g*) Shift the four-way cock to connect the burette to the oxygen absorbing chamber (4).

(*h*) Run mercury to near the top of the burette, then pour pyrogallol solution into the reservoir and draw it up into the oxygen absorbing chamber by lowering the mercury in the burette. Pour some liquid petroleum into the pyrogallol reservoir to protect the solution from air.

(*i*) Adjust the level of KOH in the thermobarometer connection to the KOH reservoir to one of the marks on the glass by means of the clamps on the leveling tub at the bottom of the thermobarometer.

(*j*) Adjust the level of the liquid to one of the marks on the carbon dioxide absorbing chamber tube by changing the mercury level in the burette. Do likewise with oxygen absorbing chamber tube.

(*k*) Be sure there is a small layer of fluid (about 1 mm.) on top of the mercury in the burette. Add a small amount of 1 percent sulfuric acid through the upper arm of the stopcock if necessary to keep the burette wet.

Collecting samples

(10) Gas samples must be collected in an apparatus like that shown in figure 1–56 (12). This seals the sample with mercury and stores it under pressure to assure that any leakage will be outward and no contamination can occur. The following steps are for sampling gas from a cylinder of mixture. Similar steps and precautions can be developed for other purposes.

(*a*) Prepare the collecting tube by opening the stopcock and raising the leveling bulb carefully to fill the tube *and stopcock* with mercury. Turn stopcock to position that connects upper arm of stopcock to discharge tube (sidearm). Keep the bulb elevated.

(*b*) Attach a reducer or needle valve to the cylinder to limit flow. Flush it with gas. Connect a length of rubber tubing to the valve and attach this to the upper arm of the collecting tube.

(*c*) Flush the system by letting gas flow through the sidearm at a moderate rate for about 1 minute.

(*d*) Turn the stopcock so that the gas pressure will force the sample into the collecting tube. When the tube is about three-fourths full, turn the stopcock to the sidearm and disconnect the tube. Be sure the leveling bulb remains above the sample chamber.

(*e*) For optimum accuracy when the sample differs greatly in composition from the last one stored in the collecting tube, discard the first filling and repeat the process.

(*f*) It is always advisable to run two determinations on each gas being analyzed to check the accuracy of the work. Since errors can occur in sampling as well as in analysis, the best check is to draw and analyze two samples from each cylinder. If these check, you can conclude that there has been no error in either sampling or analysis.

Transferring the sample

(11) The next operation is to transfer the sample from the collecting tube into the analyzer. Follow these steps:

(*a*) Connect the upper arm of the collecting-tube stopcock to that of the four-way stopcock of the analyzer. For this purpose, use an inverted U-shaped piece of glass tubing of about the same diameter and bore as the stopcock arms. Try to obtain glass-to-glass contact; use short pieces of rubber tubing like that employed in assembling the analyzer.

(*b*) Open four-way stopcock of analyzer to sample connection (upper arm); leave collecting tube stopcock in top-to-sidearm position.

(*c*) Elevate burette leveling bulb to run mercury up burette and over through collecting tube stopcock. As soon as a little mercury has gone through the sidearm and the system is free of old sample and air, shift stopcock so sample can be withdrawn from collecting tube.

(*d*) The sample is under pressure because the collecting tube leveling bulb is elevated. Lowering the burette leveling bulb will cause sample to flow into burette as mercury level in burette goes down. Take in as much sample as you can, but allow for the fact that the gas will expand when pressure is released (the 8.2 cc. mark is usually about right).

(*e*) Shift burette stopcock *clockwise* (direction of turn is important) to a point where it is not connected to anything (all holes in stopcock closed). Lower leveling bulb until both columns of mercury (in burette and in leveling bulb) are at same height. Check reading. If it is off scale, some of the sample must be let out. If it is less than about 8.5, more sample should be transferred.

NOTE.—Once the right amount of sample has been taken into the burette, the marked end of the stopcock handle must not be moved through the upper half of its arc until the analysis is finished.

(*f*) Shut stopcock on collecting tube. (Collecting tube can be disconnected at this point if no further analysis of that sample is to be done.)

Analysis of sample

(12) When the sample has been transferred, proceed with analysis according to these steps:

(*a*) With leveling bulb hanging on adjusting rack, re-check height of columns (top of mercury in bulb should be level with mercury meniscus in burette).

(*b*) Check level of KOH in thermobarometer outlet tube. Readjust to selected mark if necessary as in step (9) (i).

(*c*) Turn stopcock to connect burette with carbon dioxide absorbing chamber. Quickly crank bulb up or down to adjust fluid level in tube to the mark previously selected. Then *read the burette at once and record the reading*. Mark this "first reading."

NOTE.—Be as accurate as you can in adjusting levels to marks and in taking readings. Always "read" the same part of the meniscus (the domed or dished point where fluid and gas meet). In the case of the mercury meniscus, let the top of the "dome" be the indicator. In setting levels in the absorbing chamber tubes, adjust so the lowest part of the "dish" just barely touches the line.

(*d*) Take leveling bulb off rack, and by raising and lowering it in one hand, run mercury up and down in burette about five times to move sample in and out of CO_2 absorbing chamber. (Be careful not to run mercury all the way up to the stopcock or to pull KOH above mark.

(*e*) Return level of KOH in absorbing chamber tube to original mark by adjusting height of mercury in burette. *Read mercury meniscus and record reading*. Mark this "second reading."

(*f*) Calculate concentration of carbon dioxide in sample (volume percent): First subtract second reading from the first (original) burette reading; then

$$\%CO_2 = \frac{\text{Difference between readings}}{\text{First burette reading}} \times 100$$

(*g*) Turn four-way stopcock *clockwise* to connect burette to oxygen absorbing chamber. Raise and lower mercury level, as in step (d), about 20 times. Observe same precautions.

(*h*) Return pyrogallol level to original mark on absorption chamber tube. Turn four-way stopcock *counterclockwise* to connect burette to carbon dioxide absorption chamber again. Work the sample into the CO_2 absorbing chamber about five times to pick up any oxygen that remains on that side. Then shift back to pyrogallol and work it about 10 times. Adjust level of liquid in each absorbing chamber tube just before shifting the stopcock.

(*i*) At the conclusion of the second "working" with pyrogallol, shift back to the CO_2 absorbing chamber, adjust level of KOH solution, and read the burette. (See par. (13)(c).) *Record the reading.* Repeat working sample into pyrogallol (about 10 times with each repetition) and taking readings until they remain constant within 0.004 cc. (less than half of one of the smallest divisions). If readings do not become constant after the third or fourth washing, either the pyrogallol solution is nearly exhausted or there is a leak in the system. (See par. (13)(f).)

(*j*) Calculate the oxygen concentration in the sample: Subtract the final reading after oxygen absorption from that following CO_2 absorption ("second reading"); then

$$\text{Percent } O_2 = \frac{\text{Difference between second and last readings}}{\text{First burette reading}} \times 100$$

Additional notes

(13) The above are the basic steps in operation of the Haldane gas analyzer. The following additional information will be useful in obtaining accurate analyses.

(*a*) At the beginning of a series of analysis, run at least two samples of fresh atmospheric air. This serves two purposes: it leaves the oxygen and CO_2 absorbing tube connections filled with inert gas (all oxygen and CO_2 removed), and it provides a check on the accuracy of the apparatus. If there was oxygen or CO_2 in the tubes, the first analysis will not yield accurate values: 20.94 (plus or minus 0.03) percent O_2; 0.04 (plus or minus 0.03) percent CO_2. However, the second chould be very close if there are no leaks or other defects in the system.

(*b*) There are many possible sources of inaccuracies, but most are eliminated by correct assembly and proper care. A leaking or dirty stopcock is one of the most frequent sources of trouble. Dirty mercury (paragraph (14)) will rapidly foul the burette, and dirt and droplets of water or mercury in the burette will alter its capacity and cause errors. Droplets of mercury in the side tubes can act as check valves and lead to inaccuracy.

(*c*) Changes in temperature during the course of analysis will cause errors. The thermobarometer *does not* automatically compensate for such changes, but it does reflect them by a change in the level of KOH in its outlet tube. Theoretically, noting the amount and direction of the change permits correcting for it. For example, if the temperature drops and the level goes up one mark, a more accurate final reading of the burette would be obtained by adjusting the KOH level in the CO_2 absorbing chamber tube to the mark above that originally used. Unfortunately, this is not a comletely satisfactory procedure.

(*d*) Most Haldane analyzers are equipped with a light behind the panel to assist in setting levels and making readings. It should be turned on only when actually needed and then only briefly since it can cause considerable temperature change.

(*e*) The speed of absorption depends largely on the freshness of the solutions. The pyrogallol is the most readily exhausted. Also, when it becomes old and thick it may clog the small tubes in the oxygen absorption chamber. This will slow the reaction and may trap bubbles and cause inaccuracies.

(*f*) Inability to get constant "final" readings generally indicates a leak. If the apparatus leaks, the location is probably in the four-way stopcock or in one of the connections between the burette and the absorbing chambers. If cleaning and relubricating the stopcock do not remedy the leak, check the absorbing chamber connections by shutting them off with the fluid levels at the highest marks.

If one of the levels drop over a period of time, the leak is probably at the connection on that side. A leaking stopcock can usually be demonstrated by leaving the burette with nitrogen from the last analysis in it, then shutting it off and raising the leveling bulb to apply pressure. If the stopcock is tight, the mercury level should not rise further after the pressure is applied.

(*g*) If either solution is run over into the burette or stopcock, the apparatus must be cleaned thoroughly and rinsed with 1 percent sulfuric acid. Otherwise, absorption of oxygen or carbon dioxide will occur when it should not, and the analysis will be completely inaccurate.

(*h*) If the apparatus is to be left unattended for any length of time, open the burette to the outside to avoid having solutions pulled over by temperature changes. Leave an excess of nitrogen from the last analysis in the absorbing chambers. If no analyses are to be performed for a matter of weeks, it pays to remove the solutions, clean the apparatus, and cover it to avoid accumulation of dust. At least, clean and re-lubricate the stopcocks. A "frozen" stopcock, often not easily loosened, is a frequent result of leaving a Haldane stand idle.

Care of mercury

(14) Not only is clean mercury essential to good gas analysis, but carelessly handled mercury is a hazard to both equipment and health. Spilled mercury gradually vaporizes, and mercury vapor is very toxic if the concentration is allowed to rise as it will in an ill-ventilated space where much has been spilled. Mercury also *amalgamates* with various metals. This means that it can ruin metal equipment with which it comes in contact (eating its way through laboratory plumbing, dissolving a gold ring or pen point are examples). Mercury that has been in contact with metal and re-used without adequate cleaning leaves a scum in glass equipment.

(15) Take care not to spill mercury in the first place. Provide containers to catch it where an overflow is expected. Clean it up promptly if spilled and put it in a special well-capped "dirty mercury" container. Use only thoroughly clean mercury in your sample collecting tubes and analyzer. Although there are various ways of cleaning mercury, the only very good one is to have it *re-distilled* by a laboratory equipped for this process. Most of the methods for cleaning mercury on the spot cannot cope with heavy amalgamation, so keep mercury that has been in contact with metal separate if such a method must be used.

(16) For more detailed information concerning gas analyzers of the Haldane type, see chapter 3 of *Quantitative Clinical Chemistry, Volume II, Methods* (Peters, J. P. and Van Slyke, D. D.; Baltimore, The Williams & Wilkins Co., 1932.)

1.10.5 SCHOLANDER NITROGEN ANALYZER

(1) A much simpler, but also considerably less accurate, chemical analyzer than the Haldane is the *Scholander nitrogen analyzer* shown in figure 1–57. This does not distinguish between oxygen and carbon dioxide since it yields the percentage only of nitrogen (or other inert gas) in the sample. However, this is not usually a serious disadvantage in analyzing gas mixtures for diving since carbon dioxide is rarely present. One advantage of the Scholander nitrogen analyzer, in addition to its simplicity, is that it will analyze gases with any concentration of oxygen (the Haldane-Henderson is limited, for practical purposes, to concentrations less than 30 percent). The main drawback is that accuracy better than plus or minus 0.5 to 1.0 percent cannot be expected. However, there are many situations where this amount of possible error can be accepted. This description is provided because the instrument may be furnished to activities using gas mixtures in semiclosed circuit scuba.

Construction and principle

(2) The Scholander nitrogen analyzer consists of a burette (1) with a pear-shaped body and an elongated top. The top portion holds exactly 5 cc. of gas and is marked off from zero to 100 percent. A length of heavy rubber tubing (2) is connected to the bottom of the

burette and extends over to a small leveling bulb (3). The burette and tubing are completely filled with a solution that absorbs both carbon dioxide and oxygen.

