BUREAU OF SHIPS

DIVING MANUAL

NAVSHIPS 250-880

U. S. NAVY DEPARTMENT WASHINGTON 25, D. C.

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DIVING MANUAL

Navy Department,
Bureau of Ships,
1 July 1952.

This manual supersedes the 1943 edition of the Diving Manual, and supplements the instructions given in Bureau of Ships Manual, Chapter 94, Salvage; Section II, Diving.

It contains information in regard to the physiological aspects of diving which are not included in Chapter 94 of the Bureau of Ships Manual.

These additional instructions are given in this Manual for the purpose of training personnel.

It becomes effective immediately.

H. N. WALLIN,
Rear Admiral, U. S. N.,
Chief of Bureau.

NAVSHIPS 250–880

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Part 1—History and Development of Diving

501. ORIGIN OF DIVING IN U. S. NAVY

(1) Records do not clearly show the origin of diving in the U. S. Navy. While there are evidences of excellent work having been performed at shallow depths in the early days of diving, very little was accomplished at deep diving. A definite program of development of diving was actively begun by the U. S. Navy in 1912, when extensive tests were conducted in diving tanks ashore and later on the U. S. S. *Walke* in Long Island Sound. These tests were to determine the practicability of the stage method of decompression and to improve the standard Navy diving gear to enable deeper diving. The value of the findings was subsequently evidenced in the salvage operations of the U. S. S. *F-4* off Honolulu in 1915, during which divers decended to depths of 304 feet and other similar deep dives performed during World War II.

(2) The above-mentioned tests were followed by the preparation and issue of the U. S. Navy Diving Manual and the establishment of the Navy Diving School at the Naval Torpedo Station at Newport, R. I. This school was subsequently discontinued upon the entry of the United States into World War I. Personnel of this school and some of its graduates formed a nucleus for the overseas salvage division which was established as a unit of United States Naval Forces abroad, and which throughout the war rendered valuable service in salvage operations along the French coast.

(3) With the continuing improvement of diving techniques and equipment, there was, in addition to man's natural interest in exploring the unknown, the very real possibility of having to salvage submarines that were being constructed to operate at ever-increasing depths. Divers continued to go deeper and deeper until it was found that there was a limit to the depth to which a diver could descend using air and still maintain his mental control. In order to enable divers to attain greater depths, it was found necessary to substitute a synthetic breathing medium for air.

502. EXPERIMENTS WITH HELIUM-OXYGEN MIXTURES

In the latter part of 1924, the Bureau of Construction and Repair in conjunction with the Bureau of Mines undertook the investigation of the use of helium-oxygen mixtures. These preliminary experiments were conducted at the Bureau of Mines Experimental Station, Pittsburgh, Pa. Preliminary experiments on animals indicated advantage in the use of the synthetic medium over the air ordinarily used as a diver's air supply. 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 Naval Gun Factory, Washington, D. C., as a permanent activity under the Bureau of Construction and Repair to continue the investigation of helium-oxygen and other development work incident to diving practices and equipment. The Experimental Diving Unit has functioned accordingly up to the present time. Such methods prescribed in this edition that depart from past practices, and new diving and salvage equipment shown are, in the majority of cases, the results of findings of the Experimental Diving Unit, the Deep Sea Diving School, the Salvage School, or the experience gained from past salvage operations.

503. DEEP SEA DIVING SCHOOL

The Deep Sea Diving School was established in 1926–27 at the Washington 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 standard training curriculum. The school is operated under the cognizance of the Bureau of Naval Personnel, but the diving facilities, gear, and diving boat are furnished and maintained by the Bureau of Ships.

504. EQUIPMENT USED

(1) The facilities of the Deep Sea Diving School, see figures 21 and 22, consist of two pressure tanks capable of withstanding 350 p. s. i. working pressure and 525 p. s. i. test pressure. Each pressure tank is directly connected to a recompression chamber by means of a tunnel. There are two open tanks for training purposes. At present, there are two diving floats in the Anacostia River adjacent to the school building and two diving boats attached to the school for training purposes and emergency work. The school also has classrooms, modern workshop, patching room, and compressor room.

(2) 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 a modern workshop 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 having been done in this field at the start of World War II.

505. ESTABLISHMENT OF DIVING SCHOOLS

With the expansion of the U. S. Navy to include vessels 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 the U. S. S. *Lafayette* (ex S. S. *Normandie*) while it was moored at Pier 88, North River, New York. The righting of the vessel provided an excellent opportunity for establishing a diving school where practical experience of the type that ships salvage personnel would encounter could be obtained. In addition to the experience that could be obtained on the *Lafayette*, there were numerous diving jobs in the harbor which 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. The facilities of the Naval Training School (Salvage) included a diving float, motor rooms, two diving tanks, etc. During 1946 the school (now Naval School, Salvage) was transferred from Pier 88, New York to Bayonne, N. J. In addition to the Deep Sea Diving School and the Naval Training School (Salvage), there are diving schools within the fleet and at various naval shipyards. These schools are used for the training of second class divers.

506. DIVER RATINGS

The diver ratings in the U. S. Navy are: Master divers; diver first class; salvage diver; diver second class. Master divers and diver first class are qualified only at the Deep Sea Diving School, Naval Gun Factory, Washington, D. C. Salvage divers are qualified only at the Naval School (Salvage), Bayonne, N. J. Second-class divers are qualified at activities now designated by the Chief of Naval Personnel.

Part 2—Basic Principles of Diving

A. PHYSICS OF DIVING

511. VARIOUS ATMOSPHERIC CONDITIONS

Ordinarily not much attention is paid to the natural surroundings or atmospheric conditions under which we live. The fact that a pressure of 14.7 p. s. i. is exerted on the body, which has an area of about 2,500 square inches, is taken for granted; similarly, very little consideration is given to the fact that the air we breathe is under pressure and is of constant composition. It is not until attempts are made to remove man from these atmospheric conditions, whether it be going to the stratosphere where the pressure is reduced or descending into the ocean where the pressure is increased, that it becomes apparent that adjustments must be made.

512. PHYSICAL PROPERTIES OF GASES

(1) In the study of diving and its effects on the human body, it is important to consider the physical properties and laws governing the behavior of gases and liquids. 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; gases, which have neither a definite volume nor shape. Of the three types of matter, gas and liquids are of primary importance to the diver. Of the great number of gases that exist, there are a few of special interest to the diver. Of course, the most important gases are the two—oxygen and nitrogen—that go to make up air.

(2) Oxygen occurs 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 in lieu of air as a breathing medium. Nothing can burn except in the presence of oxygen but, on the other hand, oxygen alone cannot burn.

(3) Nitrogen is the other main component of air. It also occurs in a free state in the atmosphere and comprises approximately 79 percent by volume. This gas is odorless, colorless, and tasteless. In a free state, it is inert or chemically inactive and as such is incapable of supporting life.

(4) As the depth of diving increases, an additional gas (helium) becomes of importance to the diver. Helium, when mixed with the proper proportions of oxygen, forms an artificial atmosphere whose breathing resistance and anesthetic effects

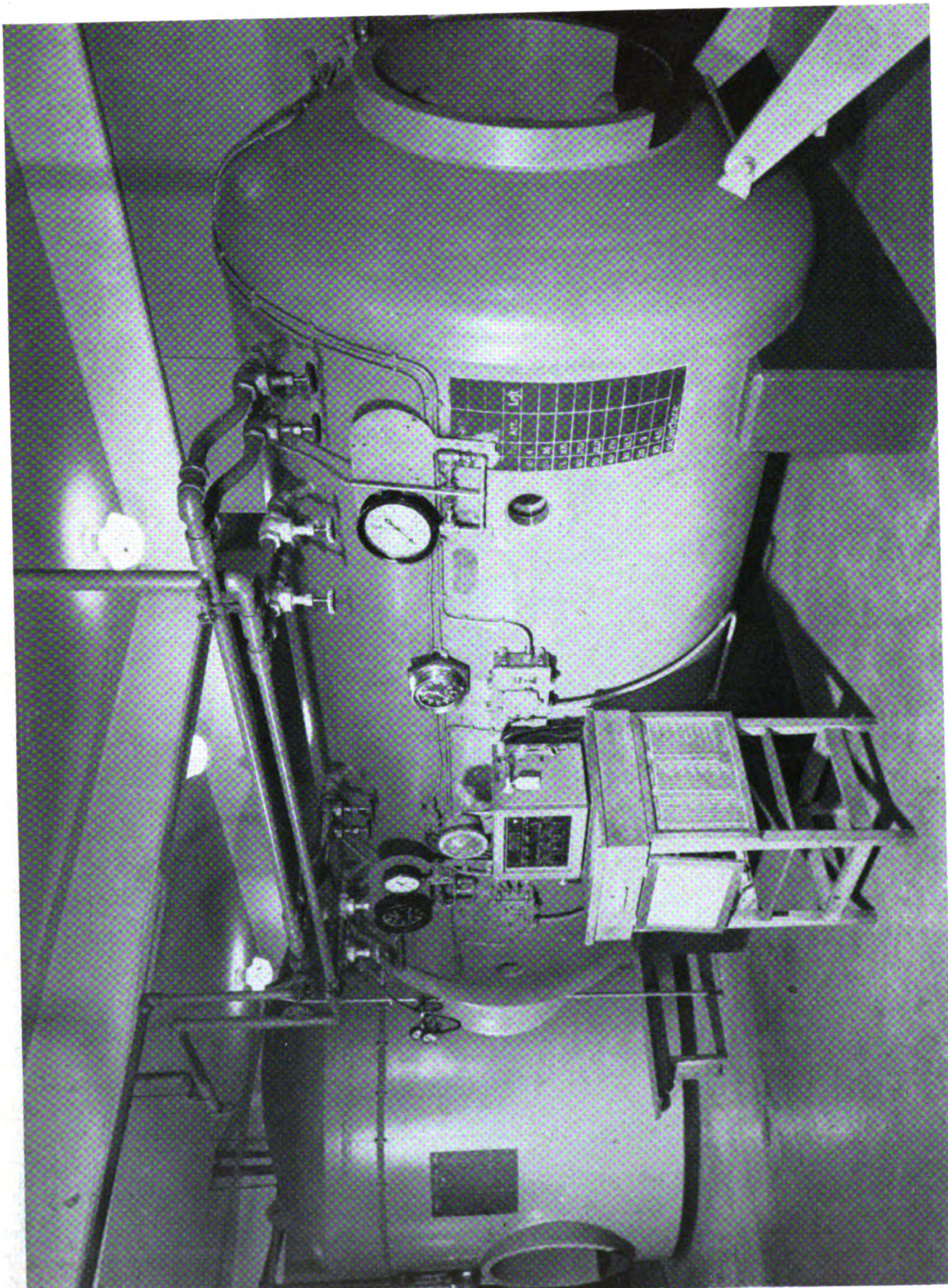

FIGURE 21.

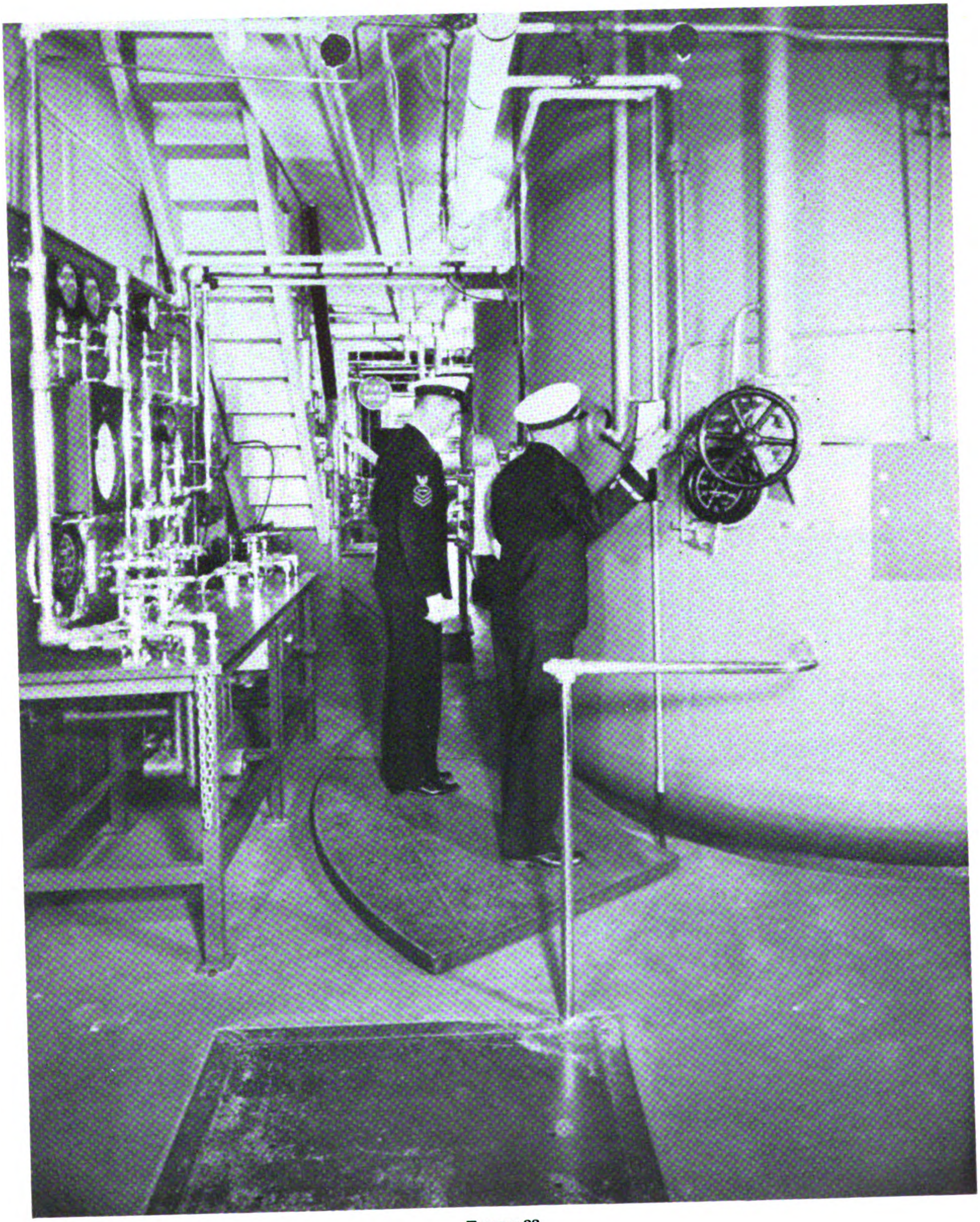

FIGURE 22.

under relatively high pressure are considerably less than in the case of air. This gas is colorless, odorless, tasteless, and inert. It is exceptionally light, nontoxic, nonexplosive, and conducts heat much more rapidly than air.

(5) Hydrogen is colorless, odorless, and tasteless. It combines readily 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. Recent investigation indicates that hydrogen and oxygen can be mixed in proper proportions to form a satisfactory breathing medium. However, as little is known on the use of hydrogen for breathing, it is mentioned here only as a matter of interest and no attempt will be made to cover the subject in more detail.

(6) In addition to the above gases, which are used alone or in combination to form breathing mediums, there are two harmful gases with which divers should be familiar. One of these gases is carbon dioxide which is colorless and 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, or by oxidation of food in the body. If the air supply is inadequate, the CO_2 concentration in the lungs will build up to cause panting and distress, and finally suffocation.

(7) The other gas is carbon monoxide which is colorless, odorless, tasteless, and highly poisonous. CO is produced by oxidation of carbon-bearing materials when oxygen supply is insufficient so that each molecule has only one atom of oxygen for one of carbon instead of two as in CO_2. Carbon monoxide is found in dangerous concentrations in engine exhausts and in closed compartments where paint or stores have been deteriorating.

513. COMPONENTS OF AIR

Normal air (the atmosphere we breathe) is a simple mixture (not a chemical combination) of the gases described above with traces of hydrogen and certain other rare gases. It is highly compressible. The proportions of the main constituents are approximately as follows:

	Percent by volume
Nitrogen (approximately)	79
Oxygen (approximately)	20.94
Carbon dioxide (approximately)	.03

Expired air varies in composition with the depth of the expiration and with the composition of the air taken in. Under normal conditions expired air contains in volume percent:

	Percent
Nitrogen (approximately)	79.7
Oxygen (approximately)	16.3
Carbon dioxide (approximately)	4.0

That is, expired air loses about 4.64 volume percent of oxygen and gains 3.96 volume percent carbon dioxide. The difference in the oxygen absorbed and the carbon dioxide (CO_2) given off is explained by the fact that in the physiological process of the body some of the oxygen is absorbed by the body, not only to oxidize carbon, but also to combine with some of the hydrogen of the food and consequently is secreted as water.

514. ATMOSPHERIC PRESSURE

Air has weight and occupies space. Due to the relative lightness of air in comparison with other materials, and the fact that the body is adjusted to withstand its weight, it is unconsciously treated as though it did not exist. Considering an area of one square inch, the miles of air above it weighs 14.7 pounds. Since this pressure is the result of the weight of the atmosphere, it is referred to as "atmospheric pressure." The word "atmosphere" is used to denote a pressure of 14.7 p. s. i. For example, the application 29.4 p. s. i. pressure also can be expressed as applying a pressure of two atmospheres.

515. ABSOLUTE PRESSURE

(1) Since measuring pressure is to determine the increase or decrease from the normal atmosphere level, most gages are constructed so that the indicating mark on the gage is zero. However, the true pressure—"Absolute Pressure"—which must be used in calculations has the zero mark 14.7 pounds lower or at the level of a perfect vacuum. In other words, to obtain the "Absolute Pressure" in equations describing the behavior of gases, it is necessary to add 14.7 pounds to the indicated "Gage Pressure."

(2) To illustrate the concept of pressure, consider a vertical pipe with a cross sectional area one square inch. If a cork is placed in the bottom and the pipe filled with sea water to a depth of 33 feet, the cork must support the entire weight—33 x 12 x 1=396 cubic inches, or 14.7 pounds. (1,728 cubic inches of sea water weighs 64 pounds.) There is an additional 14.7 pounds due to the atmosphere pressing on top of the water, making a total force of 29.4 pounds on the cork. However, the atmosphere is also pressing up on the bottom of the cork with 14.7 pounds. The two forces being equal and opposite, cancel each other out. The pressure indicated on the gage, which is located at the bottom of the column of water, is referred to as the "Gage Pressure." Now if the bottom of the pipe is placed in a closed tank from which all air is pumped, the 14.7 pounds due to air pressure action upward on the cork will be lost and the retaining force necessary to keep the cork in place will now be 29.4 pounds. This represents the "Absolute Pressure."

516. ACTION OF GASES UNDER VARYING CONDITIONS

(1) In addition to the properties of the gases described above, the behavior of gases is affected by varying conditions of pressure, volume, and temperature. There are several gas laws, which have been formulated and named for their originators, that

describe the action of gases under these varying conditions.

(2) Boyle's law states that at a constant temperature the volume of a gas varies inversely as the absolute pressure while the density varies directly as the pressure. That is, 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.

(3) Charles' law states that at a constant pressure the volume of a gas varies directly as the absolute temperature. That is, as the temperature increases, the volume increases and vice versa. Changes in volume and pressure of gases caused by variations in temperature are so small that they are not generally considered in connection with diving operations.

(4) Figure 23 illustrates the decreased volume and the increased density of the air in a bell as the pressure exerted by the water becomes greater—assuming no air is furnished to the bell and that it is filled with air at the surface. When the bell is lowered to 33 feet below the surface, the pressure exerted by the water becomes 14.7 p. s. i. greater than atmospheric pressure of 29.4 p. s. i. As a result, the density of the air is doubled and the volume is decreased one-half. At 66 feet the water exerts an excess pressure of 29.4 p. s. i. or an absolute pressure of 44.1 p. s. i. or three atmospheres. The density is three times as great and the volume one-third as great as it was at the surface.

(5) It is important to the diver to notice that the relative changes in pressure and the consequent changes in density and volume are greater nearer the surface. For example, in going from the surface to 33 feet, the pressure is doubled and the volume is decreased one-half. When going from 99 feet to 132 feet, the pressure is increased one-fourth and the volume is reduced one-fifth.

517. BASIC EQUATIONS

In actual diving, as the water pressure increases during descent, air at a corresponding increased pressure and volume is supplied in order to compensate for the water pressure. This is expressed in the following basic equations:

(1) $PV=KT$

P= Absolute pressure
V= Volume
T= Absolute temperature
K= A constant whose value depends on the kind of gas present.

Since most calculations of importance to diving deal with fixed quantities, we may eliminate K by expressing in ratio form

(2) $$\frac{P1V1}{T1}=\frac{P2V2}{T2}$$

For example, an air compressor has a maximum intake capacity of 20 cubic feet per minute. How much actual helmet ventilation can be delivered to a diver at 165 feet (73.5 p. s. i. gage reading)? Assume air and water temperatures are approximately equal, and pressure ample to overcome resistance at such depths

$$P1=0+14.7=14.7$$
$$V1=20$$
$$P2=73.5+14.7=88.2$$
$$T1=T2$$

substituting in equation (2)

$$\frac{14.7\times 20}{T1}=\frac{88.2\times V2}{T2}$$

$$V2=\frac{14.7\times 20\times T2}{88.2\times T1}$$

since $T1=T2$ they are cancelled and equation becomes

$$V2=\frac{14.7\times 20}{88.2}=3.33 \text{ cubic ft./min.}$$

518. KINETIC THEORY OF GASES

(1) In order to understand the behavior of gases under variations of pressure and temperature, we must consider their molecular structure. Any gas is a collection of infinitesimally small particles called molecules, which are in constant motion, bumping into one another or bounding off the walls of the containing vessel. If temperature is reduced, this motion becomes slower and fewer collisions will occur. Finally, when a certain degree of cold is reached, they become so sluggish as to tend to adhere to one another to liquefy. Still further down the scale, they "freeze together" into a solid. If absolute zero (minus 459.6° F. or 273.18° C.) could be reached, all motion would have ceased entirely.

(2) Think of a swarm of bumblebees flying around in a box and bumping against its walls at random. If we shake or heat the box, the bees will fly faster and strike its walls more often. Similarly, if we chill it, they will become sluggish and have fewer collisions. Now, each time one bumps into the side, it exerts a momentary push and if such collisions are frequent enough, they can be added up to a continuous force.

(3) This is exactly the case with molecules in a gas. The tiny impact of one collision is multiplied by billions per second on each square inch of surface into a steady and measurable pressure. Furthermore, if this same gas is squeezed into half its original space, twice as many collisions must occur in a given length of time and the observed pressure will then have been doubled. Again, if we increase the absolute temperature, the speed of each molecule will be correspondingly accelerated so that both frequency and force of impacts will increase with proportional rise of net pressure. Therefore, we see that pressure must increase with increasing temperature, and also with decreasing volume, as expressed in our preceding equation (1), $PV=KT$.

(4) In any mixture of gases each of the several gases contained in the mixture exerts its share of the

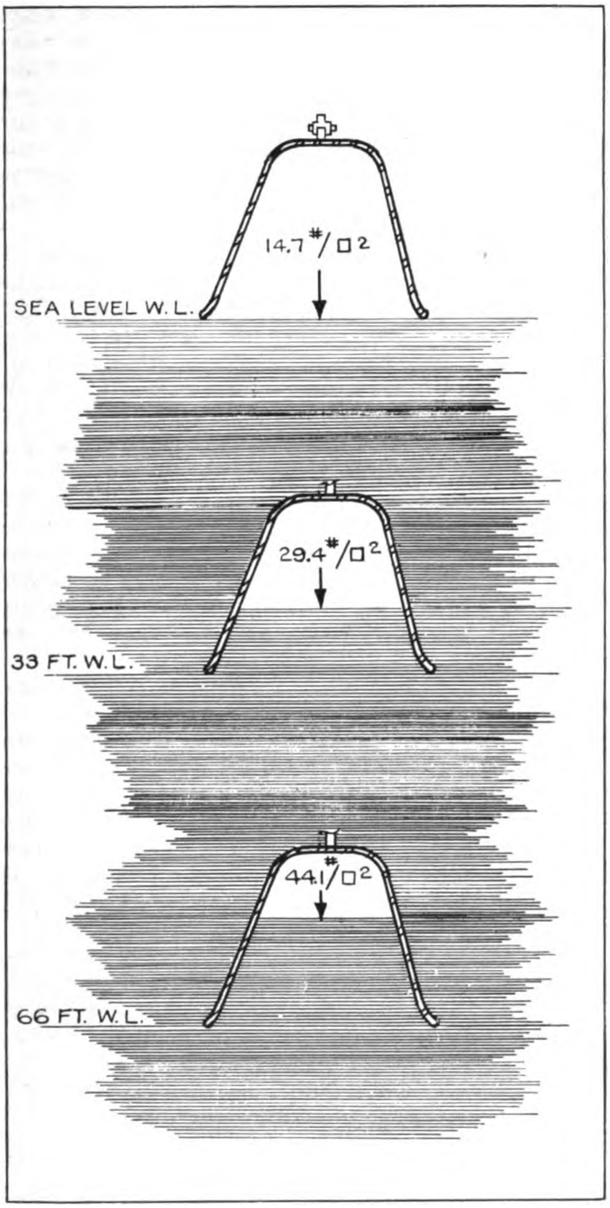

FIGURE 23.

total pressure being exerted. This law (Dalton's) states that *the total pressure exerted by a mixture of gases may be considered to be the sum of the pressures that would be exerted by each of the gases if it alone were present and occupied the total volume.* A mixture of gases may be considered to be either a combination of the partial volumes of the individual gases, each partial volume being taken at the total pressure, or as a combination of gases, each one of which occupies the entire volume at its own partial pressure. The latter consideration, however, is more definitely applicable to diving.

519. INCREASE OF TOTAL ABSOLUTE PRESSURE

As illustrated in figure 24, 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 under water, 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 one atmosphere of pressure, and the partial pressure exerted by the nitrogen is now 58.8 p. s. i. inch absolute. If we increase the total absolute pressure exerted by the 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 danger presented by a partial pressure of 2.5 atmospheres of oxygen is discussed later. It is important to notice that the almost negligibly small partial pressure of one gas in a mixture at atmospheric pressure becomes increasingly significant as the pressure of the mixture rises.

520. BASIC LAWS APPLIED TO WATER

(1) Since air is vitally important to the diver, it has been found convenient to illustrate the basic laws governing the behavior of gases by applying them to air. For the same reason, those laws governing the behavior of liquids will be generally illustrated by applying them to water.

(2) Pure water is a colorless, tasteless, transparent liquid consisting of two parts hydrogen and one part oxygen. The taste and color frequently found in water are due to the presence of substances other than hydrogen and oxygen. A major distinguishing characteristic of liquids as compared with gases is the incompressibility. As it would take many thousands of pounds per square inch to appreciably reduce the volume of water, it is assumed in the discussion on diving that it is incompressible. Besides having other values, water is an important ingredient in the tissues of animals and plants. The human body contains about 70 percent of its weight in water.

(3) For practical purposes, the weight of fresh water is considered to be 62.4 pounds per cubic foot, and the weight of sea water is considered to be about 64 pounds per cubic foot. Since water is practically incompressible, the pressure which it exerts is proportional to its depth. For example, if a tank 33 feet deep is filled with sea water, the

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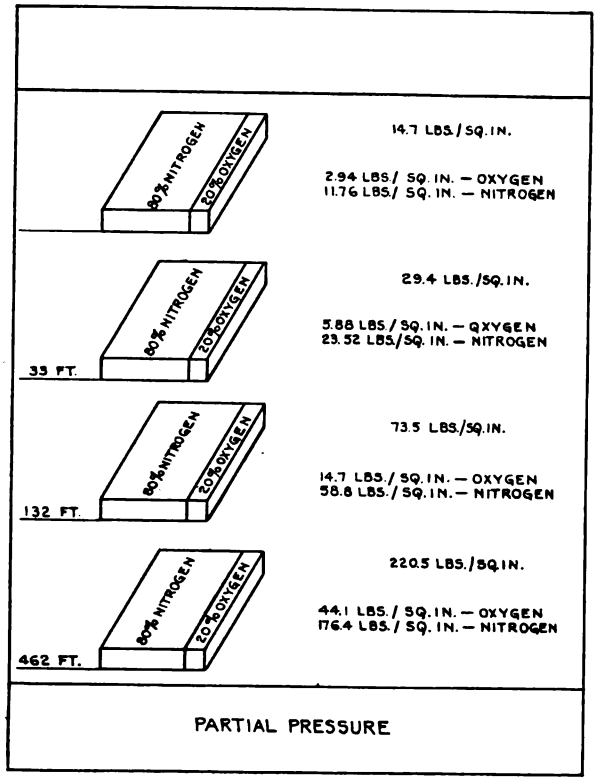


FIGURE 24.

pressure which the water exerts on the bottom will be about 2112 pounds per square foot, which is equal to 14.7 p. s. i., or one atmosphere of pressure. This is the pressure exerted by the water alone; in addition, the atmosphere above the water is exerting 14.7 p. s. i. also. The absolute pressure exerted on a body 33 feet deep in sea water is 29.4 p. s. i. Every foot in depth of sea water produces a pressure of 0.445 (or 1/33 times 14.7) p. s. i., the absolute pressure exerted on a submerged body being the pressure at that depth plus atmospheric pressure.

521. BUOYANT EFFECT OF WATER

(1) The buoyant effect of liquids is expressed by Archimedes' Principle, which states that *any object wholly or partly immersed in a liquid is buoyed by a force equal to the weight of the liquid it displaces.* For example see figure 25. If a diver, with helmet and dress weighing 384 pounds, inflates his dress so that he displaces 6.5 cubic feet of sea water, he will be buoyed by a force equal to about 32 pounds, called "positive buoyancy," for he will be displacing—(6.5 cubic feet x 64 pounds per cubic foot)—416 pounds of water (416−384=32 pounds). To overcome this positive buoyancy, weights are attached to the diver in the form of a weighted belt and weighted shoes. This gives the diver negative buoyancy. Ordinarily, only sufficient weight is added to overcome the positive buoyancy with the diving dresses moderately inflated. If the dress becomes overinflated when the diver is submerged, he acquires positive buoyancy. If this buoyancy is not reduced to the negative side, the diver is unable to remain on the bottom. In rising, the buoyancy will be increased, due to the diminished water pressure and the expansion of the air within the dress, and his speed of ascent will be accelerated. Being carried to the surface in this manner is known as "blowing up."

(2) In the opposite case, where a diver falls an appreciable distance under water, there would be a sudden increase of water pressure, the helmet escape valve would be seated, the air within the dress would be compressed and forced from it into the non-compressible helmet, the volume diminishing with the increased pressure (Boyle's law). If this volume of air does not fill the helmet and equal the pressure of water at the depth to which the diver's body has fallen, the excess pressure exerted on the diver's body will tend to drive it into the helmet. The result is most likely to be a serious injury or immediate death for the diver. Falls from shallow to deeper depths are the most serious as the relative difference in pressures is greater. This may be explained by the following:

(3) If a diver at the surface should fall from the surface to a depth of 33 feet, the volume of air in the dress would be out one-half and every square inch of his body would have 29.4 pounds of pressure absolute applied to it. As the average body has an area of about 2,500 square inches, the total force exerted on the diver's body and tending to drive him into the rigid helmet would be several tons. If a diver were to fall from 165 feet to 198 feet, the relative difference in pressure on the body would be increased by one-sixth and the relative volume of the suit would be decreased by one-seventh. From that it can be seen that falls from moderate depths to deeper depths under water are not likely to be as serious as falls from shallow depths. The effect of a fall under water is known as a "squeeze."

522. EFFECT OF PRESSURE ON GAS ABSORPTION

When water is heated, small bubbles are seen rising to the surface. These bubbles are air which was absorbed by the water at low temperatures, its liberation illustrating the fact that heating a liquid decreases its capacity for holding gases in solution. Of special importance to the diver though is the effect of pressure on gas absorption. Henry's law states that *the weight of a slightly soluble gas that dissolves in a definite weight of a liquid at a given temperature is very nearly directly proportional to the partial pressure of that gas.* That is, at two atmospheres of pressure, almost twice as much gas can be dissolved in a liquid; at three atmospheres, almost three times as much; at five atmospheres, almost five times as much; and so on. It will be easily understood then that decreasing by one-half the partial pressure of a gas absorbed in a liquid

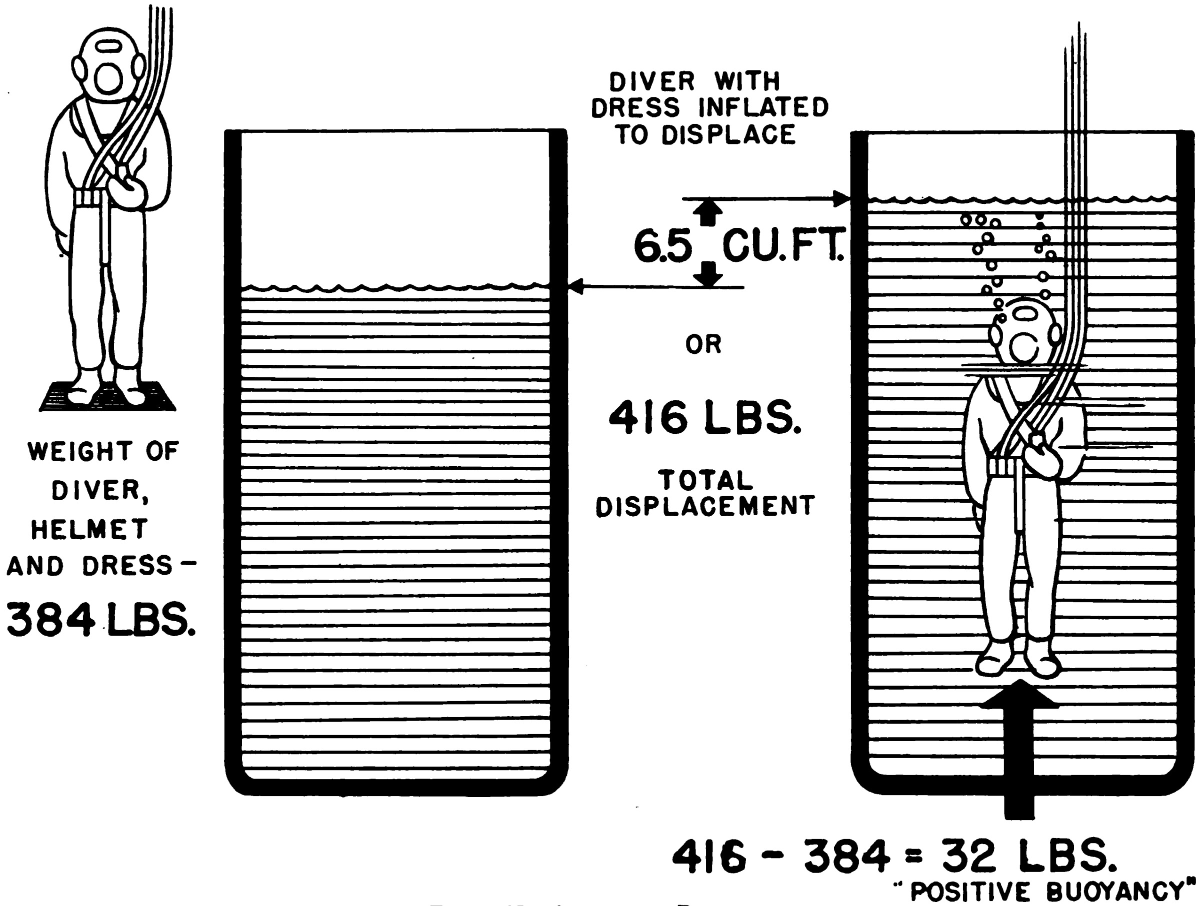


FIGURE 25.—ARCHIMEDES PRINCIPLE

will liberate one-half of that gas from the solution. For example, carbon dioxide gas is absorbed in the liquid of a carbonated drink under several atmospheres of pressure; it is liberated rapidly in the form of bubbles when the pressure is decreased by removing the cap from the bottle. The absorption by blood and body tissues of nitrogen under considerable pressure will be discussed later under "The Physiology of Diving."

B. ELEMENTARY PHYSIOLOGY OF DIVING

531. PHYSIOLOGY AS APPLIED TO DIVING

Physiology covers the study of the functions and activities of the various organs and parts of living bodies and is sometimes described as "the physics and chemistry of living matter." In order to understand the physiology concerned in diving, some knowledge of the circulatory and respiratory systems of the human body is essential. A study of certain natural air spaces within the body, such as the middle ear and sinuses, is also necessary in order to understand certain difficulties that are encountered when exposed to increased or decreased air pressures.

532. THE HEART AND THE CIRCULATORY SYSTEM

(1) The organs of the blood circulatory system are the heart, the arteries, the capillaries, and the veins. These form a closed system of tubes called *vessels* through which the blood circulates and reaches all parts of the body, with a muscular pump which propels the blood through the vessels. The *arteries* are vessels which convey blood away from the heart; the veins always return blood to the heart. A sketch of the essential component parts of the blood circulatory system is shown in figure 26.

(2) The heart is a hollow muscular organ located in the front and center of the chest cavity, between the right and left lungs, with a large part of it lying directly back of the breast bone. It is about the size of a closed fist and closely resembles a strawberry in shape. The interior of the heart is separated into right and left halves by a longitudinal muscular partition. Each half is in turn divided into an upper receiving chamber, the *auricle*, and a lower ejecting chamber, the *ventricle*. Consequently, there are four chambers in the heart. The walls of the auricles are much thinner than those of the ventricles and the wall of the left ventricle is much thicker

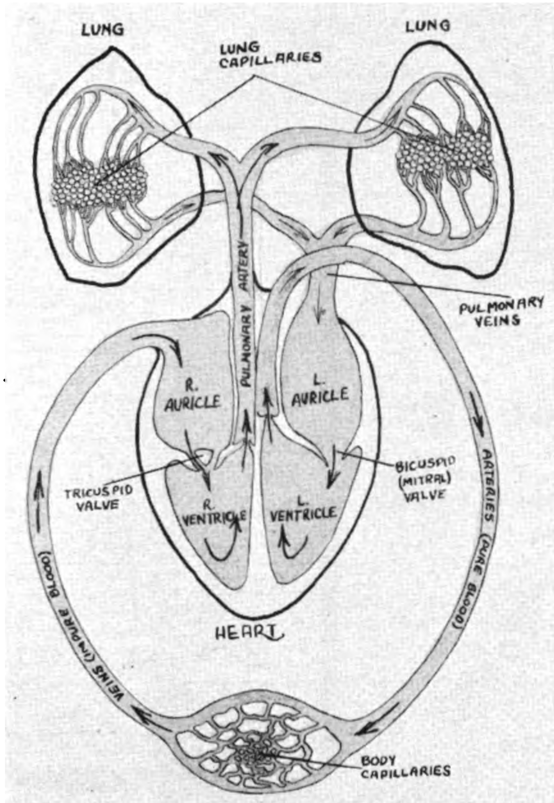


FIGURE 26.—CIRCULATION OF THE BLOOD

than that of the right. This difference in development is due to the fact that the ventricles perform a greater amount of work than the auricles, and the left ventricle performs more work than the right. A set of valves is present between each auricle and ventricle which allows blood to move freely from the former to the latter chambers and prevents a backwash when the ventricles contract. When this occurs, the blood is forced from each ventricle into its corresponding artery of exit. Another set of valves is present at the exits of each ventricle which allows free flow of blood into the artery but prevents a backwash when the ventricles again relax to receive another load of blood from the auricles. Thus the four sets of valves in the heart permit a continuous flow of blood in one direction.

(3) As can be seen from figure 26, blood from all the body tissues with its burden of carbon dioxide and lack of oxgyen is collected by the body veins which all eventually lead to the right auricle. It then enters the right ventricle and is forced into the pulmonary artery where the stream is again broken up into the fine capillary bed of the lungs. Here the venous blood gets rid of its excess carbon dioxide and takes up a fresh charge of oxygen thereby becoming arterial blood. This arterial blood is then collected by the pulmonary veins and is led into the left auricle of the heart where it flows into the left ventricle and is forcefully ejected into the main arterial trunks of the body. These arteries lead back to all tissues of the body whence the blood stream is again broken up into a fine capillary bed. Here the blood imparts its oxygen to the tissues and takes up from them another load of carbon dioxide. The cycle is thus complete. The two capillary beds (that of the lung and that of the body tissues) are the important sites that concern the exchange of gases, and their importance in diving physiology will be realized when we come to the study of saturation and desaturation of the body with inert gases.

533. THE LUNGS AND THE RESPIRATORY SYSTEM

(1) Respiration may be defined as the process of drawing air or other breathing medium into the lungs to supply oxygen and purify the blood. The utilization of oxygen by all cells of the body is necessary for the production of energy and heat and in this process, known as *metabolism,* carbon dioxide is produced. The carbon dioxide is carried off from the cells in a dissolved state by the blood of our veins and upon reaching the lungs, it diffuses out in exchange for a fresh load of oxygen.

(2) The respiratory apparatus of man consists essentially of 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 movements of respiration may be considered as accessory respiratory apparatus. The mechanism of taking fresh air into the lungs (inspiration) and expelling foul air from the lungs (expiration) is diagrammatically shown in figure 27. By elevating the ribs and lowering the diaphragm, the volume of the chest cavity is increased. According to Boyle's law, a negative pressure is thus created within the chest space and lungs. To equalize this negative pressure, fresh air automatically rushes into the lung passages and inflates the lungs. When the ribs are again lowered and the diaphragm rises to its original position, a positive pressure is created within the lungs causing the foul air to be expelled from the lung passages. In the human chest cavity, no space is present between the outer lung surfaces and the surrounding chest wall as shown for convenience in the figure. However, a potential space containing no air is present and allows the outer lung surfaces to slide over the interior surfaces of the chest wall. Should the surface of the lung be accidentally ruptured by a sudden excessive pressure inside the lungs, or, if the chest wall is perforated by some external means, air will be forced into this potential space when the chest expands and an actual air pocket will be formed between the lung and the chest wall. This condition is known as *pneumothorax* (pneumo—air/thorax—chest) and on rare occasions may occur as an accident in diving or submarine escape.

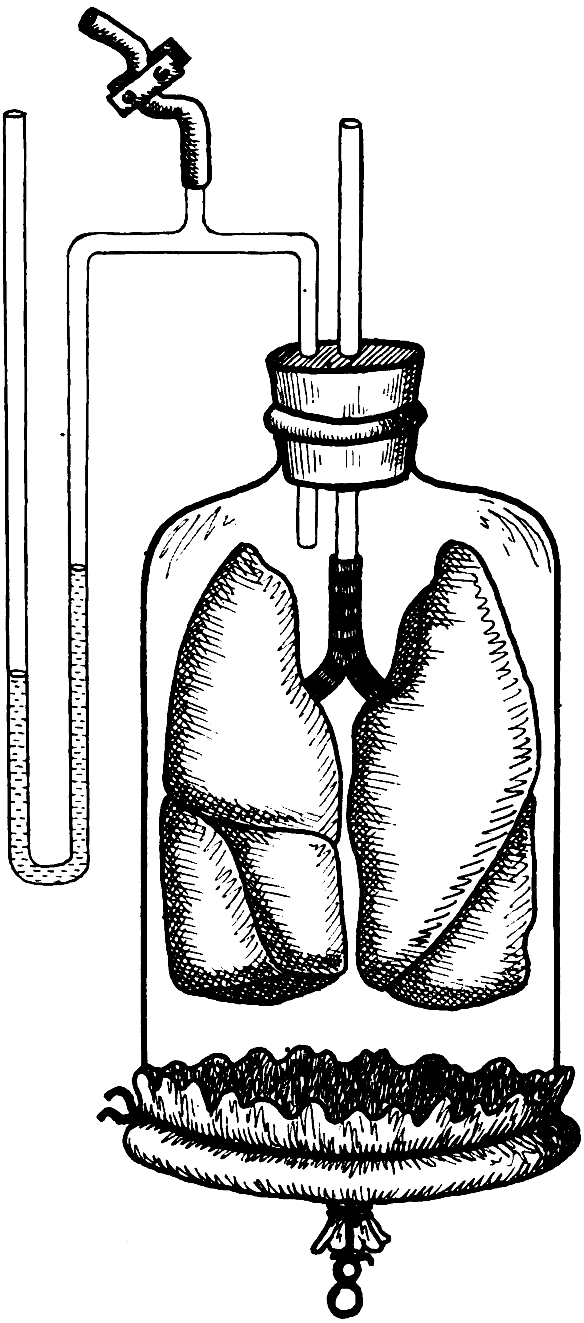


FIGURE 27.
MODEL TO DEMONSTRATE ACTION OF DIAPHRAGM. ON PULLING THE RUBBER SHEET DOWNWARD, AIR ENTERS THE LUNGS AND THEY EXPAND.

(3) The respiratory muscles which enable us to breathe normally act automatically without conscious effort of the will. Activity of these muscles produces alternate inspirations and expirations of air which, with a period of rest between movements, constitutes what is called the *cycle of respiration*. This respiratory cycle is completed about 14 to 18 times per minute in the normal adult while at rest. The lungs, when filled to their utmost capacity, hold about ten pints of air (total capacity). With normal respirations, we ordinarily breathe in and out only about one pint of air. This is called the *tidal air*. Therefore, the amount of air breathed out or in may be increased by forceful expiration and inspiration and constitutes a reserve supply when demanded by our bodies. Air that can be forcefully expired after completion of a normal expiration amounts to about two pints and is known as *supplemental air*. Air that can be forcefully inspired after completion of a normal inspiration amounts to about five pints and is known as *complemental air*. The amount of air left in the lungs after the most forceful expiration amounts to about two to three pints and is known as the *residual air*.

(4) The lungs may be compared to two elastic bags containing thousands of little distensible air sacs. These air sacs or *alveoli* can be compared to the buds of a tree. If we consider these buds to be hollow and their interiors all communicating with the air passages of the hollow branches and trunk of this "lung tree," the air that enters into the main passages of the lung gains access to the entire surface of all these alveoli. These air sacs are lined with a thin transparent membrane. Around the surface of this membrane are millions of small blood vessels—the capillary bed of the lungs previously described. Since the lining of each of these air sacs is in fact a continuous membrane with that of the main air passageways of the lung, the extent of surface area exposed to the air within the lung is tremendous. If this lining could be stripped from all 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). To compare this surface area with that of the skin of our bodies, we would find that we have about fifty times as much lung surface as we do body surface. Remembering that our capillary bed of blood vessels within the lung is situated immediately underneath this lining and that this membrane permits diffusion of gases in either direction, the facilities of the lungs for gas exchange to and from the blood passing through it are considerable.

534. PROCESS OF RESPIRATION

(1) With this anatomical background, the process of respiration can now be explained. The diffusion of gases into a liquid is governed by Henry's law and Dalton's law. Henry's law states, "With temperature constant, the quantity of gas which goes in solution of any given liquid is in direct proportion to the partial pressure of the gas." Dalton's law states,

"The pressure exerted by a gas in a mixture of gases is equal to the pressure which that quantity of gas would exert were no other gases present."

(2) The air we take into our lungs (inspired air) is a mixture of gases that exert a pressure, at sea level, of 14.7 p. s. i., which is equivalent to a pressure of 760 millimeters (mm.) of mercury (Hg). 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 moisture which in vapor form is a gas that exerts a pressure just like any other gas. The air we breathe out (expired air) has still another composition which represents a mixture of inspired and alveolar air. Table A shows the partial pressure exerted by each of the gases present in each type of air.

TABLE A.—PERCENTAGE AND PARTIAL PRESSURES OF GASES IN THE AIR OF THE LUNGS

Gas (barometer 760 mm. Hg.)	Partial pressure		
	Inspired* air	Expired air	Alveolar air
	mm. Hg.	*mm. Hg.*	*mm. Hg.*
Oxygen	156.30	116.2	101.2
Carbon dioxide	0.20	28.5	40.0
Nitrogen	588.50	568.3	571.8
Water vapor	*15.00	47.0	47.0
Total	760.00	760.0	760.0

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

(3) The composition of alveolar air remains remarkably constant during the process of normal breathing, since continuous ventilation of the lung takes place during inspiration and expiration. The blood present in the capillary bed of the lungs becomes exposed to the gas pressures of alveolar air, since they are separated only by the thin membranes of the air sacs and the capillary walls. With this exposure taking place over a tremendous surface area, it follows that the gas pressures of the blood leaving the lungs (arterial blood) are approximately equal to those present in alveolar air. In rough figures, the arterial gas pressures are 100 mm. for oxygen, 40 mm. for carbon dioxide, 47 mm. for water vapor, and 570 mm. for nitrogen. When this arterial blood passes through the other capillary bed of our bodies, i. e., the capillary network surrounding all body cells, it is exposed to and equalizes itself with the gas pressures of the tissues. It thus becomes venous blood since 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 gases, remain unchanged. Hence the partial pressures of oxygen and carbon dioxide will vary in the arterial and venous bloods as shown in table B.

TABLE B.—PARTIAL PRESSURES OF GASES DISSOLVED IN ARTERIAL AND VENOUS BLOOD

Gas	Gas tension or partial pressure	
	Arterial blood	Venous blood
	mm. Hg.	*mm. Hg.*
Oxygen	100	40
Carbon dioxide	40	46
Water vapor	47	47
Nitrogen	570	570
Total	757	703

(4) The figures shown 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, since 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 our blood. The gas exchange which takes place in the lungs is called *external respiration*, and that which takes place in the tissues is called *internal respiration*.

(5) With this physiological background, we can now understand why, on exercising, we must breathe faster and deeper. With exercise, our muscle cells demand and absorb more oxygen and produce more carbon dioxide. This increases the carbon dioxide partial pressure in our blood. Certain brain cells that control our rate of respiration become stimulated by this increase of carbon dioxide in the blood. This stimulation causes faster and deeper respirations, thereby producing better ventilation and elimination of foul air. In addition to the increased respirations, our circulation rate also increases so that more blood is brought to the lung per unit time than while at rest. Both of these factors help produce a more rapid diffusion of carbon dioxide from the blood to the alveoli of the lungs. As a result of this rapid diffusion, the arterial blood leaving the lungs contains only very little more carbon dioxide partial pressure than it did when the body was at rest. Therefore, the speed of our blood and respiratory pumps largely determine the amount or severity of exercise that our bodies can withstand.

(6) With the body at rest, about 300 cubic centimeters (cc) of oxygen is consumed each minute for sustenance of the body functions. This requires an

air supply to the lungs of about eight quarts per minute. When moderate work is performed, the body consumes about 900 cubic centimeters of oxygen per minute necessitating an air supply to the lungs of about twenty-four quarts per minute. Heavy work requires 2100 cubic centimeters of oxygen and an air supply of about forty to forty-five quarts of lung air per minute.

535. THE NATURAL AIR SPACES OF THE BODY

(1) The human body contains several natural air spaces which, because of their small entrance passageways, often cause trouble when excess air 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 28. 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. Normally, 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 symptoms of severe pain will result. If the drum continues to be subjected to this one-sided pressure, it will bulge inwardly with such

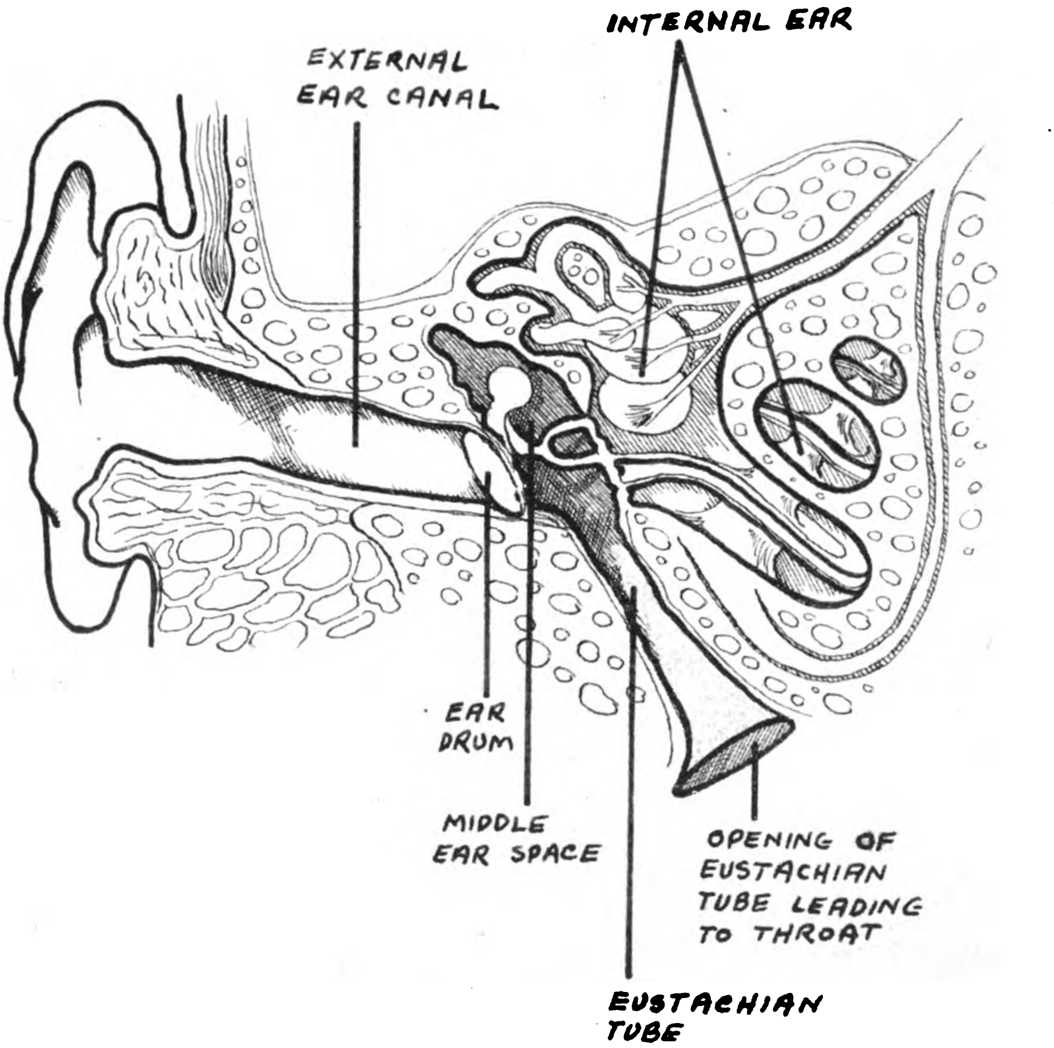


FIGURE 28.—ANATOMY OF THE EAR, SHOWING MIDDLE EAR SPACE.

force as to tear blood vessels causing hemorrhage and finally rupture. 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 by mucus can be overcome by holding the nose and lips tightly and exerting inside pressure by a forced expiration.

(3) The location of the nasal accessory sinuses are diagrammatically shown in figures 29 and 30. All sinuses are located within hollow spaces of the skull bones and are lined with the same type of membrane that covers the air passages of the nose. Their linings are in fact continuous with that of the nasal cavity so that essentially all sinuses represent small pouches containing air that sprout out from the nasal cavity and are connected with it by narrow passageways called ostia (Latin translation for "mouths"). The *frontal sinuses* are located in the forehead above the eyes just behind and between the inner half of the eyebrows. The *maxillary sinuses* are located below both eyes behind and within the cheek bones. The *ethmoidal air cells* and the *sphenoid sinus* sprout out from the roof of the nasal passage and are located deeply in the midline of the skull bones between the nasal air space and the brain space. If pressure is applied to the body and the ostia of any of these sinuses are obstructed by mucus or tissue growths, pain will be elicited in the respective areas. 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 within the sinuses by partly displacing their air spaces 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 and a return to normal pressures will bring about immediate relief as similarly occurs with 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) This chapter has dealt with the anatomy and normal physiology of the human body. Further discussion of the primary and secondary effects of increased air pressures upon the body is presented in part 5.

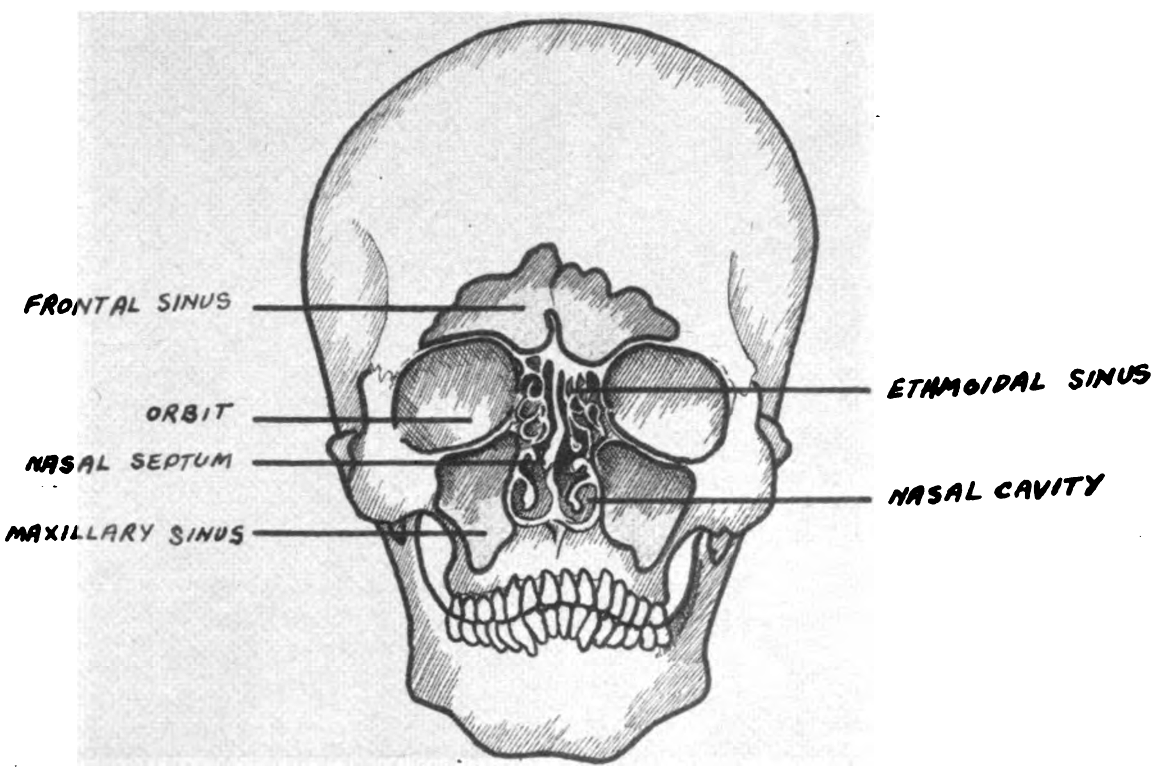


FIGURE 29.—LOCATION OF PARANASAL SINUSES (FRONT VIEW).

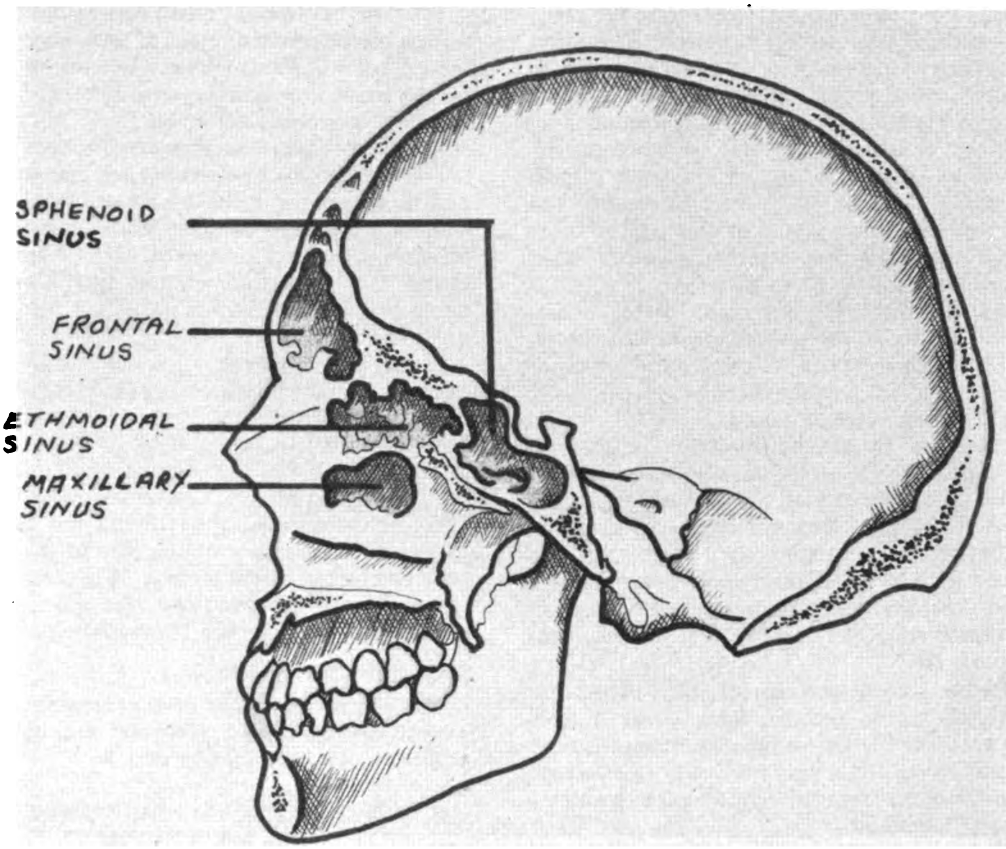


FIGURE 30.—LOCATION OF PARANASAL SINUSES (MEDIAN VIEW OF RIGHT HALF OF THE SKULL).

Part 3—Diving Equipment

A. STANDARD DIVING OUTFITS

541. DETERMINING FACTORS IN DIVING

To a considerable extent, diving has been thought of primarily in terms of depth—shallow water and deep sea. These two terms have been used so frequently that the whole subject of diving has unconsciously become divided into these two categories. Shallow-water diving has come to imply diving to less than 36 feet, and deep-sea diving meaning diving in excess of 36 feet. This distinction has led many individuals to erroneously consider depth to be the primary consideration in diving. Strictly speaking, in terms of diving where the only consideration is descending to some depth and returning to the surface, depth is the primary consideration. However, diving must be associated with accomplishing particular tasks under varying conditions. It is true that diving in excess of 250–300 feet causes a reduction in mental alertness that greatly increases the hazards of diving. However, in ordinary diving, other than diving to extreme depths, the type of work to be undertaken, location of the work, the extent of the operations, and the climatic conditions, in addition to depths, should be the determining factors in deciding upon the personnel and type of equipment to be used and the method of accomplishing the task.

542. DEEP-SEA DIVING OUTFIT

(1) The *Deep-Sea Diving Outfit* consists essentially of a helmet and dress which provides watertightness, weighted belt and shoes used for overcoming positive buoyancy gained by the volume of the helmet and inflated dress, the hose and control valve whereby air is furnished and the quantity of air required is controlled, and the nonreturn valve which is used to prevent air escaping from the dress in the event of an accidental rupturing of the air hose. (See fig. 31.)

(2) The deep-sea outfit has been used for a considerable number of years with remarkable success. In addition to all submarine rescue and salvage work undertaken in peacetime, practically all salvage work of any extent undertaken during the war was accomplished using this equipment. The outfit is designed for doing extensive rugged diving work and provides the diver with the maximum physical protection. It is intended that the deep-sea diving equipment be used for the following general types of work: Submarine salvage—initial inspection, handling rescue chamber, placing slings for pon-

toons, handling pontoons, attaching hose for blowing and venting; ship salvage—internal inspection, internal repairs, installations of large patches on ship hulls, construction of cofferdams; harbor work—where visibility is poor, working around stone walls, pilings, or where there may be sharp projections; general—diving to depths requiring decompression and working in heavy tideways. The above are merely illustrations of the type of work undertaken using the deep-sea diving outfit. They are not intended to be all-inclusive or specific. It will be noted that there are many diving operations involving the above conditions which are undertaken in shallow depths but require the use of the rugged deep-sea equipment regardless of the depth at which the work is being done.

(3) There are two deep-sea diving outfits, the No. 1, No. 2, and No. 3. The No. 1 outfit is a heavy-duty outfit and contains all the material required for two divers plus additional spares to keep the outfit in repair for approximately 1 year. The outfit is issued only to vessels and shore activities that are called upon to undertake extensive diving operations—repair ships, tenders, salvage vessels, tugs, diving boats, etc.

(4) The No. 3 outfit is a special outfit issued only to submarine rescue vessels. This outfit in conjunction with the helium-oxygen equipment is sufficient to undertake the diving necessary to effect the rescue of personnel from sunken submarines and the salvaging of a submarine.

543. SHALLOW WATER DIVING OUTFIT

The *Shallow Water Diving Outfit* consists of a face mask, hose, hand pump, nonreturn valve, and volume tank. This outfit was issued to landing craft, combat vessels, transports, etc. Due to the fact that it did not afford protection against cold water, it has been replaced by the lightweight diving outfit.

544. LIGHTWEIGHT DIVING OUTFIT

(1) The *Lightweight Diving Outfit* consists essentially of a dress, mask, hose, belt, shoes, control and nonreturn valves. The outfit is designed with view of maintaining to some extent the advantages of the skin diving attained with the shallow water outfit and eliminating the bulkiness and weight of the deep sea outfit which is due to the positive buoyancy created by the volume of the helmet and the inflated dress. This is accomplished by combining a diving dress and mask so that the air enters and exhausts direct from the mask without entering the dress, which results in the dress collapsing completely against the body. In this manner, the weight required is reduced considerably.

(2) The lightweight outfit can be used to accomplish a considerable number of jobs where the working and diving conditions are not severe and access to the work is relatively unrestricted, such as inspection, searching, clearing lines, minor external ship repairs, etc. This type of work does not require the use of the heavy deep-sea equipment but could not in many instances be accomplished with the shallow water outfit due to water and temperature conditions. The lightweight outfit can be used in either of two ways depending on the conditions—using the mask alone, or using the mask with the dress.

(3) The lightweight diving outfit contains sufficient equipment for two divers and spares to maintain the outfit in repair for a reasonable length of time. This outfit is furnished mainly to vessels—mine craft, patrol craft, auxiliaries, combatant vessels, and landing craft, whose functions are not primarily concerned with diving but may find it necessary to do minor diving jobs of the type listed above at infrequent intervals. The depth to which the outfit can be used is 60 feet which is the safe limit of the compressor furnished with the outfit.

545. COMPONENT PARTS

The component parts of the deep sea and lightweight diving outfits, with the appropriate stock numbers, can be found in part 9.

B. DESCRIPTION AND CARE OF STANDARD DIVING EQUIPMENT

551. EQUIPMENT USED IN DEEP SEA DIVING

In general, the items comprising the deep sea diving outfit can be divided into three categories: First, those items used in dressing the divers; second, the items that are used by the diver to reach his task; and, third, the auxiliary equipment to maintain the previously mentioned types of material.

552. NAVY STANDARD DIVING HELMET

(1) The *Navy Standard Diving Helmet*, figures 32 and 33, designated as the Mark V, Mod. I, consists of a spun copper helmet with fittings and breastplate. The connection between the helmet and the breastplate is made by an interrupted-screw joint. Fitted into the recess of the threaded breastplate ring is a leather helmet gasket that serves a twofold purpose of making a watertight seal between the helmet and breastplate and controlling the distance that the helmet rotates. If the helmet gasket is of proper thickness, a moderate amount of force will line up the marks on the front of the helmet and breastplate within a reasonable distance and provide the necessary seal.

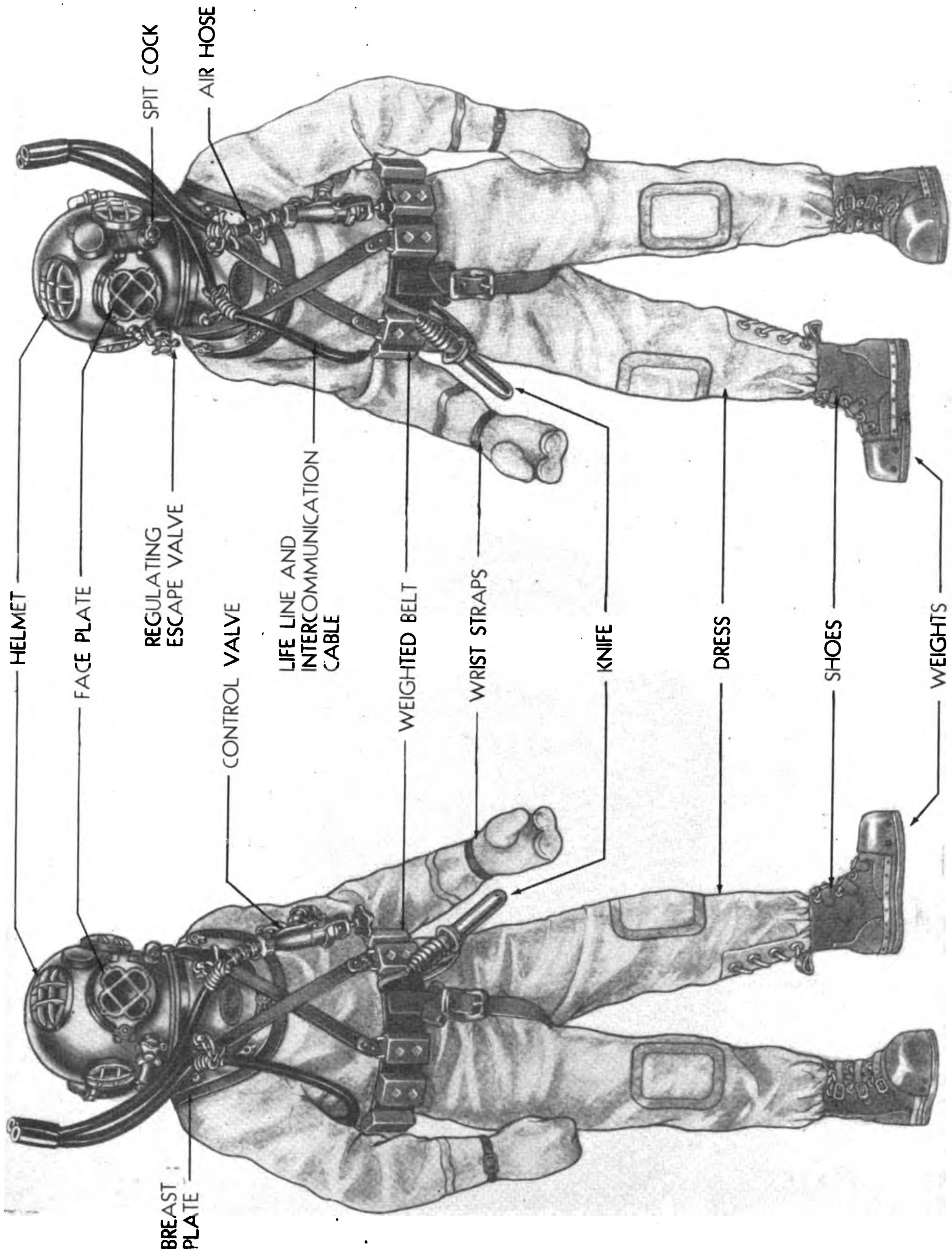

HELMET
FACE PLATE
REGULATING ESCAPE VALVE
CONTROL VALVE
LIFE LINE AND INTERCOMMUNICATION CABLE
WEIGHTED BELT
WRIST STRAPS
KNIFE
DRESS
SHOES
WEIGHTS
SPIT COCK
AIR HOSE
BREAST PLATE

Figure 31.

(2) There are a number of attachments to the helmet in order to provide the diver with necessary safety devices, sight, communication, air supply, and exhaust. In order to prevent the helmet from being accidentally disconnected from the breastplate, a safety lock, figure 33, is attached to the back of the helmet. The ball lever that is secured to the helmet fits into the safety lock recess cut in the breastplate and prevents the helmet from moving more than the length of the recess opening. To prevent the ball lever from falling out of place, there is a safety latch secured to one end of the recess. It fits over the ball lever and is secured to the other side of the recess by means of a brass split cotter pin.

(3) There are four ports on the helmet. The one directly in front of the diver's face is called the faceplate, figure 32. The faceplate is hinged and is held in a closed position by means of a swing bolt and wing nut secured to the helmet, and acting through two lugs on the faceplate. The wing nut of the bolt when screwed down fits into a countersunk recess in the two lugs of the faceplate, thereby preventing slippage or accidental displacement of the bolt from the faceplate. The joint made by the faceplate and the helmet is made watertight by a rubber gasket. The other three ports are located as follows: One on each side of the helmet, on the same level of the faceplate, to enable the diver to see laterally; and the third on the midline of the helmet above the faceplate to allow upward vision. All four ports are protected from breakage by brass guards. However, spare glasses are supplied in the event the glasses are accidentally broken.

(4) On the back of the helmet are located two goosenecks, figure 33. The one on the right side of the helmet is for attaching the safety air nonreturn valve to which in turn is secured the diver's air hose, and the one on the left side is for attaching the amplifier and life-line cable. The goosenecks are placed at an angle so that the air hose and life-line fittings will not interfere with each other when secured to the goosenecks.