(3) A 5 cc. syringe (4) is provided. This has a 25 gage needle and a special holder with a screw adjustment that limits the stroke of the plunger. In principle, the analysis involves injecting exactly 5 cc. of sample through the tubing just below the burette. Carbon dioxide and oxygen are absorbed rapidly by the solution. The remaining gas (nitrogen or other inert gas) collects in the marked portion of the burette, and the position of the meniscus on the scale indicates the percentage of that gas in the sample.

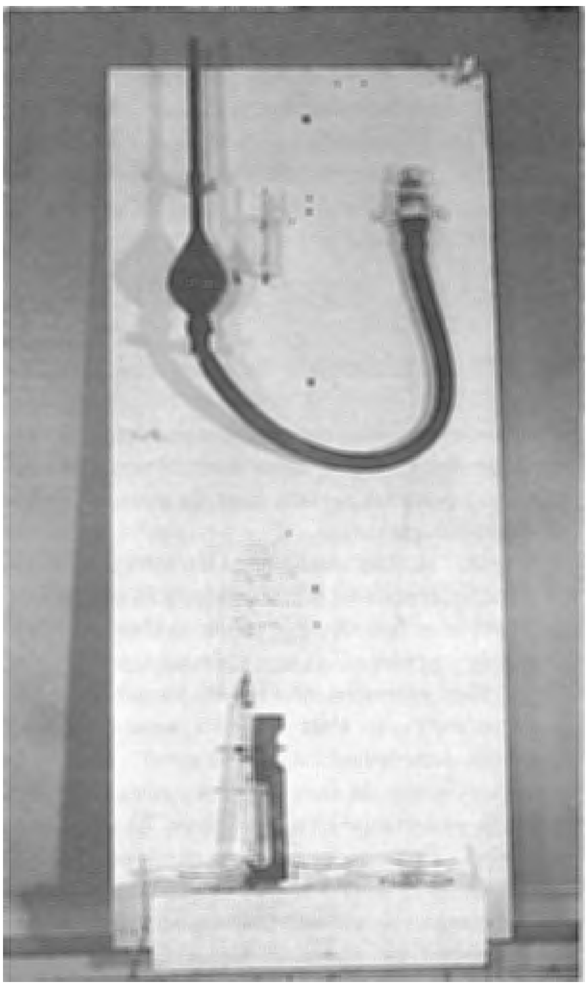


FIGURE 1–57.—Scholander nitrogen analyzer.

Setting up

(4) The rubber tubing is $\frac{5}{16}$ inch inside diameter $\frac{9}{16}$ inch outside diameter, and about 15 inches long. Prepare it for use by boiling in 1 :25 hydrochloric acid for 5 minutes and rinsing in water. See that the burette and leveling bulb are clean, and connect the tubing between them.

(5) Prepare the absorbing solution by dissolving 300 gms. of potassium hydroxide and 45 gms. of pyrogallol in 200 cc. of distilled water. (Store in a rubber-stoppered bottle.)

(6) Assemble the unit as in figure 1–57. Take the burette from its spring clamps and hold inverted while pouring solution in through the leveling bulb. Make sure that all of the air is displaced and fill until the leveling bulb is one-third full. To protect the solution from contact with air, cover it with a 2-cm. layer of heavy liquid pertolatum (mineral oil). Replace burette in its clamps.

Standardization

(7) The next step involves adjusting the screw on the syringe holder so that exactly the right amount of gas will be injected. This is done by analyzing atmospheric air with different screw settings until the correct burette reading is obtained. Air contains almost exactly 79 percent nitrogen, but temperature and water vapor factors prevent the correct reading from being exactly 79. (See par. (14).)

(*a*) Read the thermometer and consult table 1–30 to determine the factor (F) for equivalent water vapor percentage at the existing temperature. Then apply formula:

$$B = \frac{79(100-F)}{100}$$

Where: B = correct burette reading when air is analyzed.
F = water vapor factor.

(*b*) Follow the analysis procedure outlined herein, starting with the syringe holder set so the plunger comes back exactly to the 5 cc. mark on the barrel. If the resulting burette reading is too low, back off the adjusting screw to increase the volume injected and try again. If it is too high, reduce the volume. Proceed in this manner until the proper setting is found. Then tighten the locknut. Standardization may prove to be a laborious procedure; but once the proper setting is obtained, it should be good indefinitely. (However, it should be checked periodically by analyzing samples of air.)

Sampling

(8) For sampling gas from a cylinder, the simplest arrangement is to attach a needle valve and a short length of rubber tubing to the cylinder. Submerge the end of the tube about 6 inches in a container of water. Flush the valve and tube by running gas through for about 1 minute.

(9) Prepare the syringe as follows: draw in about one cc. of distilled water, point needle upwards, draw plunger back to the screw, then push plunger all the way in to eject the air and water. Make sure all air bubbles have been expelled. (This procedure fills all the dead space in the syringe and needle with water.) Hold plunger in.

(10) Insert needle into sample tube on cylinder while gas is flowing. Allow pressure in the tube to push plunger back and fill syringe. If it does not, pull plunger back slowly and gently. (Make sure it comes to rest against the stop screw in either case.)

(11) Withdraw needle from sample tube, and unless you can proceed with analysis immediately, push the needle into a rubber stopper and submerge the syringe in a beaker of water at room temperature. (Samples should be analyzed as promptly as possible.)

Analysis

(12) Follow these steps in analyzing the sample:

(*a*) Have the burette and leveling bulb in place in their clamps.

(*b*) Push needle obliquely upward through the rubber tubing about an inch below the burette. Inject the sample, taking about 10 to 15 seconds, holding the rubber tubing firmly against the needle hub while so doing. (No gas must escape during this operation.)

(*c*) Withdraw needle and remove all traces of absorbing solution from syringe and needle by rinsing once with slightly acidified water and twice with distilled water, expelling the water as in paragraph (10).

(*d*) Now take the burette from its clamp and tip it just past the horizontal position so that the gas enters the bulb. Shake for about 1 minute to speed the absorption of oxygen. (Take care not to let any gas escape into rubber tube.) Then turn burette back to the vertical position and tap it gently until all the remaining gas is collected above the solution in the calibrated portion.

(*e*) Replace burette in clamp and let it sit for 1 to 3 minutes while the solution drains from the walls and temperature stabilizes. (The time allowed for this depends on the accuracy required.) If the meniscus continues to rise after 3 minutes of draining, absorption is not complete. Return bubble to bulb of burette and shake again to complete the absorption.

(*f*) To make the final reading: take burette from clamp. Keeping it vertical, move it over close to the leveling bulb. Raise or lower burette so that the meniscus of solution in the marked-off portion is level with the *middle* of the oil layer in the leveling bulb. (This balances the columns of fluid and assures that the gas being measured is at atmospheric pressure.) Using the *bottom* of the meniscus as the indicator, note and record the scale reading in percent.

(*g*) After the reading has been taken, invert the burette, letting it hang down at the end of the rubber tubing so that the gas bubble will rise and escape through the leveling bulb. Milk the tubing to aid in ejecting bubble. After bubble is ejected, replace burette in clamp. The apparatus is now ready for the next analysis.

Correction for water vapor

(13) The Scholander nitrogen analyzer can be used at any barometric pressure so long as this remains constant throughout the period of sampling and analysis. It can be used at temperatures from 0° C. to 40° C., but the temperature must not vary much during the analysis.

(14) Even if the original sample is a com-

pletely dry gas, contact with water in the sampling syringe will cause it to become completely saturated with water vapor. This vapor takes up space and accounts for part of the volume of the gas injected into the burette. During analysis, the vapor is taken up by the solution, so even a sample of pure nitrogen would decrease somewhat in volume in the course of analysis. Since this would yield a value lower than the true "dry gas" percentage of nitrogen, the change due to absorption of water vapor must be compensated by a correction factor.

(15) The partial pressure (and volume) of water vapor depends on the temperature. Table 1–30 indicates the "equivalent percentage" of water vapor present and absorbed at different temperatures (F). To correct the burette reading to the true "dry gas" percentage of nitrogen (or other inert gas), use this formula:

$$\text{Nitrogen (dry gas)} = \frac{N \times 100}{100.0 - F}$$

Where:

N=burette reading in percent.

F=factor from table 1–30.

TABLE 1–30.—*Water vapor correction Factors for Scholander Nitrogen Analyzer (for use at sea level)*

Temp. ° C.	Correction factor (F)	Temp. ° C.	Correction factor (F)
10	1. 2	26	3. 3
11	1. 3	27	3. 5
12	1. 4	28	3. 7
13	1. 5	29	4. 0
14	1. 6	30	4. 2
15	1. 7	31	4. 4
16	1. 8	32	4. 7
17	1. 9	33	5. 0
18	2. 0	34	5. 3
19	2. 2	35	5. 6
20	2. 3	36	5. 9
21	2. 4	37	6. 2
22	2. 6	38	6. 5
23	2. 8	39	6. 9
24	2. 9	40	7. 3
25	3. 1		

Percent oxygen

(16) If you are reasonably sure that no more than a trace of carbon dioxide is present in the gas mixture, the percentage of oxygen in the mixture can be obtained simply by subtracting the nitrogen percent from 100. If carbon dioxide is present, its concentration must be determined in order to find the oxygen percentage. Another type of analyzer can be used (art. 1.10.8), or a new Scholander nitrogen analyzer (or one from which all traces of pyrogallol have been removed by thorough washing with acid) can be set up and filled with a 20 percent solution of potassium hydroxide (KOH). If this is used according to the procedure above, the difference between the corrected "nitrogen" percentage (actually nitrogen plus oxygen, here) and 100 will approximate the percentage of carbon dioxide present. Once the approximate percentage of carbon dioxide is known, the oxygen percentage can be obtained by subtracting the combined values for nitrogen and carbon dioxide from 100.

1.10.6 BECKMAN MODEL "C" OXYGEN ANALYZER

(1) The instrument supplied for shipboard use by ASR's for analysis of helium-oxygen mixtures is the *Beckman Model "C" Oxygen Analyzer* (fig. 1–58). The Beckman employs a *physical* property of oxygen as the basis of analysis, so no solutions or chemicals are used; and the sample is unchanged in passing through the instrument. The analyzer can be used satisfactorily aboard ship unless motion and vibration are unusually strong. The manufacturer claims an accuracy of plus or minus 1 percent of full scale, but greater precision is possible when accurate calibration is obtained and all other details of technique carefully observed. Most of the Beckman Model "C" instruments in use in diving are designed for the range between 0 and 25 or 10 and 25 percent oxygen. They are, thus, unsuitable for analyzing high-oxygen mixtures. However, other ranges can be obtained. The main drawback of the Beckman is that it is a rather delicate instrument from the standpoint of rough handling, but many of them have given years of trouble-free performance with reasonable care.

FIGURE 1–58.—Beckman oxygen analyzers.
Left, Model D; right, Model C.

Principle of operation

(2) The "heart" of the Beckman analyzer is an extremely small dumbbell-shaped test body made of glass and suspended on a quartz thread. The dumbbell is centered in the analysis cell of the instrument. Two large permanent magnets terminate in shaped pole-pieces above and below the spheres of the dumbbell, producing strong magnetic fields around them.

(3) Oxygen is strongly *paramagnetic* (attracted by a magnetic field). This physical property of oxygen forms the basis of analysis. The oxygen molecules in a sample of gas are attracted into the magnetic field and actually tend to displace the spheres. This forces the dumbbell to rotate. The suspending quartz fiber resists being twisted, so the final position of the dumbbell represents a balance between the force of oxygen molecules being attracted into the field and the torsion of the fiber. The more oxygen molecules are present, the more the dumbbell is displaced.

(4) A small mirror is mounted on the dumbbell, and a narrow beam of light is reflected from this mirror to the translucent scale on the front of the analyzer. As the dumbbell rotates, the light beam moves across the scale.

(5) The rotation of the test body, and thus the deflection on the scale, is proportional to the *number of oxygen molecules present*—in other words, to the *partial pressure* of oxygen in the analysis cell. Note that several factors besides the concentration (percentage) of oxygen in the sample will influence the partial pressure of oxygen. These include:

(*a*) The atmospheric (barometric) pressure.

(*b*) Any excess pressure (or vaccum) in the sample cell.

(*c*) The temperature of the gas.

(*d*) The amount of water vapor present.

(6) The scale of the instrument is usually marked off in percent, but a given reading is

accurate in terms of percent only if these factors all have the intended values. Some of these factors can be controlled, but others require use of correction factors. They are discussed in the following paragraphs.

(7) The instrument is designed to read correctly in percent at a barometric pressure of 760 mm. Hg (29.92 in. Hg). Consequently, the barometric pressure at the time of analysis must be known; and if it differs more than a small amount from 760, a correction factor must be employed. See paragraphs (30) and (33).