553. SAFETY AIR NONRETURN VALVE

(1) The *safety air nonreturn valve*, figure 34, is one of the most important safety devices supplied the diver. Its purpose is to prevent the diver from being injured by "squeeze" in the event that his

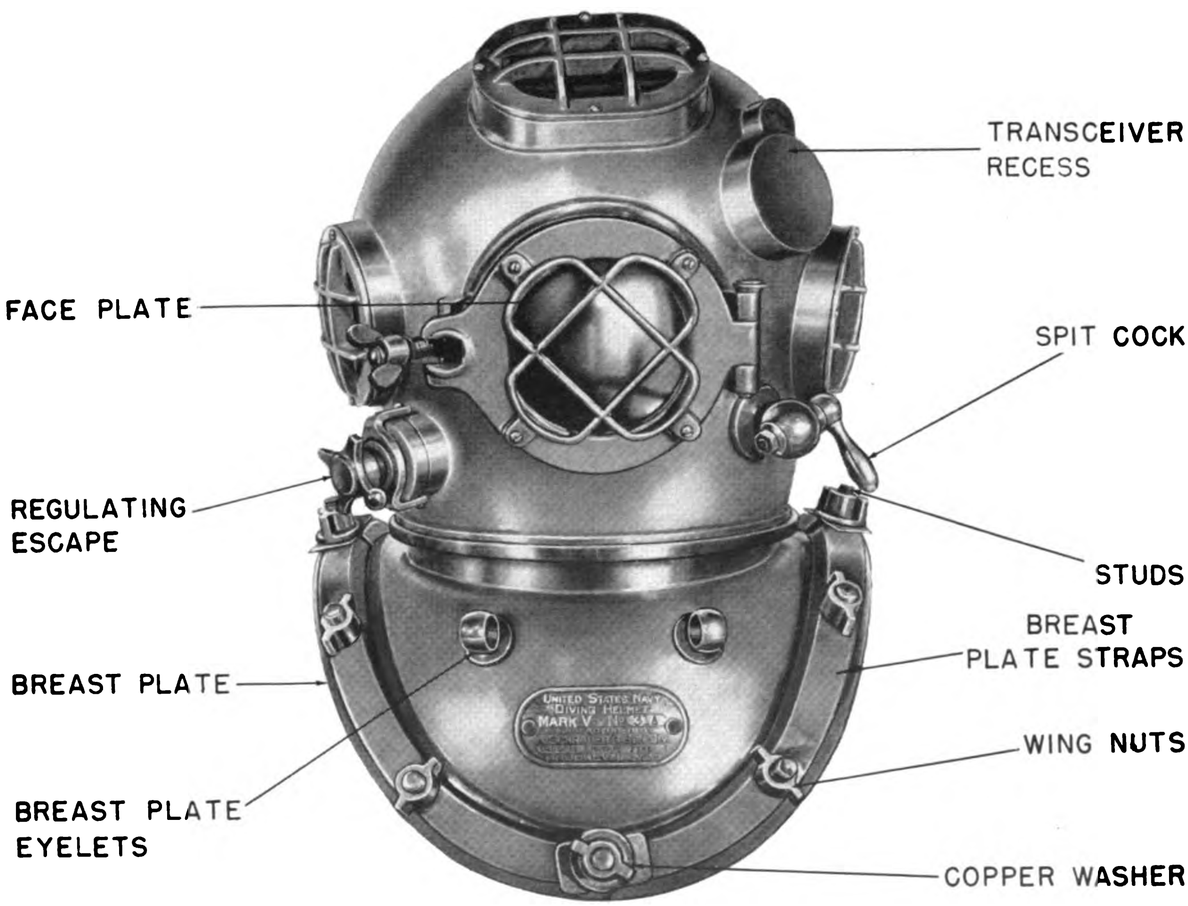


FIGURE 32.

air hose bursts, or the air-supply system becomes so seriously damaged as to fail to maintain an air pressure sufficient to counteract the external water pressure. Under either of these conditions the air pressure in the hose would fall suddenly. If the compressed air in the helmet and dress should escape through the air hose, the pressure within the helmet and dress would become less than the external water pressure. The helmet being rigid and the dress being flexible, the effect of the greater external pressure would be to squeeze the diver's body into his helmet in the same manner as a cork is forced into an empty bottle when lowered into deep water.

(2) It can readily be seen that the proper functioning of the safety (nonreturn) valve is most important, and it must always be carefully tested before a diver is permitted to descend. It should be examined frequently, disassembled, and cleaned. The leather valve-seat washer should be inspected for wear and tear, cleaned, and given a coating of neat's-foot oil. The valve spring and valve stem should also be given a light coat of oil. To test the valve after assembly, screw it in the reverse manner to the end of a length of air hose, attach the hose to the air supply, and apply pressure.

(3) In this connection, the pressure applied should be over a range beginning with one-half to three-fourths of 1 p. s. i. The lower pressures are more likely to be vital in that the higher pressure will tend to seat the valve and assist in making an airtight seal. In actual diving the internal pressure is not likely to exceed the external pressure by more than 1 p. s. i. The valve should be immersed in water to see if any bubbles of air come from it. If none appear, the valve is tight; if not tight, a new valve leather or spring, or both, should be installed and the test repeated. When screwed in place on the air connection of the helmet, the valve should be tried to see that it works freely and seats smartly on release of pressure. Verdigris sometimes causes the valve to be sluggish in its action, the spring may be weak, or the follower nut may not be screwed all the way down. The inside diameter of the gasket between the valve and gooseneck should be checked, as it is possible, by setting up tight on the valve, to spread the gasket so that its edge is forced into the air passage, thereby greatly restricting the flow of air to the diver. If these precautions are carefully observed, the safety valve can be absolutely depended upon in an emergency; if neglected, the

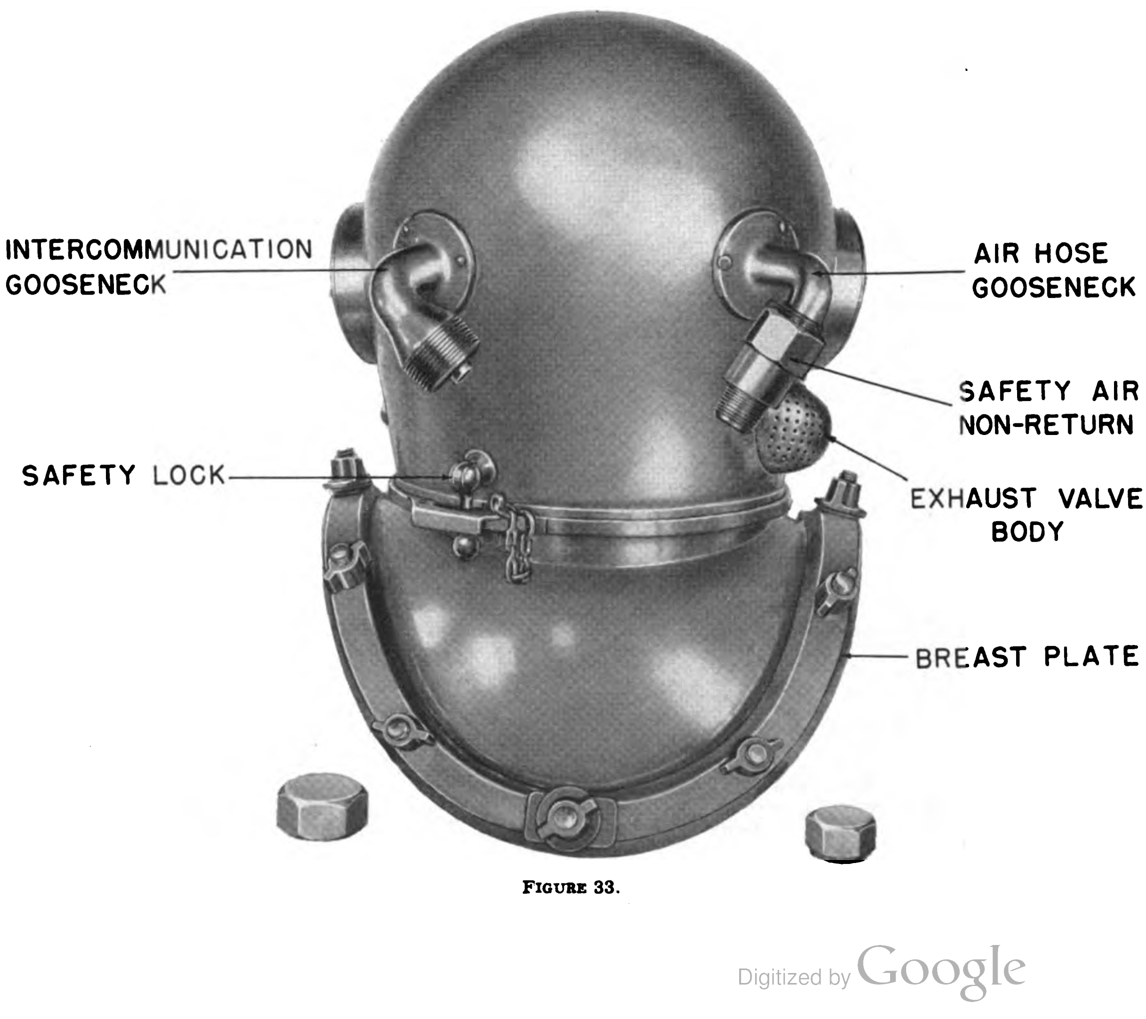


FIGURE 33.

safety valve may fail at a critical time with disastrous results.

554. AIR-REGULATING EXHAUST VALVE

(1) *The air-regulating exhaust valve,* figure 35, is located below the port along the right side of the helmet, together with the escape channel, so that the point of exhaust is toward the rear of the helmet. The position of the exhaust prevents air bubbles from passing in front of the faceplate and obstructing the diver's view. The purpose of the air-regulating exhaust valve is to maintain automatically an air pressure in the diving helmet slightly in excess of the outside water pressure and to provide a means whereby the diver can regulate the inflation of his dress and consequently his buoyancy.

(2) As the diver enters the water, the diving dress is subjected to an external pressure which tends to force the air in the dress up into the helmet and then out of the air-regulating exhaust valve. If the escape of this air is not retarded, or if the air supply is inadequate, the dress will collapse and the diver's breathing will be retarded. With a normal air supply and no means to regulate its flow properly from the helmet, too great an inflation of the dress will result and be followed by an excess of positive buoyancy.

(3) If a diver finds it necessary to provide increased buoyancy, it is accomplished by closing the air-regulating exhaust valve the necessary amount, thus allowing the dress to inflate. If the danger of overinflating becomes evident, the buoyancy is decreased by opening the valve which causes the dress to deflate. The throw of the stem, through the medium of the chin button, should be such as to permit immediate discharge of all excess air.

(4) It is obvious from the foregoing that the air-regulating exhaust valve is one of the most important features of the diving helmet. The principles of operation are as follows: The internal pressure in the diving dress is normally maintained at about one-half p. s. i. in excess of the external water pressure. As the pressure builds up in the suit, it is exerted against the stem seat (*H*), which is closed against the air pressure by the primary spring (*K*). When the internal pressure is one-half p. s. i. in excess of the external pressure, the valve stem is unseated, allowing air to escape. The valve stem continues to move forward, increasing the exhaust opening until the valve stem adjusting sleeve (*J*) comes in contact with the secondary spring follower

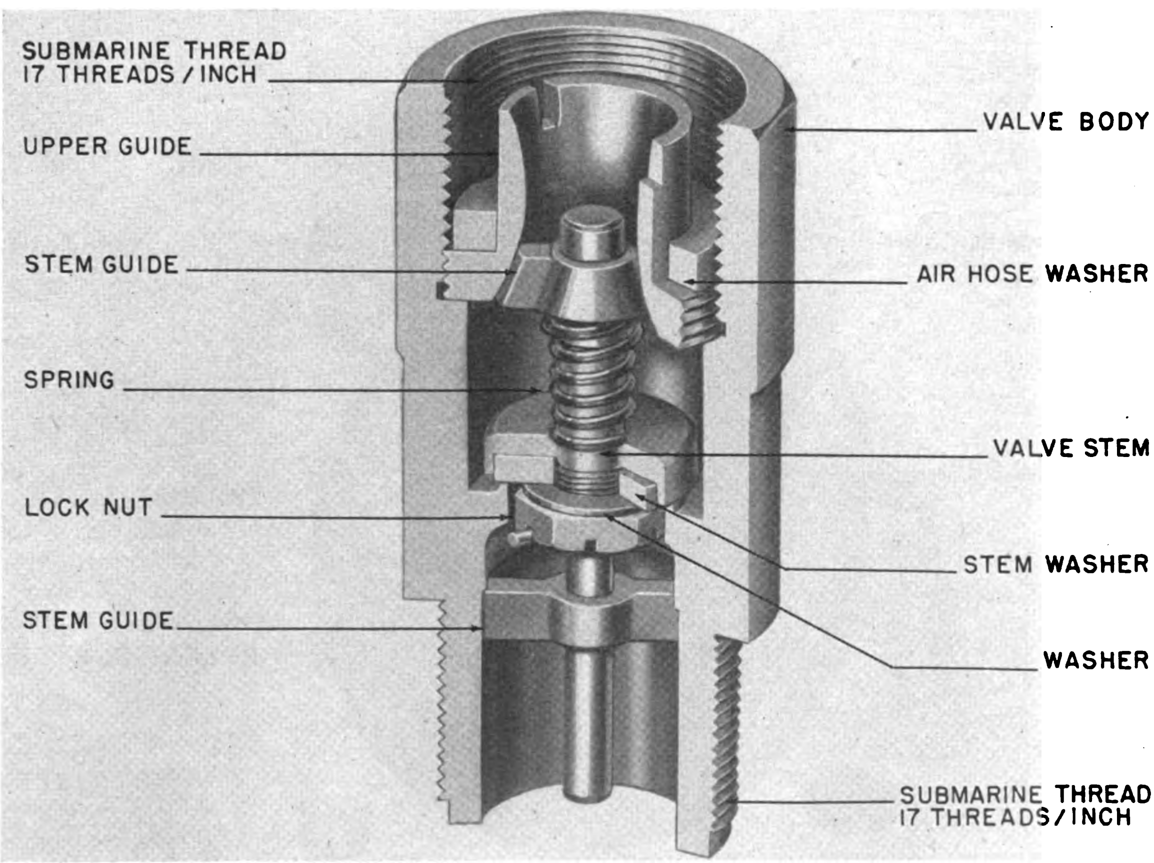
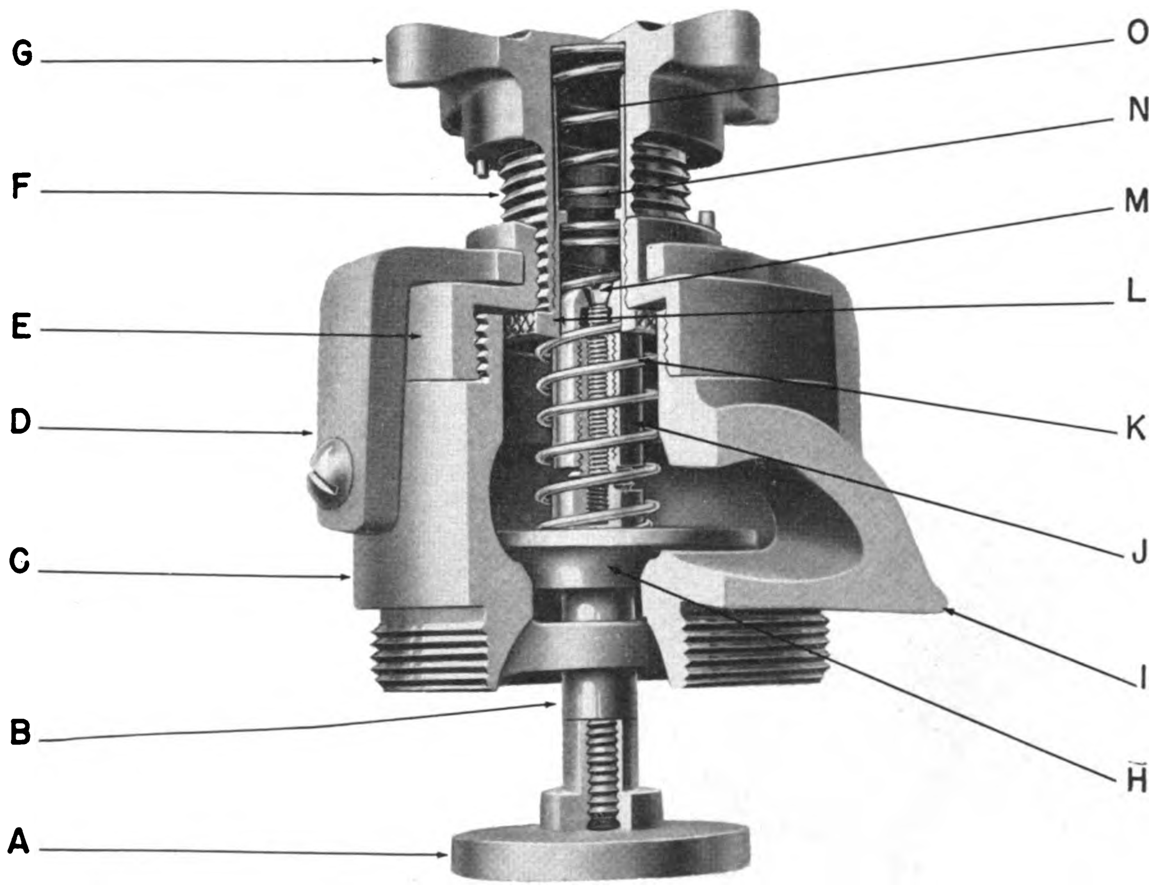


FIGURE 34.

(*N*), one end of which fits into the secondary spring (*O*). This secondary spring is designed and constructed to maintain 2 p. s. i. internal pressure over the external pressure when the valve is fully closed, a condition which exists when the regulating screw (*F*) is screwed until the follower disk (*N*) bears directly against the valve stem adjusting sleeve.

(5) The exhaust opening desired is obtained by regulating the distance that the valve stem travels before coming in contact with the secondary valve spring. This distance is controlled by the valve stem adjusting sleeve (*J*) that screws on the valve stem (*B*) and its longitudinal travels in either direction to give the desired setting for length. When the proper setting is obtained, the sleeve is locked in place by the setscrew (*M*) which screws into a threaded hole in the end of the valve stem. The initial setting should be made so that the secondary valve spring follower disk (*N*) comes in contact with the sleeve when the adjusting wheel (*G*) is about one-eighth of a turn short of the fully closed position. The diver then is able to produce any desired air flow by manipulation of the handwheel. Regardless of the setting, it is always possible to obtain full opening immediately by manually depressing the chin button (*A*) because after the one-half p. s. i. spring is compressed until the setscrew (*M*) brings it up against the disk (*N*), the longitudinal motion of the valve stem may be continued to the maximum degree of travel by compressing the secondary spring (*O*). When the valve is fully opened, the shoulder on the under side of the chin



A - CHIN BUTTON
B - VALVE STEM
C - VALVE BODY
D - BONNET GUARD
E - BONNET
F - ADJUSTING SCREW
G - ADJUSTING HAND WHEEL
H - STEM VALVE DISC
I - AIR ESCAPE CHANNEL
J - ADJUSTING SLEEVE
K - PRIMARY VALVE SPRING
L - RETAINER RING
M - ADJUSTING SLEEVE SET SCREW
N - SECONDARY SPRING FOLLOWER DISC.
O - SECONDARY SPRING

FIGURE 35.

button strikes the valve stem guide and this prevents the chin button from partly closing off the air passage, with consequent restriction of the air flow.

(6) The regulating screw (*F*) is provided with a handwheel (*G*) of improved design which permits a diver who is wearing gloves to grasp it more easily and to estimate the degree of turn more readily than with wheels of conventional type. A dowel pin on the underside of the handwheel strikes against another dowel pin on the bonnet (*E*) when the valve is in the fully closed position and thus prevents the wheel from continuing its travel until it becomes jammed against the bonnet. The bonnet guard (*D*) prevents the bonnet from backing off the exhaust valve body (*C*).

(7) The air-regulating exhaust valve should be inspected frequently to insure that it is clean and lightly oiled, that the exhaust tube is clean, and that the valve seat is tight. The primary spring should be activated when the pressure on the seat exceeds the outside pressure by one-half p. s. i. and the secondary spring should be activated when the internal pressure exceeds external pressure by 2 p. s. i. A failure of the air-regulating exhaust valve might result in "blowing up" of the diver.

555. OTHER ATTACHMENTS TO HELMET

(1) Directly opposite the regulating exhaust valve is a supplementary relief valve called the "Spit Cock," figure 32. The valve is operated by means of a lever-type handle and when used in conjunction with the regulating exhaust valve, permits a fine adjustment of the diver's buoyancy.

(2) On the inside of the helmet an air channel is sweated to the top of the helmet, with branches leading to and terminating just over the top and side windows to deflect incoming air away from the diver's head and over the window glasses.

(3) The necessary screw, bolts, and clips are located inside the helmet for securing the diver's reproducer and to hold the electrical wires in place.

556. BREASTPLATE

The breastplate, figure 36, is shaped so that it fits comfortably over the shoulders, chest, and back. The neck portion of the breastplate has a threaded ring that screws into the ring on the helmet. Around the edge of the breastplate is soldered a heavy shoulder collar through which are secured 12 equally spaced studs that fit into the holes that are molded into the diving dress gasket. A watertight seal is made by placing the dress gasket over the studs and then placing four removable breastplate straps over the dress gasket. Copper washers are placed under the removable breastplate straps at the junction to assist in making a seal at these points. The breastplate straps are then clamped in place by wing nuts, large wing nuts being

FIGURE 36.

used at the junction of the breastplate strap. On the left side of the breastplate is one long stud used for securing the link of the air control valve. The two eyelets on the front of the breastplate are used for securing the life line and air hose.

557. FACEPLATE

The *welding faceplate,* figure 37, consists of a metal frame with an open section for inserting the welding lens, and is attached to the helmet by means of the helmet faceplate hinge bolt. The diving helmet has spring clips for holding the welding faceplate in an open or closed position.

558. WELDING LENSES

The *welding lenses* are furnished in three shades, No. 4, No. 6, and No. 8. The shade number signifies the visible rays transmitted through the lens—the amount of light transmitted through the lens decreases as the shade number increases. The lens that are to be used for an underwater welding job will depend on the turbid conditions of the water. In muddy water the No. 4 should be used and, as the water becomes clearer, the No. 6 or No. 8 lenses should be used.

559. MAINTENANCE OF HELMET

(1) After use the helmet should be wiped over inside and out with a dry cloth to prevent any accumulation of moisture. If the helmet is not to be used for some time, it should be stowed in the helmet chest. When the helmet is used frequently, it is recommended that a permanent rack with an electric light bulb that fits inside the helmet be made for holding the helmet. This will assist in keeping the helmet dry and keep the diver's reproducer in good working condition.

(2) Inspect the gooseneck washers and see that the telephone connections are made watertight. Any time the air hose or life line and telephone cable are not attached to the helmet, the blank caps should be screwed on the goosenecks to protect

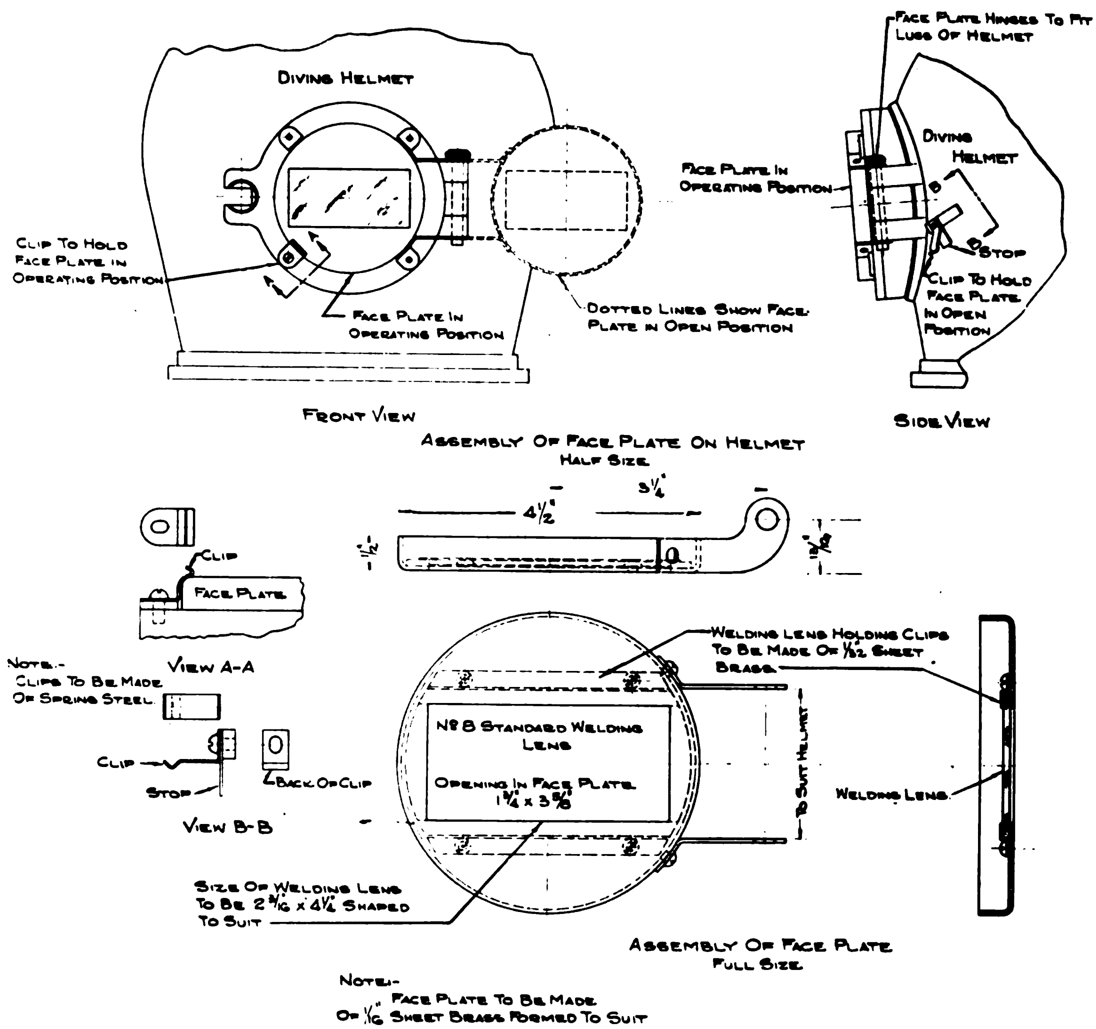


FIGURE 37.

the threads. Examine the faceplate hinge, hinge pin, rubber gasket, and wing nut for possible defects. See that the helmet and screw ring threads are free of all burrs and other defects.

(3) Inspect the breastplate stud for defects and tightness and see that the nuts turn freely on them. Special care should be taken to see that the breastplate straps do not become bent or injured, thus saving an endless amount of trouble in making a tight joint at the junction of the diving dress and breastplate. The straps should be put in place and the wing nuts lightly screwed onto the studs to prevent damage to the threads.

(4) Check the leather helmet gasket to see that it seats evenly all around, and see that it is treated with neat's-foot oil occasionally. If, as a result of wear, the helmet when screwed onto its breastplate will turn so far that the safety lock at the back is past its recess, and the faceplate is not directly in front of the diver's face, one or more paper washers should be cut and inserted under the helmet gasket on the breastplate, or a new gasket should be fitted. See that all metal parts are free from verdigris and corrosion.

560. DIVING DRESS

(1) The *diving dress*, figure 38, is so constructed that it encloses the entire body with the exception of the head and hands, and when used in conjunction with the diving helmet and gloves, provides the diver with a complete watertight covering. The dress is made of vulcanized sheet rubber between layers of cotton twill. Around the neck of the dress is fitted a heavy rubber gasket through which reinforced holes are molded to fit the studs of the helmet breastplate. On the inside of the dress around the neck is a fitted dress fabric called the bib. The bib is in the form of a cylinder that fits loosely and comes up well around the diver's neck and serves to trap any water that may enter the helmet through the valves.

(2) In order to prevent an accumulation of air in the lower portion of the dress, flaps for lacing are provided over the rear portion of both legs of the dress. The lacing of the lower part of the dress lessens the danger of accidental "blow-up" and risks incident to capsizing. A diver should not be put into the water unless the flaps are snugly laced.

(3) Navy diving dresses are designed especially to fit the Mark V, Mod. I helmet and are furnished in three sizes: No. 1, small; No. 2, medium; and No. 3, large. The No. 1 dress is designed to fit divers 5 feet 7 inches to 5 feet 9 inches tall; the No. 2 dress for divers 5 feet 9 inches to 5 feet 11 inches tall; the No. 3 dress is for divers 5 feet 11 inches to 6 feet 2 inches tall.

(4) In order to lengthen the life of the diving dress, chafing patches have been cemented to the dress at the points which are most likely to be subjected to the greatest amount of wear—elbow, knees, crotch, and toe. Repair cloth of rubberized twill is furnished for making any repairs to the dress. In order to patch a diving dress:

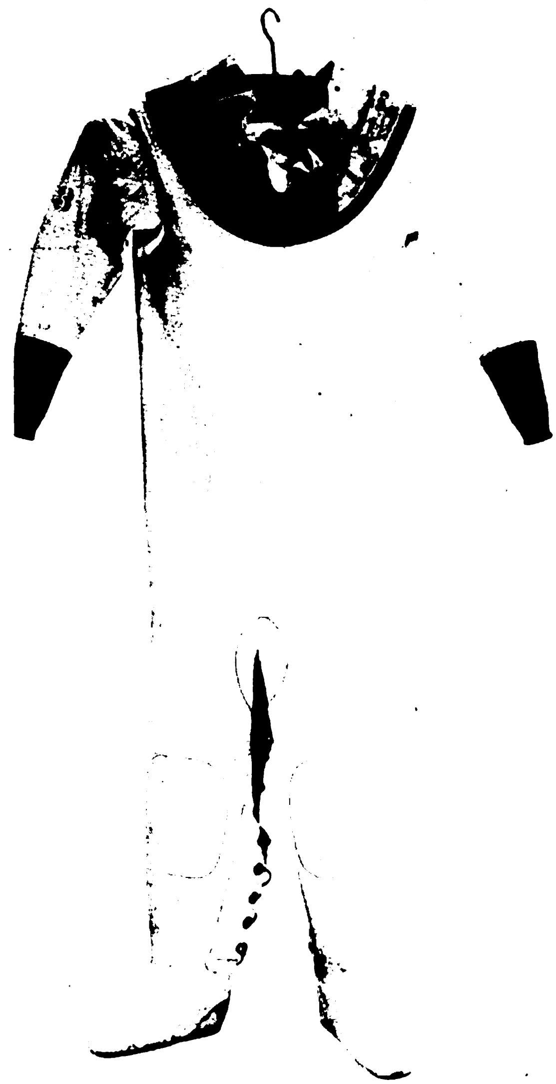


FIGURE 38.

(*a*) Remove loose fabric or other material and old cement from the dress with benzine, gasoline, or carbon tetrachloride.

(*b*) Roughen the area with sandpaper and clean with one of the above-named cleaning fluids.

(*c*) Cut a piece of patching cloth of the desired size and shape, rounding all corners.

(*d*) Strip protective cloth from patch and clamp it flat to a board with the heads of thumb tacks so that the tacks do not pierce the patch.

(*e*) Apply a least three coats of rubber cement to both the dress and patch, allowing each coat to dry until it is tacky, approximately 45 minutes, before applying the succeeding coat. The cement should be applied with a brush.

(*f*) When the last coat of cement is dry enough, lay the patch on the dress and press down firmly or tap with a wooden mallet, working from center to edge, to remove all air bubbles and wrinkles.

(*g*) If any part of the edge of the patch does not adhere thoroughly and is inclined to curl, trim loose parts with sharp scissors.

(*h*) Do not use the dress, if possible, for 24 hours.

Tears in the collars of diving dresses are usually confined to the vicinity of the stud bolt holes. Tears should be sewed together with herringbone stitches, the needle holes filled with cement and allowed to dry, after which a patch should be cemented around the damaged hole on each side of the collar.

(5) After using the diving dress, it should be washed inside and out with clean fresh water. Turn the dress inside out and hang in the shade to dry and then turn it right side out; repair the dress if necessary. An easy and efficient mode of drying the dress is to take two wooden battens about 8 feet long and secure them together, and place them inside the dress. Pass another straight piece of wood through the arms so they are extended. The dress should be thoroughly dry inside and out before storing; otherwise it will mildew and rot. The dress should not be folded during storage but should be hung on a hanger or left on the wooden batten.

561. RUBBER CUFFS

(1) In order to enclose the hands or make a watertight seal at the wrist, either divers-tenders gloves or rubber cuffs can be used, depending on the water temperature and type of work to be undertaken.

(2) The rubber cuffs, figure 39, are used where conditions are such that it is desirable and feasible to have the hands exposed. The cuff is designed so that one end is equal to the diameter of the lower part of the dress sleeve, and the other end is about equal to the size of the average diver's wrist. In the case of divers having large wrists the cuff will interfere with circulation of blood to the hands. In such cases the remedy is to cut a little off the small ends of the cuffs until a comfortable fit is obtained. If the wrist end of the cuff is too large, a piece of elastic tubing is used to make a watertight seal between the diver's wrist and the cuff. The elastic tubing is made of pure rubber with an inside diameter of 1½ inches and is furnished in 3-foot lengths. The length of tubing used is generally between 1 to 2 inches. However, the length will depend on the individual diver's preference.

(3) The following method of attaching the cuff to the dress is recommended:

(*a*) Make a tapered wooden plug, figure 40, that will fit tightly into the sleeve of the dress and extend past the sleeve edge about 4 inches.

(*b*) Roughen the outside of the sleeve edge about 3 inches from the edge with sandpaper.

(*c*) Turn the sleeve edge of the cuff back about 2½ inches and roughen.

(*d*) Slip the cuff over the small end of the wooden plug until it touches the sleeve edge.

(*e*) Apply at least three coats of rubber cement to the sleeve and turned back portion of the cuff, allowing each coat to dry until it is tacky, approximately 45 minutes, before applying the succeeding coats.

(*f*) Roll the turned back part of the cuff up over the sleeve and press down firmly.

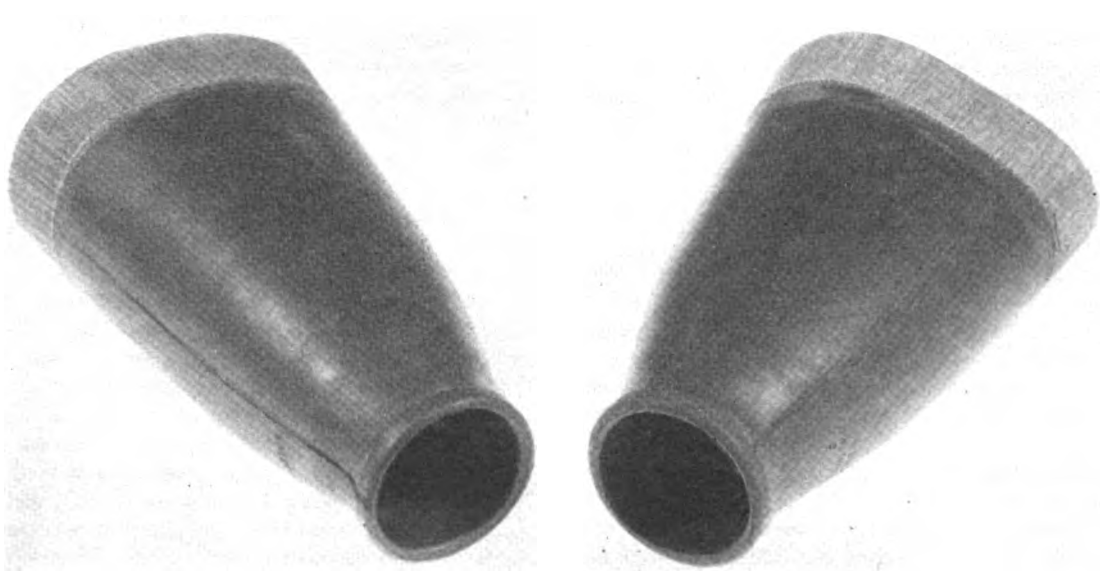


FIGURE 39.

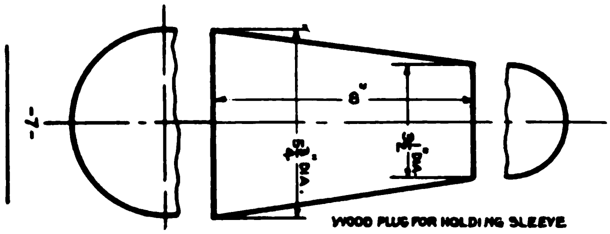


FIGURE 40.

(*g*) Cut two curved strips of patching cloth in accordance with figure 41 (*a*). Roughen with sand paper and apply three coats of cement in the same manner as the cuff and dress.

(*h*) Apply one strip evenly over the joint between the cuff and the sleeve.

(*i*) Turn the dress sleeve inside out and apply a strip between the cuff and the sleeve joint.

(*j*) The dress should not be used for 24 hours, if possible, to permit the rubber cement to dry thoroughly.

562. DIVERS-TENDERS GLOVES

(1) *The gloves* shown on figure 42 used by both divers and divers' tenders are generally referred to as divers-tenders gloves. The gloves are intended for use in cold water or where the type of work to be done is likely to injure the hands.

(2) The divers-tenders glove is a three-fingered glove molded in a semiclosed position so that there will be no strain on the diver's hand when holding a tool. The palm of the glove is shaped so that it still conforms to the shape of the diver's palm when the hand is closed. The arms of the dress with the gloves attached are not adjustable and, because of this, some divers have difficulty keeping the hands all the way in the gloves. In order to overcome this condition, wrist straps, figure 43, made of chrome-tanned leather are furnished.

(3) In order to attach the divers-tenders gloves to the diving dress:

(*a*) Insert the wooden plug, figure 40, into the sleeve of the dress.

(*b*) Loosen the lower part of the elbow patches and fold back.

(*c*) Cut 1 inch off the top (gauntlet) of the glove for attaching to a No. 3 dress; cut 2 inches off for attaching to a No. 2 dress; and 3 inches for attaching to a No. 1 dress.

(*d*) Turn 2 or 3 inches of glove gauntlet back and place glove over the sleeve plug until it touches sleeve.

(*e*) Cut two strips of patching cloth as indicated on figure 41 (*a*).

(*f*) Prepare the surfaces of dress sleeve, gauntlet, and strip of patching cloth as indicated in the sections on dresses and cuffs.

(*g*) Have the glove thumb line up with the dress sleeve so that the glove will hang in the natural position of the diver's hand.

(*h*) Roll the turned back section of the glove in place over the prepared section of the dress.

(*i*) Place the patching strip in place.

(*j*) If time permits, allow the cement to dry for 24 hours.

(4) The repair of the glove is made similar to the method of repairing the diving dress: Remove work fabric from glove and roughen with sandpaper. Cut patches for the glove according to the patterns shown on figure 41 (*b*), (*c*), (*d*). Prepare the patches and glove at the same time. When both are ready, have an assistant put on the glove and half close his hand to conform to the natural curvature of the glove. The thumb patch, figure 41 (*d*), is then applied, with care being taken to smooth out all wrinkles. Palm patches, figure 41 (*b*), (*c*), if necessary are next applied, and the wrinkles smoothed out along the entire surface of the patch. Clip off rough edges of the patches and remove glove. The glove should be allowed to set if possible for 24–48 hours. Before storing, the gloves should be washed with clean water and allowed to dry thoroughly.

563. HELMET CUSHION

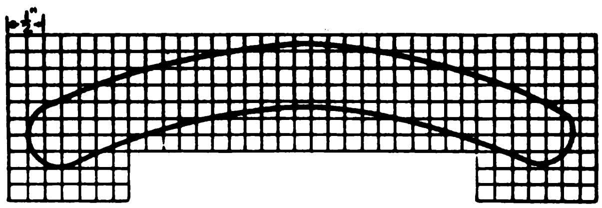
The *helmet cushion*, figure 44, is worn around the neck under the dress to prevent the helmet and weighted belt from bearing directly on the diver's shoulders when he is out of the water. The cushion is made of canvas padded with hair felt. The cushion should be thoroughly dry before stowing.

564. OVERALLS

The *trousers* (overalls), figure 45, are made of light canvas and are used to protect the diving dress against wear and chafe. The overalls are secured to the diver by means of cord which is run through the top of the trousers. After use, the trousers should be washed with clean water and allowed to dry thoroughly before storing them.

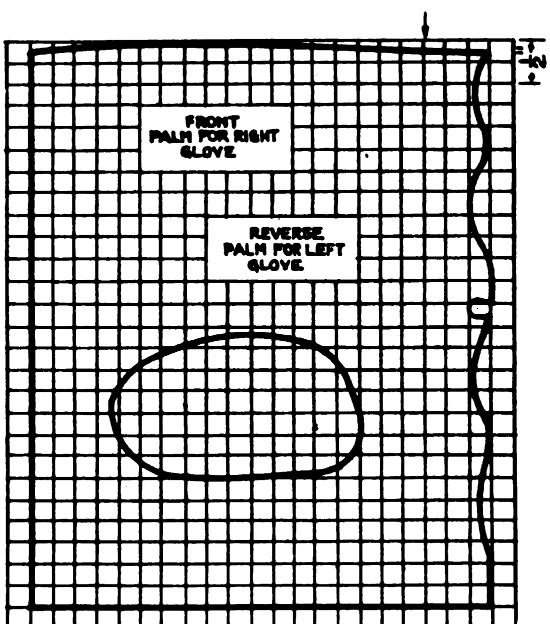
565. UNDERWEAR

(1) The diver's *underwear*, figure 46, consisting of undershirts, drawers, socks, and gloves, is made of 100 percent pure wool and provides, together with the diving dress, protection against the cold water. Frequently the underwear will be worn over the ordinary working clothes, or several sets of underwear will be worn depending on the temperature and the individual diver's preference. At least one set of underclothing should be worn to prevent the body from being chafed or bruised from the diving dress. It has been found that when the diver is working moderately hard, one set of underwear will, under average conditions, provide the necessary insulation and warmth. Under more extreme conditions of cold, two sets of underwear will be satisfactory.



PATTERN, STRIP FOR SECURING GLOVE OR CUFF TO SLEEVE

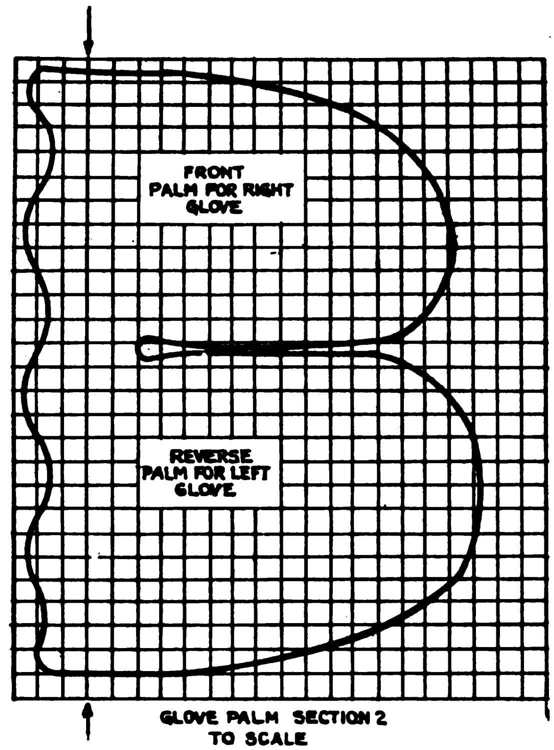
(a)



GLOVE PALM SECTION 1. TO SCALE

SECOND FORM OF GLOVES WITH HAND SLIGHTLY CUPPED

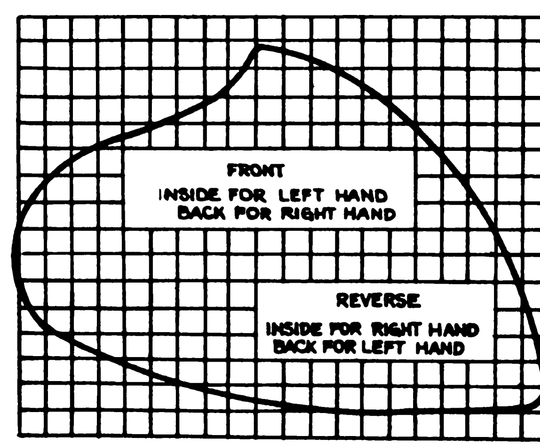
(b)



GLOVE PALM SECTION 2

TO SCALE

(c)



PATCH FOR GLOVE THUMB

TO SCALE

(d)

FIGURE 41.

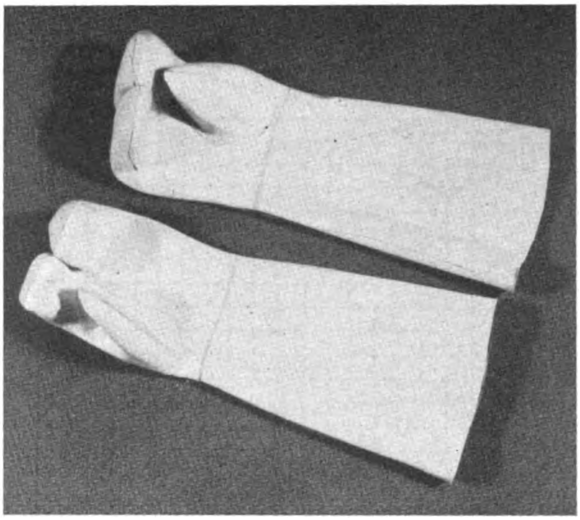


FIGURE 42.

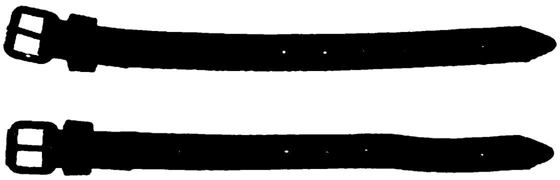


FIGURE 43.

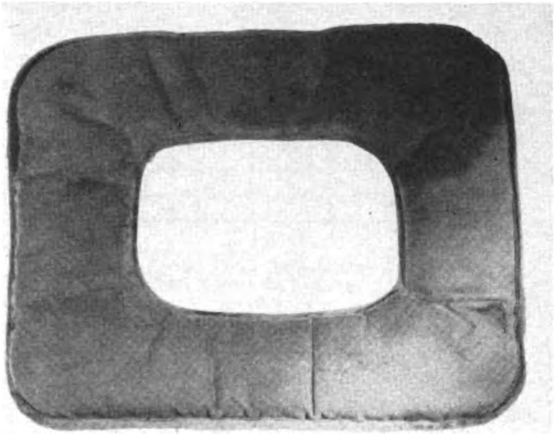


FIGURE 44.

(2) The underdrawers are furnished in sizes 36, 38, and 40, and the undershirts in sizes 38, 42, and 44. The gloves and socks are furnished in medium sizes. In addition, size 42 and 44 underdrawers and size 36 and 40 undershirts are stocked in limited quantities. The underwear should be washed and allowed to dry thoroughly before storing. As woolens will stretch under their own weight when wet, they should not be hung on a line but should be laid on a flat surface for drying. When not in use, the woolens should be stowed in larvicide, such as naphthalene, and kept tightly wrapped in paper.

566. BELT

(1) *The weighted belt,* figure 47, provides the necessary negative buoyancy to overcome the positive buoyancy of the helmet and diving dress when it is moderately inflated. The weight of the complete belt is approximately 84 pounds. However, the weight can be varied as desired by adding or removing the individual 7½-pound lead weights. Metal strap fittings are cast in four of the weights and are set at angles to give the proper lead to the shoulder strap which passes over the helmet breast-

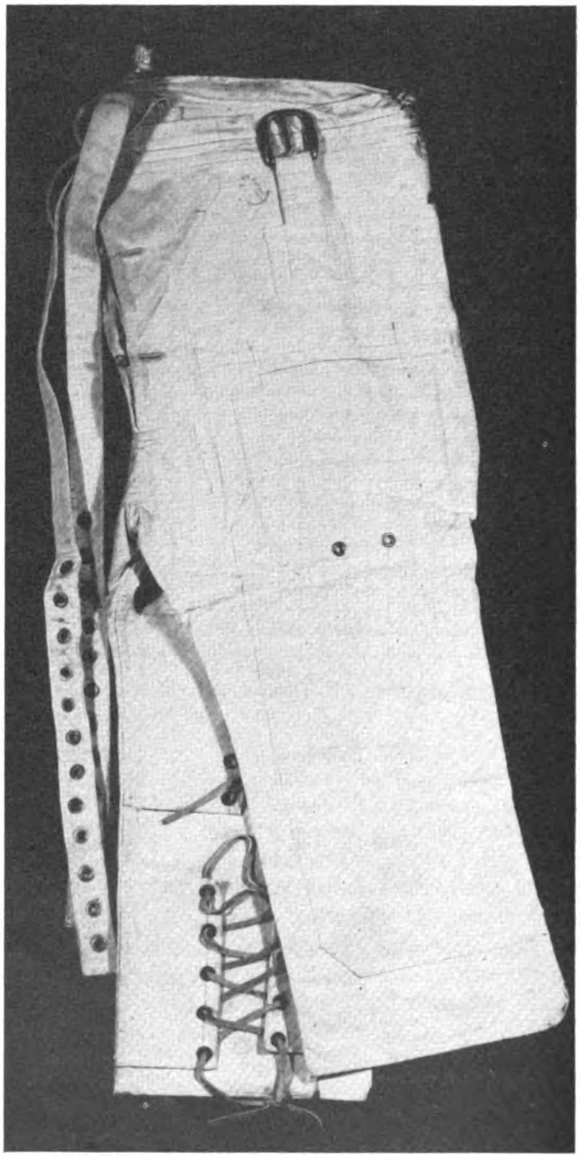


FIGURE 45.

FIGURE 46.

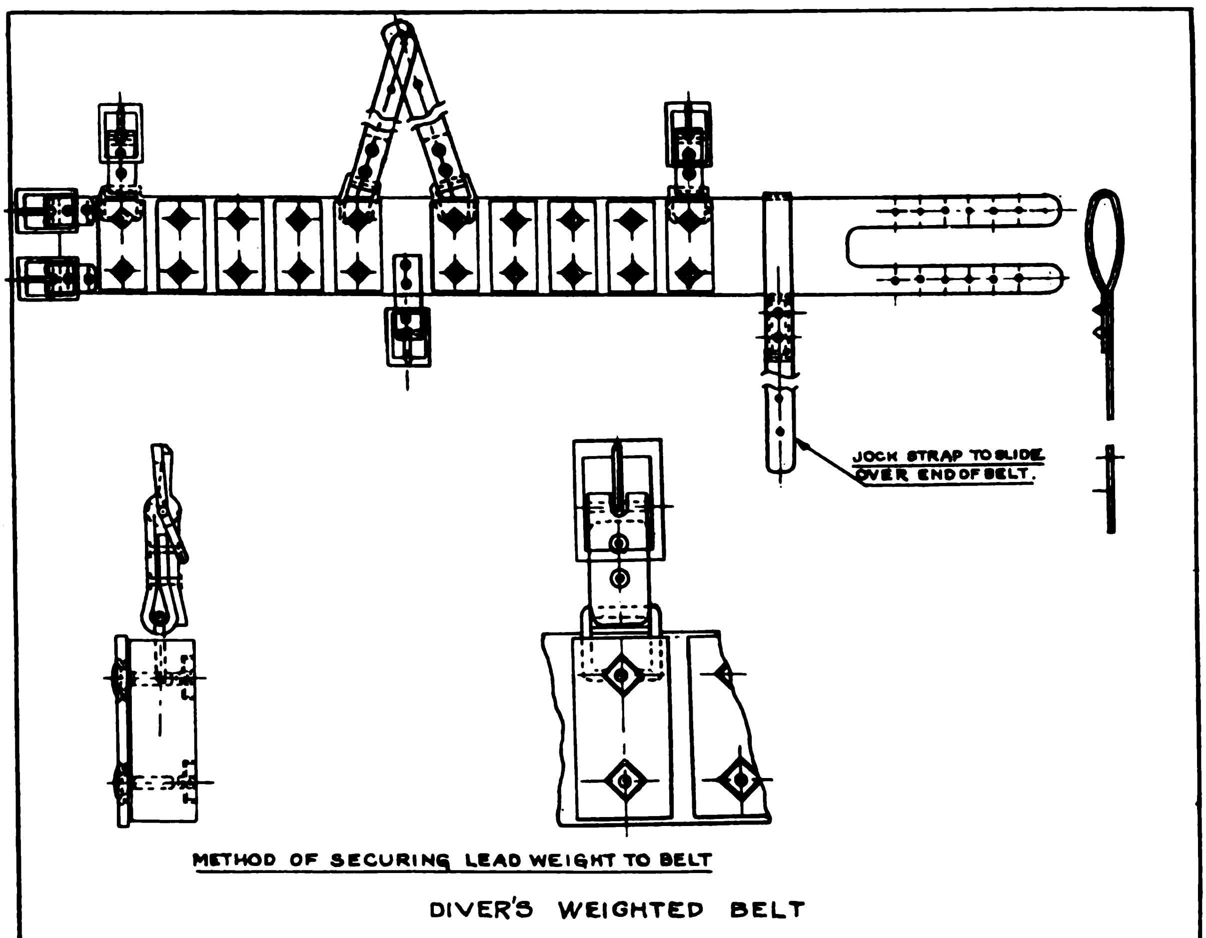


FIGURE 47.

FIGURE 48.

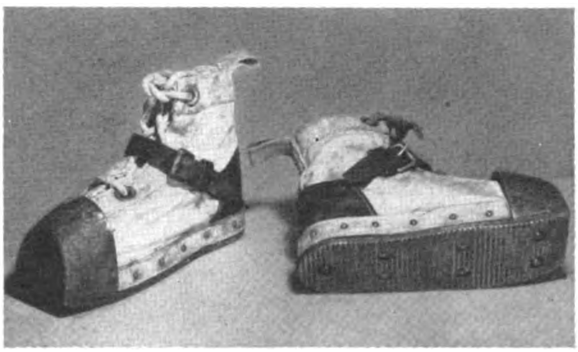


FIGURE 49.

plate and crosses in the back and front so as to counteract any tendency the belt may have to shift.

(2) The jock strap is provided for the dual purpose of preventing the helmet from rising over the diver's head as it would if the dress were permitted to elongate due to overinflation, and to hold the belt in its proper location.

(3) In order to protect the belt leather, it should be given a coat of neat's-foot oil, well rubbed in, so that it will not be disagreeable to handle. As leather used in water will soon become dry and hard, the frequency of applying oil will depend on how frequently the belt is used. Deterioration of leather is not always discernible from visual examination; consequently, the belt strap including the shoulder and jock straps should be tested for tensile strength. This may be accomplished by securing a regular diving belt buckle to the overhead, run the strap to be tested through the buckle; then have a man of about 160 pounds weight gradually put his entire weight on the strap which will withstand the load if in a satisfactory condition.

567. SHOES

(1) The *diver's shoes* are used in conjunction with the weighted diving belt to overcome the positive buoyancy of the inflated diving dress and helmet and to give stability to the diver.

(2) The standard weighted shoes, figure 48, consist essentially of a lead sole, hardwood upper sole, either leather or canvas upper, lacing cord and leather straps for holding the shoe in place, and a protective brass toe clip. The shoes weigh approximately 40 pounds per pair.

(3) The lightweight diver's shoes, figure 49, are essentially the same as the standard weighted shoe with the exception that a brass sole is used in lieu of the lead sole, and the weight of a pair is approximately 20 pounds. The use of the lightweight diving shoes will depend on the dress inflation and the individual diver's preference.

568. KNIFE

(1) The *diver's knife*, figure 50, is made of a tough tool-steel, bayonet-shaped blade with one cutting and one saw edge, a metal sheath, hardwood handle, and a leather strap. The use of the term "knife" is misleading as the instrument is actually a utility tool which is used for prying, hacking, sawing, or cutting such material as wood, wire

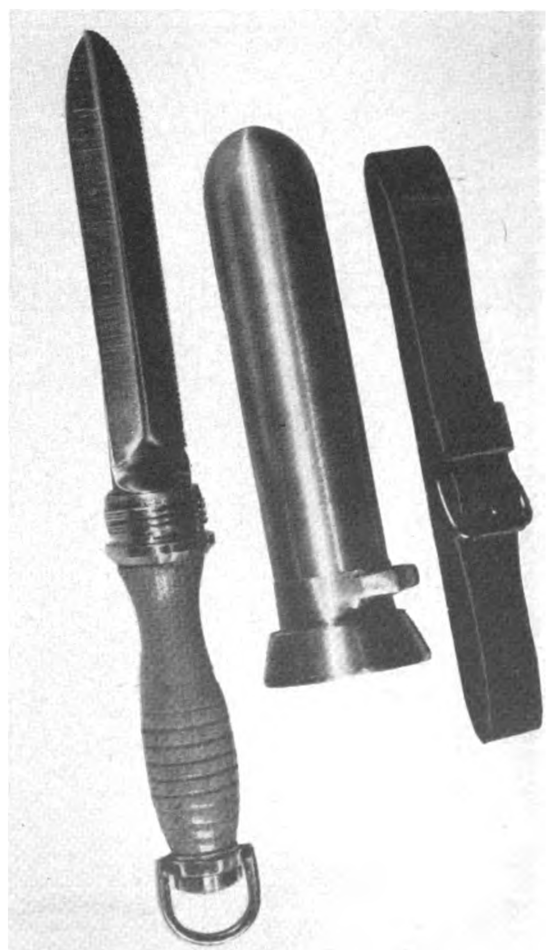


FIGURE 50.

or manila rope, sheet metal, etc. As such, the knife represents a compromise of the individual features that go to make up the knife.

(2) The knife sheath is made of brass, cylindrically shaped with a conical bottom. The top of the sheath has a wide mouth opening to facilitate placing the knife in the sheath. A hole is drilled in the bottom of the sheath to permit drainage. The leather strap is used for securing the sheath to the diver's belt. If the knife is to be stowed for any extended time, the sheath should be filled with grease to prevent the steel blade from corroding. While the knife is being used frequently, it should be covered with a thin layer of grease.

569. AIR HOSE

(1) Diver's air hose, figure 51, is a sinking type. having an internal diameter of one-half inch and an external diameter of $1\frac{1}{16}$ inches. It is constructed of a vulcanized-rubber tube reinforced by three plies of braided cotton laid on the bias to prevent the hose from wriggling, twisting, or turning while under pressure. The hose is furnished in two standard lengths—50- and 3-foot lengths. The 50-foot lengths of hose connect the surface air supply to the air control valve. The 3-foot length of hose connects the air control valve to the air safety non-return valve on the diver's helmet. A special $3\frac{3}{4}$-foot length of hose is used for this purpose when helium-oxygen helmets are being used.

(2) Diving hose when manufactured is required to withstand a working pressure of 500 p. s. i. and a proof pressure of 1,000 p. s. i. held for 30 seconds. In addition, representative lengths are required to withstand a burst pressure of 2,000 p. s. i. instantaneously. In connecting up the lengths, it should be remembered that the hose nearest the diver will be subjected to the least difference in pressure and, therefore, if there is any preference, the best hose should be on the end and nearest the surface.

(3) The use and stowage of the diver's air hose should be governed by the following:

(*a*) Hose more than 3 years old shall not be used as diving hose.

(*b*) Diving hose in store more than 2 years should be surface-inspected and hydrostatically tested to 75 percent of the working and the proof pressures listed above for new hose. In addition, one length of hose, selected at random from each lot of the same date of manufacture as representative of the lot, should be subjected to the burst test (75 percent of the 2,000 p. s. i. test). The lengths of hose which have been subjected to bursting tests should not again be used for diving purposes.

(4) When diving air hose is requested, the issuing activity should furnish the receiving activity with a copy of the report of the last test made on the hose. Hose received from store without this report should not be placed in service until the report is received. If emergency requires the use of the hose before such report is received, it may be so used provided it is retested by the ship.

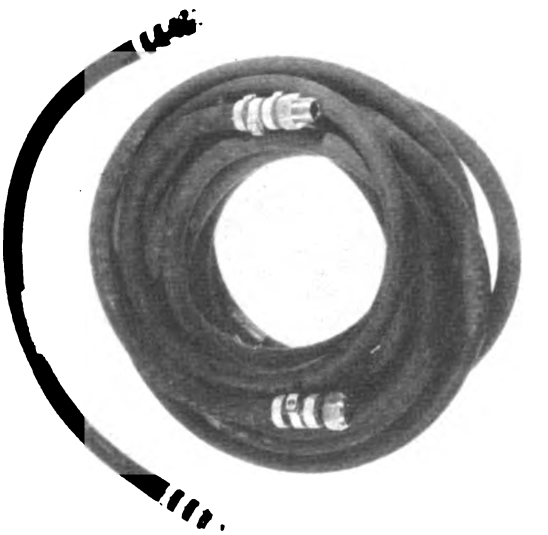


FIGURE 51.

(5) Diving hose in service should be hydrostatically tested when it is 2 years old and again when it is $2\frac{1}{2}$ years old. If facilities are available, the hose should be subjected to the same test given for hose in stock more than 2 years. If facilities are not available to conduct the required tests and it is necessary to use the hose, it should be subjected to a pressure at least 100 percent greater than the maximum pressure that will be applied to the hose top side.

(6) The ends of each length of diving hose are capped with a rubber compound to give the ends a smooth and watertight finish. Except in an emergency, the hose should not be cut as the uncapped sections permit water to permeate along the braid and inner tube of the hose thus forming bubbles which weaken it.

(7) When coupling lengths of air hose together, a leather washer should always be placed in each female coupling and care taken to insure that the inside of new hose is free of soapstone. Air hose should not be coupled directly to the air supply but to the oil separators. If a long length of air hose has been in use, moisture is sure to have accumulated in it. Therefore, 50-foot sections should be separated and drained before stowing.

(8) The various types of air-hose fittings are shown on figure 52. The ends of each 50-foot length of hose are fitted alternately with male and female couplings. The ends of the 3-foot length of hose are fitted with female couplings. In fitting the air hose couplings on the hose, the following procedure is recommended:

(*a*) Slip three clamps over the end of the hose.

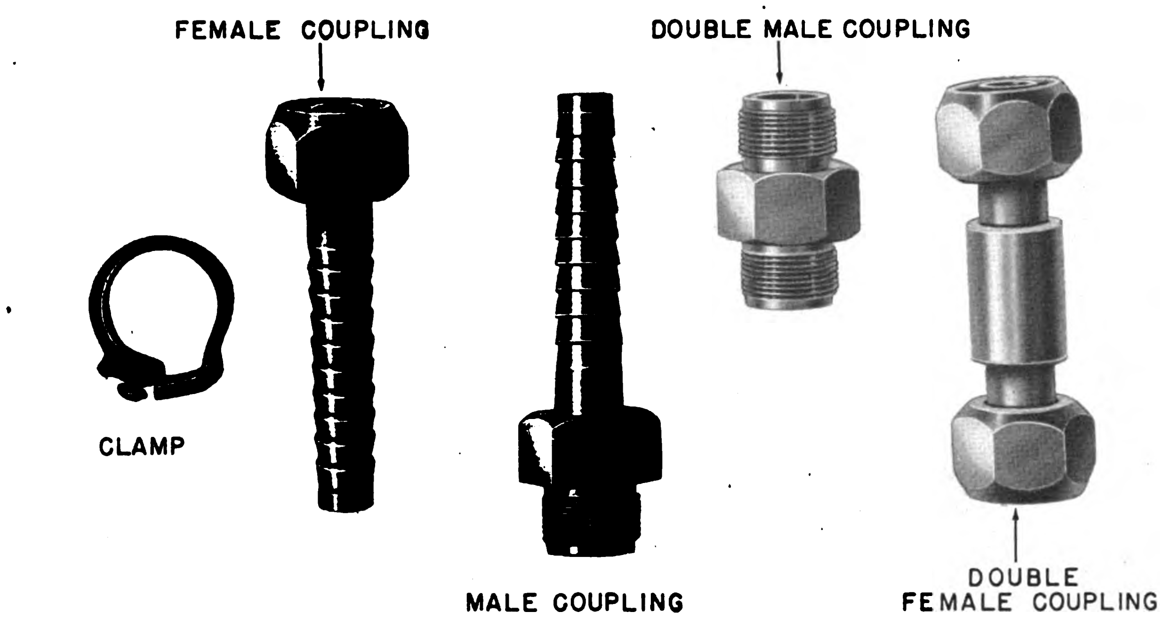


FIGURE 52.

(*b*) Coat the shank of the couplings with rubber cement and clamp in a vise. When attaching a female coupling, it should be assembled to a male coupling, rubber-coated, and clamped in a vise.

(*c*) The hose is then forced over the coupling shank until it is against the shoulder of the coupling.

(*d*) The first clamp is placed in position and set into a vise. Screw up on the vise until the clamps are compressed, bringing the clamp screw holes in line. The clamp screw is then screwed in place and the operation repeated on the next clamp.

(9) As the shank of the coupling is slightly larger in diameter than the bore of the hose and as the clamp is smaller than the external diameter, forcing the hose onto the corrugations of the shank and gripping tightly with the clamps will insure the coupling a firm hold on the end of the hose. A firm hold is absolutely necessary in view of the serious consequences that would result should a coupling pull out of the hose when a diver is under water. The joints between male and female parts of the hose coupling are made watertight by means of leather washers. Double-male and female standard air-hose couplings are provided for use when it is desired to make a special connection, e. g., when the alternations of male and female connections are not continuous. Wherever special couplings such as double-male or double-female couplings are used, they should be placed in the line of air hose so they will not be under water. Such couplings are intended for use in making surface connections.

(10) There are two diving hose *reducers* (*adapters*) furnished for making special connections, figure 53. The (S) reducers have a standard ¾-inch pipe thread on one end and a standard diver's

FIGURE 53.

air-hose thread—1 1/16-inch–17 threads, and are used for making connections from an air source having a standard pipe thread to a diver's air-hose fitting. The T reducers have a standard diver's air-hose thread cut on one end and a torpedo-air-pipe thread on the opposite end. The T reducers are used for connecting the diver's air hose to the torpedo charging lines when torpedo air flasks are used as a diver's air supply.

570. AIR-CONTROL VALVE

(1) The *diver's air-control valve,* figures 54 and 55, is of the needle-valve design and is used to control the flow of air to the diver's helmet. The valve consists of the body, valve stem, stuffing box, packing gland, cap nut, handle, and the link and eye pad. The body of the valve is a brass casting with standard male air hose threaded inlet and exhaust connections. Attached to the lashing eye of the body is a link and eye pad for securing the control valve to the long stud on the left side of the helmet breastplate. The body valve seat and the stem seat are ground at a 60° angle. The valve stem and the stuffing box have a 5/8-inch—8 acme

FIGURE 54.

threads of sufficient length so that when the valve is in a completely open or closed position, referring to figure 55, a minimum of two threads are engaged.

(2) The following method of assembling the control valve is recommended:

(*a*) Screw the valve stem into the stuffing box.

(*b*) Place the copper ring washer into the groove on the top of the valve body, and apply red lead to the top surface.

(*c*) Insert the valve stem into the body and screw the stuffing box up tight with a wrench. The valve stem should not be in contact with the body while the stuffing box is being drawn up tight.

(*d*) Insert the first lead packing ring over the valve stem.

(*e*) Take several turns around the valve stem with the flax packing, and insert the second lead packing ring.

(*f*) Insert the stuffing box gland and screw the cap nut into position.

(*g*) The bracket is secured by means of screws to the valve body. The bracket prevents the cap nut from backing off.

(*h*) Place the valve handle, stem nut, and cotter pin in place. The valve handle is designed so that it can be readily grasped when wearing the diver's gloves.

(3) The packing of the diver's air-control valve is very important and should be carefully adjusted so that the valve works stiffly enough to prevent its being opened or closed accidentally but is sufficiently free to be readily manipulated by the diver even though wearing the heavy divers-tenders gloves.

C. DIVING COMMUNICATIONS

581. METHODS OF COMMUNICATION

Communication between the diver and his tender is of the utmost importance to the safety of the diver and to the efficient accomplishment of the work being attempted. In addition, it is desirable to provide adequate communication between divers who are working together in order that they may assist each other effectively. To accomplish communication, two basic means are available—mechanical and electrical.

582. MECHANICAL COMMUNICATION

(1) Mechanical communication consists of transmission of a series of coded pulls on the life line or by messages written on slates which are lowered to the diver from the tending vessel. The method of communication using a series of coded pulls on the life line provides a positive method of transmitting essential simple messages having to do with the operations associated with the diver.

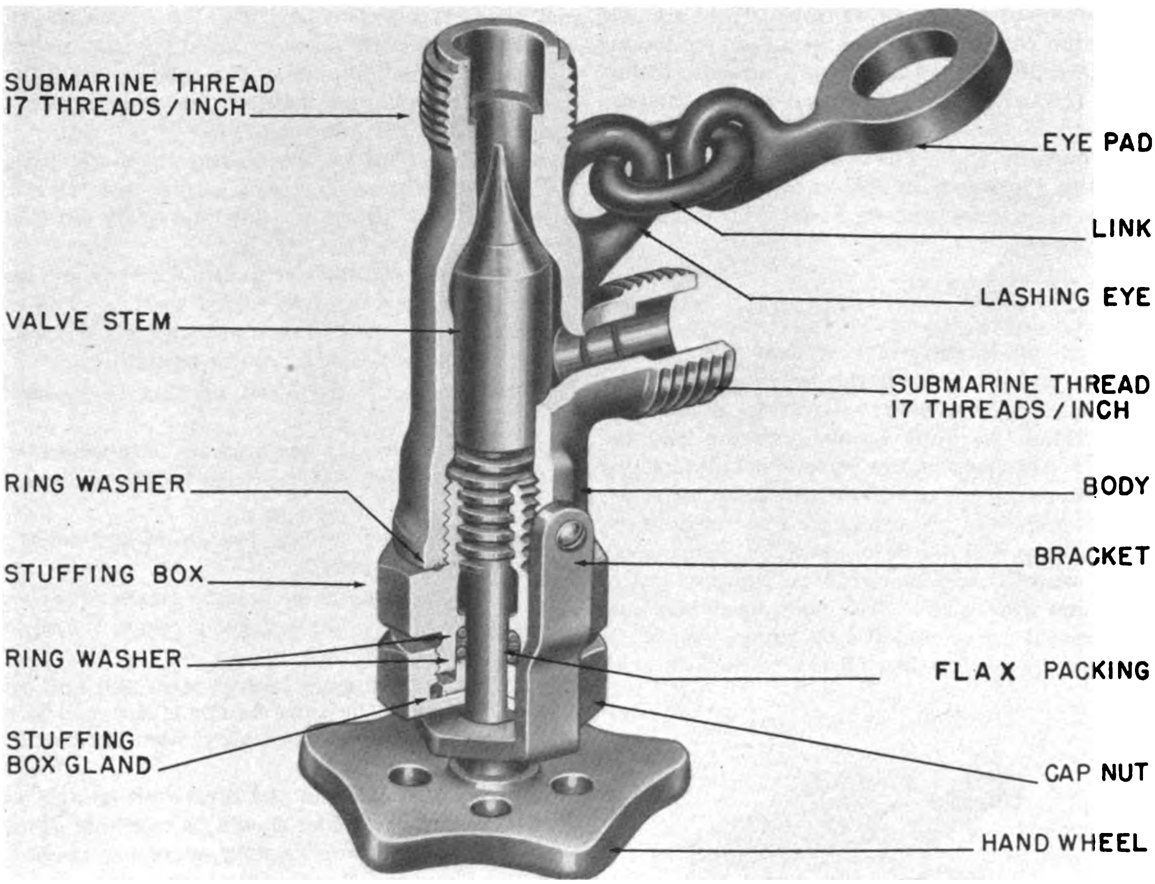


FIGURE 55.

(2) The following table should be employed as the standard system of naval signals:

From tender to diver:

1	Pull	Are you all right? When diver is going down, stop.
2	Pulls	Going down. During ascent, you have come up too far, go back down until we stop you.
3	Pulls	Stand by to come up.
4	Pulls	Come up.
2-1	Pulls	I understand you, or answer the telephone.

From diver to tender:

1	Pull	I am all right.
2	Pulls	Lower, or give me slack.
3	Pulls	Take up my slack.
4	Pulls	Haul me up.
2-1	Pulls	I understand you, or answer the telephone.

Special signals from the diver:

1-2-3	Pulls	Send me a square mark.

Searching signals:	*Without circling line*	*With circling line*
1 Pull	Stop and search where you are.	Stop and search where you are.
2 Pulls	Go straight ahead.	Go away from the weight.
3 Pulls	Go to your right.	Face the weight and go right.
4 Pulls	Go to your left.	Face the weight and go left.

Air signals:

3-2	Pulls	More air.
4-3	Pulls	Less air.

Emergency signals:

2-2-2	I am fouled and need the assistance of another diver.
3-3-3	I am fouled but can clear myself.
4-4-4	Haul me up.

All signals will be answered as given

Supplementary signals in addition to those listed above may be made up between the diving officer and the diver to take care of any special circumstances that may occur.

(3) In transmitting pull signals, it is necessary that the slack in the line be pulled up enough to permit the tender to feel the diver. Be careful not to hold the lines too taut for this may pull the diver away from his work. The tender should repeat all signals received to show that he understood. If the signal is not acknowledged, the sender should repeat the signal to give the receiver another chance to read it. When a diver makes a signal and his attendant does not answer, it is probably because there is too much slack line out, and hence the diver should gather in the slack and repeat the signal.

(4) The use of hand signals is limited necessarily to a few simple words and phrases for which a code can be memorized. Where complex salvage or rescue operations are in progress, this method of communication is inadequate to cover the many different problems that arise. In addition, under conditions of a running tide or deep dives, the strain on the cable and the weight of the cable make the use of hand signals a questionable means of communication. However, the code for mechanical communication by hand signals shall be memorized and practiced by every diver so that in the event

of failure of electrical communication, he will be able to communicate with the tender concerning essential diving operations. Both diver and tender shall be able to recognize and correctly interpret instantly every one of these signals.

583. ELECTRICAL COMMUNICATION

In view of the limitations of hand signals, some form of electrical communication that permits the use of voice communication is necessary. By suitable equipment design, it is possible to provide dependable two-way amplified voice communication which will permit talking from the diver to the tender and will not require the person on either end to wear any sort of headband or microphone harness. To provide a convenient term to describe the amplified type of system as compared with the older telephone types, it is recommended that the terminology "Divers' Intercom" be used. To talk on this system would be to talk on the "intercom."

584. DIVING INTERCOMMUNICATION SYSTEM

The diving intercommunication system that has been adopted as the standard for use in the United States Navy consists of the following basic items:

(*a*) The diving amplifier.

(*b*) The diver's reproducer (loud-speaker).

(*c*) The combination diving amplifier and life line cable.

Several different models of diving intercommunication systems exist, but each works basically in the same manner.

585. DIVING AMPLIFIER

(1) The diving amplifier is portable and is placed in convenient location on the tending vessel, barge, or pier. The combination diving amplifier and life line cable plugs into the amplifier and extends from the tender to the diver. The diver's reproducer is mounted in the diver's helmet.