(8) Running a sample through the analyzer at an excessively rapid rate will increase the pressure in the cell. For this reason a rate between 50 and 250 cc. per minute is recommended. (If there is no convenient method of measuring flow, stop the inflow briefly while taking a reading.)

(9) To eliminate errors due to temperature, the Model C Beckman has thermostatically controlled heaters on the sample cell. Samples are automatically warmed to a standard temperature higher than any room temperature likely to be encountered. The pilot light on the front of the instrument glows when the heaters are on and goes off when the proper temperature has been reached. Readings taken when the light is on may be inaccurate. The instrument will operate properly at any room temperature between 40 and 105° F. Warmup requires about 30 minutes when the analyzer is first turned on.

(10) Water vapor in a sample increases its volume and decreases the partial pressure of oxygen. Samples drawn directly from high pressure cylinders without any contact with water are generally quite dry, so this is not usually a problem. Samples from "wet" sources (including room air) should be run through a drying tube filled with fresh silica gel or other drying agent on their way to the analyzer.

(11) Another complicating factor in use of the Beckman concerns the *diamagnetic* effect of gases other than oxygen. If a given percentage of oxygen is in helium, the reading will differ slightly from that obtained with the same percent in nitrogen. The diamagnetic molecules are repelled by the magnetic field and move away from it. This somewhat offsets the sphere-displacing effect of the oxygen molecules. Since nitrogen molecules are *more* diamagnetic than helium molecules, the instrument will give a slightly *lower* reading with nitrogen as the "background gas" than with helium. Methods of correcting for this possible source of error are discussed in paragraphs (28) and (33).

(12) In most Beckman Model C analyzers in field use, the fragile test body and its suspension are protected from possible damage from excessively high sample flow rates. This has been accomplished by placing a porous filter in the analysis cell. Time is, therefore, required not only for flushing the cell but also for the sample to diffuse through the filter. More than a minute usually elapses before the analyzer responds fully to a change in sample composition. Be sure that it has stabilized completely before taking a final reading.

Precautions

(13) It is quite possible for a Beckman oxygen analyzer to get out of adjustment and give erroneous readings even under ideal conditions. Therefore, complete accuracy requires checking the *calibration* of the instrument periodically and either making certain adjustments or preparing a calibration graph (or both). Methods for doing this are described in paragraphs (18) and (33).

(14) A Beckman oxygen analyzer is not readily damaged except by rough handling. The sample cell will withstand negative and positive pressures between complete vacuum and 15 p.s.i.g. Although excessively high flows of sample should be avoided, they will not usually cause damage. Avoid sudden surges of pressure. Trying to analyze a sample whose oxygen concentration is beyond the range of the instrument will cause the reading to go off scale but will not harm the analyzer.

(15) The fragility of the test body and the quartz-fiber suspension is such that jarring the instrument (as by setting it down hard or bumping it against something) can cause damage requiring factory repairs. Flooding the instrument with water or using excessively

moist samples can also cause serious damage. Mercury, dust, and corrosive gases must also be avoided. Maintenance is generally simple. It is discussed in paragraph (41).

Setting up

(16) Preparing the Beckman Model "C" analyzer for use involves these steps:

(*a*) Locate it on a firm shelf or table in a location as free of motion and vibration as is practical.

(*b*) Plug the power cord into a 115 volt 50–60 cycle a.c. source.

(*c*) Turn the instrument on and allow it to warm up for about 30 minutes.

(*d*) Arrange sampling connections, making sure that flow can be controlled readily. Put a flowmeter in the line if possible.

(*e*) Especially if the sample is from a source other than compressed gas cylinders and may be moist, insert a drying tube (containing fresh silica gel, activated alumina, or other drying agent) in the line. Using a drying tube routinely is good practice.

(*f*) If the sample may contain dust or other foreign matter, insert a filter. (A wad of glass wool in the end of a drying tube is satisfactory. Such a filter must be used if a drying agent is employed to prevent any carry-over of dust or particles of absorbent.)

(*g*) If warm gas is to be analyzed (over 110° F), provide a coil of metal tubing to cool it. If the warm gas is also moist, provide a trap upstream from the drying tube to collect the moisture that will condense on cooling.

(*h*) Connect sample tube to one of the metal nipples in the lower right hand corner of the face of the instrument.

Operation

(17) Before actual analysis of samples, the calibration of the instrument must be checked and adjustments made or a calibration graph prepared. (See pars. (18) and (33).) When this has been done, proceed according to these steps:

(*a*) Run sample through instrument at a flow-rate between 50 and 250 cc. per minute.

(*b*) Observe the reading and wait until it stabilizes (usually at least 1 minute).

(*c*) If pilot light is glowing, wait until it goes out before taking reading.

(*d*) If not sure flow rate is correct, interrupt flow while taking reading.

(*e*) Take final reading and record it. (Read one edge of the light beam for maximum precision.)

(*f*) Determine barometric pressure and record it.

(*g*) Make corrections for barometric pressure, background gas effect, and calibration errors as required. (See below.)

Calibration

(18) Sometimes when the Beckman is moved (and sometimes for no evident reason), the relationship between true oxygen percentage or partial pressure and the scale reading will shift. If such a shift occurs and is not discovered, and if some means of compensation is not employed, all analyses will be incorrect. The term *calibration* here indicates the process of checking and compensating for such errors. Checking requires putting samples of gas whose oxygen concentration is *known* in the instrument and seeing what readings are obtained. There are several methods of correcting or compensating if errors are found.

(19) Several types of calibration-error are possible:

(*a*) The readings may simply shift up or down the scale. Example: 0 percent oxygen might read 1 percent while 20 percent oxygen would read 21 percent. If such an error is found, the instrument can be readily adjusted. In the meantime, the amount of error can simply be added-to or subtracted-from the readings.

(*b*) The "span" may change. For example: 0 percent oxygen might read 1 percent, while 20 percent reads 19 percent. The instrument could be adjusted so that 20 percent would read 20 percent on the scale, but then the lower part of the range would be even farther off. This type of error cannot be corrected by simple addition or subtraction. It requires a calibration graph.

(*c*) Both of the above types of error can occur in the same instrument.

(*d*) A type of error more difficult to compensate, fortunately seldom if ever seen in the Beckman analyzer, is an irregular one. For example, the scale readings might be correct from 0 to 15 percent and incorrect from 15 to 25 percent. The calibration procedures described here assure that this type of error will not be encountered. Should it ever be discovered, the instrument should be returned to the factory for recalibration.

(20) The calibration process requires use of at least two *known* samples, preferably close to the extremes of the instrument's range. Since fresh air has a constant oxygen concentration (20.94 percent), it is a good mixture for the "high" point in calibration of a 0–25 or 10–25 percent instrument. (It should also be used as an intermediate check-point in calibration of a 0 to 100 percent analyzer). Pure helium or pure nitrogen can be used to obtain a "zero point." Oxygen serves as the "high point" for a 0–100 percent instrument ("pure" oxygen can be assumed to contain at least 99.5 percent oxygen). Note that no gas mixing or analysis by other means is required if the gases mentioned suffice for calibration. However, a 10–25 percent Beckman requires preparation and careful analysis (preferably by Haldane) of a calibration mixture with an oxygen concentration slightly above 10 percent to use for the "low point."

(21) With suitable gases in hand for calibration, the next step is to determine what readings these gases *should* yield if the analyzer is properly calibrated. This first requires a decision whether the instrument is to be calibrated for nitrogen-oxygen mixtures or for helium-oxygen mixtures. If a 0–25 or 10–25 percent analyzer was originally calibrated for nitrogen and still has the proper span (paragraph (19) (b)), it may prove more convenient to retain the "nitrogen" calibration even though only helium-oxygen mixtures will be analyzed. Otherwise, the "background gas" to be encountered most frequently should determine the calibration. Once this decision is made, it is possible to specify what readings should be obtained *at a barometric pressure of 760 mm. Hg (29.9 in. Hg)*. Then, if the barometric pressure differs from the 760 on the day of calibration, this difference must be taken into account.

(22) Proper readings for various calibration-gases *at 760 mm. Hg* can be specified or determined as follows:

(*a*) Pure nitrogen: should read zero on a nitrogen-calibrated instrument; *minus* 0.3 percent on a helium-calibrated instrument. (This shows the greater diamagnetic effect (11) of nitrogen. Any reading below the scale will have to be estimated as well as possible.)

(*b*) Pure helium: should read +0.3 percent on a nitrogen-calibrated instrument; zero on an instrument calibrated for helium.

(*c*) Fresh air: should read 20.9 percent on a nitrogen-calibrated analyzer; 20.7 percent on a helium-calibrated instrument. (It is not difficult to estimate to the nearest 0.1 percent on 0–25 and 10–25 percent instruments, but it is impossible to read to the second decimal place. Therefore, all readings and corrections can be rounded to the nearest 0.1 percent.)

(*d*) Pure oxygen should read between 99.5 and 100 percent on any 0–100 percent instrument.

(*e*) If another concentration of oxygen must be used for calibration, prepare the mixture using the background gas for which the instrument is to be calibrated. The correct Beckman reading at 760 mm. Hg will then be the same as the Haldane analysis.

(23) The reading that should be obtained with a "calibration gas" at a barometric pressure other than 760 mm. Hg can be determined with this formula:

$$R_b = R_{760} \times \frac{B}{S}$$

Where:

R_b = correct reading at a barometric pressure other than 760 mm. Hg.

R_{760} = correct reading at 760 mm. Hg. (See (22).)

B = barometric pressure at time of calibration (inches or mm. of Hg).

S = standard barometric pressure (760 mm. Hg or 29.9 in. Hg— use same units as for B).

(Barometric pressure makes no significant difference when no oxygen is present in the gas, so no barometric correction for the "zero" reading is needed.)

(24) Proceed to obtain readings with the calibration gases, observing the details of technique described for analysis (16), (17). If the readings are within about 0.2 percent of their correct values, the instrument's calibration can be considered satisfactory for most purposes and the readings used directly. (Correction for barometric pressure and background gas are still required in actual analysis as discussed in paragraphs (29), (31), and (34).)

(25) If the error observed is simply a shift up or down the scale (the same amount of shift at both points), *adjusting* the instrument is worthwhile. Follow these steps (the process is simplified by working in a darkened room since the light beam will not show on the scale in broad daylight when the cover is removed):

(*a*) Remove cover. (Be careful not to jar the instrument in the process. Avoid touching the aluminum mirrors inside.)

(*b*) Have one of the calibrating gases running slowly through the analyzer.

(*c*) If the shift is large, loosen the lamp arm clamp and move the analyzer lamp assembly so that the reading comes close to the correct one for the gas being used. Retighten the clamp.

(*d*) If the shift is small, or after a gross adjustment has been made as in (*c*) above, find the small hole in the block between the two magnets above the analysis cell. Take an Allen wrench (of the same size that fits the keyway on the lamp body) and insert it deep into this hole until it engages the keyway in the adjusting screw. Turn to make fine adjustments. (Hang onto the wrench firmly when getting it close to the magnets.)

(e) When one of the calibration points has been adjusted in this way, try the calibration gas that produces a reading toward the opposite end of the scale. Note whether it now gives the correct reading. (If it does not, you are dealing with more than a simple scale-shift error.)

(*f*) Recheck readings and replace cover.

(*g*) Recheck again after replacement of cover.

(26) If the error involves a change in span, you must prepare a calibration graph. The graphical procedure outlined in paragraphs (34) to (38) is recommended since it also takes the barometric and background gas corrections into account in a single process.

(27) If there is a scale shift larger than can be corrected as in paragraph (25), or if there is a span change larger than about 10 percent of full scale, it is advisable to return the instrument to the factory for repair and recalibration (paragraph (46)). However, preparation of a calibration graph may permit the analyzer to be used until it can be spared for repairs.

Correction for background gas effect

(28) As was previously explained, the Beckman oxygen analyzer measures the *magnetic effect* produced by the gas sample in the analysis cell. What is measured is actually the *difference* between the *paramagnetic* effect of oxygen tending to rotate the test body in one direction and the slight *diamagnetic* effect of the other gas tending to rotate it in the opposite direction. Each analyzer is calibrated so that its scale will give correct readings with a particular "background gas." If the actual sample contains a background gas with a different amount of diamagnetic effect, the readings will be in error. Since nitrogen is much more strongly diamagnetic than helium, helium-oxygen analyses with an instrument calibrated for nitrogen will be incorrect—and vice versa.