(2) Three models of diving amplifiers are now in general use. The following table will serve to identify each model:

Manufacturer	Mfg. model No.	I. C. Instruction Book No.	Number of selector or keys
(*a*) Guided Radio Corp.	957	82A (NAVSHIPS 3650220).	6
(*b*) Guided Radio Corp.	H-919	82 (NAVSHIPS 3650288) . .	3
(*c*) Radio Corp. of America.	MI-2832	81	3

(3) The diving amplifier, figure 56, is the heart of the system and contains the amplifier, the tender's reproducer, the control switches, the volume controls, the tone controls, the power switch, the power jacks, the diver's jacks, and the grounding binding post. The amplifier is designed to amplify the voice from either the diver or the tender to sufficient volume so that, regardless of the surrounding noise, a message can be transmitted. In order that the system can be operated anywhere it is needed, the amplifier is designed to operate from power supplies of 12 volts D. C.; 110 volts D. C., or 110 volts, 60 cycles A. C. Details of the amplifier circuits are found in the I. C. Instruction Book furnished with the equipment.

586. TENDER'S REPRODUCER

The tender's reproducer is mounted on the top of the amplifier case. This acts as a loud-speaker when the diver is talking and as a microphone when the tender is talking. Two sets of control switches are used on this model. The three spring-return switches marked "Tender to Diver" provide switching for communication among the tender and any of three divers. In the normal position, the diver's reproducers are acting as microphones and anything any one of the divers says is heard by the tender through his reproducer. When one of the switches is pressed, the tender's reproducer, which corresponds to the switch pressed, acts as a loud-speaker and the tender talks to the diver. At this time the other two divers are disconnected from the circuit. Thus the tender always can hear messages from any of three divers at any time that a switch is not pressed and he can also call individually any one of three divers.

587. COMMUNICATION BETWEEN DIVERS

(1) An additional feature especially useful when several divers are working together is provided by a second set of spring-return control switches marked "Diver to Diver." By pressing one of these switches the tender can make the selected diver's reproducer act as a loud-speaker while the other diver's reproducers act as microphones. Thus the diver selected can hear a message from either of the other two divers. Reversing the switching makes a return call possible. At all times, when using this feature, the tender's reproducer is acting as a loud-speaker, thus making it possible for the tender to hear both sides of the conversation. In this manner divers working together can actually talk with one another as they work on the assigned job.

(2) To use this feature efficiently requires a certain amount of circuit procedure. All switching is done by the tender to relieve the diver from having to accomplish it. Diver No. 1 wishing to speak with diver No. 2 calls "Diver No. 1 calling diver No. 2." The tender presses the tender-to-diver No. 1 key and says "Go ahead" and immediately releases the tender-to-diver No. 1 key and presses and holds diver-to-diver key No. 2. The tender will hear diver No. 1's message to diver No. 2 and at the end of the message diver No. 1 will say "Over." The tender then releases the diver-to-diver key No. 2 to talk with diver No. 1. At the end of his message diver No. 2 also

FIGURE 56.

signals "Over." Thus the call continues until it is completed at which time diver No. 1 says "End of Call." The tender releases all switches and then tells diver No. 1 "O. K."

588. VOLUME CONTROLS

Two volume controls are provided. One control adjusts the volume of sound to the diver and the second adjusts the volume to the tender. In this manner the volume can be varied in each direction separately to provide satisfactory volume for both the diver and the tender. These controls should be adjusted before the diving is begun and as necessary during the dive. The tender should check with the diver to determine whether or not the volume at the diver's end is satisfactory.

589. TONE CONTROLS

Two tone controls are provided. One control adjusts the tone of the sound to the diver and the second adjusts the tone of the sound to the tender. In the center or zero position, normal tone results.

The air hiss in the helmet and external noise at the tender's station may make adjustment of these controls necessary to permit maximum intelligibility. These controls are helpful in deep dives and especially when helium-oxygen mixture is used because the voice of the diver changes and adjustment of the tone controls will aid greatly in understanding the messages.

590. POWER SWITCH

The power switch and its associated pilot lamp are used to turn the amplifier on and off. Prior to each dive, operation of the entire intercom system should be checked at the same time that the diver checks his air valves.

591. POWER JACKS

Three power jacks are provided, figure 57, one for each type of power supply—12 volts D. C., 110 volts D. C., and 110 volts, 60 cycle A. C. Three power cords are provided, each having a different special plug to fit into one of the three jacks. After determining the type of power supply available, the power cord for that type of supply is selected and the special plug is plugged into the appropriate jack

FIGURE 57.

FIGURE 58.

in the amplifier. The special plug automatically makes the necessary connections for operation on the selected power source. *WARNING: Do not plug in more than one cord at a time* for this will cause a direct short circuit of the power supply, with resultant destruction of the plug and jack and may also cause serious electrical shock.

592. DIVER'S JACKS

Three diver's jacks are provided on the side of the amplifier case, figure 58. Each consists of a special jack manufactured in accordance with Bureau of Ships plan 9000–86502–73015. Each is designed to receive a plug on the end of the diving cable and thus make possible the separate connections to three divers.

593. GROUND POST ON DIVING AMPLIFIER

When diving operations are conducted from wooden rafts, hulls, or docks, the intercom equipment often is insulated from ground. As a result of this, a static electric charge sometimes exists between the equipment and ground and when the helmet is placed on the diver, this charge will discharge through his body and produce electric shock. To prevent electric shock, the diving amplifier is provided with a ground binding post. A copper wire No. 10 B & S gage or larger should be run from this post to any metal that is in continuous contact with the water. The diver's metal ladder will serve as a good grounding point. If any metal-sheathed cable is used to make connection to a shore power supply, the sheath should be grounded in a similar manner.

594. DIVER'S REPRODUCER

The diver's reproducer, figure 59, is a small permanent magnet, cone type of loud-speaker especially designed to be mounted in the recess of the helmet. It is connected electrically to the diving cable through the helmet gooseneck. The helmet jack assembly (discussed in detail under fittings) is mounted in the outer end of the gooseneck. A pair of wires run from the jack to the reproducer. The excess space in the gooseneck is sealed with melted beeswax to prevent water seepage. The diver's reproducer serves both as a microphone and a loudspeaker as described above.

595. CONNECTING CABLES

Three connecting cables, figure 60, are provided, each with special plugs to plug into each of the special jacks on the amplifier as described above. These plugs serve to connect the amplifier to the available power supply; and, as they make the connections necessary for the particular supply, only one can be plugged in at once without causing a short circuit. The other end of the 12-volt cable is provided with battery clips. The other two have no plugs so that the activity using the intercom system will attach the standard fittings that match the available receptacles.

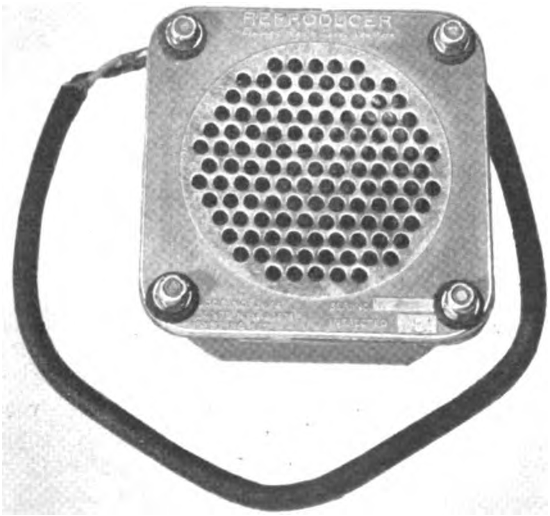


FIGURE 59.

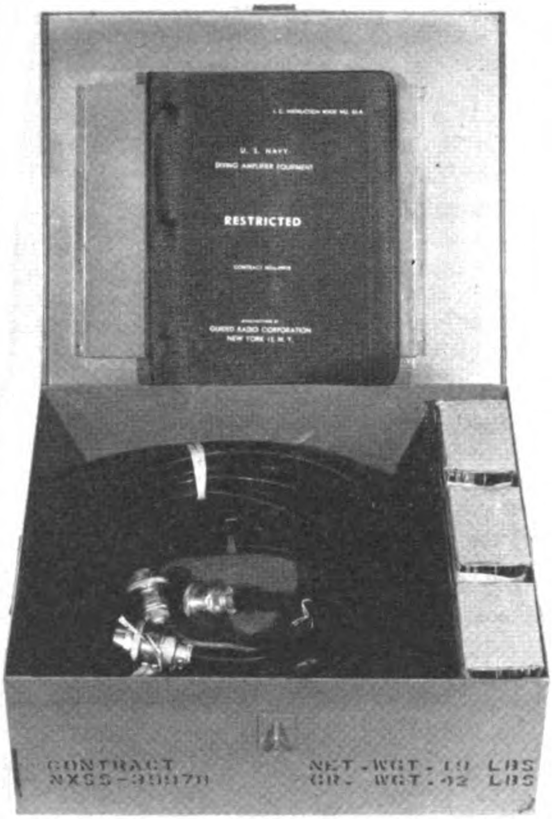


FIGURE 60.

596. SPARE PARTS SET

A spare parts set, figure 61, which includes all parts necessary is provided for the maintenance and repair of the intercom system. To avoid possible delays in the procurement of replacement parts from supply depots, the parts in this set should be carefully kept under lock and key, and should be used only for the repair of this system.

597. INSTRUCTION BOOKS

The detailed information on the maintenance and repair of the diver's intercom system is available in the instruction books that accompany the systems. These books contain detailed mechanical drawings, electrical schematic diagrams, and photographs of the equipment. They are the best source of information on maintenance and repair problems and should, therefore, be consulted freely.

598. SIMILAR TYPES OF AMPLIFIER EQUIPMENT

The diving amplifier equipment described above represents the most complex system that has been developed. The Guided Radio Corp. Model H-919 is equivalent to the Model 957 in every respect except that it does not include the "diver-to-diver talk" feature, but it will provide excellent communication

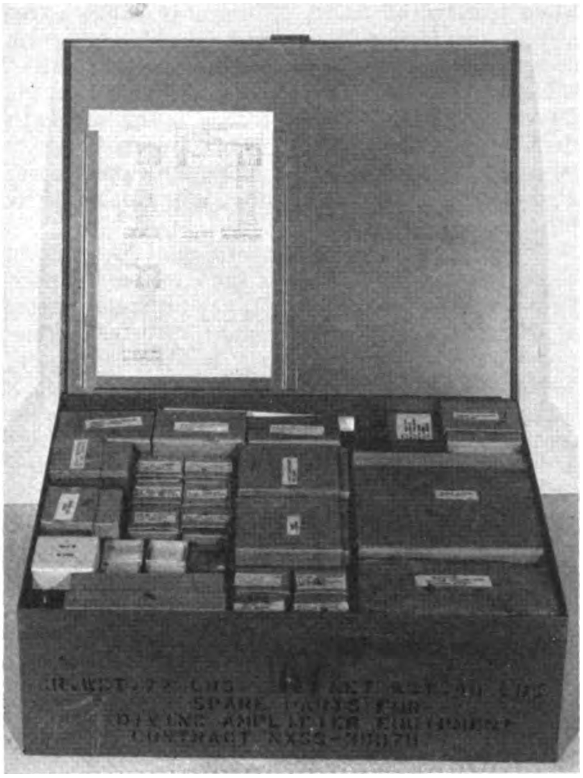


FIGURE 61.

and, therefore, except where special justification can be given, will not be replaced by the Model 957. The Radio Corp. of America Model MI–2932 is, in function, equivalent in every respect to the Guided Radio Corp. Model H–919 and is listed only for identification. It was issued only to submarine rescue vessels and is not available for other uses. Any equipment not of the types listed above is considered obsolete and should be replaced in any active diving outfits by one of the types described above manufactured by the Guided Radio Corp.

599. COMBINATION DIVING AMPLIFIER AND LIFE-LINE CABLE

(1) In order to carry the wire necessary for using the diving intercommunication system and to eliminate the need for a separate cable containing these wires, a special cable has been developed for use by United States Navy divers. This cable is called the Combination Diving Amplifier and Life-Line Cable, figure 62. As its name implies, this cable has sufficient mechanical strength to serve as a life line for the diver and at the same time provide the electrical conductors necessary for the operation of the intercommunication system.

(2) The cable consists of a stranded steel core which is coated with high-grade rubber. Around this core are wound four rubber-insulated wires. The winding of these wires is spiral, much like a coil spring, so the cable despite its size is fairly flexible. Over these wires is another coat of rubber and then a final coat of tough oil-resisting neoprene. The result of this construction is a tough, high tensile strength (2,250 p. s. i. test), water- and pressure-resisting cable that is ⅝ inch in diameter and weighs about 0.35 pound per foot.

(3) The cable is usually made up in lengths of 200 or 600 feet. Each length is supplied with the following items:

- 2 male plugs (attached to cable ends),
- 1 coupling (for connecting cables together),
- 1 coupling wrench (for tightening fittings),
- 2 leather washers (used between plug and couplings), and
- 1 spanner wrench (for disassembling plug).

The diving cable is plugged into the diving amplifier unit of the intercom system. It is then secured and passed over the side and down to the diver. When more than one length of cable is needed, additional lengths are added by connecting the two male plugs together with a female coupling. The plugs and couplings are constructed heavily enough so that both a strong mechanical connection as well as a good electrical connection is made. The cable is secured at the diver's end by lashing it to the breastplate. It then passes to the helmet gooseneck where the plug is attached, thus making positive mechanical and electrical connections to the helmet. A leather washer is inserted into each connection to act as a spacer and watertight gasket.

600. CARE TO BE USED IN HANDLING AMPLIFIER EQUIPMENT

(1) The diving intercommunication system is designed to be as rugged as possible consistent with the permissible weight. However, it still is fundamentally a piece of electrical equipment. For this reason, care should be used in handling the diving amplifier to avoid dropping. Power cables should be attached only one at a time in order to avoid the possibility of a short circuit.

(2) Every effort should be made to keep water, especially salt water, out of the amplifier and the cable fittings. The helmet reproducer is especially vulnerable to mechanical and water damage, and the helmet should always be handled with consideration for this vital unit. To avoid damage, the male section of the diving cable plug should be suitably protected with a screw cap as shown on Bureau of Ships Plan 9000–S6502–73009. This is especially important on the plugs that have a plastic base on the plug insert assembly.

(3) The internal parts of the amplifier should be kept dry at all times. If water does accidentally get into the amplifier, the units should be carefully dried out before the power is connected.

601. FAILURE OF AMPLIFIER

(1) If the amplifier becomes inoperative, the

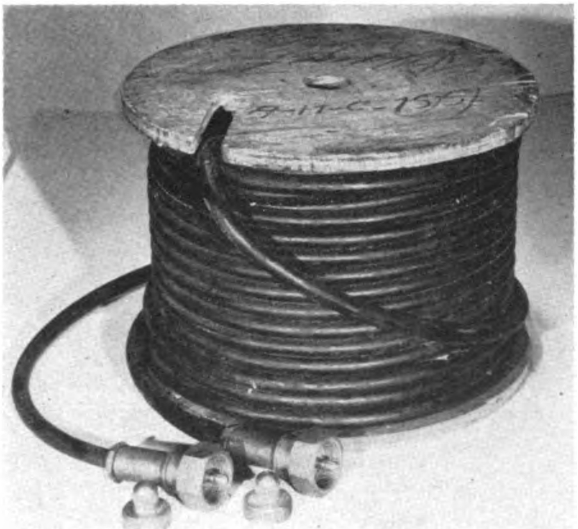


FIGURE 62.

power supply should be checked to see if it is energized and, in the case of D. C., of the right polarity. If a storage battery is used as a source of power, the battery voltage should be at least 11.5 volts with the amplifier turned on. If the power circuit is found to be unsatisfactory, remove the fuse posts on the amplifier with a screw driver and examine the fuses for burn-outs. Defective fuses should be replaced with good ones of the rating shown in the instruction book.

(2) If the foregoing procedure does not restore operation, the most likely source of trouble is failure of one or more of the vacuum tubes or failure of the power supply vibrator. To check or replace these tubes, the amplifier must be removed from its case by removing the panel screws. This will enable the main amplifier panel, the cover, and the rear panel to be withdrawn from the case as a unit. Before removing the tubes, it is necessary to loosen the locking clamps around the tube bases. Defective tubes and vibrators should be replaced with new ones. Only tubes of the type furnished with the amplifier should be used. The tubes are not interchangeable and replacement tubes should be installed in the sockets marked for the particular type of tube used.

(3) If the foregoing check does not disclose the cause of failure, the trouble may be due to an open or short circuit in the amplifier connections or failure of component parts. The circuit may be checked by reference to the respective wiring diagrams and list of parts as shown in the instruction book accompanying the equipment.

602. HANDLING OF COMBINATION DIVING AMPLIFIER AND LIFE-LINE CABLE

(1) Care should be exercised in unreeling the combination diving amplifier and life-line cable when received on board. The coil of cable, as received, should be placed on a revolving platform or reel and uncoiled as the platform or reel revolves. The cable should not be pulled from the coil in the manner commonly used with rope as this will twist the cable and cause kinks. Kinks especially should be avoided, as they may damage the rubber cover or displace the conductor wires, thus causing early failure of the cable.

(2) It is unnecessary to test the cable for strength as the central core, which is the strength member, is of corrosion-resisting steel, has an ample factor of safety, and is not susceptible to deterioration. Unfortunately, however, this is not the case as regards the conductor wires which, being of copper, may in time stretch or break, thus impairing or destroying the electrical circuit. When the breakage occurs, it is usually at the points of greater flexing of the cable. The points of greatest flexing are usually a few inches from either end of the cable due to the bend in the cable at these points when it is under tension. Care should be taken to prevent the cable from getting a sharp nip or permanent bend at these points. Experience will facilitate the locating of such breaks, and a study of the drawings showing the construction of jack plugs will enable the jack plugs to be assembled and reassembled when removing defective sections of the cable.

(3) Continuity of circuit or grounds may be determined by test with a megger, a test lamp, or an ohmmeter, following the same procedure as for determining an open or a ground in any other circuit. In testing the cables, remember there is a complete electrical circuit from the metal sleeve of one amplifier to the other plug through the cable core. If through any cause an open or a short circuit develops in the cable and causes failure of the communication circuits, the jack plug at the damaged end of the cable should be removed, and the faulty section of the cable cut off and the jack plug replaced.

(4) Referring to figure 63, the removal of the jack plug involves the following operations:

(*a*) Unscrew the gland nut at rear of plug housing.

(*b*) Remove packing.

(*c*) Remove lock nut at front of plug housing with spanner wrench supplied.

(*d*) Heat plug housing to soften the sealing compound.

(*e*) Slide plug housing back on cable away from plug.

(*f*) Loosen connections to plug terminals and remove plug.

(*g*) Melt solder which secures stainless steel core in the anchor plug, and remove the wood screw wedge and anchor plug.

The cable may now be cut back until, from the appearance of the butt end, it is evident that all the

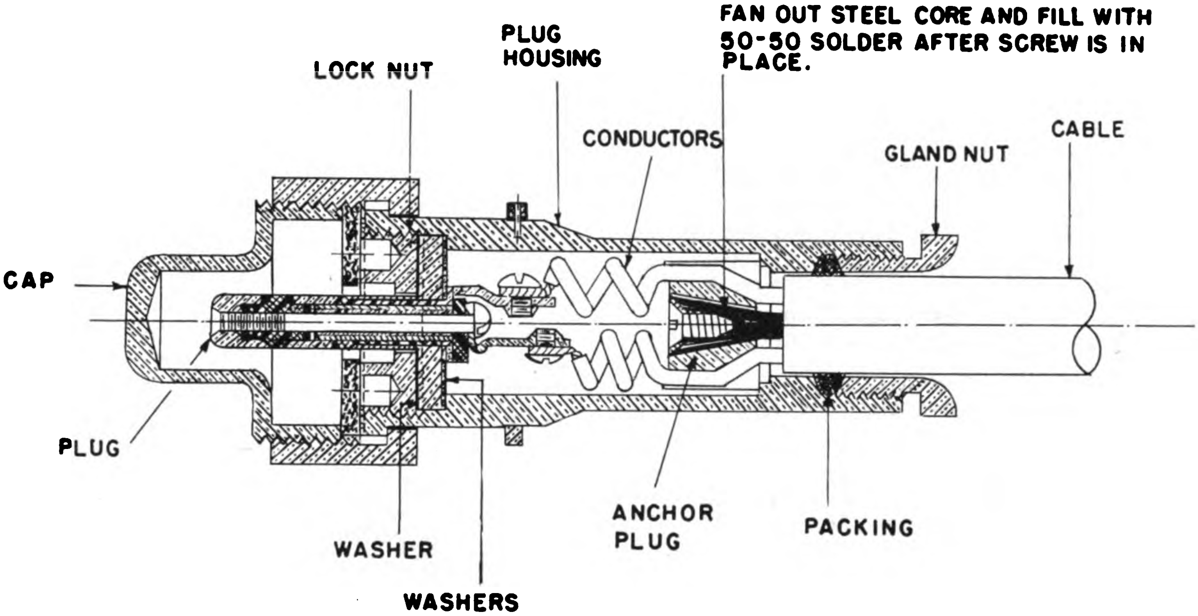


FIGURE 63

damaged cable has been removed, and until the communication lines test through.

(5) To reassemble the jack plug the procedure is as follows:

(*a*) Slide gland nut and jack plug housing onto cable.

(*b*) Remove the two outer rubber coverings for a distance of about 4 inches; untwist the four conductors and remove the rubber covering of the stainless-steel core also for about 4 inches.

(*c*) Separate the exposed strands of steel core and tin thoroughly.

(*d*) Slip anchor plug over the tinned strands and bring up as close as possible to rubber covering.

(*e*) Distribute strands around circumference of hole in plug and drive in wood screw wedge.

(*f*) Solder the steel core and wedge securely into anchor plug.

(*g*) Cut off loose ends of steel core even with anchor plug and smooth with file.

(*h*) Bare the ends of the conductors and twist together into two pairs—red with green, black with white. It is very important that this color coding be observed.

(*i*) Form an eye in the end of each pair and solder.

(*j*) Pull plug housing down over anchor plug as far as possible. Length of conductors should be such that eyes project about one-fourth inch out of plug housing.

(*k*) Several turns of suitable packing material should be inserted in the gland, and the gland nut screwed in and pulled up tight.

(*l*) Place the thin leather washer over conductors and attach conductors to plug terminals making sure that *red and green pair is connected to the side terminal and black and white pair to the center terminal.*

(*m*) Pour melted sealing compound or beeswax into open end of housing to within one-fourth inch of the plug seat.

(*n*) While the sealing compound is still soft, seat the jack plug in plug housing, making certain that thin leather washer is properly situated on seat. Care must be taken to see that all space in the plug housing is filled with the sealing compound.

(*o*) Screw in locking nut and pull up tight to complete the assembly.

(6) In case a bubble forms in the outer rubber covering of the cable due to leakage of compressed air from the diver's helmet, it is not necessary to cut off the injured section of cable unless the communication circuit is opened. The correct procedure is to puncture the bubble and wrap the puncture with several layers of rubber tape, using plenty of rubber cement between layers. The rubber tape should be covered with one layer of friction tape and the whole patch then thoroughly shellacked. Before returning the cable to service after a repair, it is essential that the cable jack plug be opened and inspected for leaks in the sealing compound. If any are found, the plug should be resealed. A similar inspection should be made of the telephone gooseneck fitting on the helmet, and the necessary repairs made.

603. CARE OF REPRODUCERS

The reproducer units of the standard diving intercom system are exceptionally rugged and unsusceptible to trouble usually experienced from the effect of moisture. Ordinarily no serious damage is caused by short submersion, but continued submersion or continuous exposure to moisture will result in corrosion of the metal parts and the grounding or short circuiting of the coils. If any of the units should be accidentally submerged in salt water, they should be washed out with fresh water and dried out by exposure to heat. Care should be taken, however, that the applied heat is not sufficient to burn the insulation of the wire. If any of the units become inoperative due to collection of dirt, they should be carefully dismantled and cleaned. The diaphragms and pole pieces especially should be kept free from dirt and sediment. After use, the units should be wiped dry with a clean rag to remove all moisture before storing.

604. ELECTRICAL CONNECTIONS

(1) The electrical connections between the diver's reproducer and the amplifier and between cable lengths are made through the jack boxes. The new style jack box is shown on figure 64 and the old style on figure 65. The corresponding helmet goosenecks are shown on figure 66.

(2) The installation of the helmet gooseneck jack into the gooseneck involves the following steps:

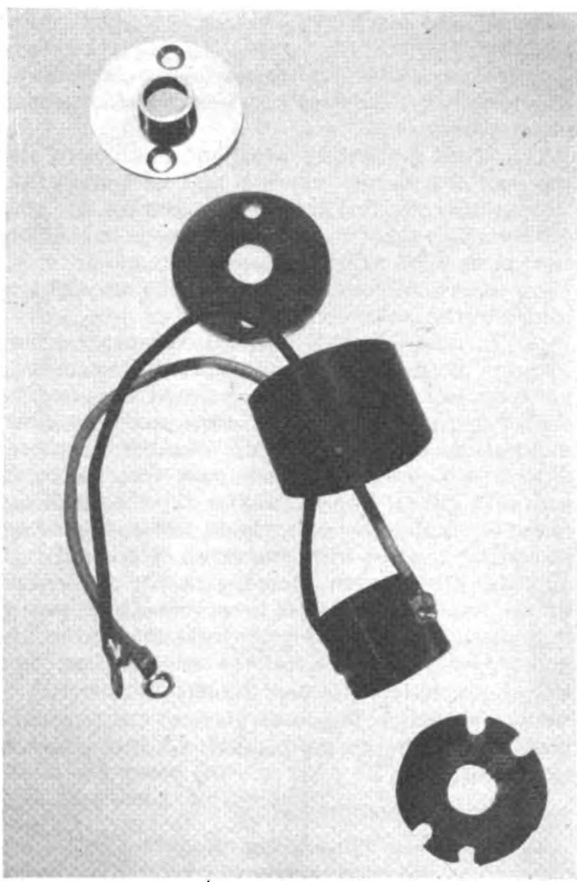


FIGURE 64.

(*a*) If leads are not furnished on the jack unit, solder a 12-inch insulated wire to each of the terminals of the jack.

(*b*) Insert the jack element, wires down, into the gooseneck and secure with two screws.

(*c*) Trim and attach leads to the reproducer unit and secure the reproducer unit in place.

(*d*) Pour melted beeswax into the helmet gooseneck from inside the helmet to produce a watertight seal.

605. SIGNAL HALLIARD

One-inch cotton braided signal halliard, figure 67, is used for securing the hose and amplifier and life-line cable to the eyelets on the helmet breastplate.

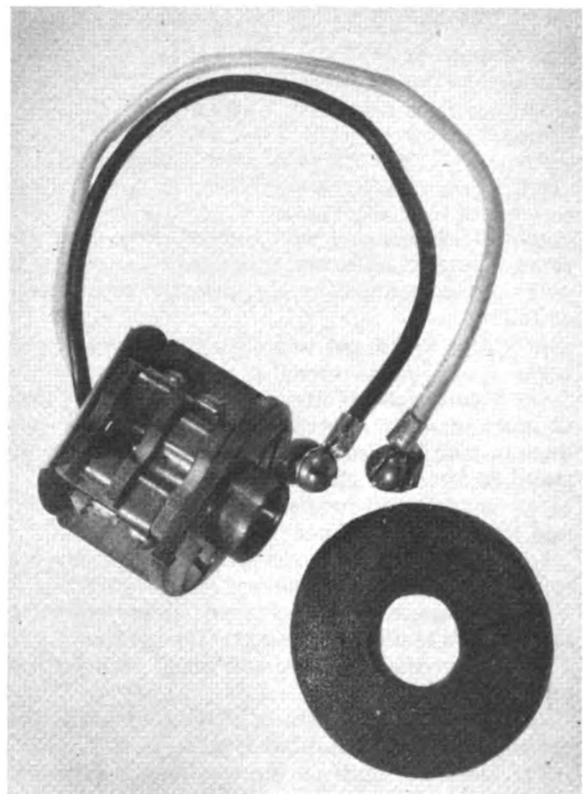


FIGURE 65.

606. SOUNDING LINE AND LEAD

The sounding line and lead, figure 68, are provided for determining the depth to which the diver must descend. It is important that this depth be determined with reasonable accuracy in order to anticipate the diving conditions, type of equipment, and personnel to be used, and to insure proper decompression. Accurate determinations may be made as outlined in Article 925 (1).

607. DESCENDING LINE

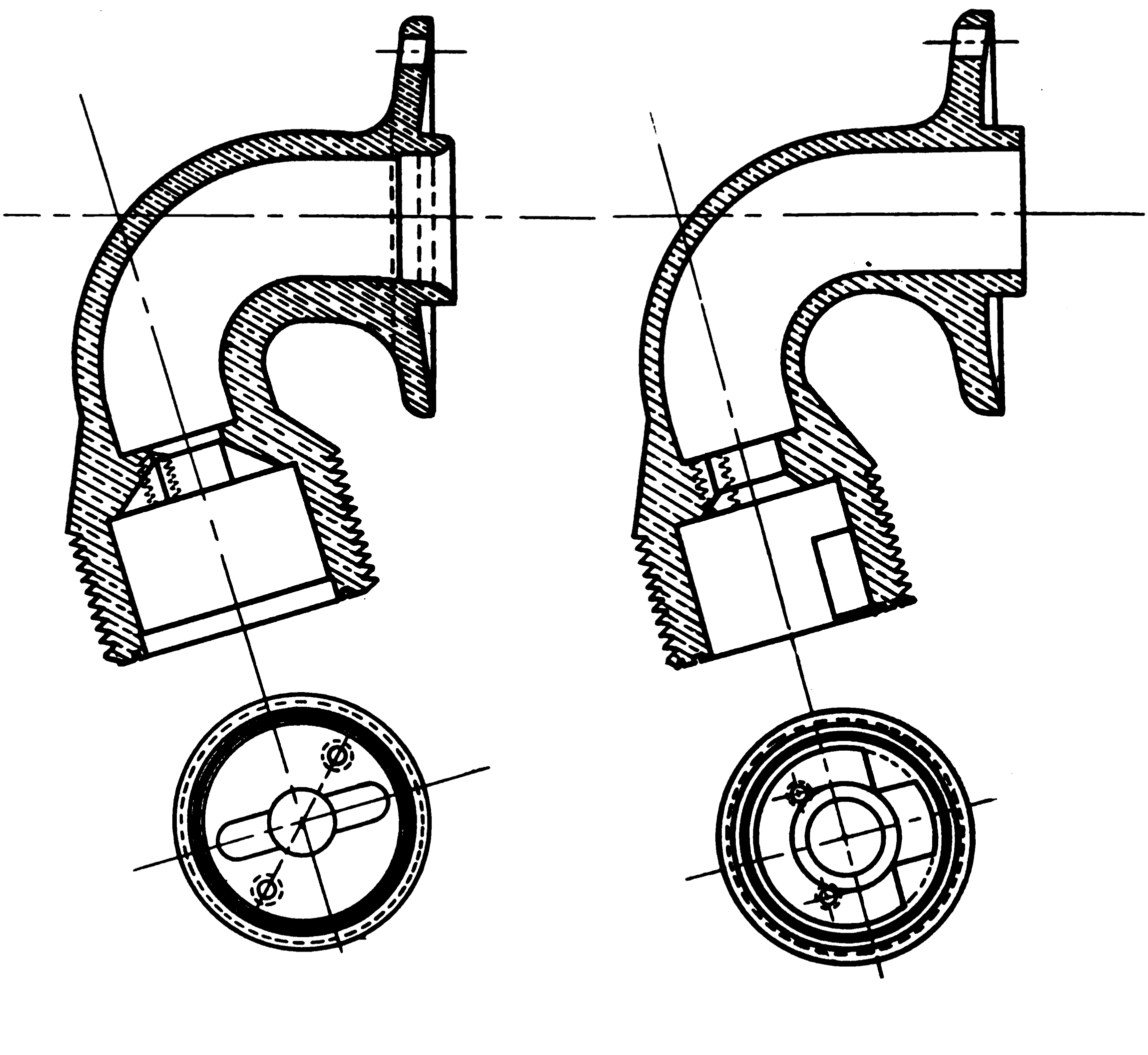
The descending line, figure 69, is the means of guiding the diver to the bottom and for lowering tools and equipment. The line is made of 3-inch circumference manila rope, and is cable-laid to prevent twisting and to make identification by the diver easy. In rescue and salvage work, after the sunken vessel has been located, a line is usually attached to the wreck by the diver. In subsequent dives the diver slides down the line to reach the desired point on the wreck. In diving operation requiring searching or observations, etc., the descending line is lowered direct to the bottom by shackling its end to the eye of a 100-pound weight. In strong tide ways, should the 100-pound weight not remain on the bottom, additional weight may be added.

608. DISTANCE LINE

A distance line, figure 69, made of 15-thread cable laid manila, 60 feet long, is attached to the descending line above the weight. This line is used by the diver in rotary searching and as a guide for relocating the descending line when he is ready to ascend.

609. DECOMPRESSION STAGES

(1) The divers' decompression stages, figure 70, are used for putting one or two divers over the side and for bringing the divers to the surface in accordance with the decompression tables. The single-diver stage is 3 feet in length and 18 inches wide; the two-diver stage is 5 by 4 feet. The stage platform is made of flat cross-bars spaced about



HELMET GOOSENECK REQUIRING USE OF NEW STYLE JACK BOX

HELMET GOOSENECK REQUIRING USE OF OLD STYLE JACK BOX

FIGURE 66.

1 inch apart to permit it to pass through the water with a minimum of resistance. The platform is mounted on two wooden skids for deck protection. Eye bolts approximately 1⅜ inches inside diameter are welded to the middle of each end of the platform

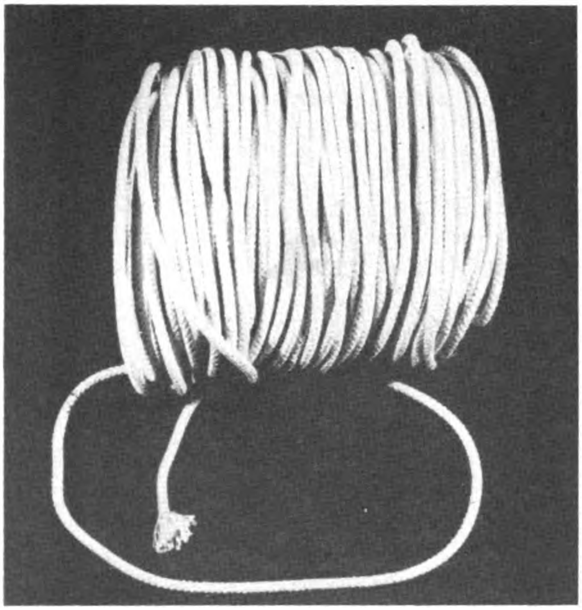


FIGURE 67.

for attaching guy ropes for steadying the stage, suspending weights, or permitting the diver to brace himself. On the front of the single-stage platform and on the side frame of the two-diver stage is secured a guide through which the descending line is passed when lowering the stage to the diver. The bails of both stages are made in two sections to permit the stage to collapse for ready stowage. At the top of the stage is a 2½-inch inside diameter ring for securing the stage lines.

FIGURE 68.

(2) *Stage lines* are not furnished with the stage but should be made up on board to suit the particular needs of the vessel. The lines are made of 3- or 4-inch manila rope with marks made 10 feet apart, corresponding to the decompression stops. As the decompression tables are prepared on the basis of the entire body being below that required by the decompression stop, the depth of each decompression stop is measured from the surface of the water to the top of the diver's head. As individuals vary in height, it is necessary to use an average distance in determining the location of the first marker. The distance used is 16 feet from the deck of the platform.

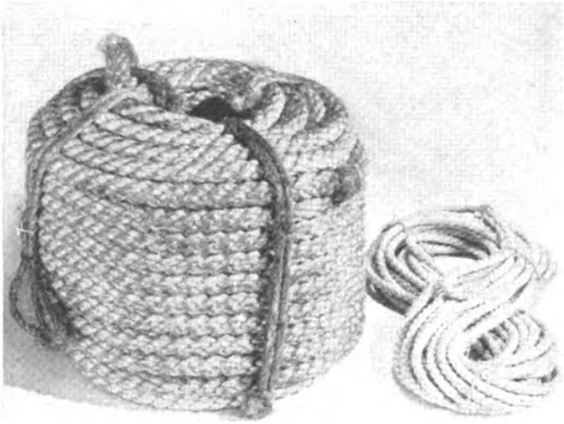


FIGURE 69.

(3) Stage lines usually are marked with colored rags (flag bunting) to indicate the depth of submergence, as follows:

10 feet, 1 cloth tag (red).
20 feet, 1 cloth tag (yellow).
30 feet, 1 cloth tag (blue).
40 feet, 2 cloth tags (red).
50 feet, 2 cloth tags (yellow).
60 feet, 2 cloth tags (blue).
70 feet, 3 cloth tags (red).
80 feet, 3 cloth tags (yellow).
90 feet, 3 cloth tags (blue).
100 feet, 4 cloth tags (red).
110 feet, 4 cloth tags (yellow).
120 feet, 4 cloth tags (blue).
130 feet, 5 cloth tags (red).
140 feet, 5 cloth tags (yellow).
150 feet, 5 cloth tags (blue).