(29) The amount of error is actually rather small. Around 20 percent oxygen, the difference is about 0.2 percent. (It is smaller at higher percentages of oxygen since there is less background gas present). Even though it is small, the difference should not be ignored because it might combine with other sources of error to produce a serious inaccuracy. However, it is not necessary except in precise work to calculate an exact correction. The following factors may be used:

(*a*) When a helium-oxygen mixture is being analyzed with an analyzer calibrated for nitrogen-oxygen:

Scale reading (percent)	*Subtract from scale reading (percent)*
0–15	0.3
15–50	0.2
50–85	0.1
85–100	0

(*b*) When a nitrogen-oxygen mixture is being analyzed with an instrument calibrated for helium-oxygen, use same factors, but *add.*

Barometric pressure correction

(30) Assuming that the calibration of the instrument is correct and that the factor for background gas has been added or subtracted if needed, it remains necessary to correct the scale reading for *barometric pressure* unless the pressure at the time of analysis is within a very few millimeters of 760 mm. Hg. Use this formula:

$$P=R\times\frac{(760)}{B}$$

Where:

P= corrected (true) percentage.

R= Beckman reading (assuming that calibration is correct and that background gas correction has been made if needed).

B= barometric pressure in mm. Hg at time of analysis.

(NOTE.—Barometric pressure can be expressed in inches of mercury if 29.9 is substituted for 760.)

If desired, a table or graph of correction factors for various percentages and pressures can be prepared using this formula.

Summary of corrections

(31) The various corrections that may be needed to correct a Beckman scale reading to true oxygen percentage are:

(*a*) Correction for calibration errors, if any.

(*b*) Correction for "background gas" factor (if analysis involves a gas other than that for which the instrument was calibrated).

(*c*) Correction for barometric pressure other than 760 mm. Hg at time of analysis.

(32) Example: A mixture of helium and oxygen is analyzed with an instrument calibrated for nitrogen-oxygen. The barometric pressure is 775 mm. Hg. The scale-reading is 20 percent.

(*a*) The calibration of the instrument was checked previously. The reading was found to be 0.5 percent *high* at 20 percent. The reading should, therefore, have been 19.5 percent.

(*b*) According to paragraph (29)(*a*), 0.2 percent must be subtracted because of the background gas effect. This yields a value of 19.3 percent.

(*c*) The barametric pressure correction called for by paragraph (31) is found to yield $P=19.3\times\frac{760}{775}=19.3\times0.98=18.9$ percent Therefore, the actual oxygen percentage is only 18.9 percent. Note that although all of the corrections are small, in this case (not unusual) they add up to more than 1 percent—a serious error in many situations.

Graphical method of correction

(33) If many analyses have to be done, going through two or three steps of correction for each one can add up to a lot of work over a period of time. Almost all of this work can be avoided by preparing a graph that takes *all* of the corrections into account and that can be used with no calculations whatever. Such a graph is based mainly on the data that must be obtained anyhow in the essential process of checking the analyzer's calibration. The calculations required in making the graph amount to less work than would be required in correcting one or two individual analysis by the methods discussed herein. Directions for constructing correction graphs are given in the following paragraphs.

(34) *General description.*—A correction graph has a horizontal scale representing actual Beckman readings and a vertical scale representing true oxygen percentages. It also has several lines running diagonally across the graph from the lower left to the upper right. These are labeled with different barometric pressures. To use the graph, the operator locates (on the horizontal scale) the Beckman reading produced by the sample he is analyzing. He then follows this reading up the graph to the point where it crosses the diagonal line for the existing barometric pressure. He then

follows this point to the left to see where it lies on the "true percentage" (vertical) scale. This single operation takes into account any calibration error of the instrument as well as the corrections for background gas and barometric pressure. A *sample* correction graph is shown in fig. 1–59. (Note that a different graph must be prepared for each instrument.)

(35) Instructions: To prepare a calibration graph for helium-oxygen analysis with a 0–25 percent Beckman Model "C" analyzer, follow these steps:

(*a*) Review paragraphs (20) to (24) for basic calibration procedure.

(*b*) Obtain a large sheet of graph paper and a long ruler.

(*c*) Label the bottom edge (horizontal scale) of the graph paper "Beckman Reading" and mark it off from *minus* 1 or 2 percent to plus 25 percent.

(*d*) Label the left side of the paper (vertical scale) "True Percent Oxygen in Helium" and mark it off from zero to 25 percent.

(*e*) With the instrument fully warmed up,

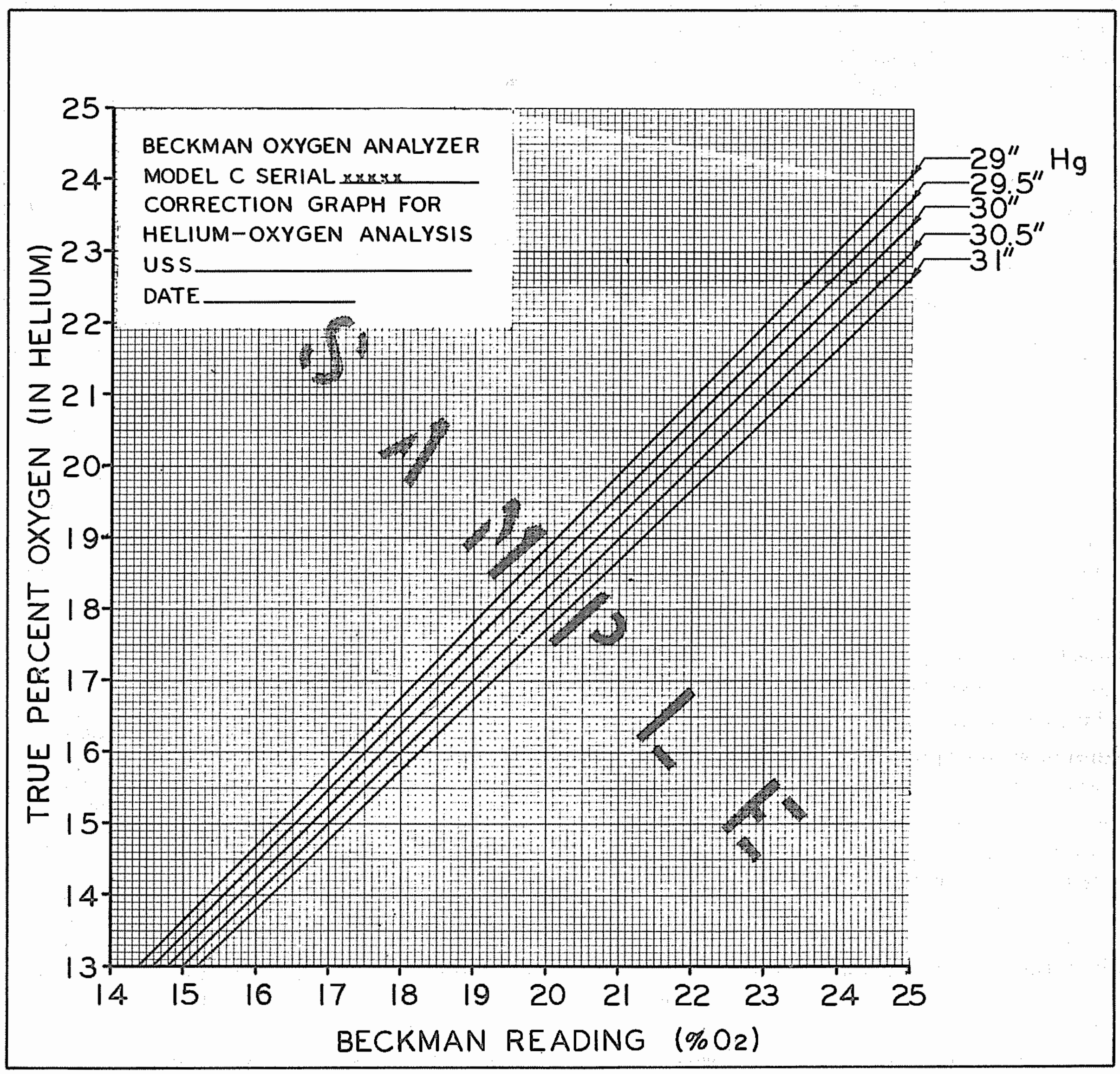


FIGURE 1–59.—Sample correction graph for Beckman oxygen analyzer.

run pure helium from a fresh cylinder through the analyzer at the proper rate. Run it long enough to secure complete flushing of all tubing and corrections and of the sample cell. Note and record the reading. Repeat to assure complete washout.

(*f*) Find the line on the "Beckman reading" scale of the graph that corresponds to the reading. Make a small dot where this line crosses the *zero* line of the "true percent" scale.

(*g*) Run fresh air through a drying tube into the analyzer. (This can be done by attaching a piece of tubing to one of the nipples on the instrument and applying mild suction to draw the air through.) Make the reading and record it. Repeat the process several times to make sure washout is complete and to verify the reading.

(*h*) Find the line on the "Beckman reading" scale that corresponds to this reading and make a mark. Then follow this line up to the point that corresponds to 20.7 percent on the "true percent" scale and make a small dot. (NOTE.—We know that the air contains 20.94 percent oxygen, but we also know that because of the different diamagnetic effects of nitrogen and helium, 20.7 percent oxygen *in helium* would give the same Beckman reading as air.)

(*i*) If a line were now drawn between the two points on the graph, it would indicate the correct relationship between any Beckman reading and the corresponding true percentage of oxygen in helium *at the existing barometric pressure*. However, the graph will be less cluttered and more useful if lines are drawn only for *even* steps through the probable range of barometric pressures. Lines for the following pressures are suggested (use "millimeters" in all the following steps if your barometer is marked in millimeters, use "inches" if it is marked in inches):

Inches Hg	*Millimeters Hg*
29.0	740
29.5	750
30.0	760
30.5	770
31.0	780
	790

(*j*) If the existing barometric pressure happens to correspond to one of the values, take a sharp pencil and very accurately draw a distinct line between the "zero" and "air" points and extend it up to about 25 percent on the "reading" scale. Label this line with the barometric pressure it represents. If the barometric pressure is something other than one of those values, draw only a light line along the ruler, extending it about 2 percent above and below the air point.

(*k*) To obtain the additional points needed for drawing the indicated barometric pressure lines, follow this procedure:

1. Calculate a "reference percent" for a barometric pressure of 29.5 in. Hg (750 mm. Hg) by using this formula:

Reference percent=

$$20.7\times\left(\frac{29.5\text{ (or 750)}}{\text{Existing barometric pressure}}\right)$$

2. Find the "reference percent" on the "true percent" scale and follow it over to the diagonal line you have drawn. Make a dot at the point where it meets the diagonal and draw a straight vertical line lightly through the dot.

3. Follow this vertical line to the point where it corresponds to 20.7 percent on the "true percent" scale and make another dot. Carefully draw a line through this dot and the "zero" point, extending it out to about 25 percent. Label the line "29.5 in. Hg" or "750 mm. Hg."

4. Return to the vertical line you drew in step (*b*) and place dots where it crosses the following "true percents," so you can draw diagonals representing the corresponding barometric pressures:

"True percent"	*Barometric pressure (in. Hg)*
21.1	29.0
20.7	[1] 29.5
20.4	30.0
20.0	30.5
19.7	31.0
(or)	*Mm. Hg*
21.0	740
20.7	[1] 750
20.4	760
20.2	770
19.9	780
19.7	790

[1] Already drawn.

5. Draw lines carefully through these points and the zero point, extending the lines to about

25 percent and labeling them. This completes the correction graph.

(*l*) To make the graph easier to use accurately, you can enlarge the portion that covers the percentage range in which you will be working. For example, if you do not expect to be analyzing mixtures with concentrations below 15 percent, you can make a large graph of the 15–25 percent portion. To do this, very carefully read the points where the barometric pressure lines cross the graph lines representing true percentages of 15 and 25 percent and replot them on the spread out scales of the new graph. (Fig. 1–59 is a sample of such an enlargement.)

(*m*) In using the graph, read from the barometric pressure line closet to the actual barometer reading. Interpolation between the lines increases the accuracy, but it is seldom essential.

(36) The procedure for making a similar correction graph for *nitrogen-oxygen mixtures* is almost identical, but there are some differences:

(*a*) Use pure nitrogen instead of pure helium for the zero point. (If pure helium is the only oxygen-free gas available, it can be used; but plot the zero point at plus 0.3 percent instead of zero on the "true percent" scale.)

(*b*) Plot the initial air point at 20.9 percent on the "true percent" scale instead of 20.7 percent as when calibrating for helium.

(*c*) In finding the points for drawing the various barometric pressure lines, use the same procedure as in (36) (k); but use 20.9 percent instead of 20.7 percent and add 0.2 percent to each of the "true percents" given in subparagraph (*k*) (4).

(37) In making a correction-graph for an instrument with a *10–25 percent scale*, you must use a carefully analyzed mixture containing slightly over 10 percent oxygen as the "low point," just as was discussed under "calibration," paragraph (22). Make up the mixture with the "background gas" for which the instrument is to be used. Separate points must be plotted at the "10 percent+" level to permit correct barometric pressure lines to be drawn. Follow this procedure after obtaining readings for the "10 percent+" mixture and air:

(*a*) Plot points for air at different barometric pressures as described in paragraph (36) (k).

(*b*) Draw a straight vertical line lightly at the point on the horizontal scale that corresponds to the Beckman reading for the "10 percent+" mixture.

(*c*) Determine the barometric pressure.

(*d*) Multiply the barometric pressure by the true oxygen percentage of the mixture (as determined by Haldane analysis). This yields the partial pressure of oxygen that gave the Beckman reading you found.

(*e*) Now determine what true percentages of oxygen would give the same oxygen partial pressure (and thus the same reading) at the different barometric pressures. To do this, simply divide the partial pressure determined above by the barometric pressures for which you want points.

(*f*) Plot points on the vertical line where it crosses the true percentages found in (*e*).

(*g*) Carefully draw a line through the "air" and "10 percent+" points for each barometric pressure line.

(38) To use the correction graph, follow these steps:

(*a*) Run sample through analyzer according to proper analysis procedure (see (16), (17)).

(*b*) Record the reading obtained.

(*c*) Determine the barometric pressure.

(*d*) Find the Beckman reading on the horizontal scale of the graph.

(*e*) Follow it up to the barometric pressure line closest to the actual barometric pressure.

(*f*) From the point where it crosses this line, follow it left to the vertical scale and read off the true percentage of oxygen in the mixture.

(39) Example (refer to fig. 1–59): The Beckman gives a reading of "20 percent" for a helium-oxygen mixture. The barometric pressure is 30.5 in. Hg. The true percentage, corrected for the instrument's calibration error, the background gas effect, and barometric pressure, is 18 percent.

(40) Once a correction graph has been constructed, it can be used as long as the calibra-

tion of the instrument remains the same. To assure accuracy, it is necessary to check the calibration periodically whether a graph is used or not. The graph simplifies this process. To check the "air point," for example, run air through the instrument as you did during the original calibration check. Record the reading and use the graph to obtain the "true percentage." If the calibration is still the same, it will give you a value very close to 20.9 percent or 20.7 percent, depending on whether the graph was made for nitrogen-oxygen or helium-oxygen mixtures.

Maintenance

(41) If the relatively few possible causes of damage are avoided (see paragraphs (14) and (15)), the Beckman oxygen analyzer requires little maintenance effort.

(*a*) Calibration (18) should be checked at least once a month and after each time the analyzer is moved any distance or unintentionally jarred. It is most desirable to check at least an air reading every time a series of analyses is to be run. Make adjustments or re-make correction graph if required.

(42) If no light beam appears on scale when the instrument is turned on, consider and rule out possible causes in this order:

(*a*) Power failure or poor cord connection. (Ruled out if pilot light glows.)

(*b*) Beam thrown off scale by sample beyond instrument's range. (Flush with air.)

(*c*) Analyzer lamp burned out. (Remove cover and hold white card in front of suspension housing. If no spot of light is seen on card, lamp is not operating.)

(*d*) Test body or suspension broken; or mirror has been fouled or desilvered by moisture or corrosive gas. (Hold instrument so test body can be seen; give instrument slight rotary twist. Test body should swing freely, mirror should appear shiny.)

(43) To replace analyzer lamp (G.E.PR3): Remove cover. Be careful not to touch aluminum mirrors inside. Carefully lift spring contact and remove old bulb. Place new lamp in socket. If necessary, bend spring contact slightly to assure necessary tension to hold lamp in place. Rotate lamp until good image is formed on scale. Recheck calibration. If off, try rotating bulb further; otherwise adjust lamp arm, etc. (18).

(44) If anything is wrong with test body, suspension, or mirror, return instrument to manufacturer for repair and recalibration (46).

(45) If pilot light fails to glow when instrument is first turned on and occasionally after warmup, heater is failing to operate and all analyses will be in error. Check pilot light (Mazda No. 43). Clean relay contacts by drawing clean sheet of paper between them while holding them closed with finger. Check for loose connections. If trouble is not corrected, return for repairs.

Moving and shipment

(46) If the Beckman oxygen analyzer is to be moved any distance or shipped, replace it in the original shipping box if this is available. In any case, be sure that it is surrounded by about 6 inches of shock absorbent packing in a carton. If returning to the factory, ship by prepaid express with appropriate correspondence. Indicate purchase order number assigned to cover repairs. Be especially sure to include the name of your activity with the instrument. Address: Arnold O. Beckman, Inc., 1020 Mission Street, South Pasadena, Calif.

1.10.7 BECKMAN MODEL "D" OXYGEN ANALYZER

(1) As fig. 1–58 indicates the Model "D" Beckman instrument is much smaller than the Model "C." The basic principle is exactly the same but there are several important differences in construction and operation:

(*a*) It is battery-operated. The indicating light beam appears only when the button on the top of the case is pressed.

(*b*) There is no heater, so the readings will vary with temperature as well as with barometric pressure.

(*c*) It is not designed for continuous-flow sampling, and the test body is not protected against excessive flow rates of sample. It should be used only with the sampling bulb and tubes provided.

(*d*) A drying tube is provided for use of indicator silica gel to dry the gas samples. (The gel must be changed as soon as much of the color has changed from blue to pink.)

(*e*) Most of the Model D's in use have a zero–100 percent scale, usually marked in oxygen partial pressure as well as percent.

(*f*) Since the scale is much smaller than that of the Model C, less accuracy is possible in making readings. (The manufacturer claims an accuracy of plus or minus 2 percent of full scale at 75° F. With proper attention to calibration and corrections, better accuracy than this is possible, but without attention to these details, the results can be seriously misleading.)

Operation

(2) *Sampling* of gas must be accomplished with the bulb-and-tube system provided, never by connecting the analyzer to a cylinder. If gas from a cylinder is to be sampled, one of the best methods is to run gas from the cylinder into a small rubber bag or balloon with an open end. Insert the sampling tube well into the bag. Run gas from the cylinder fast enough to keep the bag flushed and filled but not so fast that it will be pressurized. Then use the bulb to draw sample through the analyzer. In some situations, it is convenient to place a Luer-type hypodermic needle (18 gage or so) on the sampling tube adapter. The needle can be inserted through the wall of a mask, tube, or rubber bladder with little damage. (Be sure the needle is open and that the connections between the needle and the adapter and the tube do not leak.)

(3) Follow these general steps:

(*a*) Place end of sampling tube at point from which sample is desired. (See par. (2).)

(*b*) Slowly squeeze and release aspirator bulb at least four times to insure complete removal of previous sample.

(*c*) Press light switch button on top of instrument.

(*d*) When light beam stops oscillating, read oxygen percentage or partial pressure from position of beam on graduated scale. (Determine by calibration procedure which edge of the beam gives the most accurate reading and always read the same edge.)

Calibration

(4) Calibration of the instrument can be checked by the same procedure described for the Model C (art. 1.10.6(20)). Because of the smaller scale and consequently less precise readings, the background gas factor can be neglected. However, the barometric pressure must be considered in calibration, and an additional correction made for *temperature* if this is not between 70° and 80° F. at the time of calibration. (See par. (6).) Adjustment of the instrument to correct calibration errors is not very satisfactory with the Model D, so it is generally better to compensate for a scale-shift error by making a note of how much to add or subtract. If there is a significant span error, construction of a calibration correction graph along the lines of that described for the Model C is recommended (art. 1.10.6(33).)

Corrections

(5) *Barometric pressure* corrections can be made by using the formula given for the Model C analyzer (art. 1.10.6(31)). Assuming that the instrument is properly calibrated, the *partial pressure* reading is correct at *any* barometric pressure and can be converted to true percent oxygen by dividing it by the existing barometric pressure in mm. Hg.

(6) Temperature corrections are not essential when analyses are performed at temperatures between 65° and 85° F. (18°–30° C.) but should be made beyond this range for reasonable accuracy. (*High* temperature causes falsely *low* readings, and vice versa.)

(*a*) Use one of these factors for accurate correction:

$$P=\frac{R\times(460+{}^\circ\text{ F.})}{535}\quad\text{(Fahrenheit)}$$

$$P=\frac{R\times(273+{}^\circ\text{ C.})}{297}\quad\text{(Centigrade)}$$

Where:

P=percent corrected for temperature.

R=Beckman reading, corrected for calibration error and barometric pressure, if necessary.

° F. or ° C.=temperature at time of analysis.

(*b*) For rough corrections, the following rules and factors can be employed:

For each 10° *above* 75° F., *add* the amount of the factor to the reading. For each 10° *below* 75° F., *subtract* the amount of the factor from the reading. (If temperature is 20° below 75° F., subtract the factor twice, etc.)

Reading	*Factor*
0 –15	0
15–35	0. 5
35–65	1. 0
65–85	1. 5
85–100	2. 0

(*c*) Example of rough correction:

A reading of 50 percent is obtained when the temperature is 95° F. Since 95° F. is 20° above 75, the factor 1.0 is added twice. This gives a corrected percentage of 52 percent.

Maintenance

(7) Precautions and maintenance of the Model D Beckman Oxygen Analyzer are much the same as for the Model C (art. 1.10.6(41)) although certain exceptions are obvious. Some of the matters that may require attention are:

(*a*) Replacement of silica gel (1)(e): Be sure to renew the cotton packing in tube each time. (Silica gel can be regenerated by heating to about 300° F.)

(*b*) Replacement of batteries (standard size D flashlight cells): Remove cover and sponge rubber pads and stand instrument on its back, scale up. Rotate battery clips downward and outward to remove batteries. Note that one is inverted in respect to the other. Insert new batteries, hold them in position with thumbs, and rotate clips back into position. Press light switch to check operation. Replace sponge rubber pads and cover.

(*c*) Replacement of lamp (standard Mazda prefocused flashlight bulb PR–2): Remove batteries as in (*b*). Slide square knurled clip back and downward to release contact spring and bulb. Put in new bulb and replace the batteries. Rotate bulb until satisfactory beam on scale is obtained. If beam remains unsatisfactory, try another bulb.

(*d*) Replacement of rubber aspirator bulb: Note that check valve is positioned so that gas is drawn rather than pushed through analyzer. Reverse check valve in replacement bulb if necessary.

(8) Return instrument to manufacturer for any repairs involving the test body, mirror, or the suspension, or for correction of large calibration errors. (See art. 1.10.6(43).)

1.10.8 CARBON DIOXIDE ANALYSIS

(1) Analysis of gas for carbon dioxide in diving may be desired for two main reasons:

(*a*) Checking for CO_2 as a contaminant in compressed air and gas mixtures for breathing.

(*b*) Determination of CO_2 levels in closed and semiclosed-circuit scuba.

(2) Carbon dioxide is an unlikely contaminant in compressed air and gases from reliable commercial sources, but it can be present in air from compressors used in the field (art. 1.10.10.(6)). Small concentrations could cause trouble in deep diving. For example, 1 percent CO_2 breathed at 132 feet would have the same effects as 5 percent CO_2 breathed at the surface. Sufficiently accurate analysis for amounts of CO_2 in this range requires an instrument like the Haldane (art. 1.10.4). Analyzers like those discussed below (3) would be useful in detecting the presence of a gross amount (over 1 or 2 percent) and should be used if the presence of CO_2 is suspected and a more precise analyzer is not available.

(3) Reasonably accurate analysis for larger concentrations of carbon dioxide can be accomplished with several types of analyzers manufactured for such purposes as analyzing flue gases. The one of this type most commonly found in the Navy is the Dwyer CO_2 analyzer. One of these is carried aboard every submarine. It is a simply-operated chemical analyzer, and if properly maintained will give sufficiently accurate results in the range for which it is intended. Another possibility is use of a Scholander Nitrogen analyzer filled with KOH (art. 1.10.5(66).

(4) Attempting to analyze gas from the breathing bag of a closed or semiclosed-circuit scuba has several possible pitfalls. Such an analysis might be desired, for example, in a case of unexplained loss of consciousness in the use of such a rig. However, unless a

sample can be obtained immediately, the absorbent (even if almost completely exhausted) will produce a considerable reduction in the concentration of carbon dioxide in the system. Sampling from the breathing bag (inspiratory side if it is a split bag) while the rig is being used by a working subject is more likely to produce meaningful results when questions of this sort arise.