(4) *The diving ladder*, figure 71, is used for entering and leaving the water when diving over the side of a motor launch. The struts that give the correct inclination of the ladder when in use may be folded against the frame after removing the securing bolt to facilitate stowage. The ladder is made of medium steel and is heavily galvanized.

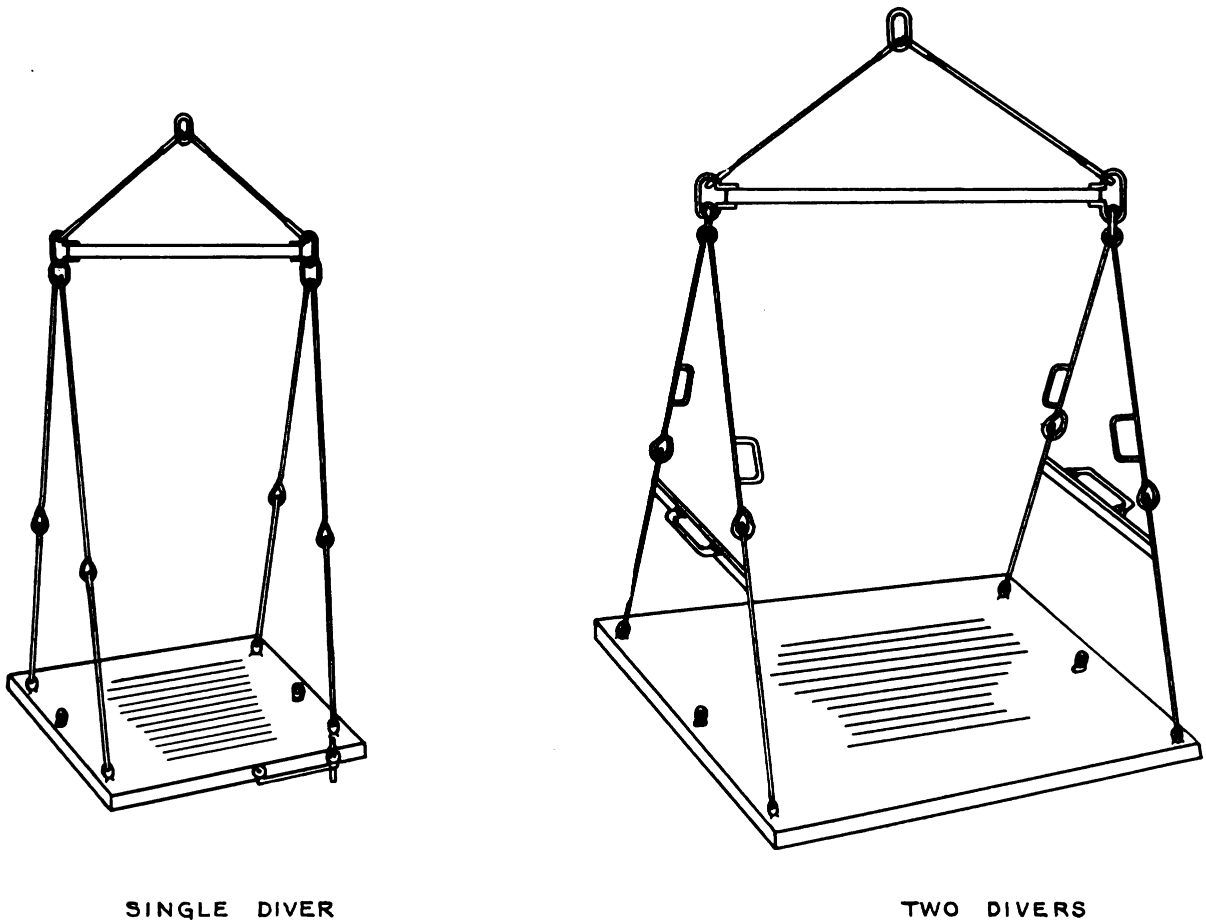


FIGURE 70 (decompression stages).

(5) *Cast-iron weights* are provided in two sizes, 50 and 100 pounds. The 50-pound weights are generally used with the decompression stage or as marker-buoy weights, and the 100-pound weights are descending line weights.

(6) The *tool bag*, fig. 72, is used for carrying any tools that may be required by the diver for doing a job. Usually the tool bag, if not too heavily loaded, will be looped over the diver's right arm while he is on the ladder, just before entering the water. If it is heavily loaded, it should be sent down the descending line. The bag is made of heavy canvas and perforated with grommets, for easy drainage and for securing tools. After use, the bag should be washed with clean water and allowed to dry thoroughly before stowing.

(7) *Lights*.—(*a*) One of the greatest handicaps experienced by divers is reduced vision under water which may range from 0–100 percent of normal, depending on the turbidity of the water. In many instances the diver working on muddy bottoms has to depend entirely on his sense of touch to accomplish a job. The value of underwater lights will depend on the water conditions. The extent of light penetration or diffusion of light under water depends principally on the amount of opaque matter suspended in the water inasmuch as the opaque matter scatters the light, creating a haze. Increasing the power of the light increases the intensity of illumination but does not materially increase the radius of diffusion, nor does the use of reflectors to project the rays contribute materially to greater penetration. Reflectors are useful in protecting the diver's eyes from the glare of the light at its source.

(*b*) In order to provide light where it may be feasible, two underwater lights have been developed. The medium pressure underwater light, figure 73, consists of the lamp with a rubber socket for making a water-tight seal with a commercial 100-watt photo flood bulb (any commercial medium base bulb may be used), and 200 feet of cable. The light has been found satisfactory for use in moderate depths—down to 150 feet. The second light, figure 74, consists of a 1,000-watt lamp, lamp holder of seamless brass tubing, and a chromium-plated copper reflector fitted with a wire mesh guard. This light is designed to withstand pressures equivalent to those at 500-foot depths.

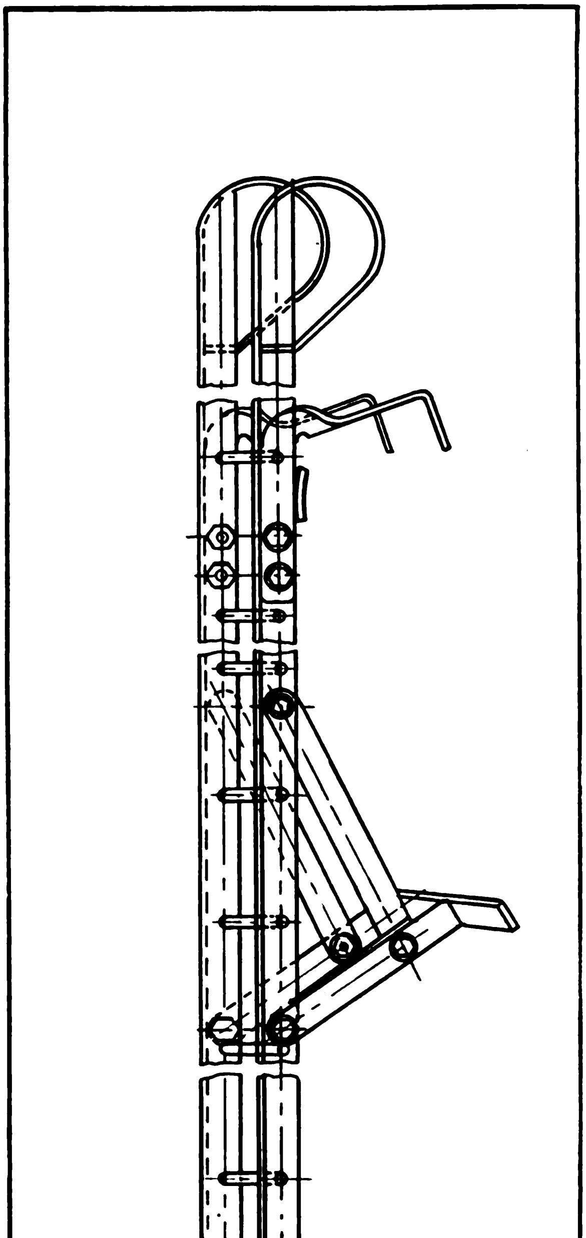


FIGURE 71.

FIGURE 72.

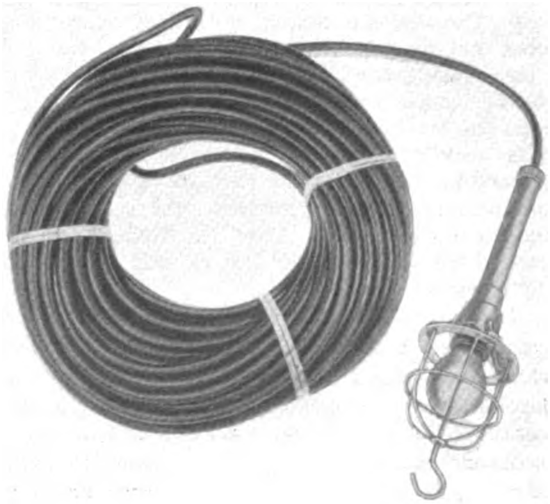


FIGURE 73.

(8) The stop watch is furnished primarily for timing the decompression stops.

(9) The *spare part box*, figure 75, is used for storing in one place small fittings, springs, and tools that are furnished with the diving outfit. The box is made of 22-gage sheet steel and is 15 inches long, 8 inches wide, and 9 inches deep. The box should be inspected regularly to guard against rusting.

(10) *Rubber cement* is furnished for patching the diving dress and for attaching the divers-tenders gloves or cuffs to the dress. As the cement contains a curing agent that will cause it to lose its adhesive properties within a short time if left exposed to air, it should be kept in a tightly sealed container when not in actual use.

(11) *Helmet and outfit chests*, figure 76, are used for stowing the diving helmets and the various other parts of the diving outfit. Both chests are made of sheet metal and are 37 inches long, 17 inches wide, and 23 inches high. The chests should be checked periodically to guard against rusting.

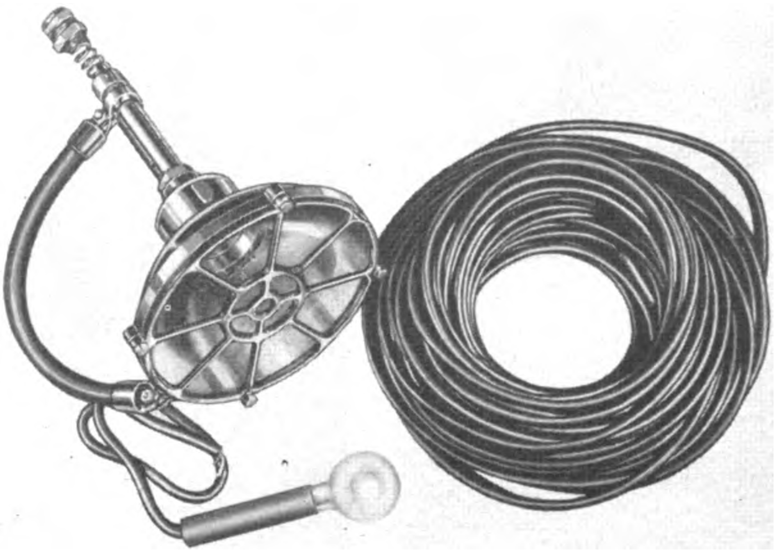


FIGURE 74.

FIGURE 75.

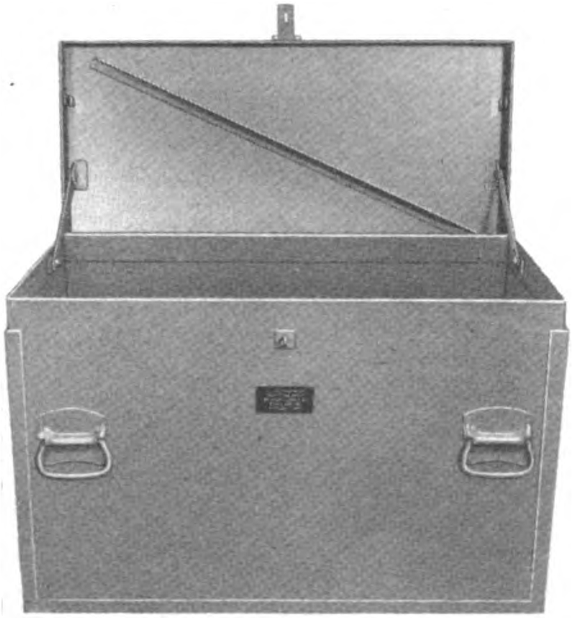


FIGURE 76.

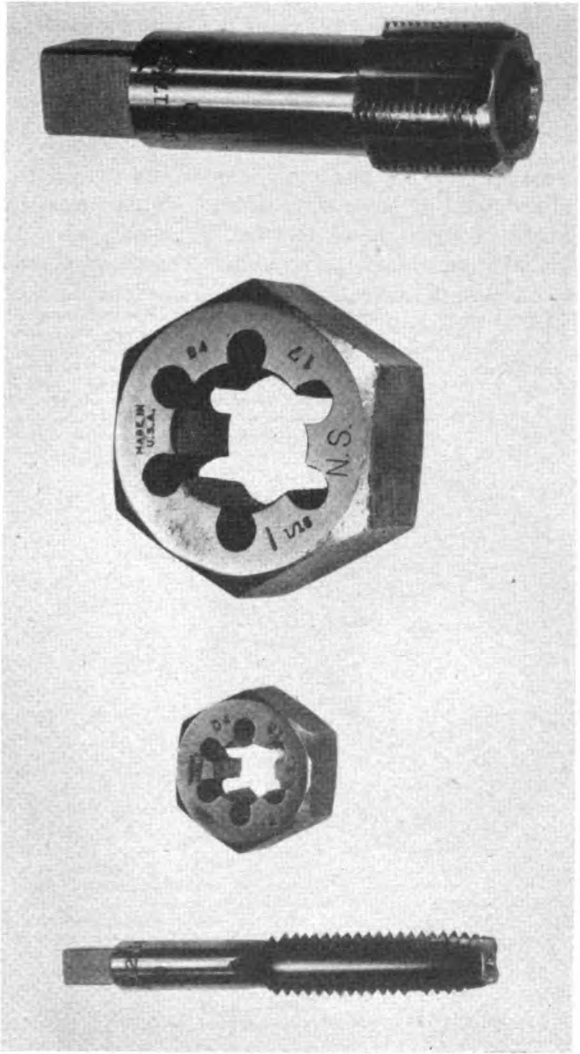


FIGURE 77.

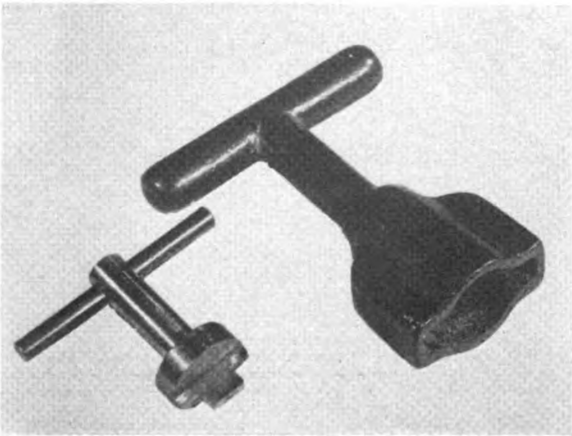


FIGURE 78.

FIGURE 79.

(12) *Dies and taps,* figure 77, are furnished for rethreading damaged bolts, nuts, couplings, and other diving fittings. There are two sets of taps and dies—one for rethreading the helmet breastplate studs and wingnuts—½-inch 12 threads. The other set is for rethreading air-hose fittings, reducers, manifolds, etc., 1$\frac{1}{16}$-inch 17 threads. The taps and dies sould be given a protective coating of heavy oil when not in use.

(13) *Wrenches* are furnished for the air-hose couplings, telephone couplings, and for securing the helmet breastplate nuts and for disassembling the safety air nonreturn valve, figure 78.

610. LIGHTWEIGHT DIVING OUTFIT

The Lightweight Diving Outfit, figure 79, consists of the following items: Breathing bag, standard rifle cartridge belt, leather belt, rubberized fabric dress, and mask.

611. BREATHING BAG

The breathing bag, figure 80, acts as a reservoir to conserve air and essentially serves the same function as a demand valve. With the old-style, shallow-water mask it is necessary to maintain the same flow of air during both the inhalation and exhalation part of the breathing cycle, thereby wasting a considerable percentage of the available air. By using a breathing bag the volume of air flow can be reduced because while the diver is exhaling, the breathing bag is being inflated with fresh air and then, during inhalation, air is received by the diver both from the air hose and from the breathing-bag reservoir. In order to realize fully its advantages, careful attention must be given to the detail of positioning and securing the bag and to adjustment of the air-control valve. To prevent resistance to breathing, the bag must be located around the neck at mouth level and adequately anchored in place. A few inches displacement up or down can completely nullify its advantages. The thin rubber intake flapper valve on the mask side of the attachment fitting must be maintained in flexible condition and in accurate alinement to prevent exhaled air from reentering the breathing bag, with consequent danger of carbon-dioxide poisoning. A shut-off cock is provided to bypass the bag in case of rupture or leakage. Whether the breathing bag is used will be dependent upon the available air supply and the diver's individual preference.

612. RIFLE CARTRIDGE BELT

A standard rifle cartridge belt, figure 81, with lead weights cut to fit the pockets is satisfactory when using the mask alone. The buckle used on the cartridge belt permits the belt to be readily removed, enabling the diver to surface rapidly in the event the air supply is lost or the mask is accidentally dislocated.

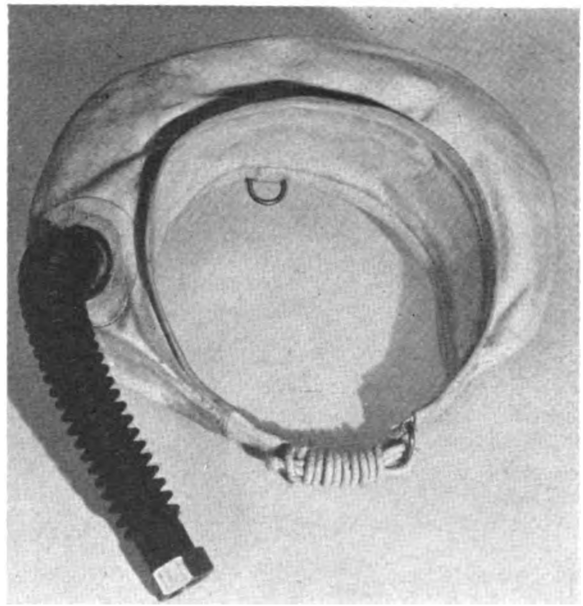


FIGURE 80.

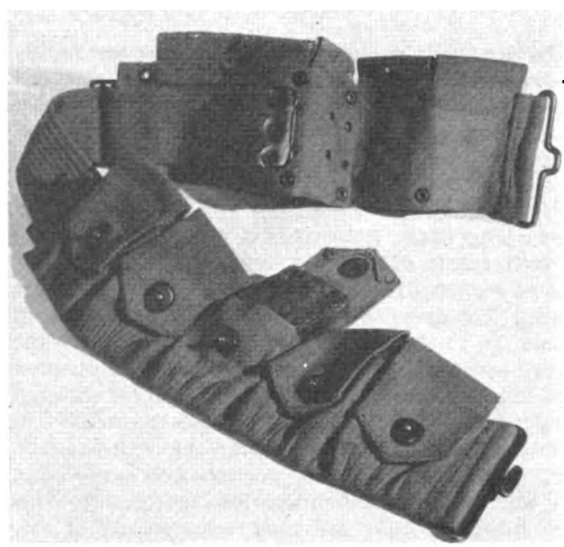


FIGURE 81.

613. LEATHER BELT

In order to compensate for the additional buoyancy gained when using the diving dress and underwear, a leather weighted belt (fig. 82) is substituted for the cartridge belt. The weight of the belt may be varied up to 45 pounds by removing or adding weight depending upon the amount of clothing worn, water condition, and the diver's preference. The belt buckle also permits the belt

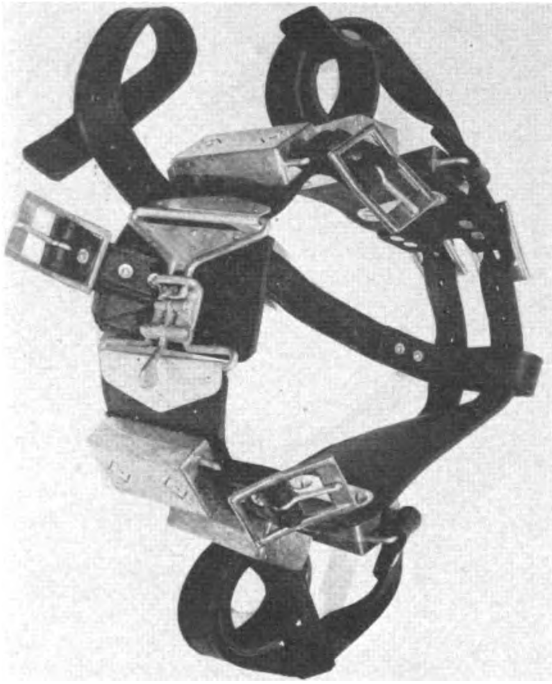


FIGURE 82.

to be discarded rapidly in the event the air supply is lost or the mask is accidentally torn from the face. In order to permit the belt to be discarded in an emergency, the shoulder straps should be crossed only in back.

614. LIGHTWEIGHT DIVING DRESS

(1) The dress, figure 83, is made from a rubberized fabric of two-ply construction, the outer ply of cotton drill and the inner ply of airplane cloth. The dress is made in one piece, with a hood cemented to the body of the dress, and covers the entire body with the exception of the face opening and hands. Entrance to the dress is made through a cylindrical opening in the back of the dress. In dressing, the diver enters through the back opening, feet first, pulls the lower portion well up around the waist, and then, bending forward, inserts arms and head. If cuffs are used, soap should be applied on the hands before dressing to facilitate putting the hands through the cuffs. If the diver's wrist is small, an elastic tubing should be used over the edge of each cuff to insure watertightness.

(2) After the entrance is made, the back opening is made watertight by gathering the material together and using the metal clamp. The following method of making a watertight seal is recommended: Fold the material into approximately 2½ pleats; then fold across the middle to make a five-ply bundle; finally, the bundle is doubled over and inserted in the metal clamp. After the watertight seal is made, the hood should be laced up the back

FIGURE 83.

so that it will fit as snugly as comfort will permit and in order that the hood volume can be reduced to a minimum.

(3) Cemented to the front of the dress hood is a thin rubber gasket which has a face opening extending from the forehead to the chin. The gasket should be placed under a slight tension in order to eliminate wrinkling, which would cause leaks when the mask is put on. The face opening of the gasket may be enlarged to fit the face. However, if the opening is enlarged, the rim should be folded over approximately one-fourth inch and cemented to prevent the gasket from tearing. The following method of replacing the face gasket is recommended:

(*a*) Remove old strapping gasket, and old cement from dress with benzine, carbon tetrachloride, etc.

(*b*) Sandpaper lightly the edges of suit hood where old gasket was attached, and the strapping for new gasket.

(*c*) Spread a thin film of rubber cement on each sanded surface and allow to dry until tacky. Repeat for two or three coats.

(*d*) As the last application of cement becomes tacky, press new gasket firmly into position on the hood. If marks left by removal of old gasket are followed accurately, the fit will be perfect.

(*e*) Cement old binding tape (or facsimile cut from patching cloth) over the seam. Allow to dry over night before use.

(4) As stated before, the principle of operation of the lightweight equipment is based on the elimination of air from the dress. In order to dispose of any air in the dress, an exhaust valve is placed in the top of the hood. The dress is improperly adjusted if accumulated air is prevented from entering the hood section from which it can be exhausted through the valve. In order to release the air trapped in the dress, the diver should enter the water slowly enough to permit the air in the suit to escape through the exhaust valve.

(5) Standard $^5/_{16}$-inch oxygen hose in 50-foot lengths is used to supply air to the diver. The hose is furnished with two female couplings and the necessary double male fitting. The hose should be secured to the diver's belt by a piece of marlin or other suitable arrangement in order to prevent strain or pull from being transmitted to the mask.

615. MASK

(1) The essential parts of the mask, figure 84, are the copper frame, rubber seal, plastic front window, inlet valve, exhaust valve, and head harness. The copper frame and rubber are molded in a shape that provides a seal with the dress hood facepiece and provides a broad field of vision with minimum distortion. The mask complete with fittings does not include the air control valve or nonreturn valve, which are furnished as separate items.

FIGURE 84.

(2) Air enters the mask through the two-way inhalation valve on the side of the mask. When the inhalation-valve handle is pointing toward the rear, air enters directly from the air line into the mask. When the handle is pointing forward, air is entering both the breathing bag and the mask simultaneously. The section of the inhalation valve on the inside of the mask is a rubber flapper valve which prevents air in the mask from escaping back into the breathing bag.

(3) On the opposite side of the mask from the inhalation valve is the exhaust valve, consisting of a rubber disk which opens during exhalation and closes by water pressure at the end of the exhalation period. The rubber disk is held in place by an adjustable stem. The adjustment of the stem is usually set in the proper position. However, if the entire mask seems to bounce or gives a "water hammer" effect, the valve stem should be readjusted. The mask is held in position by means of an adjustable head harness.

(4) While the mask is reasonably rugged, care should be taken in the handling and storing of it. The mask should be kept away from sunlight, heat, and oil when not in use and should be thoroughly cleansed with fresh water and dried before storing.

616. CONTROL VALVE

The control valve, figure 85, used to control the quantity of air entering the mask is a modified standard commercial globe valve. The valve is attached to the inhalation valve on the mask. It is placed so as to maintain a fixed position, and so it will be in the most accessible place for controlling the air supply where the supply is least likely to be closed by accidentally hitting the valve handwheel. The control valve handwheel should be maintained sufficiently tight by means of the packing-gland nut to prevent the handle from turning loosely or too readily.

FIGURE 85.

617. NONRETURN VALVE

(1) The nonreturn valve, figure 86, is located between the air-control valve and the air hose. The purpose of the nonreturn valve is to prevent the

diver from being injured by "squeeze" in the event that the air hose bursts or the supply system becomes so seriously damaged as to fail to maintain an air pressure within the mask sufficient to maintain a pressure equilibrium. Under either condition the air pressure to the hose would decrease suddenly and, should there be no nonreturn valve, the compressed air in the mask would escape through the air hose, thereby causing the pressure within the mask to become less than the external pressure, thus causing a "squeeze." The mask being rigid, the effect of the greater external pressure would be to squeeze the diver's face into the mask. This condition might have serious results.

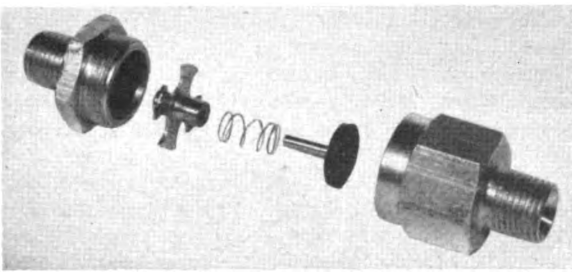


FIGURE 86.

(2) The use of the nonreturn valve is so essential that no diving, regardless of depth, should be undertaken unless there is a nonreturn valve operating satisfactorily in the line. A simple method of determining whether the valve is operating satisfactorily is by attempting to blow smoke through it in a direction opposite to the normal flow of air.

618. SPARES

Spares consist of cement, patching cloth, face gasket, head harness, dress and mask flapper valves (fig. 87).

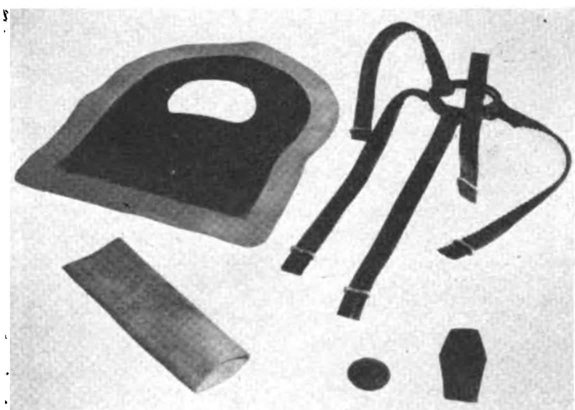


FIGURE 87.

619. LIFE LINE

The life line should be made up on board from 1¼-inch circumference manila rope or sisal rope of equal strength. The life line is secured around the diver's chest, with the line extending to the surface from the front of the diver. The line should not be connected to or looped around the weighted belt and should be arranged so there will be no interference with the releasing of the belt. The life line serves two purposes—first, for making normal and emergency ascent and, second, for maintaining communications with the surface. In the event of an emergency ascent involving either the loss of air or face mask, the diver shall continue to exhale during the ascent. If this is not done, air embolism is likely to result. All divers should be familiar with hand signals listed in article 582.

620. OTHER EQUIPMENT

(1) The remaining items—cuffs, gloves, knives, overalls, shoes, and underwear of the lightweight diving outfit—are the same as those furnished with the deep sea diving outfit, previously described.

621. MAINTENANCE OF EQUIPMENT

(1) Every effort shall be made to keep the diving apparatus in repair and ready for immediate use. With this in mind the following general recommendations on the maintenace of equipment are made.

(2) Diving apparatus should not be stowed in compartments below the water line or in places difficult of access in time of emergency. All chests of diving apparatus should, when sufficient space is available, be habitually stowed under cover, away from steam pipes or excessive heat. When it is necessary to keep the equipment in the open and exposed to the weather, suitable canvas cover should be provided and used to protect the outfit.

(3) *Spare parts* of diving apparatus not required for immediate use shall be kept in suitable storeroom space and, when drawn for use, shall be replaced by new parts immediately.

(4) *Leather articles* used in water soon will become dry and hard and are likely to crack unless properly cared for. Finished leather contains a certain amount of oil and grease and, when this is washed out, the leather loses its flexible quality and soon will show signs of deterioration. Occasionally the leather parts of diving apparatus should be given a coat of neat's-foot oil, well rubbed in, so the articles will not be disagreeable to handle. To treat leather properly with neat's-foot oil, place the article to be treated in as flat a position as possible. Then soak a rag in oil and apply one coat of oil at a time until the oil soaks through on the other side. Do not attempt to apply the oil from both sides at once and do not submerge the article to be treated in the oil.

(5) *All metal parts* of diving apparatus should be kept free of rust or verdigris, in efficient working order, and protected from injury. Special precautions are to be taken with valves, valve seats, and

like parts. Parts not kept painted, polished, or galvanized should be kept lightly coated with oil.

(6) *Rubber.*—As oil or grease is specially destructive to rubber, parts of diving apparatus composed of rubber such as dress, hose, cuffs, etc., must be protected from oil or grease in any form. Diving dresses and other parts consisting of rubber with cloth coverings or cloth insertions must not be put away while damp or wet. Rubber materials, when folded, acquire a permanent set at the bends and later, when used, are likely to crack open or break at these points. Such materials should so far as practicable be stowed without folding. The instructions for making repairs to diving dresses apply also to other rubber or rubberized materials.

(7) The longevity of rubber is limited by the characteristics inherent to material of this nature. In using rubber parts of diving apparatus, preference should be given to those of the oldest date of manufacture so far as it is practicable to do so without jeopardy. For example, hose, so far as concerns its use as diving air hose, has a stipulated life limitation. The entire amount of diving air hose furnished with diving outfits is seldom required for an individual routine diving operation. Consequently when new hose is obtained to complete a diving outfit, it should not be put into use until the old hose has reached its age limitation or has become unserviceable for further use.

(8) All cotton and woolen goods should be kept clean, dry, and in repair. When not in use, they should be stowed with a larvicide such as naphthalene and kept tightly wrapped in paper. Dirty woolens should be washed with soap and tepid fresh water, thoroughly rinsed, and carefully dried.

622. INSPECTIONS AND TESTS

(1) Upon receipt of diving outfits, in whole or in part, the gear shall be carefully inspected, tested, and made ready for immediate use in every detail. It will thereafter be maintained in the best possible state of efficiency.

(2) When it is known that the commanding officer is about to inspect the parts of the ship in which diving apparatus is stowed, the apparatus should be conveniently arranged for his inspection. All chests should be unlocked, the covers opened, and the men should stand by to exhibit the contents as he may require.

(3) All diving apparatus, except spare parts, shall be inspected once each week for cleanliness, conditions of stowage, etc. Helmet valves, faceplates, and fittings shall be examined; telephone batteries (if telephones are of battery type) tested; diving dresses inspected for damage or dampness and repaired and aired, if necessary; dirty woolens washed and dried; oil separators cleaned, if necessary, and their filters washed in hot water and dried; diving knives and their cases, all tools and metal fittings cleaned and lightly oiled; diving shoes, belts, etc., attended to; lengths of air hose that have been coupled together a long time shall be parted, the coupling threads lightly oiled, cleaned of grease or dirt; the interior of all chests must be cleaned of any oil, grease, or dirt.

(4) All diving equipment on board ship shall be closely inspected once each month. Each outfit shall be inspected as to its completeness and satisfactory condition. Air-regulating escape valves, air control, safety, and nonreturn valves of the diving helmet, and all valves of the diver's air supply system shall be tested for satisfactory operation. Diving telephone systems shall be checked and tested.

D. DIVER'S AIR SUPPLY

631. RATE OF BREATHING

The average man at rest breathes about 0.25 cubic foot of air per minute. The breathing is so regulated as to keep the partial pressure of alveolar CO_2 steady at about 5.25 percent of an atmosphere (wet analysis) though the volume percent under conditions of varied barometric pressure differs widely. This means that at rest and at normal atmospheric pressure the alveolar CO_2 is maintained at about 40 mm. mercury, since 40 is 5.25 percent of 760 mm. mercury (/atm.) If the alveolar CO_2 pressure falls, breathing is diminished, and if it rises, the breathing is increased. Moderate work increases the CO_2 secreted by the lungs three or four times, and hard work six to eight times the normal resting amount; therefore, the air breathed is increased. Hence, it is the partial pressure of the alveolar CO_2 that regulates the rate of breathing.

632. PRODUCTION OF CARBON DIOXIDE

The average adult man at rest produces about 0.008 cubic feet of CO_2 per minute (measured at atmospheric pressure). The diver at rest produces about 0.02 cubic foot per minute, and when performing hard work, about 0.06 cubic foot of CO_2 per minute (measured at atmospheric pressure). As the diver is constantly exhaling CO_2 into the helmet, it is evident that unless the helmet is ventilated constantly with fresh air in sufficient quantity, he would soon suffer from the effects of an accumulation of CO_2.

633. AIR SUPPLY REQUIRED BY DIVER

(1) Since 3 percent CO_2 at atmospheric pressure is about the maximum that can be tolerated without distress, it is essential that this equivalent partial pressure percentage should not be exceeded in the helmet. To keep the CO_2 content of the helmet within this maximum permissible percentage, a minimum air supply of 1.5 cubic feet per minute (measured at the absolute pressure to which the dive is made) is necessary. Since, according to Boyle's law, the volume of a gas is inversely pro-

portional to the pressure, the air supply measured at the surface must be increased in proportion to the absolute pressure. Since each 33 feet of sea water exercises a pressure of 1 atmosphere, the air supply measured at the surface must be increased one thirty-third for each foot of depth. Using the reciprocal 0.0303, the minimum air supply for any depth may be calculated:

$$S=1.5(1+F\ (0.0303)),$$

in which S is the required air supply in cubic feet of free air (measured at surface), and F is the number of feet the diver is below the surface. For example, one diver going to 100 feet would require 6.05 cubic feet of free air.

$S=1.5\ (1+100\ (0.0303))$
$S=1.5\ (1+3.03)$
$S=1.5\times4.03=6.05$ cubic feet of free air.

The figure of 1.5 cubic feet of air is considered to be the minimum air requirement, with the diver doing very little work or at rest. Better ventilation than this is essential and arrangements, wherever possible, should be made for supplying three times (4.5 c. f. m.) this quantity of air per minute. This will provide sufficient ventilation to keep the CO_2 content within the maximum permissible percentage under all working conditions.

(2) For example, 2 divers going to a depth 80 feet would require:

$S=4.5\times$ number of divers $(1+80\ (0.0303))$
$S=4.5\times2\ (1+2.4)$
$S=4.5\times2\times3.4=30.6$ cubic feet of free air.

In the above illustration diving to a depth of 80 feet requires that air be furnished (not considering friction losses) at a minimum pressure of 50.3 p. s. i.: 33 feet of water exerts a pressure of 1 atms. (14.7 p. s. i.) or 0.445 p. s. i. for each foot of depth.

Absolute Pressure on Bottom $=14.7+(0.445\times80$ feet$)=50.3$ p. s. i.

(3) It is considered advisable, whenever possible, to maintain in the diver's hose an air pressure at least one atmosphere in excess of the absolute bottom pressure. The excess pressure is provided so that there will be immediately available additional pressure over absolute bottom pressure to compensate for the increase in pressure in the event that the diver falls, thereby possibly preventing a "squeeze." The amount of overbottom pressure to be maintained in the line will depend primarily upon the available pressure of the air source, whether the type of work will be such that the possibility of falling is present, how rapidly the diver or the tenders will be able to check the fall, etc. A pressure of 30–50 p. s. i. overbottom pressure is considered desirable.