1.10.9 CARBON MONOXIDE ANALYSIS

(1) Detection of this gas as a contaminant in compressed air for breathing is the main reason for carbon monoxide analysis in diving. Since 20 parts per million (0.002 percent) has been specified as the maximum allowable concentration, a sensitive method of analysis is required.

(2) The Mine Safety Appliances Company produces a small portable carbon monoxide tester (fig. 1–60) that is simple to operate and sufficiently sensitive and accurate. It is rugged and can readily be carried along on diving operations. Analysis is accomplished by drawing the sample through a glass tube containing a chemical that changes color in the presence of carbon monoxide. The color produced indicates the concentration of carbon monoxide, and a built-in color scale is provided. The sample is drawn through the tube by means of a rubber bulb, and the sensitivity of analysis depends on the number of times the bulb is squeezed. If the smallest color change shown by the scale is produced with five squeezes of the bulb, this indicates 0.001 percent CO—half the maximum limit for air to be used in diving. If this same color develops after two squeezes, the concentration is over the limit.

(3) The tester is designed for direct sampling from room air, so a modification must be employed for testing air from cylinders. It is recommended that a short nipple be attached tightly to the normal intake-hole, taking care not to interfere with the sealing arrangement at the end of the glass tube. (An accessory of this kind can be obtained.) One possible method of sampling would be to attach the nipple securely to the hub of a large hypodermic needle. The needle could then be in-

FIGURE 1–60.—MSA carbon monoxide tester.

serted into a rubber tube or bag kept flushed with the gas in question during the sampling period.

(4) Read the detailed instructions that accompany the analyzer. Follow them carefully. Be sure to maintain an ample supply of indicating tubes.

1.10.10 PURITY STANDARDS FOR COMPRESSED GASES

Oxygen

(1) Oxygen is covered by Federal Specification BB–O–925. Three grades of Type I (gaseous) oxygen are described:

Grade A—Aviator's breathing
Grade B—Industrial and medical
Grade C—Technical

(2) Grades A and B, differing only in moisture content, must both contain not less than 99.5 percent oxygen and pass the tests specified by the *U.S. Pharmacopoeia* (XIV Revision). Aviator's breathing oxygen must be extremely dry to avoid the possibility of moisture freezing in valves or lines with consequent stoppage of flow at low temperatures at altitude. The amount of moisture in Grade B

oxygen (not more than 5 ml. of free water per cylinder is specified) rarely presents a problem in diving, so this grade is generally satisfactory. Technical (grade C) oxygen is not suitable for breathing; and to prevent mixups, diving ships and activities should, if possible, avoid having it aboard for any purpose.

(3) The tests specified by the *U.S. Pharmacopoeia* are for acidity or alkalinity, carbon dioxide, other oxidizing substances, halogens, and carbon monoxide.

(4) Activities using oxygen should return cylinders with the valve closed and with a residual pressure of not less than 25 p.s.i. They must avoid damaging or contaminating cylinders (art. 1.10.1(8)).

Nitrogen

(5) Federal Specification BB–N–411a (1955) and Military Specification MIL–N–6011 (1950) are concerned with nitrogen. Both specifications include both oil-free and nonoil-free types. Only oil-free nitrogen is suitable for use in diving. The federal specification describes three grades of Type I (gaseous), Class 1 (oil-free) nitrogen:

- Grade A—99.95 percent pure, maximum moisture content 0.02 mg. per liter.
- Grade B—99.5 percent pure, maximum moisture content 0.02 mg. per liter.
- Grade C—99.5 percent pure, not more than 5 ml. of free water per cylinder.

(6) Moisture content of compressed gases is rarely critical in diving, and 99.5 percent purity is satisfactory provided that the remainder consists of oxygen with no more than a trace of carbon dioxide and no other contaminants. Class 1 Grade C nitrogen should generally be satisfactory for use in preparing breathing mixtures. However, the specifications evidently do not take into consideration the use of nitrogen for breathing, and tests for various possible trace-contaminants are not specified as they are for oxygen. In obtaining nitrogen for use in making up breathing mixtures, inform the supplier of the intended use and consult him concerning the possibility of harmful substances in the grades available. Care exercised in preparing and filling cylinders will sometimes vary with the grade and thus may also influence the choice. Where there is doubt concerning presence of contaminants, some of the tests described for oxygen in the *Pharmacopoeia* (2) may be applied by a qualified laboratory.

Helium

(7) Helium is produced by the Federal Government. Four grades, A, B, C, and D, are listed; but only grades A and D are currently being produced. Grade A helium is approximately 99.999 percent pure and is free of oil and moisture. Grade D is of similar purity except that it is oil-pumped and therefore unsuitable for preparation of breathing mixtures. (Grades B and C, if again produced according to existing specifications, would both presumably be suitable for use in diving.)

Compressed air

(8) Comparable specifications and purity standards for high pressure compressed air for breathing have not yet been established. The following are considered as *tentative* minimum standards for compressed air to be used in charging open-circuit scuba cylinders:

- Oxygen concentration: 20–21 percent
- Carbon dioxide: not more than 0.1 percent.
- Carbon monoxide: not more than 0.002 percent (20 parts per million).
- Oil vapor: not more than 130 micrograms per liter.
- To be free of gross moisture, dust, or other foreign matter.

NOTE.—Further research, especially concerning CO and oil vapor, may result in revision of these limits.

(9) Almost all high-pressure air available aboard ships or in field activities is pumped by oil-lubricated compressors and may contain harmful contaminants. Contamination with oil vapor may be heavy, and unacceptable amounts of carbon monoxide may be present. Some oil vapor will be present in the output of any oil-lubricated compressor. Wear and inadequate maintenance will increase the amount. Contamination with carbon monox-

ide (and in some cases carbon dioxide as well) can arise from two main sources:

(*a*) The gas may be present in the intake air from having the intake too close to (or downwind from) the exhaust of a gasoline-driven compressor or other source of exhaust gas. (In some ships, the compressor draws air from a compartment that may be contaminated with carbon monoxide or carbon dioxide.)

(*b*) Some oil-lubricated compressors, and perhaps all of them if not carefully operated, can develop cylinder temperatures that cause partial combustion of the lubricating oil. Products of combustion can consequently be formed within the compressor itself.

(10) Filtering systems are the only means of dealing with contaminants when the output of an unsatisfactory compressor must be used. Studies are being conducted with the aim of producing optimal detailed specifications for filter systems. Materials like activated alumina, activated charcoal, and substances that remove carbon monoxide and carbon dioxide must be used, often in combination, depending upon the contaminants concerned. The system must also prevent carryover of dust or particles from the absorbents employed. Care must be exercised to be sure that the materials are renewed or regenerated at appropriate intervals. Even with a good filter system, it is seldom completely safe to mix oxygen with air from an oil-lubricated compressor (art. 1.10.1).

(11) Where the source is not satisfactory beyond all doubt, air samples must be submitted at intervals to a suitable laboratory for analysis. There is no simple, reliable method for analyzing air for oil vapor in the field, but checks for carbon monoxide can be obtained with the instrument described above (art. 1.10.9). Sufficiently accurate analysis for small concentrations of carbon dioxide requires use of the Haldane analyzer (art. 1.10.4) or a similar instrument, but gross contamination can be detected with simpler apparatus described (art. 1.10.8).

(12) Despite the lack of formal standards, most manufacturers of compressed gases can supply water-pumped air of satisfactory purity and will do so if *air for breathing* is specified. (Specifying the intended use is important since some concerns also supply a lower grade of compressed air for commercial purposes; and this may be oil-pumped, contain various contaminants, or be sold in cylinders inadequately cleaned and evacuated.)

(13) Where the requirement for pure compressed air under high pressure does not involve great quantities and where the source is not too distant, use of extra large cylinders of commercial compressed breathing air in a *cascade* system may be the most satisfactory solution. A cascade system involves use of three or more cylinders manifolded together. The cylinder being charged is filled first from the large cylinder having the lowest pressure, next from that with somewhat higher pressure, and finally topped off from that having the highest pressure. When the pressure in the latter gets too low for topping off, the lowest cylinder is replaced with a full one which is then used for topping off. Very little air is wasted with such a system, many smaller cylinders can be charged close to their capacity with it, and periodic renewal of one large cylinder is much easier than taking many scuba cylinders to the source.

1.10.11 CLEANING OXYGEN SYSTEMS

(1) Many diving ships and activities have, or may consider installing, a system by which oxygen is piped from a central bank to the recompression chamber, the diving station, or a charging board. Smaller systems such as manifolds are in common use. The necessity for avoiding all possible contact between high pressure oxygen and oily materials has been stressed repeatedly in this manual because of the risk of explosion and fire. Any kind of system used with oxygen must be cleaned thoroughly on installation, kept clean, and recleaned whenever there is known or possible contamination (as by allowing compressed air from an oil-lubricated compressor to enter it). The following discussion of procedure for cleaning oxygen systems was adapted from the April 1957 issue of the Bureau of Ships Journal.

(2) The original article was published because the Bureau had received a report of an

oxygen system being *contaminated as the result of improper cleaning procedure.* An example of such contamination was once provided by a manufacturer who "cleaned" the oxygen cylinders and high pressure fittings of a scuba unit with a highly inflammable solvent and left a considerable residue of this material in the system. Only the alert intelligence of a diver kept the unit from being charged with oxygen—an operation that would almost certainly have caused an explosion resulting in several deaths and much damage. The Bureau's approved method for cleaning shipboard oxygen distribution systems, if followed carefully, will *safely* remove all foreign matter.

(3) The term, "cleaned for oxygen service," means that all dirt, filings, grease, oil, and other foreign materials have been removed from all parts of equipment and piping to be used in oxygen service. Equipment received from a manufacturer, such as cylinders and valves, that has been cleaned for oxygen service and that has all connections sealed when delivered, need not be recleaned. If the systems are received with unsealed connections, they should be cleaned according to the method described here.

Materials needed

(4) Materials needed for cleaning are:

(*a*) A fresh, clean water supply for mixing the solution and for rinsing.

(*b*) Steam or other source of heat for the cleaning solution and rinse water.

(*c*) Rubber gloves, safety goggles, rubber boots and aprons, or other protective clothing to be worn while cleaning.

(*d*) A brush for scrubbing the parts with the solution, or a paddle to stir the solution if scrubbing is not practical, or a Kenick hydrosteam cleaner, type S–D, or equivalent. (Use oil-free steam for steam cleaner.)

(*e*) A portable cleaning machine for large equipment. The machine consists of two 55-gallon tanks connected to a ½-horsepower bronze centrifugal pump (or equivalent) with a capacity of 15 gallons per minute at 20 p.s.i., mounted on an appropriate platform truck. Tanks should have steam heating coils capable of heating the cleaning solution to over 160° F.

(*f*) A supply of detergent such as steam cleaning compound Standard Navy Stock Number 51–C–1616–500.

(5) The cleaning solution, for the strength needed, must have 2 pounds of detergent to each 5 gallons of water (approximate 5 percent solution). The solution should be used at a temperature of 160° F. minimum.

Cleaning procedure

(6) The cleaning procedure is as follows:

(*a*) All parts, including fittings, piping, valves, and so on, must be completely disassembled and washed before final assembly.

(*b*) The cleaning solution should be prepared as described in the preceding paragraph.

(*c*) Small parts should be placed in the cleaning bath and soaked for at least 10 minutes. Agitate the solution, or scrub with a brush, until all visible traces of dirt or grease disappear.

(*d*) Use of the hydrosteam cleaner, if the shape of the material to be washed prevents the use of a brush.

(*e*) Wash large equipment with a portable washer by circulating or spraying solution for at least 10 minutes after the equipment has warmed to solution temperature.

(*f*) Rinse thoroughly with running water at approximately 160° F. immediately after washing. Do not use the same rinse water again.

(*g*) Dry with clean oil-free air or water pumped nitrogen. (See par. (10).)

(7) Clean indicating, recording, and controlling equipment, or other small or delicate equipment that cannot be cleaned with detergent, with trichloroethylene.

Special precautions

(8) The solutions mentioned in this article are harmful to eyes and skin and should be used cautiously. If the solution comes in contact with the skin, flush the area with large quantities of water.

(9) In using trichoroethylene, observe all precautions. Work only in a well-ventilated

area, avoid inhaling the vapor, and be sure that all parts cleaned are thoroughly dry before they are reassembled.

(10) Being sure that air used for drying the system is completely oil-free is of utmost importance, and shipboard and yard air supplies are seldom suitable. When the slightest doubt exists, water-pumped nitrogen should be used instead. (Breathing-grade helium is also suitable but is generally more expensive.) In some cases, drying can be accomplished by *drawing* suitably filtered fresh air through the system by means of a vacuum pump.

(11) Employ only materials approved for use with oxygen for "pipe dope," gaskets, etc., in reassembling oxygen systems.

(12) When systems have been cleaned, take extreme care to prevent oil or any other combustible material from entering.

1.10.12 CALIBRATION OF GAGES

(1) Serious difficulties can arise in diving from use of inaccurate gages. This is particularly true with gages employed to determine depth pressure—as on a recompression chamber or pneumofathometer. A relatively small error could result in improper decompression of a diver.

(2) Testing of gages is covered in *The Bureau of Ships Technical Manual*, Chapter 87, Section I, wherein it is specified that all gages, except high pressure air gages which are tested annually, should be tested at least every 6 months or whenever it is suspected that they are not accurate (as following the possibility of damage by excessive pressure, sudden pressure release, extreme vibration, or shock of any sort). Follow the testing instructions provided in that section. Utilize the following supplemental information where applicable.

(3) Use a deadweight tester where possible. If using a pneumatic gage comparator, be sure that it has been tested recently with a deadweight tester. If a "master gage" must be used, set it up and use it as nearly as possible in the same way as a comparator. Ascertain that the gage is in good condition, have it calibrated with a deadweight tester before use, handle it with care, and take any noted deviations into account.

(4) Under no circumstances use an oil-filled tester with a gage that will be used with oxygen or high-oxygen mixtures. Avoid any possible source of contamination of such a gage in the testing process. If there is doubt as to the cleanliness of the gage, follow the instructions given in Bureau of Ships Technical Manual, chapter 87, article 87–13. When cleaning oxygen systems as described in article 1.10.11, gages and gage lines should be removed and cleaned separately, after first cleaning the system with them attached, in order to insure that the gages and lines are thoroughly flushed.

Calibration of sea water depth gages

(5) Gages reading in depth, feet of sea water, are especially important in diving. Since almost all gage testers are graduated in pounds per square inch, conversions are needed. It is helpful to make up a conversion table in appropriate increments, giving pounds per square inch in one column and the corresponding depths in another. (Note that 1 foot of depth equals 0.445 p.s.i., 9 feet of depth equals almost exactly 4 p.s.i., 10 p.s.i. equals almost exactly 22.5 feet, etc.)

(6) Check an appropriate number of points depending on the scale of the gage and the increments available with the tester. For example:

(*a*) If the gage scale is in 1-foot increments, check 10-p.s.i. increments of pressure to obtain readings for 22½, 45, 67½, 90, etc. feet.

(*b*) If the gage is marked off in 2-foot or 5-foot increments, 20-p.s.i. steps of pressure (45, 90, 135, etc. feet) should be sufficient.

(7) At each increment of pressure, record the actual reading of the gage being tested together with the true depth that corresponds to the pressure.

(8) In testing a gage, it is desirable to run more than one test (or at least to note readings both with increasing and decreasing steps of pressure) to check the consistency of errors. A gage that shows large or variable errors, or one that sticks excessively, should be turned over for repairs or surveyed.

(9) An attempt may be made to adjust a gage according to chapter 87, Article 87–17 of

the Bureau of Ships Technical Manual. If this is not done or is not wholly successful, prepare a calibration curve (graph) or table to indicate the relationship between true depths and gage readings. If the deviations are within 5 feet of true depth and vary less than 2 feet in a 50-foot change of depth, use 50-foot increments in the calibration table. If the deviations are greater than this, use 10-foot increments. (In such a case, readjustment, repair, or replacement of the gage is actually preferable.)

(10) The calibration table should be affixed to the inside of the gage face glass. It should resemble the sample in fig. 1–61 and should include this information:

(*a*) Identification of depth gage.
(*b*) True depths in feet.
(*c*) Corresponding actual gage readings.
(*d*) Name of ship or activity.
(*e*) Initials of individual responsible.
(*f*) Date of calibration.

DEPTH GAGE #2

True depth	*Gage reads*
0	0
50	49
100	98
150	148
200	199
250	250
300	301
350	352
400	402½
450	453

USS PENGUIN

6/25/57

FIGURE 1–61

(11) In using a gage with such a table, some interpolation is necessary. For example, the gage whose calibration table is shown in fig. 1–61 could be expected to read about 275½ for a true depth of 275 feet, or to indicate a true depth of about 323½ when it reads 325 feet. For most purposes, such estimates are close enough. A calibration graph, with true depth on one axis and actual reading on the other would permit more exact and more rapid corrections.

1.10.13 UNITS OF MEASUREMENT

(1) Distances, pressures, volumes, and the like, can be expressed in various different *units*. For example, a length can be measured in inches, feet, yards, or miles; and we use the unit which is of most convenient size for what we are measuring. Having different units becomes inconvenient when we have to convert a measurement from one unit to another. The situation is complicated by the fact that there is more than one system of units. English-speaking countries use the system of feet, pounds, pounds per square inch, etc.; while the rest of the world uses the *metric* system of meters, grams, etc. Because it is more logical, more widely understood, and easier to handle, the metric system is used for most scientific measurements.

The metric system

(2) The metric system is so widely used that a diver sooner or later will run into it. He should understand how it works and should be able to convert from metric to English units and vice versa (tables 1–31 through 1–34, Tables of Conversion Factors, provide information for this purpose).

(3) The metric system has the advantage that all of its units are related to each other in such a way that it is not necessary to use calculations in going from one metric unit to another. It is based on decimals, as is the American system of money. We can express a sum of money either in dollars or cents just by moving the decimal point. Instead of having to multiply or divide by factors like 3, 12, and 5,280, the metric system handles its units of measurement the same way.

(*a*) *Length*.—The principal metric unit of length is the *meter* (about 39 inches). For measuring smaller lengths, *millimeters* (mm.) or *centimeters* (cm.) are used:

1 meter = 100 centimeters (cm.)
= 1,000 millimeters (mm.)

1 millimeter = 0.10 (one-tenth) centimeter
= 0.001 (one-thousandth) meter

For longer distances, the metric system uses the *kilometer* (about 6-tenths of a mile).

1 kilometer = 1,000 meters
1 meter = 0.001 kilometer

(*b*) *Area.*—The metric system "squares" its units of length to measure area just as the U.S. system does. As in converting from one metric unit of length to another, converting the units of area is just a matter of moving the decimal point. In this case, it is moved twice as many places as in measures of length. For example, 1.0 meter = 100.0 cm.; 1.0 square meter = 10,000.0 square centimeters. (Compare this with multiplying by 144 to convert from square feet to square inches.)

(*c*) *Volume* or *capacity.*—Volumes can be expressed as "cubes" of the metric units of length. Conversion of volumes from one metric unit to another requires only moving the decimal point three times as many places as in converting the units of length. For example, 1,662 cubic millimeters equals 1.662 cubic centimeters. (To convert cubic inches to cubic feet, you would have to divide by 1,728 ($12 \times 12 \times 12$).) In addition to cubic feet and the like, the U.S. system also uses pints and quarts, etc. as units of volume or capacity. There is no simple relationship between these and the cubic measurements, so conversion involves a lot of odd numbers. The metric system uses the liter (about the same as a quart) for similar purposes, but a liter equals 1,000 cubic centimeters (cc.) or 0.001 cubic meter (cm.) so conversions are simple.

1 liter = 1,000 cubic centimeters
= 0.001 cubic meter

(*d*) *Weight.*—The gram (gm.) is the basic metric unit of weight. It is defined as the weight of one cubic centimeter (cc.) of water. For larger weights, the *kilogram* (kg.) is the usual unit. It is equal to 1,000 gm., or the weight of a liter of water. (This is about 2.2 pounds.) For very small weights, the milligram (mg.) is used (one-thousandth of a gram).

1 gram = 0.001 kilogram
= 1000 milligrams
1 kilogram = 1000 grams
1 milligram = 0.001 gram

(*e*) *Pressure.*—Instead of using "pounds per square inch," the metric system measures pressure in terms of *grams or kilograms per square centimeter.* One kilogram per square centimeter (kg./cm.^{2}) is equal to 14.22 p.s.i. A pressure of 1 gram per square centimeter is equal to a manometer reading of 1 centimeter of water (1 cm. H_2O) because, by definition, a gram is the weight of 1 cubic centimeter of (fresh) water. Consequently, a pressure of one kg./cm.^{2} is equal to that exerted by a column of water 1,000 centimeters, or 10 meters, high. It is thus the gage pressure at a depth of 10 meters in fresh water. (10 meters = 32.8 feet.) Note that 1 kg./cm.^{2} is very close to *1 atmosphere:* 14.22 p.s.i., or about 32 feet of sea water.

1 kg./cm.^{2} = 1,000 gm./cm.^{2}
= 1,000 cm. H_2O
= 10 meters H_2O
= (approx.) 1 atmosphere

(4) Notice that the decimal basis of the metric system and the relationships between the units of length, area, volume, weight, and pressure make many things simpler than they are in the U.S. system. Even the process of converting between the English and metric units is fairly simple as a result.

(*a*) If you know that 1 inch equals 2.54 cm., you also know that it equals 25.4 mm. and 0.0254 meter. If you know that a liter of water weighs 1 kilogram or about 2.2 pounds, you also know that 1 cc. of water weighs one-thousandth of that, or 0.0022 pounds, and that a cubic meter of water weighs a thousand times 2.2, or 2,200 pounds.

(*b*) Take a problem like the following one, with all the units in the metric system, and consider how many more steps and how much more arithmetic would be required to estimate the answer if the English system had been used: You have several gas cylinders with an internal volume of 12 liters, charged to 150 kg./cm.^{2} (gage). You want to raise a 165 kg. anchor off the bottom in 50 meters of water using a collapsible pontoon which weighs 45 kg. How many cylinders will you need to inflate the pontoon enough to start raising the anchor?

Solution: You need at least 165 + 45 = 210 kg. of buoyancy to offset the weight of anchor and pontoon. The pressure at the depth is about 1 atmosphere per 10 meters, or 5 atm. (gage) + 1 = 6 atm. absolute. Each cylinder will deliver one volume (12 liters) of free air at the surface for each atmosphere of pressure released. It will deliver one 6th of that volume, or 2 liters, at the depth concerned. Since the cylinder pressure is 150 – 5 = 145 kg./cm.^{2} (or about 145 atm.) above the depth-pressure, each cylinder should deliver about 145 × 2 = 290 liters at depth. This would yield about 290 kg. of buoyancy, so one cylinder should be sufficient.

Temperature scales

(5) Countries which use the English or the United States system of weights and measures generally employ the *Fahrenheit* temperature scale. Countries which use the metric system, and most scientific laboratories, use the *centigrade* scale instead. The centigrade scale uses the temperature of melting ice (32° F.) as zero and the temperature of boiling water (212° F.) as 100°. The Fahrenheit scale is said to have been based partly on the body temperature of a certain sick cow (100° F.).

(6) The rules for converting from one temperature scale to the other can be summed up by these formulas and statements:

(*a*) To convert Fahrenheit to centigrade:

Formula:

$$^\circ\text{C.}=\frac{5}{9}\times(^\circ\text{F.}-32)$$

Steps:

1. Subtract 32 from the Fahrenheit reading.
2. Multiply the result by $\frac{5}{9}$.

(*b*) To convert centigrade to Fahrenheit:

Formula:

$$^\circ\text{F.}=\left(\frac{9}{5}\times^\circ\text{C.}\right)+32$$

Steps:

1. Multiply the centigrade reading by $\frac{9}{5}$.
2. Add 32 to the result.

(*c*) Notes:

1. When adding or subtracting 32, do this algebraically: In the first step of the ° F. to ° C. formula, if the original F. temperature is positive (above zero) simply subtract 32; if it is minus (below zero), add 32 and keep the minus sign. In the second step of converting ° C. to ° F., if the value is positive (above zero), simply add 32; if it is negative (minus) and greater than 32, subtract 32 from it and keep the minus sign; if it is negative but less than 32, find the difference and discard the minus sign.

2. If the value you multiply by $\frac{9}{5}$ or $\frac{5}{9}$ has a minus sign, the product is also a negative value, so keep the minus sign.

3. Instead of multiplying by $\frac{9}{5}$, you can multiply by 1.8 if you prefer. Instead of multiplying by $\frac{5}{9}$, you can divide by 1.8 or multiply by 0.556.

(7) If it is difficult to remember which of these formulas is which and how they work, try considering it this way: The freezing point of water is 0° C. or 32° F. The boiling point is 100° C. or 212° F. Therefore, the range from the freezing point to the boiling point of water is 100–0=100° on the centigrade scale and 212–32=180° of the Fahrenheit scale. Therefore, it must take $\frac{180}{100}$ or $\frac{9}{5}$ or 1.8 times as many Fahrenheit degrees to cover any part of the scale as it does centigrade degrees. In other words, a Fahrenheit degree is $\frac{100}{180}$ or $\frac{5}{9}$ or 0.556 the "size" of a centigrade degree; and a centigrade degree is $\frac{9}{5}$ or 1.8 times the size of a Fahrenheit degree. If you keep this 100 versus 180 relationship in mind and remember that the freezing point is zero degrees centi-

grade and +32° F., the conversion process becomes fairly simple and does not have to be memorized by rote. The basic idea is first to find out how many degrees *above or below freezing* a temperature reading is on its own scale. Then find out how many degrees in the other scale would cover this same span. Finally, consider where freezing is on this scale and adjust the value if necessary.