634. SOURCES OF COMPRESSED AIR

There are four general sources of compressed air:
(*a*) Gas-driven air compressors.
(*b*) Hand pumps.
(*c*) Air flasks.
(*d*) Shipboard air (ASR Divers' Air System).

635. TYPES OF AIR COMPRESSORS

(1) To meet the various diving requirements of the large number of activities having diving equipment and that are called upon to undertake diving operations, two general types of air compressors are available: Heavy duty and lightweight. The type compressor to be used will depend upon the type of diving operations to be undertaken. Operations that require keeping a diver or divers in the water for extended periods, where the compressor will be subjected to rigorous usage, or where the work is located in such a place that the diver cannot make a direct ascent to the surface, or for reasons of decompression, the heavy-duty compressor should be used. The lightweight air compressor is used for minor jobs, inspection, or searching, where ascent can be made direct to the surface without decompression, where the compressor is not subjected to continuous use, etc. While the heavy-duty compressor may be substituted for the lightweight compressor for minor diving jobs, the lightweight compressor should not be used where the working condition requires the use of a heavy-duty compressor.

636. HEAVY-DUTY AIR COMPRESSOR

(1) The air compressors furnished with the deep-sea diving outfits are the heavy-duty portable units designed to operate for long periods of time with maximum reliability. The units have a rated capacity of 55 c. f. m. with an operating pressure of 100 p. s. i. These compressors are furnished to activities having an allowance of deep-sea diving equipment and who are called upon to undertake extensive diving operations—repair ships, tenders, salvage vessels, tugs, and other activities as approved by Bureau of Ships.

(2) There are at the present time two makes of heavy-duty compressors being issued with the deep sea outfit. The unit shown on figures 88 and 88a is a four-cylinder engine with two single-stage compressor cylinders in a one-piece "en bloc" cylinder construction, with a crankshaft common to both the engine and the compressor. The crankcase, although in one piece, is divided and sealed between the engine and air compressor to prevent any engine fumes and gases from entering the compressor system and contaminating the breathing air. This unit has an over-all length of 83 inches, width 23 inches, height 52 inches, and a total weight of 1,800 pounds.

(3) A mechanical flyball type governor is located on the outside of the timing gear cover and is connected to an auxiliary butterfly valve for limiting

the maximum engine speed. The slow-down assembly, connected to the throttle body butterfly, controls the acceleration and deceleration of the engine in relation to the loading and unloading of the compressor cylinder. This unit has a water cooling system consisting of a large capacity radiator, centrifugal water pump, thermostat, and fan. The cooling system is designed so that the compressor will operate satisfactorily at ambient temperatures ranging up to 140° F. An air receiver having a volumetric capacity of 5 cubic feet with a working pressure of 125 p. s. i. is mounted in a vertical position and is contained within the limits of the frame. The receiver is connected to the discharge ports of the compressor cylinder head by a flexible metallic connection.

(4) The second unit, figures 89 and 89a, consists of a 4-cylinder, 4-cycle, V-type engine that develops 23 horsepower at 2,200 r. p. m. (full load). The engine is connected by multiple V-belts to a 2-cylinder single-stage air compressor. The unit has an overall length of 70 inches, width 32 inches, height 37 inches, and weight of 1,750 pounds.

(5) The compressor control regulator consists of a mechanical pilot valve, delay valve, engine throttle control, and cylinder unloader. A governor automatically regulates the engine speed by controlling the throttle valve of the carburetor. When the load on the engine decreases, the governor closes the throttle valve and will not let the engine operate beyond its maximum rated speed. Both the engine and compressor are air cooled. An air receiver having a 1.69-cubic-foot capacity at an operating pressure of 125 p. s. i. is located at the compressor end of the unit and acts as a storage tank and pulsation chamber.

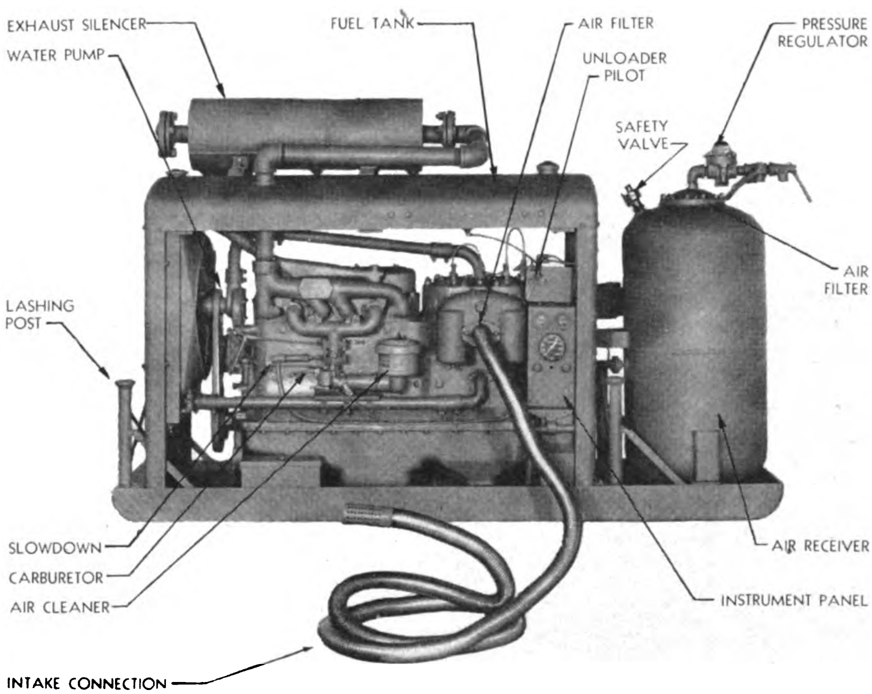


FIGURE 88.—Air compressor, 60G1, Carburetor side.

637. AIR PURIFICATION

(1) In order to insure that air of adequate purity and within reasonable limits of pressure variation is furnished, several special pieces of equipment are supplied with the compressor. To prevent the breathing air from being contaminated with the engine exhaust fumes, both compressor models are furnished with a flexible metallic pipe extension approximately 15 feet long, for connection to the compressor intake. The compressed breathing air is exhausted into a volume tank where, as a result of expansion, it is cooled and some of the oil and moisture are eliminated. There is a tendency in all oil-lubricated compressors for the compressed air to pick up a quantity of lubricating oil and vapor and to carry them over to the diver's line. In order to prevent this condition, the air is passed from the receiver through an oil filter where the oil vapors are removed from the air.

(2) It is essential that the oil filter be kept in first-class condition, otherwise the breathing air will become contaminated with oil and become exceedingly repugnant to the diver. In addition to the contamination of the breathing air, oil in the air will accelerate deterioration of the diver's hose. The air is then passed from the oil filter through a pres-

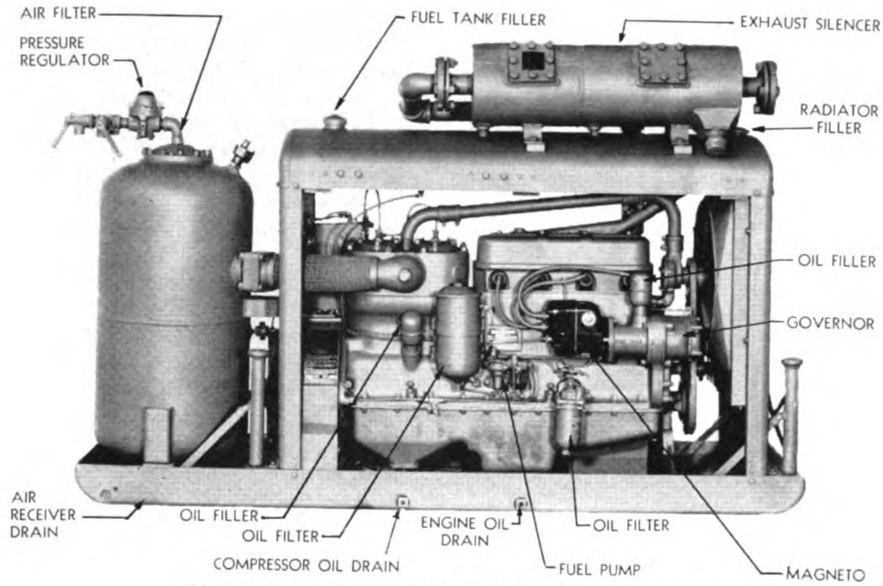
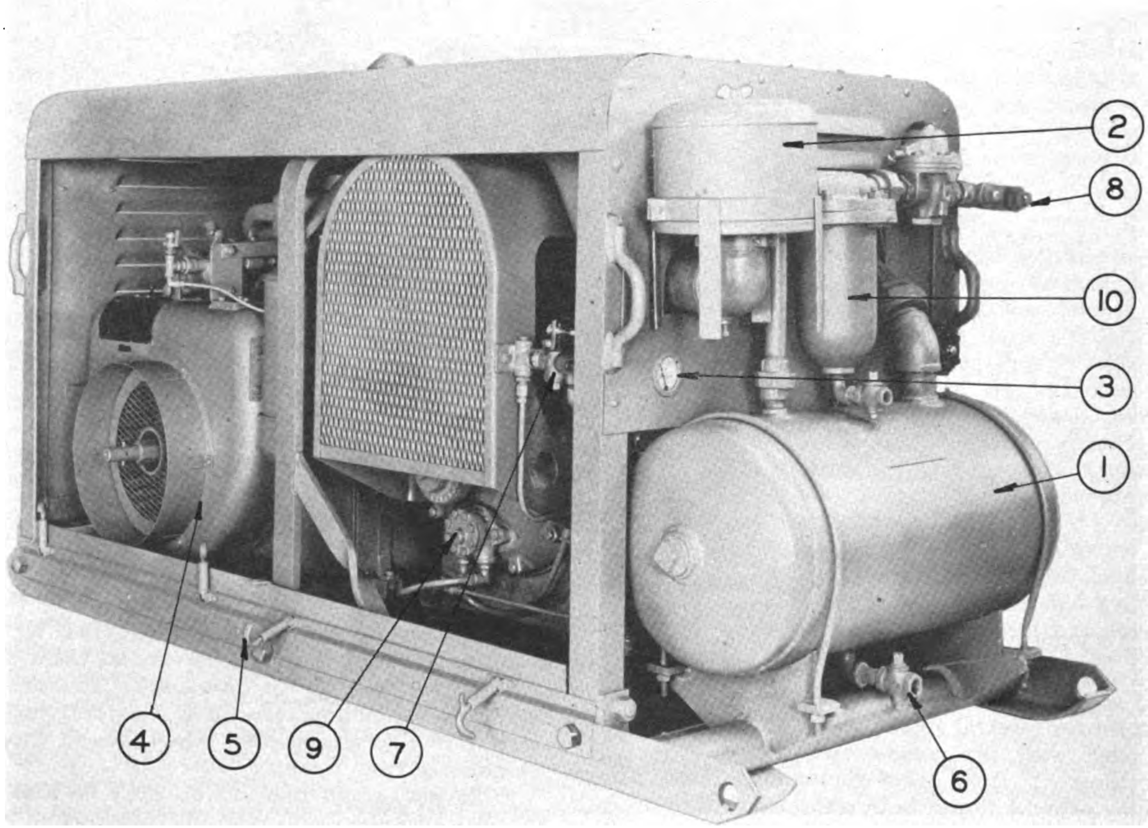


FIGURE 88a.—Air compressor, 60G1, Magneto side.



Right side of unit (side covers removed).

1. Air receiver.
2. Compressor air filter.
3. Oil pressure gauge.
4. Engine.
5. Hood clips.
6. Air receiver drain.
7. Pilot valve.
8. Hose connections.
9. Oil pump.
10. Air line filter.

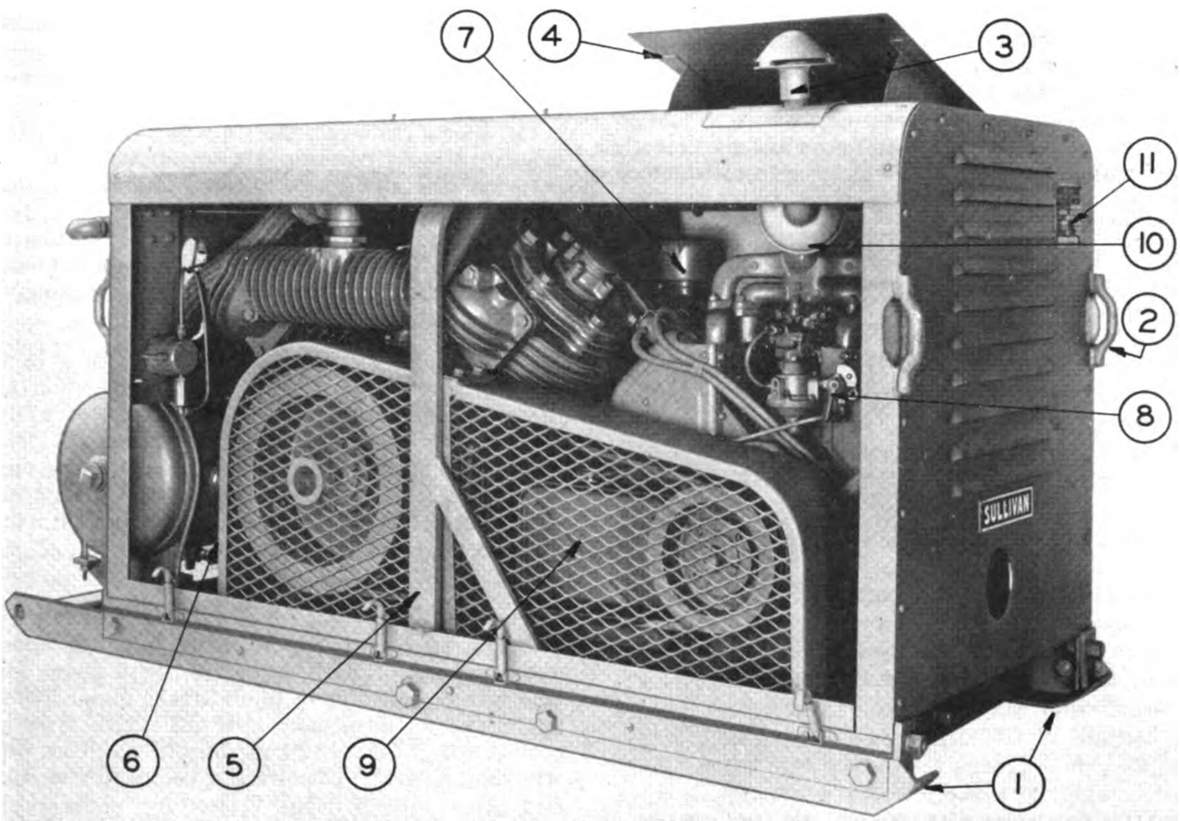
FIGURE 89.

sure regulator that is designed to furnish air to the diver at constant pressure. In this way the pressure fluctuations between the fully loaded and unloaded compressor position will not be transmitted to the diver, with the result that the necessity of the diver changing the valve setting is reduced.

638. MAINTENANCE OF COMPRESSORS

(1) The compressor, being one of the most vital items of the diving equipment, requires that it be maintained in first-class operating condition at all times, regardless of whether it is being used or stowed. The compressors should be kept clean in order to maintain maximum efficiency. The unit should be gone over frequently; and, in addition to removing dirt and grease, many troubles caused by loose connections, nuts, or cap screws will be discovered before they develop.

(2) *Cooling.*—To maintain the water-cooled compressor in efficient operating condition, the radiators should be filled with clean soft water. The use of rain or distilled water should only be used in emergencies, and the use of hard water should also be avoided because of the tendency for scale to form in the water jackets and passages. Radiator hose connections should be inspected at time of draining and replaced if necessary. When using the compressor in cold climates, adequate antifreeze should be added. In the event that the engine overheats, water should not be poured into the cooling system, as sudden changes in temperatures may cause the cylinder head to crack. The radiators should be filled only after boiling has ceased and engine has cooled, then add the water slowly. The air-cooled units depend for cooling upon air being forced over the large exposed area of the compressor and engine cylinder head and cylinder fins. It can be readily seen that for adequate heat dissipation it is necessary to keep the cylinder head and cylinder cooling fins free from foreign material and to make sure that there are no obstructions in the engine shrouding or air-intake grill to hamper air circulation. This is essential when using the unit under hot-weather conditions.



Left side of unit (side covers removed). FIGURE 89a.

1. Skid.
2. Lashing ring.
3. Exhaust stack.
4. Ventilator.
5. Lifting bail.
6. Bail guard.
7. Engine air filter.
8. Fuel pump.
9. Fuel tank.
10. Muffler.
11. Name plate.

FIGURE 89a.

(3) *Lubrication.*—One of the important considerations in the maintenance of the compressor in satisfactory condition is the one of lubrication. In starting the compressor after storage the oil in the unit should be drained and oil of proper viscosity for the prevailing climatic conditions should be placed in the engine and compressor. During the time that the unit is in use the quantity of oil in the crankcase should be kept at the "Full" mark on the dip stick. If necessary the oil supply in the engine and compressor should be checked daily and replenished as required. However, overfilling should be avoided as it may permit the connecting rods to dip into the oil supply, thus splashing an excessive quantity of oil on the cylinder walls, causing smoking, oil pumping, excessive carbon deposits. All oil containers and funnels should be kept clean and well covered when not in use. It is essential that oil pans be drained and refilled with new oil regularly, since oil gradually accumulates small particles of dust, grit, metal, etc., that will cause unnecessary wear. The oil pans should only be drained when oil is hot.

639. OPERATING PRECAUTIONS

(1) In addition to the above general maintenance problems, there are a number of precautions that should be taken while using the compressor units. When the compressor is in use, personnel should be assigned whose duties are concerned primarily with the maintenance of the compressor in satisfactory operating condition. The personnel assigned to the compressor should be responsible for removing the unit from storage and preparing the unit for use—removing protective covers, seals, adding proper lubrication, gasoline, cooler, starting unit, insuring there is no contamination of breathing air, the unit is running smoothly, etc. Any indications that the unit is not running smoothly or gives any indication of failure should be reported immediately to the diving officer, and the diver brought to the surface in the prescribed manner. The compressor should be run until it is warmed up and running smoothly before any attempt is made to put a diver over the side.

(2) The compressor should never be operated in an unventilated room. However, when it is necessary to operate a unit indoors, a pipe should be run from the engine exhaust to the outside atmosphere. Regardless of whether the unit is operated indoors or outside, it should never be covered so that the engine exhaust fumes are thrown onto the compressor intake. The compressors are equipped with lashing rings or posts for securing the compressor in position. While the units will operate satisfactorily when tipped 15° in any direction, it is preferable that the unit be operated on a horizontal plane whenever possible.

640. STOWAGE MAINTENANCE

(1) Due to the fact that diving operations are not conducted continuously but rather at intervals, resulting in the equipment sometimes standing idle for long periods of time, the problem of stowage maintenance must be given careful consideration. In preparing the compressor for stowage it should be stored in a dry, protected place. If the unit is to be stored for a period of 30 days or more, the following general precautions should be taken:

(2) The engine and compressor crankcases should be drained and refilled with a light engine oil plus an antitrust preventive. Allow the engine to run for a few minutes to permit the oil to reach all passages. As gasoline contains gums which separate and adhere to the various valves and passages which result in serious trouble, the entire fuel system should be drained. Remove spark plugs and pour a few ounces of antirust oil into each cylinder. The engine should then be turned over a few times with the crank to work oil down around the piston rings. Every entrance to the unit—exhaust pipes, cylinder head, breather, oil filler, carburetor, oil filters—should be sealed carefully to prevent entrance of moisture. In the case of the water-cooled compressor the cooling system should be drained, flushed, and refilled with fresh, clean, soft water and antifreeze if required.

(3) When removing the unit from storage, the protective seals covering all entrances should be removed, the fuel tank filled, proper lubrication should be added, etc. The compressor should then be started and run a sufficient length of time to insure that it is operating normally before any attempt is made to undertake diving operations.

641. INSTRUCTION BOOKS

Each compressor unit is furnished with a complete instruction book containing information on the operation, maintenance, stowage, and parts list of the engine, compressor, and accessories. The instruction book should be retained with the unit at all times, and personnel using the diver's air compressor should be completely familiar with the information in the instruction books.

642. LIGHTWEIGHT AIR COMPRESSOR

(1) The lightweight diver's air compressor is intended to be used by the many activities whose duties are not primarily concerned with diving but who may be called upon to undertake minor diving operations at infrequent intervals. This type of compressor is furnished generally to auxiliary vessels, landing craft, patrol craft, combatant vessels, and other miscellaneous vessels for undertaking minor diving jobs, such as inspection, searching, clearing lines, etc. In addition the lightweight compressor is issued as supplementary equipment to repair ships, tenders, salvage vessels, etc., for use when called upon to do minor diving jobs away

from the vessel. It is important that it be clearly understood that the lightweight air compressor cannot be used as a substitute for the heavy duty diver's air compressors.

(2) The assembly consists of a twin head type compressor directly connected to a gasoline-driven engine. The unit is mounted in a tubular frame for protection of the unit and absorbing the air pulsations. The over-all dimensions of the compressor unit are 24 inches long, 17½ inches wide, 22¾ inches high, and weighs approximately 125 pounds.

(3) The compressor, figure 90, is of the semi-diaphragm air seal type. The two pistons operate opposed to each other by means of an eccentric on the engine shaft. On the intake stroke a partial vacuum is created between the diaphragm air seal and the compressor plate. On the compression stroke the inlet valves close, and the air trapped between the plate and diaphragm air seal is compressed and then forced through the exhaust valves. The air hose manifold has three outlets—one outlet is threaded to take the standard deep sea diver's air hose coupling; the other two outlets are threaded to take the standard 5/16-inch oxygen hose coupling.

(4) In order to maintain an adequate amount of grease in the compressor roller and needle bearings, it is essential that they be inspected after each 30 hours of operation and grease added if necessary. In putting grease in the bearings, caution should be exercised to insure that too much grease is not used, as this condition is as apt to cause the bearings to "freeze up" as would not enough grease.

(5) The engine is a standard single-cylinder, 4-cycle, air-cooled type developing 1.9 horsepower at 2,400 r. p. m. It has a magnetic type ignition system, splash lubrication system, oil bath type air cleaner, exhaust muffler, and a gravity float feed type carburetor.

643. AUXILIARY AIR SUPPLY IN CASE OF COMPRESSOR FAILURE

(1) In order to provide the greatest possible degree of safety, provisions should be made to furnish air to the divers from an auxiliary air supply in the event the compressor fails. The following standby arrangements should be made:

(*a*) Vessels having a shipboard supply of air should arrange suitable outlets with necessary valves so that a line can be run to the manifold on the diver's air compressor during diving operations.

(*b*) Vessels that do not have a shipboard air supply should use a compressed air flask as a standby.

(*c*) A shallow water hand pump may be used as a standby if the depth of dive does not exceed 36 feet.

(2) The lightweight compressor should be used only on diving jobs where the diver can make a direct ascent to the surface in the event the compressor fails. The compressor would not be used for diving to greater depths than 60 feet, and the maximum length of time that the diver spends in the water shall be such that no decompression will be required. For example the maximum duration of a 60-foot dive would be 55 minutes.

(3) Any information contained in the compressor manufacturers' catalogs as to the depth to which the compressor can furnish air or the use of a standby air supply that conflicts with the above instructions should be disregarded, and the Bureau's attention invited to that fact.

644. STORAGE OF LIGHTWEIGHT COMPRESSOR

As the lightweight compressor is furnished to activities that will undertake very limited diving operations, the equipment will be subject to very long periods of storage. It is, therefore, important that the compressor be prepared properly for storage. Prior to storage the water should be removed from the frame by running the compressor, with all outlets closed to build up the maximum pressure, then open the drain cock in the bottom of the frame. Gasoline should be drained from the tank and the engine run until it stops. Remove spark plug, and spray into the cylinder head and block sufficient rust preventive to cover the cylinder walls and valve surfaces. The engine should be drained of oil when hot and refilled with a light engine oil plus an anti-rust preventive. When the engine is to be used, the light oil should be drained and oil of proper viscosity, depending on temperature conditions, should be added. All exposed parts should be thoroughly dry before storage. If the compressor and engine have been exposed to salt water or spray, wash down with fresh water. Check all connections for tightness and seal every entrance to the unit to prevent moisture from entering. Cover frame with canvas and stow in a dry place. If the unit is stowed for more than 1 month, the compressor should be run and the above process should be repeated at the end of each 30 days.

645. HAND PUMPS

(1) The hand pump was issued in the past with the deep sea diving outfits for undertaking diving operations at moderate depths. However, the limited quantity of air furnished by the pump and the quantity of personnel required to keep the pump operating did not make it suitable for the tremendous amount of salvage work undertaken during the war. The hand pump has been generally replaced by the gas-driven compressors for all heavy diving work.

(2) In utilizing manually operated diving air pumps to furnish air for divers, it is evident that the delivery of the amount of air required by a diver at various depths of submergence under water depends upon the capacities of the pumps, the number in

use, and the rate of pumping. As the capacity of the standard diving pump is small and as the rate of pumping may be varied only within small limits, which become less and less as the pressure increases, it is apparent that, with only one diving pump to furnish air, the depth to which a diver may descend and perform useful work is limited to comparatively shallow depths. If the pump so used is not efficient, the depth of dive will be further restricted.

(3) When using manually operated diving air pumps to furnish air for divers, the following conditions shall be observed:

(*a*) Arrangements shall be made to furnish at least the minimum allowable air supply (1.5 cubic feet per minute, measured at the absolute pressure to which the dive is to be made) to each diver, and, if practicable, a reserve air supply.

(*b*) Arrangements shall be made to insure the dispatch of a relief diver.

(*c*) More than one diver shall not be permitted to dive simultaneously from the same diving pump or group of pumps except under the following conditions:

(1) Where one diver is working on the bottom and an emergency occurs requiring descent of a relief diver, the relief diver may be supplied with air from the same pump or group of pumps, provided the pump reserve capacity is ample to fill the requirements of two divers at the depth of the dive.

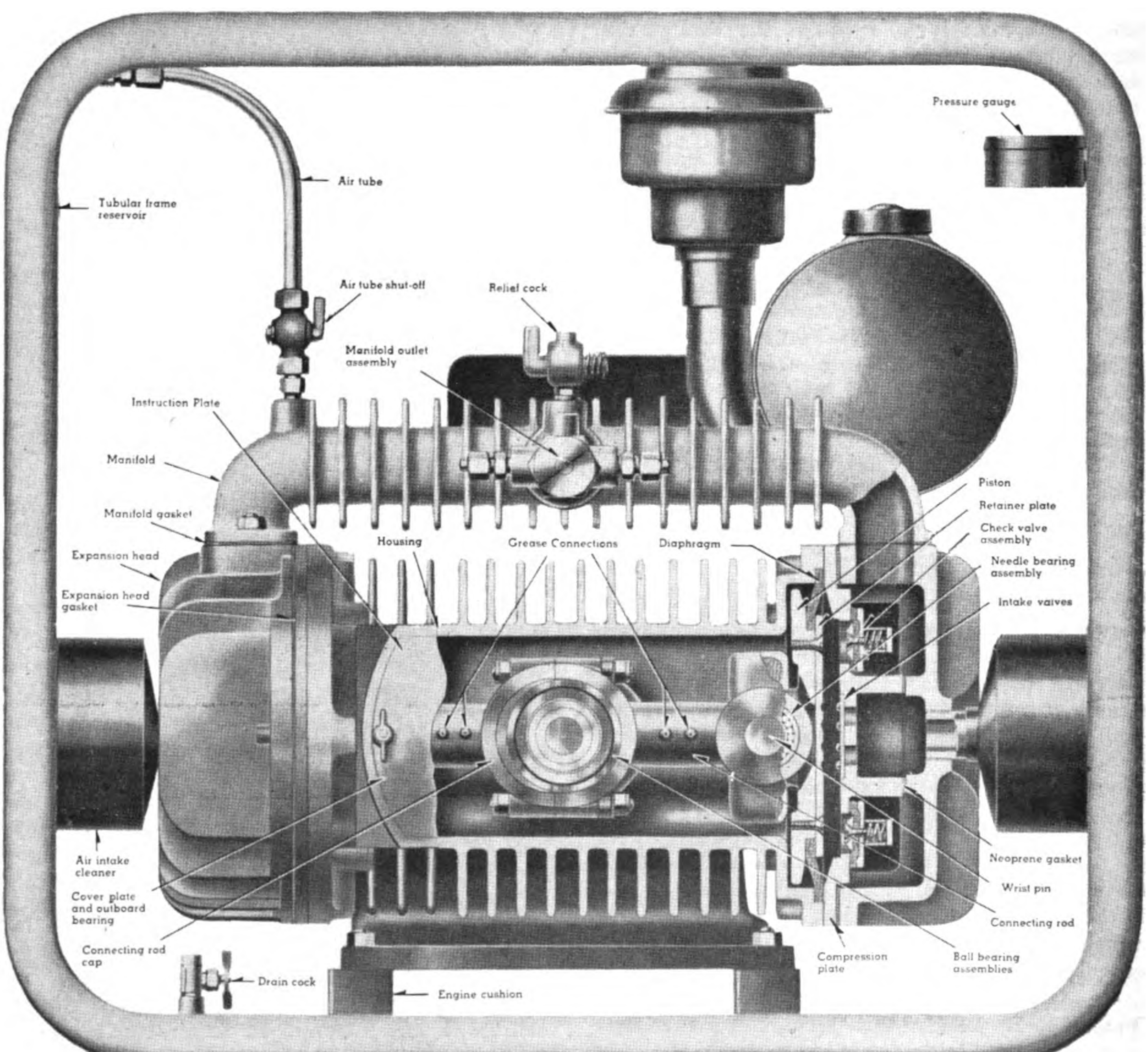


FIGURE 90.

(2) Where the efficiency of the pump or pumps is sufficiently high and the water sufficiently shallow and there is no danger of the divers becoming foul of obstructions on the bottom, two divers may dive simultaneously from the same pump or group of pumps, provided an adequate reserve supply of air is available for a relief diver.

(*d*) The rate of pumping shall be regular.

(*e*) If the air being supplied to a diver is uncomfortably warm, cold water shall be placed in the cisterns of diving air pumps, and kept cold by the addition of ice if necessary.

646. REQUIRED CAPACITY OF PUMPS

(1) Assuming a diving air pump to be 100 percent efficient at all pressures, the number of revolutions per minute the pump should be run to furnish the minimum allowable air supply to one diver may be determined as follows:

When

D=Depth of sea water, in feet, to which dive is made.

N=Number of cubic inches of air pump will furnish per revolution measured at atmospheric pressure.

R=Number of revolutions per minute to furnish 1.5 cubic feet (2,592 cubic inches) of air per minute, measured at atmospheric pressure.

X=Number of revolutions per minute to furnish allowable air supply (1.5 cubic feet per minute at D).

$R=\frac{2{,}592}{N}$ and

$X=R\ (1+D(0.0303))$.

E=Efficiency of pump.

$$X=\frac{100R(1+D(0.0303))}{E}$$

(2) The value of N for the Navy standard Mark III diving pump when 100 percent efficient is 405 cubic inches. Therefore, R equals 2,592÷405 or 6.4 revolutions per minute.

Example: Diving air pump, Mark III, is 80 percent efficient; depth of sea water is 66 feet. At how many revolutions per minute should the pump be run to furnish the minimum allowable air supply (1.5 cubic feet per minute) to a diver working at that depth?

Solution:

$$X=100\times\frac{2{,}592}{405}(1+66(0.0303))$$

$$=\frac{100\times 6.4\times 2.99}{80}=24 \text{ r. p. m.}$$

(3) The maximum rate of pumping that it is possible to maintain by a pumping crew over a practical period of time is approximately 30 revolutions per minute. With the pump 80 percent efficient, this rate would barely supply the minimum amount of air required at a depth of 90 feet. If the number of revolutions required are in excess of the number that it is possible to maintain, the work should be divided between two or more pumps. For example, using the above formula to determine the number of revolutions required to furnish the minimum amount of air necessary for one diver working at a depth of, say, 168 feet, it will be found that with a pump 80 percent efficient, 48.7 revolutions per minute are necessary—a rate which is beyond the capacity of a pump crew to maintain. Hence two standard pumps, with efficiencies of not less than 80 percent each, operated at approximately 24.5 revolutions per minute each, would be required.

647. SHALLOW WATER DIVING PUMP

(1) The shallow-water diving pump is a 2-cylinder, single-acting, manually-operated pump. This type of pump was furnished with the shallow-water diving outfit for use where the diving operations were not conducted in excess of 36 feet and the type of work performed did not require excessive exertion on the part of the diver. The pump cylinders have a bore of 3⅜ inches, a stroke of 4 inches, and a cubic capacity of approximately 72 inches. The number of strokes required to furnish the minimum air supply of 1.5 cubic feet per minute would be:

$$X=R\ (1+D\ (0.0303))$$

Where D=Depth of dive.

N=Number of cubic inches of air pump will furnish.

R=Number of strokes required of pump per minute to furnish 1.5 cubic feet (2,592 cubic inches) of air per minute.

X=Number of strokes required of pump per minute to furnish minimum allowable air supply at D.

$$X=\frac{2{,}592}{72}(1+\overline{36\times 0.0303})$$

$$=36\times 2.09=75 \text{ strokes per minute.}$$

(2) The shallow-water hand pump is being replaced by the lightweight gas-driven air compressor previously described.

648. OPERATION WITH TORPEDO OR AIR FLASKS

(1) When diving operations are to be conducted from a vessel carrying torpedo or air flasks, a very satisfactory and convenient air system can be obtained by connection of three or more air flasks together. A typical air-flask installation is shown on figure 91. This arrangement consists essentially of four 8-cubic-foot, high-pressure air flasks, connected by copper tubing to a high-pressure strainer, then to a pressure-reducing valve, to a 1-cubic-foot volume tank, and then to the diver's manifold. A high-pressure gage should be located on the high-pressure side of the reducing valve and a low-pressure gage should be connected to the

volume tank. A complete detailed description and bill of materials is contained in BuShips Plan 19738–S4904–298223 Alt. 1.

(2) When diving with compressed air from torpedo or air flasks, at least one flask shall be open and left open during the time the helmet is being worn by the diver. The diver's air supply shall be taken from the testing tank, and the pressure of the air therein shall be prescribed by the officer in charge.

(3) When diving at a depth over 120 feet from a small boat and using torpedo air flasks, a relief diving boat shall be equipped fully and kept ready for emergency use. Also, not more than two divers shall be permitted to dive from the same boat. When the diver's air is supplied from torpedo air flasks, at least three or more flasks must be connected, ready for use, and *one flask shall be held in reserve*. The pressure in the working flasks, as indicated on the high-pressure gage, shall not be permitted to fall below 220 p. s. i. in excess of that at which the divers are working while on the bottom. If the gage pressure in the last flasks (excluding the one held in reserve) approaches 220 p. s. i., the divers shall be brought up. After they are clear of the bottom and safely on their way toward the surface, the reserve flask may be used. An exception of this rule will be permitted if there is available an additional independent air supply which can be connected immediately to the diving air manifold.

649. DURATION OF SUPPLY FROM AIR FLASK

(1) The duration of air supply from the air flask may be calculated according to the following formula:

$$\frac{CN\ (A-(15+E+1))}{4.5D(E+1)}=\text{Number of minutes.}$$

C=Capacity of one air flask in cubic feet.

A=Atmosphere pressure of air in flask (p. s. i. divided by 14.7).

E=Pressure in atmospheres to which dive is to be made (depth in feet divided by 33).

D=Number of dives.

N=Number of flasks.

(2) In this formula, the "1" in the numerator is one air flask atmosphere which is allowed for charging the testing tank, air hose, and helmet. The "15" is the 15 atmospheres constituting the 220 p. s. i. pressure which has to be preserved in the flask as a minimum reserve. In the denominator, the 4.5 is the cubic feet of air required by each diver per minute measured at absolute pressure, and the "1" is the 1 atmosphere of pressure which has to be added to the pressure at which the dive is made to obtain

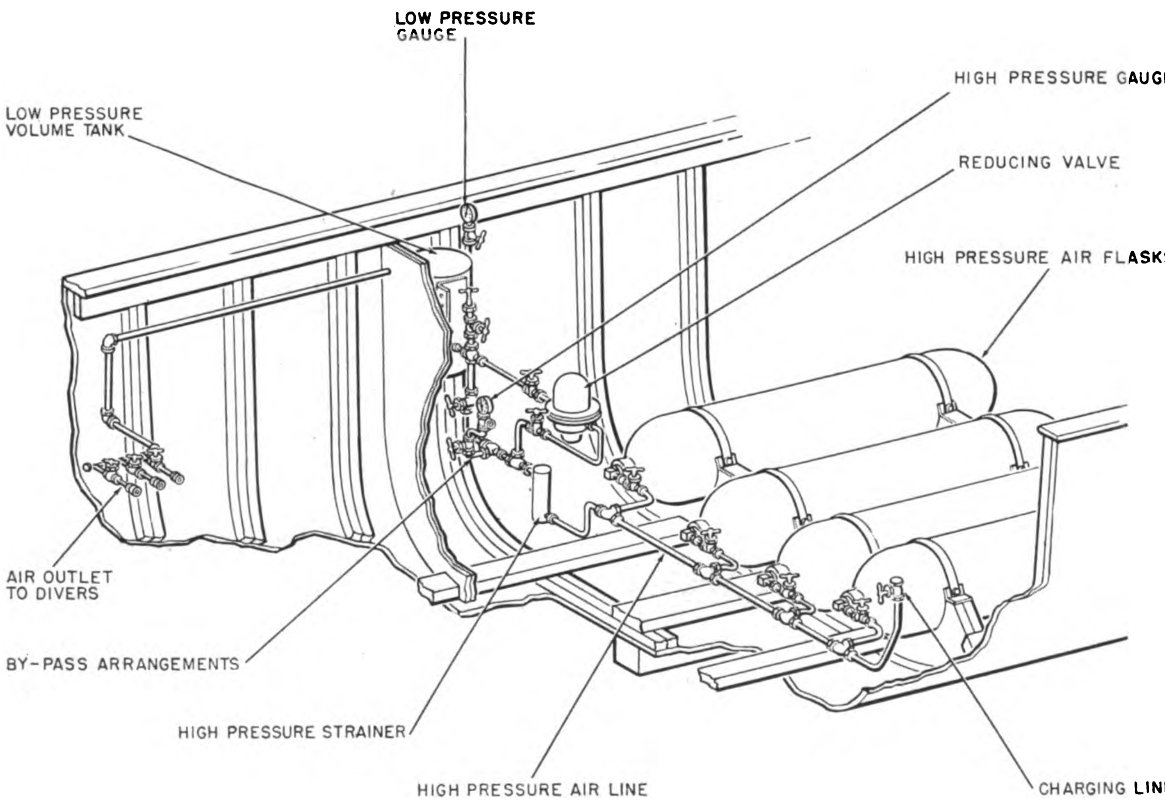


FIGURE 91.

the absolute pressure. One air flask is held in reserve and should not be considered as available except in an emergency.