(*a*) For example, convert normal body temperature from degrees Fahrenheit (98.6) to centigrade.

1. 98.6 is $98.6-32=66.6$ Fahrenheit degrees above freezing.

2. $\frac{5}{9}\times 66.6=37°$ C. above freezing.

3. Freezing is 0° C., so 37° C. is the final answer.

(*b*) Another example: Convert 25° C. to Fahrenheit.

1. Since 0° C.=freezing, 25° C. is 25 centigrade degrees above freezing.

2. $\frac{9}{5}\times 25=45$ Fahrenheit degrees above freezing.

3. Freezing=32° F., so the final answer is $45+32=77°$ F.

(*c*) The same principles apply even if both readings are below zero: Convert −10° F. to centigrade:

1. Since freezing is 32° F., −10° F. is $32+10=42$ Fahrenheit degrees below freezing.

2. $42\times\frac{5}{9}=23.3$ centigrade degrees below freezing.

3. Since freezing is 0° C., −23.3° C. is the final answer. (Note the minus.)

(*d*) The same process works when one reading is below zero and the other is not: Convert −10° C. to Fahrenheit:

1. −10° C. is 10 centigrade degrees below freezing.

2. $10\times\frac{9}{5}$ (or 10×1.8) $=18$ Fahrenheit degrees below freezing.

3. Since freezing is 32° F., 18° F. below freezing=$32-18=14°$ F.

Absolute temperature

(8) Temperature must be converted to "absolute" when working with the gas laws. This involves the idea of "absolute zero"—the lowest temperature which could possibly be reached. This is assumed to be 273.13° below zero on the centigrade scale or 459.72° below zero on the Fahrenheit scale. Usually, absolute temperatures are used for setting up ratios between "before" and "after" temperatures in gas law calculations. Therefore, it does not matter whether the figures are in centigrade or Fahrenheit units as long as the *same* units are used for all temperatures in each calculation. Because the numbers are so large, it is usually permissible to round the values to the nearest whole number: add 273 to the temperature if using centigrade; add 460 to the temperature if using Fahrenheit units.

Barometric pressure

(9) Barometric pressure is usually measured in inches or millimeters of mercury. Although we now have mechanical (aneroid) barometers, the standard instrument is still a vertical glass tube with its upper end closed and its open lower end immersed in a cup of mercury. The atmospheric pressure is measured by the height of the column of mercury which it is able to support in the tube, and this is read directly in units of length. Readings can be converted by the usual method of converting inches to millimeters and vice versa (1 inch = 25.4 mm.). When the barometric pressure is employed in calculations related to gas laws or gas analysis, it is usually used to establish the ratio between "before" and "after" pressures or between the existing pressure and "standard" pressure (760 mm. Hg or 29.92 inches of Hg). Either inches or millimeters can be used for this purpose as long as the same units are used throughout a given calculation.

(10) Some barometers are calibrated in *millibars*. Usually, they are also provided with an inch scale; and this should be used in preference for calculations related to diving. If not, the millibar reading can be used directly in most calculations, just as it is possible to use either inches or millimieters of mercury. "Standard pressure" (equivalent to 760 mm. Hg or 29.92 in. Hg) is 1013.3 on the millibar scale.

(11) It is rarely necessary to convert barometric readings from inches or millimeters of mercury to p.s.i. or kg./cm.² For most calculations involving higher pressures, 14.7 p.s.i. or 1.033 kg./cm.² are sufficiently accurate approximations of barometric pressure. In some cases, it is permissible to round these figures even further: 15 p.s.i. or 1.0 kg./cm.² However, if such conversions are necessary, refer to tables 1–31 to 1–34 for the appropriate factors.

Use of conversion factors

(12) Tables 1–31 to 1–34 provide the majority of factors likely to be required for converting measures of length, area, volume or capacity, weight, or pressure from one unit to another in diving. They are presented in four groups: factors for converting from one unit to another in the U.S. or English system (U.S. to U.S.), metric to metric, U.S. to metric, and metric to U.S. Not every conversion is given directly since many of them are sel-

TABLE 1–31

TABLE OF CONVERSION FACTORS

(U.S. units to other U.S. units)

Length

1 inch (in.)	=0.083 ft.
1 foot (ft.)	=12 in.
1 yard (yd.)	=36 in.
	=3 ft.
1 fathom	=6 feet
1 statute mile	=5,280 feet
1 nautical mile	=6,080 ft.
	=2,026.7 yd.

Area

1 sq. in.	=0.0069 sq. ft.
1 sq. ft.	=144 sq. in.
1 sq. yd.	=1,296 sq. in.
	=9 sq. ft.
1 acre	=43,560 sq. ft.
	=0.00156 sq. mi.
1 sq. mile	=640 acres

Volume (cubic measurements)

1 cu. in.	=0.00058 cu. ft.
1 cu. ft.	=1,728 cu. in.
	=29.92 quarts
	=7.48 gallons
1 cu. yd.	=27 cu. ft.

Capacity (liquid measure)

1 pint (pt.)	=16 fluid ounces
	=28.88 cu. in.
1 quart (qt.)	=2 pt.
	=57.75 cu. in.
1 gallon (gal.)	=4 qt.
	=231 cu. in.

Weight (avoirdupois)

1 ounce (oz.)	=0.0625 lb.
1 pound (lb.)	=16 oz.
1 short ton	=2,000 lb.

Weights of water

1 quart	=2 pounds (fresh water)
1 cu. ft.	=62.4 lbs. (fresh water)
	=64 lbs. (sea water)

Pressure

1 pound per square inch (p.s.i.)	=2.31 feet of fresh water
	=2.25 feet of sea water
	=0.068 atm.
	=2.036 in. Hg.
1 atmosphere (atm.)	=14.696 p.s.i.
	=29.92 in. Hg.
	=33.9 ft. of fresh water
	=33 ft. of sea water
1 foot of sea water	=0.445 p.s.i.
1 inch of mercury (in. Hg.)	=0.491 p.s.i.
	=1.133 feet of fresh water
	=13.60 inches of fresh water

dom used and can be derived readily from other factors. For example, no factor is listed for converting miles to meters; but the mile-kilometer and kilometer-meter factors are listed.

(13) In most cases, the desired conversion can be made directly by multiplying the original measurement by the appropriate factor from the table. For example, if you wish to convert a length of 9 inches into equivalent number of centimeters, find *1 inch* in the U.S. —to—metric table and note that it equals 2.54 cm. Multiply 9 by 2.54 to obtain the answer. Where no direct factor is given, one of the values must be converted into another unit either before or after employing the nearest

TABLE 1–32

TABLE OF CONVERSION FACTORS

(Metric units to other metric units)

Length

1 millimeter (mm.)	=0.1 cm.
	=0.001 m.
1 centimeter (cm.)	=10 mm.
	=0.01 m.
1 decimeter † (dm.)	=100 mm.
	=10 cm.
	=0.1 m.
1 meter (m.)	=1000 mm.
	=100 cm.
	=10 dm.
	=0.001 km.
1 kilometer (km.)	=1000 m.

Area

1 sq. cm. ($cm.^2$)	=100 $mm.^2$
1 sq. m. ($m.^2$)	=10,000 $cm.^2$
1 sq. km. ($km.^2$)	=1,000,000 $m.^2$

NOTE.—European usage employs a comma where we use a decimal point and a period where we use a comma (in large numbers).

Volume and capacity

1 cubic centimeter (cc.) (or 1 millimeter (ml.))	=0.001 liter
1 liter (l.)	=1000.027 cc.*
	=1000 ml.
	=0.001 cu. m. ($m.^3$)
1 cubic meter ($m.^3$)	=1000 l.

Weight

1 milligram (mgm.)	=0.001 gm.
1 gram (gm.)	=1000 mgm.
	=0.001 kg.
1 kilogram (kg.)	=1000 gm.

Weights of fresh water

1 cc. or 1 ml.	=1 gm.
1 liter	=1 kilogram

Pressure

1 gram per square centimeter (gm./$cm.^2$)	=0.001 kg./$cm.^2$
	=1 cm. of fresh water
1 kilogram per square centimeter (kg./$cm.^2$)	=1000 gm./$cm.^2$
	=10 meters of fresh water
	=9.75 meters of sea water
	=73.56 cm. Hg.
	=0.968 atm.
1 centimeter of mercury (cm. Hg.)	=13.6 gm./$cm.^2$
	=13.6 cm. of fresh water
1 centimeter of fresh water	=1 gm./$cm.^2$
1 atmosphere	=1.033 kg./$cm.^2$
	=760 mm. Hg.

† Seldom used.
* For almost all purposes, a liter is considered equal to exactly 1,000 cc.

usable factor. For example, you will not find a factor for converting 0.96 kilometers directly into feet, but the kilometer-mile and meter-foot factors are given. Since conversions within the metric system require only moving the decimal point, it is usually simpler to make the "secondary" conversion in the metric units. In this example, it is much easier to change 0.96 km. to 960 meters and use the meter-foot factor than to convert kilometers to miles and multiply by 5,280.

(14) Where conversions must be made frequently, it pays to learn how to use a slide rule. A single setting on the rule permits you to read off a whole series of converted values very rapidly. If a particular conversion has to be made repeatedly, it may pay to make up a table or graph of equivalent values. Unless great accuracy is required, a graph is the simplest scheme: To convert from p.s.i. to kg./cm.^{2}, for example, you can mark off p.s.i. in the horizontal direction and kg./cm.^{2} on the vertical axis of the graph paper. Then calculate a few equivalent values, plot them on the graph, and draw a straight line to connect the points. To convert p.s.i. to kg./cm.^{2}, you can then find the pressure in p.s.i. on the horizontal scale, note where this hits the straight line you have drawn, and then see where this point lies on the kg./cm.^{2} scale. Using such a graph is about as simple as reading a gage or a thermometer, and the same graph can be used for conversions in either direction.

TABLE 1–33

TABLE OF CONVERSION FACTORS

(U.S. units to metric units)

Length

1 inch	=25.4 mm.
	=2.54 cm.
1 foot	=30.48 cm.
	=0.3048 m.
1 statute mile	=1.609 km.
1 nautical mile	=1.853 km.

Area

1 sq. in.	=6.45 cm.^{2}
1 sq. ft.	=929.03 cm.^{2}
	=0.0929 m.^{2}

Volume and capacity

1 cubic inch	=16.39 cc.
1 cubic foot	=28,317 cc.
	=28.317 liters
	=0.028317 cu. m.
1 quart	=0.946 liter

Weight

1 ounce	=28.35 gm.
1 pound	=453.6 gm.
	=0.454 kg.
1 short ton	=907.2 kg.

Pressure

1 p.s.i.	=70.3 gm./cm.^{2}
	=0.0703 kg./cm.^{2}
	=0.703 meter of fresh water
	=5.17 cm. Hg.
1 in. of fresh water	=25.4 mm. water
	=2.54 gm./cm.^{2}
1 in. of mercury	=25.4 mm. Hg.
	=34.54 gm./cm.^{2}

TABLE 1–34

TABLE OF CONVERSION FACTORS

(Metric units to U.S. units)

Length

1 cm.	=0.394 in.
1 meter	=39.37 in.
	=3.28 ft.
1 kilometer	=0.621 mi.

Area

1 cm.^{2}	=0.155 sq. in.
1 m.^{2}	=10.76 sq. ft.
1 sq. km.	=0.386 sq. mi.

Volume and capacity

1 cc. or ml.	=0.061 cu. in.
1 cu. m.	=35.31 cu. ft.
1 liter	=61.02 cu. in.
	=0.035 cu. ft.
	=33.81 fl. oz.
	=1.057 quarts

Weight

1 gram	=0.035 oz.
1 kg.	=35.27 oz.
	=2.205 lb.

Pressure

1 gm./cm.^{2}	=0.394 inch of fresh water
1 kg./cm.^{2}	=14.22 p.s.i.
	=32.8 feet of fresh water
	=28.96 inches of mercury
1 cm. Hg.	=0.193 p.s.i.
	=0.446 foot of fresh water
	=0.394 inch of mercury
1 cm. of fresh water	=0.394 inch of fresh water

557535 O - 60 - 17

PART 1, INDEX