Example: Two divers are to descend to a depth of 165 feet. Determine the total time of the dive if air is furnished from four 8-cubic-foot air flasks charged to a pressure of 3,000 p. s.i.

$C=8$ $E=\frac{165}{33}$ or 5

$A=205$ $D=2$
$N=3$ (the fourth flask held in reserve)

Calculation: $\frac{8\times3\ (205-(15+5+1))}{4.5\times2\times(5+1)}=81$ minutes

(3) This means that it is possible for two divers to stay at 165 feet for the optimum time listed in the decompressor table for the depth and still use sufficient air for decompression. However, when calculating how long the air flasks will last, it is important that the time for decompression be considered. In the above illustration, if it was decided to use the 75-minute table, it would require 2,662 cubic feet of free air to decompress two divers.

	Cubic feet
4 minutes to reach (bottom average depth of 83 feet)	63
50-foot stop for 9 minutes	101
40-foot stop for 19 minutes	188
30-foot stop for 23 minutes	197
20-foot stop for 38 minutes	274
10-foot stop for 68 minutes	397
time between stops 7 minutes at average depth of 83 feet	111
Required air per diver	1,331
Required air for two divers	2,662

This would exceed the volume of the reserve flask (assuming that it was entirely consumed) by $2{,}662-8\ (204-1)=1{,}038$ cubic feet which must be obtained from the other three cylinders. This in turn would reduce the time that the divers can stay on the bottom as follows:

The total quantity of free air in the 3 cylinders

$$CN\ (A-(15+5+2)=8\times3\times184=4{,}416$$

The length of time the divers can stay on the bottom is equal to:

$$\frac{4{,}416-1{,}038\times81}{4{,}416}=62 \text{ minutes}$$

This is the maximum time that two divers can stay at 165 feet and still have an adequate amount of air for decompression.

(4) In order to maintain the CO_2 content within safe limits, it may not be necessary to furnish 4.5 cubic feet per minute during decompression, measured at the absolute pressure of the dive, as the diver's physical activity will be at a minimum. However, in computing the length of time that a flask will last the 4.5 cubic feet figure should be used.

650. DIVING OPERATIONS FROM A VESSEL

(1) When diving operations are to be conducted from a vessel, using the vessel itself as a diving platform, the necessary air connections should be made and precautions taken to insure a continuous and adequate quantity of air of desired purity. In the case of the submarine rescue vessel, diving operations are conducted directly from the vessel, and a compressed-air system is made an integral part of the vessel. A typical air system consists of:

(*a*) Diver's air supply consists of two compressors capable of supplying approximately 150 cf. of air at a pressure of 400 p. s. i.

(*b*) Salvage air supply consisting of a dual set of low-pressure compressors capable of supplying air at 200 p. s. i.

(*c*) High-pressure air compressors capable of supplying air at 3,000 p. s. i.

(*d*) High-pressure air banks containing air at approximately 3,000 p. s. i.

(2) The operation of the air system is an important part of the diving, rescue, and salvage routine. An officer should be placed in charge of the plant, whose duties shall be to start the system and route the air as ordered by the officer in charge of diving operations. The officer in charge of the air system should stand a continuous watch, assisted by a chief petty officer, and insure that desired temperature and pressure are maintained and reported to the officer in charge of diving operations. These should be maintained within specified limits except in emergencies. When diving, rescue, or salvage operations are in progress and air is being used for both diving and blowing purposes, it is necessary to safeguard the diver's air supply; therefore, orders shall be such that they will insure against opening or closing any air valve without the knowledge of those supervising the diving. The plant officer should always inform the engineer officer when the operation of additional compressors is needed.

(3) It is customary when diving is in progress to have one or both 400 p. s. i. compressors running on their governors, though air in sufficient quantity can be supplied by one. The reason for two compressors running is that, should one compressor fail, the other is available immediately to take up the load. The governors are set so that the compressor pumps against a certain pressure. If one should stop, the other can be speeded up immediately, thereby maintaining the air in the volume tank at the desired pressure. Further, with both machines on the air-supply line, the load is divided and the safety factor of each compressor is increased. The air ends of the compressor should be cleaned each night after diving has ceased. The valves should be removed, cleaned with soapy water, and wiped off with a castor-oiled rag. The high-pressure air banks

should be kept charged to their maximum capacity as emergency diving air supply in event of failure of the air compressors. The banks are connected to the diver's air hose through a reducing valve that reduces the air to the desired pressure.

(4) The diving air plants installed on the submarine rescue vessels have 400 p. s. i. compressors which permit reaching a low dew point and give a greater volume of air gained through expansion down to 300, 200, or 100 p. s. i., as required. This system also has two after coolers. This complete circuit includes the volume tank, heaters, and coolers.

(5) Since the relative humidity at no time is sufficiently low to insure the delivery of air from the compressors at less than 100 percent humidity, the relative humidity of the atmospheric air is not a determining factor in regulating the dew point of the air supplied to the divers. The relative humidity of the atmospheric air is, however, a gage of the amount of moisture in the air which has to be extracted during the reconditioning process, and serves as a means of regulating the interval of blowing down the coolers. When the relative humidity is from 50 to 70 percent, the coolers should be blown every 15 or 20 minutes; if from 70 to 80 percent, they should be blown every 15 minutes; and if it is 80 to 100 percent, they should be blown every 10 minutes.

651. DEHYDRATION OF AIR SUPPLY

(1) To apply this system intelligently, it is necessary to know how to use a table called "Dew point temperature curve" (fig. 92), and have a knowledge of the following definitions:

(*a*) *Dew point* is that temperature at which air is saturated and below which precipitation of moisture occurs. It varies with the humidity of the atmosphere.

(*b*) *Absolute humidity* is the mass of water vapor present in the atmosphere, usually grains per cubic foot measured as per pound of air.

(*c*) *Relative humidity* is the ratio between the amount of water vapor as determined by the existing dew point and the amount that would be present if the dew point corresponded to the wet and dry bulb readings. When air is saturated, the dew point, wet bulb, and dry bulb readings are all the same.

(2) An inspection of the dew point temperature chart (fig. 92) will show, by comparison of the column marked "Temp" with the figures set opposite the various temperatures, that a change in temperature causes a change in humidity; e. g., saturated air at 40° F. contains 2.849 grains of water vapor per cubic foot, whereas at 30° F. it contains 1.935 grains; therefore, cooling will cause precipitation.

(3) The amount of percentage of dehydration that it is possible to produce by a reduction of dew point depends entirely on the temperature it is possible to attain by the air-cooling systems of the plant. In this case having produced a reduction of 10°, i. e., 40° F. with 2.849 grains of water vapor to 30° F. with 1.935 grains water vapor, the difference of 0.914 grain per cubic foot of air would be precipitated in the form of water which at a temperature of 30° F. would form slush ice, and could be discharged from the cooler through the blow valve. The air will not be 100 percent saturated for the new temperature, i. e., 30° F., and a further drop in temperature will cause further precipitation.

(4) As the cooling agent consists of the circulation of sea water through the cooler, it is obvious that the degree of dehydration possible by cooling depends entirely on the temperature of the sea water. In this case 30° F. would be called the dew point temperature since the air is saturated. However, a further reduction of the dew point may be brought about by expansion as follows: 34° F. (table 138) contains 2.279 grains of water vapor per cubic foot. Initial pressure of air from the compressors at 150 p. s. i. (gage) or 164.7 p. s. i. (absolute) and the reducing valve to be set at 100 p. s. i. (gage), or 114.7 p. s. i. (absolute), the air passes through the cooler. The reduction in pressure from 150 p. s. i. to 100 p. s. i. has, in accordance with Boyle's law, reduced the density of the air to approximately 70 percent. Therefore, the air, instead of having 2.279 grains of water vapor, now contains only 70 percent of 2.279 grains, or 1.596 grains of water vapor. Thus, we have reduced the dew point to 25.5° F. by a reduction in pressure. Hence, the diver's air at temperatures about 25.5° F. would not precipitate moisture and no freezing could occur.

(5) To use the curves, figure 92, run a line from the dew point temperature scale to the percent pressure scale. From this intersection drop a perpendicular line to the initial pressure curve, and from this point run a line to the dew point scale. Using the dew point as indicated on this scale, the grains of water vapor will be found by reference to the inserted table. Otherwise, the perpendicular line between the percent pressure and initial pressure curves can be extended to the base and the figure for aqueous vapor determined by interpolation.

(6) From service tests of the air-conditioning plants on submarine rescue vessels, it never has been found necessary to reduce the aqueous vapor below 1.355 grains. Since air that is dehydrated completely would probably be injurious to the diver, the dew point should not be lowered beyond that necessary to prevent freezing of the diver's air line.

(7) In addition to the expansion caused by the main reducing valve, there is a further expansion at the diver's air-control valve. Hence, without the reducing valve, the air pressure at the diver's air-control valve that allows a drop in pressure of 15 p. s. i. would be reduced from approximately 135 p. s. i. (the pressure in the diver's air line) to ap-

proximately 45 p. s. i. (gage). With the reducing valve in operation and set for 85 p. s. i., the expansion may be from 85 to 45 p. s. i. thus the original factor of 3 to 1 is lowered to a new ratio of 2 to 1.

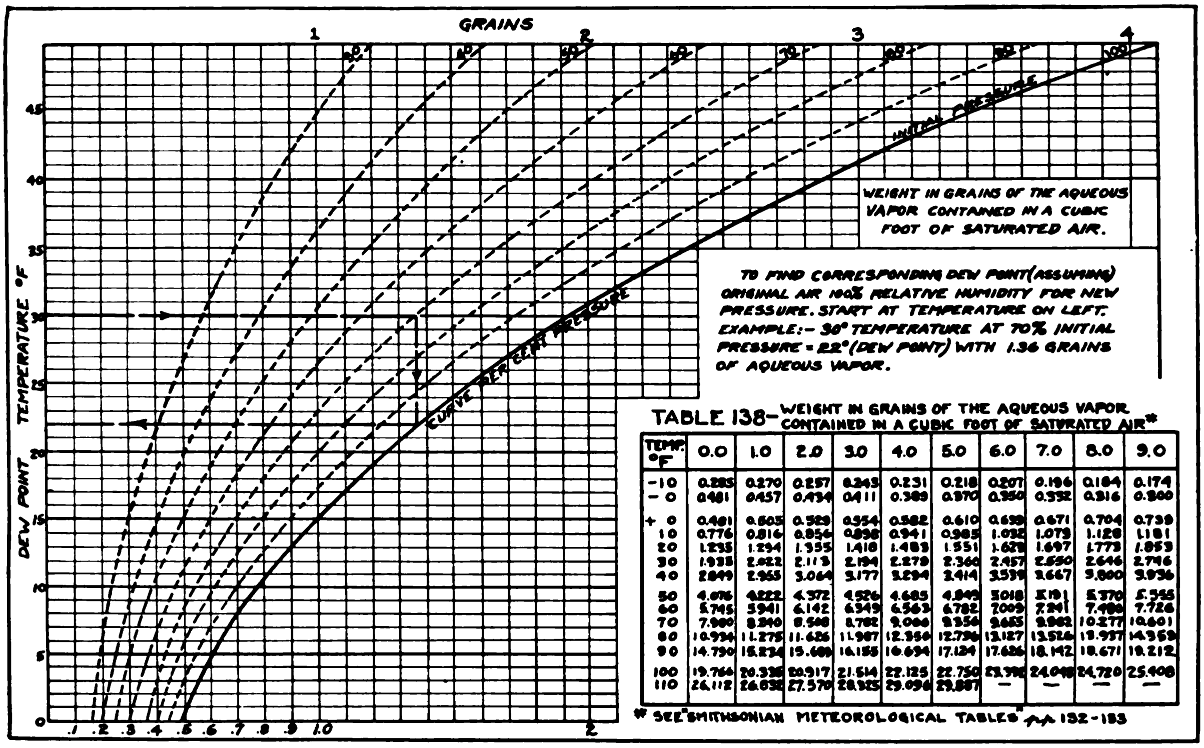


TABLE 138—WEIGHT IN GRAINS OF THE AQUEOUS VAPOR CONTAINED IN A CUBIC FOOT OF SATURATED AIR*

TEMP. °F	0.0	1.0	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0
-10	0.285	0.270	0.257	0.243	0.231	0.218	0.207	0.196	0.184	0.174
-0	0.481	0.457	0.434	0.411	0.389	0.370	0.350	0.332	0.316	0.300
+0	0.481	0.505	0.529	0.554	0.582	0.610	0.639	0.671	0.704	0.739
10	0.776	0.816	0.856	0.898	0.941	0.985	1.032	1.079	1.128	1.181
20	1.235	1.294	1.355	1.418	1.483	1.551	1.623	1.697	1.773	1.853
30	1.935	2.022	2.113	2.194	2.279	2.360	2.457	2.550	2.646	2.746
40	2.849	2.955	3.064	3.177	3.294	3.414	3.539	3.667	3.800	3.936
50	4.076	4.222	4.372	4.526	4.685	4.849	5.018	5.191	5.370	5.555
60	5.745	5.941	6.142	6.349	6.563	6.782	7.009	7.241	7.480	7.726
70	7.980	8.240	8.508	8.782	9.066	9.356	9.655	9.962	10.277	10.601
80	10.934	11.275	11.626	11.987	12.356	12.736	13.127	13.526	13.937	14.359
90	14.790	15.234	15.689	16.155	16.634	17.124	17.626	18.142	18.671	19.212
100	19.766	20.335	20.917	21.514	22.125	22.750	23.392	24.048	24.720	25.408
110	26.112	26.832	27.570	28.325	29.096	29.887	—	—	—	—

* SEE "SMITHSONIAN METEOROLOGICAL TABLES" pp. 132-133

FIGURE 92.

(8) With the air-conditioning plant in operation, it has been found possible to maintain desired air temperatures by the use of bleeders. These are short lengths of hose, one to three in number, connected to outlets on the diving mains on the opposite side from which diving is being conducted, and are weighted a few feet below the surface of the water to eliminate noise. To raise the temperature in the diving air mains, it is necessary only to increase the flow of air by opening bleeders as much as necessary; to decrease the temperature in the diving air mains, decrease the flow of air and cut out the bleeders. The following is a list of the title heads of a record that should be kept of the temperatures of the air during the use of the air-conditioning plant:

Air temperatures.	Water to cooler.
Water at surface.	Water from cooler.
Water one-half way down.	Air line—port.
Water at bottom.	Air lines—starboard.
Humidity.	Diver's air hose from starboard side.
Air to cooler.	Bleeders from port side.
Air from cooler.	

652. LOW-PRESSURE ACCUMULATORS

Air for diving can be furnished using high- and low-pressure accumulators. The supplying of air to divers from low-pressure accumulators is applicable to vessels equipped with a gas-ejector system, to submarine rescue vessels, to naval shipyards, etc. The air pressure in the accumulators is maintained constant by large capacity low-pressure, steam or electrically-driven, automatically-controlled air compressors. The capacity of these compressors is such that there is never a question of shortage of air supply. The maximum depth to which a diver or divers may descend will depend upon the pressure of the air supply and the amount of air that is required to pass through the diver's helmet and, since there is no accurate method of determining the latter when using this source of supply, the only means of knowing whether adequate ventilation exists is by the diver's own feeling of well-being.

653. HIGH-PRESSURE ACCUMULATORS

By high-pressure accumulators, reference is made to the air accumulators of the torpedo installation aboard vessels equipped with air-driven torpedoes. When connections are made to accumulators, diving operations should be conducted directly from or in the immediate vicinity of the vessel carrying the accumulators, thus obviating the necessity for use of long lengths of air hose. If the accumulators are of sufficient capacity, diving may be undertaken from those already fully charged, but if they are not of sufficient capacity to meet the requirements of depth and duration of the dive without recharging, then the compressor shall be operated as necessary, and care taken that the water cooling system is in order and in operation to insure cool air supply.

654. CAPACITY OF AIR COMPRESSOR AND ACCUMULATORS

(1) The capacity of the air compressor and the accumulators must be known and taken into consideration when calculating the air supply. For example, the capacity of a compressor is 15 cubic feet at 2,500 p. s. i. per hour or 0.25 cubic foot at 2,500 p. s. i. per minute. As 2,500 p. s. i. would equal $\frac{2500}{14.7}$ or 170 atmospheres, 0.25 cubic foot at 2,500 p. s. i. pressure would equal 170×0.25 or 42.5 cubic feet at atmospheric pressure. Therefore, since a diver must have an air supply of 4.5 cubic feet per minute at a pressure equal to the absolute pressure at which the dive is made, a dive by one diver to, say, 274 feet, or 8.3 atmospheres, excess pressure (9.3 atmospheres absolute) would require 4.5×9.3 or 41.85 cubic feet of air per minute at atmospheric pressure. From this, it is evident that this power-driven compressor working at full capacity would just be able to furnish this supply of air. Under no circumstances, however, should divers be permitted to dive to the limit of their air supply, whatever the source utilized may be.

(2) Also, sufficient air must be held in reserve to enable the dispatch of a relief diver. The capacity of the air accumulators aboard may be augmented by connecting them to the torpedo air flasks that have their stop valves open, and taking the air lead from this connection. When charging high-pressure accumulators, it must be remembered that the air is heated by the compressor's cylinders; hence, castor oil should be used to prevent flashing in the cylinders and thus preventing CO and CO_2 production; or, if not available, use Navy symbol 2190T or equal. For this and other reasons, as little oil as possible should be used in the cylinders. Likewise, the air intakes of any compressors used for supplying diver's air must be located in atmosphere that is free from obnoxious or toxic fumes.

655. PRECAUTIONS IN SUPPLYING AIR

The following is a summary of the safety precautions that should be taken to insure proper operation of the diver's air system.

(1) *Heavy-duty compressor.*

(*a*) Personnel should be assigned to maintain the compressor in first-class operating condition.

(*b*) The proper grade of oil and correct quantity should be added to the engine and compressor.

(*c*) Water and antifreeze as necessary should be added to water-cooled engines and, in case of air-cooled engines, the cooling fins must be kept free from foreign matter.

(*d*) All filters, cleaners, and separators should be kept clean.

(*e*) Make certain that the engine exhaust fumes are not permitted to enter the compressor intake.

(*f*) Service the engine and compressor regularly in accordance with the manufacturers' instruction manuals.

(*g*) Insure that the engine and compressor are warmed up and running smoothly before a diver is put over the side. Any indication that the unit is not operating in a completely satisfactory manner should be reported immediately to the officer in charge of diving operations.

(*h*) When unit is stored, it should be removed every 30 days and operated. It should be prepared again for storage in the same manner as if the unit had been used for some time.

(2) *Lightweight divers' air compressor.*—In the case of the lightweight divers' air compressor, the following precautions should be taken in addition to those listed above for the heavy duty compressor:

(*a*) The lightweight compressor should be used only where it is possible for the diver to make a direct ascent to the surface.

(*b*) Compressor bearings should be inspected every 30 hours.

(3) *Torpedo air flasks.*

(*a*) One flask should be held in reserve.

(*b*) Sufficient air should be maintained for adequate decompression.

(*c*) Valves, gages, fittings, separators, and reducers should be checked and in satisfactory condition before diving is undertaken.

(*d*) If diving is to be done in excess of 120 feet, a fully equipped boat should be available as a standby.

(4) *When diving from a vessel.*

(*a*) The necessary air connections should be made to insure continuous air supply and to prevent air from being accidently diverted or shut off.

(*b*) An officer should be placed in charge of the air plant, whose duties shall be to control the air to the divers.

(*c*) A standby air supply in the form of a second compressor or air flasks should be available in the event the primary air source fails.

(5) Regardless of the type of air supply used, the following conditions are essential:

(*a*) The temperature of the air should be such as not to cause discomfort to the diver.

(*b*) The air must be free from noxious fumes and as near standard purity as possible. (In utilizing air from high-pressure accumulators, the air in the cylinders of the compressors is greatly heated in charging the accumulators, and oil with a high flash point should be used, castor oil if possible.)

(*c*) Whenever possible, it is desirable to maintain 30 to 50 p. s. i. pressure in the line over the water pressure (at the depth of dive).

(*d*) The reserve air supply should be maintained in case of failure of the air supply.

E. RECOMPRESSION CHAMBER

671. NEED FOR RECOMPRESSION CHAMBER

One of the greatest dangers and inconveniences connected with diving is that of decompression. Under ordinary conditions the diver, after having spent a certain length of time on the bottom, will be safely brought to the surface in accordance with the standard decompression tables, with the minimum of inconveniences. However, there are occasions, particularly in deep dives and relatively shallow dives of long exposure, where conditions such as heavy tideway, cold, heavy seas, or other emergencies prevent giving adequate decompression on the way to surface. In addition, there are the special cases where the diver even though decompressed in the prescribed manner will be subject to the "bends." In order to provide for these special cases, recompression chambers are furnished to those activities that will be doing either very deep diving or a large amount of relatively shallow diving or both, such as submarine rescue vessels, submarine tenders, salvage vessels, and others as authorized by the Bureau of Ships.

672. TYPES OF RECOMPRESSION CHAMBER

There are two types of recompression chambers. One is a two-lock chamber having a working pressure of 200 p. s. i. The other is a one-lock chamber having a working pressure of 100 p. s. i.

(1) The recompression chamber shown in figure 93 has two locks—the inner lock and outer lock. When it is necessary to recompress for treatment of caisson disease or for surface recompression, the diver is placed in the inner lock and pressure is built up to the desired point. In the event it is necessary for personnel to enter or leave the inner lock, the pressure is built up in the outer lock until the pressures in the two locks are in equilibrium at which time the inner chamber door can be opened. Decompression of the attendants leaving the inner lock will be accomplished in the outer lock, depending on the length of time attendant has been under pressure. In addition, there is a small medical lock, with the necessary valves for equalization of pressure, to permit small articles such as food, water,

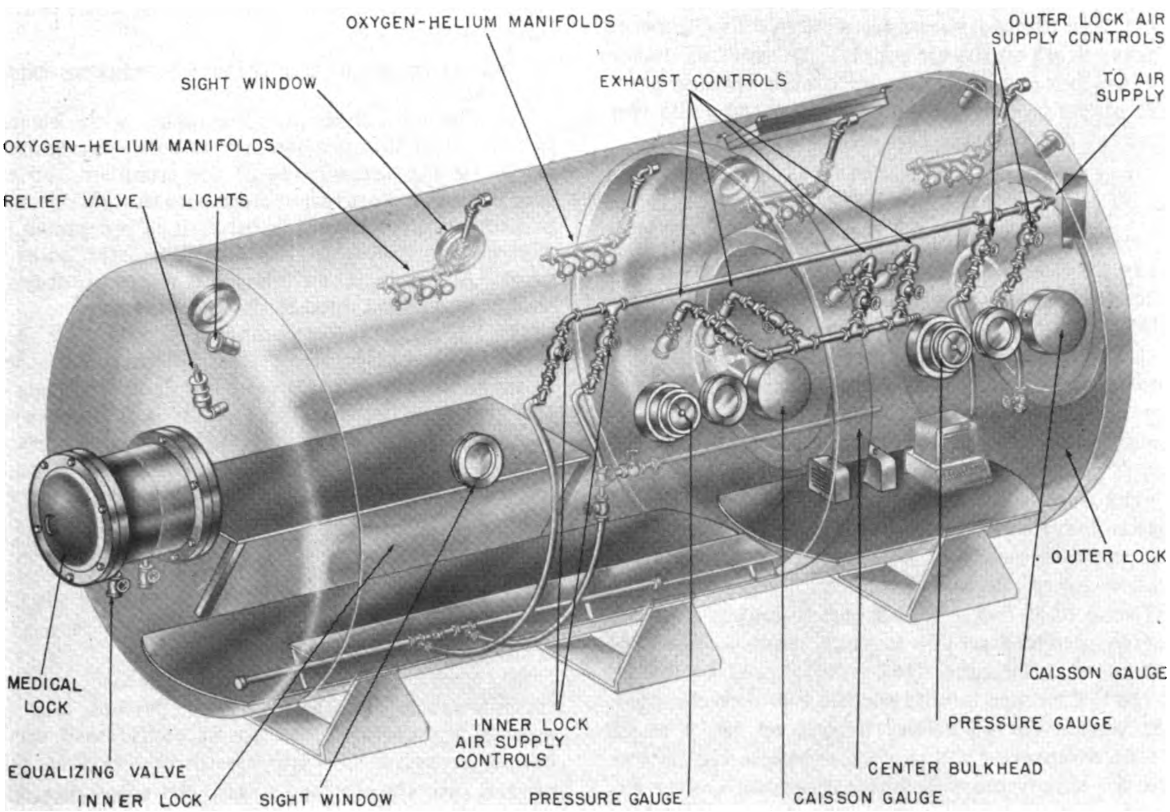


FIGURE 93.

and medicines to be sent or removed from the inner lock. This large recompression chamber has a total volume of about 500 cubic feet—inner lock 370 cubic feet, outer lock 130 cubic feet. In general, this type of chamber is furnished to activities that are called upon to dive to extreme depths and where resultant cases of compressed air illness are apt to involve complications necessitating not only long recompression but the assistance of medical personnel. In general, the two-lock chambers are furnished to submarine rescue vessels and submarine tenders.

(2) The other recompression chamber is similar to the two-lock chamber with the exception that it has a working pressure of only 100 p. s. i. and only one lock. In the event it is necessary for attendants to be in the chamber, they should enter the chamber with the diver and remain there until decompression is completed. The small chamber is, however, equipped with a medical lock which can be used for passing small articles in or out of the chamber. In general, the one-lock chamber is furnished to activities doing a considerable amount of diving at relatively shallow depths and where cases of compressed air illness are not likely to involve any serious medical complications. The one-lock chamber has a volume of approximately 250 cubic feet.

673. AIR SUPPLY FOR RECOMPRESSION CHAMBER

(1) The use of a recompression chamber imposes a heavy drain on the air supply. In order to charge the two-lock chamber to its maximum working pressure of 200 p. s. i., it would require 6,800 cubic feet of air at atmospheric pressure:

$$\frac{200}{14.7}=13.6 \text{ atmos.}$$

$$13.6\times500=6{,}800 \text{ cubic feet of air.}$$

(2) To charge the one-lock chamber to its maximum working pressure of 100 p. s. i., it would require 1,700 cubic feet of air at atmospheric pressure.

(3) For safety the chamber should be ventilated continuously during use. This is necessary to keep down the CO_2 and oxygen concentration. It is particularly important during the periods that pure oxygen is being supplied. The oxygen from the mask is exhausted into the chamber resultant in a higher oxygen percentage. In order to keep the concentration down there should be a change of air approximately every 10 minutes. The deepest stop on oxygen is at 60 feet. This is approximately 3 atmospheres absolute which is equivalent to chamber volume of 1,500 cubic feet. This would be a load of 150 c. f. m. per minute for the two-lock chamber. For ventilation at deeper depths on air a 50–60 c. f. m. compressor will provide adequate ventilation. The air supply must be pure, free from engine exhaust or oil fumes, and as cool and dry as possible.

(4) The piping is arranged so that the air flow can be controlled from inside or outside the chamber. One supply and one exhaust line is fitted with a single valve located on the outside of the chamber for control by the tenders. The other supply and exhaust lines have double valves, one on the inside and the other on the outside, so that the rate of descent and ascent can be regulated by the patient or his attendant subject to final control by outside tenders.

(5) In addition to the piping for the regular air supply, there are two couplings in each lock of the large chamber that lead to a three-outlet manifold on the inside of the chamber for connecting flasks of oxygen or oxygen-helium mixtures. Inhalators through which these breathing mixtures are administered to the diver are attached by rubber tubing to the manifold on the inside of the chamber. In general, it is advisable to have two inhalators connected to each manifold. Figure 94 illustrates a typical arrangement of oxygen and helium-oxygen flasks.

(6) In order to determine the pressure being built up in the chamber, caisson gages reading in pounds per square inch with corresponding foot gradations are placed inside the chamber. In some larger shore installations where extra precise readings are desired, a mercury manometer with absolute depth calibration may also be connected to the main or inner lock.

674. PRECAUTIONS IN USE OF RECOMPRESSION CHAMBER

(1) The chambers are equipped with electric lights and communication system between personnel on the inside and outside of the chamber. In the case of the recompression chambers that do not have pressure-proof lighting fixtures, it is recommended that standard 60-watt daylight-blue light bulbs be used. All electrical switches and distribution boxes should be located outside the chamber.

(2) In using the recompression chamber, care should be exercised when tightening up on the door to make an air seal. Unless the door is sprung or the gasket is improperly fitted, it is not necessary to apply more than a moderate amount of pressure on the hatch "dogs." All that is required is to make an initial seal; then as the pressure builds up in the chamber, a tighter and tighter seal will be made due to the increased pressure. The "dogs" should be released before reducing the pressure in the chamber. This is very important in the case of the new chambers where connecting rods extending from the crank are used.

(3) The danger of explosive fires occurring in recompression chambers is ever present and increases greatly with the use of compressed air of higher pressures or with the introduction of pure oxygen into the chamber. In both cases, the concentration of oxygen is effectively increased. In

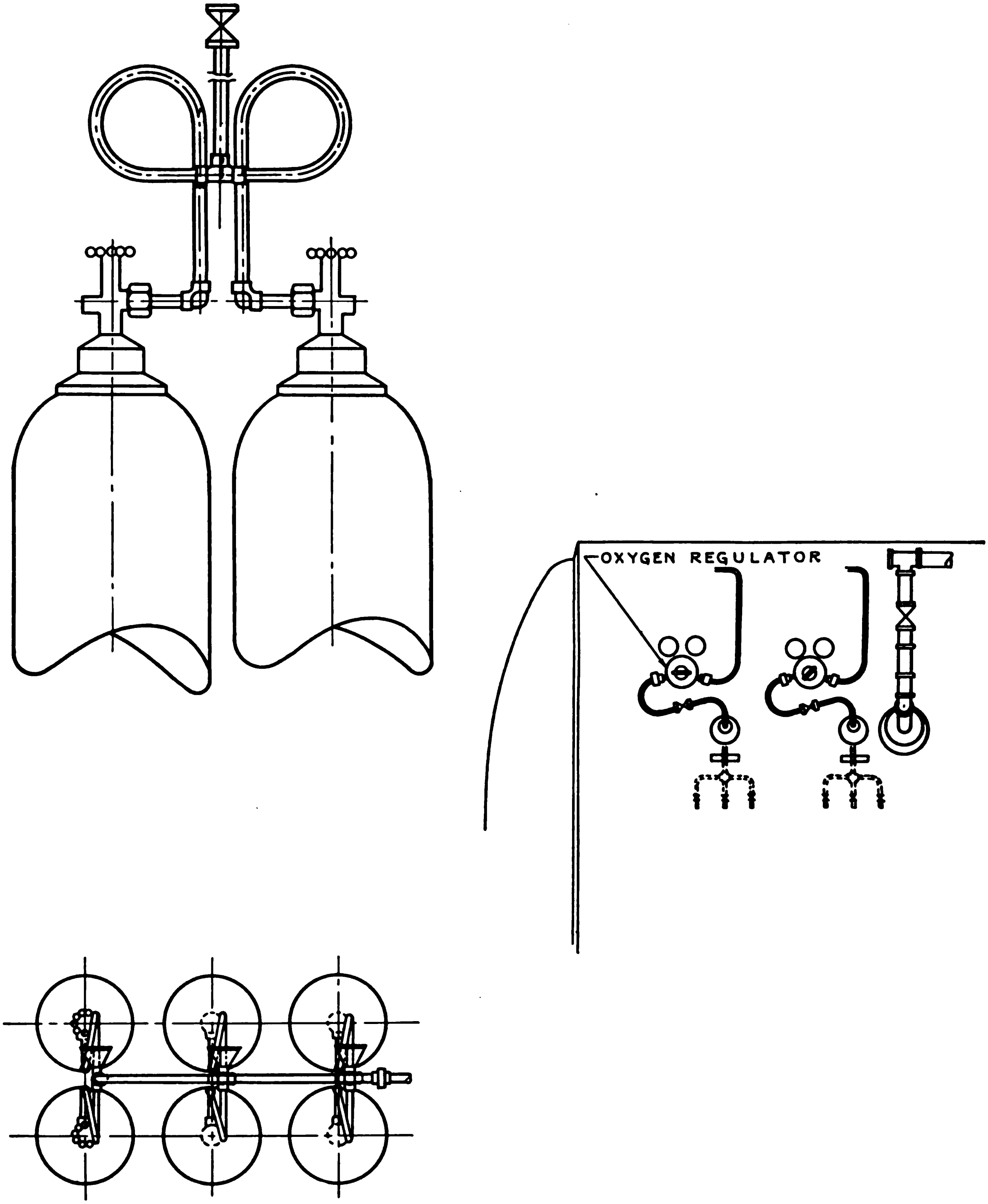


FIGURE 94.—Typical flask installation.

order to reduce the possibility of fire within the chamber, the following precautions should be taken:

(*a*) All wooden deck gratings, benches, shelving, etc., not made of fireproof material, shall be replaced by metal or other fire-resistant or fireproof treated material.

(*b*) Mattresses, if used, shall be covered by fire-resistant sheeting on all sides. Blankets and clothing used by patients and tender shall be free from grease or oil and clean. Such clothing shall be kept to a minimum consistent with the patient's condition and in accordance with standard precaution against flash burns. Flameproof bedding material can be obtained from the Naval Supply Center, Oakland, or the Naval Supply Depot, Bayonne, under Stock No. 27–C–3173–100 or 27–C–3173–110.

(*c*) Inflammable liquids or their vapors, such as ether, chloroform, alcohol, gasoline, or volatile oils, should not be present in the chamber. If vapors have been present, thorough ventilation must precede the use of the chamber. No oils should be on or in the high-pressure lines or apparatus of the oxygen breathing equipment and installation. No oils or volatile materials should be allowed to collect or soak into any absorbent material within the chamber or in the well of the chamber under the deck grating. All air filters and accumulators in airlines leading to the recompression chambers must be periodically cleaned to prevent oil vapors from being carried into the chamber.

(*d*) Only fire-retarding paint, similar to that listed in the Federal Standard Stock Catalog, Federal Stock No. 52–R–3500, shall be used, and painting should be kept to an absolute minimum—one coat preservative and one white coat. If it is not known that chambers have been painted in this manner, the paint should be removed and repainted as indicated. If chambers have recently been painted, thorough drying by ventilation must be accomplished to rid the compartments of volatile vapors.

(*e*) No open flames, matches, cigarette lighters, lighted cigarettes, pipes, etc., are to be taken in or used in the chamber during its use at any time.

(*f*) While breathing oxygen, the chamber must be ventilated at frequent intervals, 3 minutes for each 15 minutes of use. Continuous, slow but thorough, ventilation is preferable to intermittent ventilation, and should be used where the air supply is sufficient.

(*g*) Water and sand buckets shall be on hand within the chamber.

(*h*) Where fan and heater are installed, a disconnect switch should be placed in the circuit on the outside of the chamber with a warning plate stating that the fan and heater circuits must be disconnected before admitting oxygen and until the chamber has been ventilated sufficiently to reduce the oxygen concentration to the equivalent of that of air.

(*i*) The following caution sign should be placed in a prominent place adjacent to the heater and fan on the inside of each chamber, and adjacent to the heater and fan switches on the outside of each chamber:

> Danger of fire and explosion greater in oxygen or compressed air than in normal atmosphere. Do not admit flames, sparks, combustible liquids, volatiles, or unnecessary inflammables of any kind. Ventilate thoroughly by admitting and exhausting air before starting electric fan or heater and do not use them while admitting oxygen.

If the above simple precautions are taken, the possibilities of fire within the chambers will be reauced to an absolute minimum. A copy of the safety precautions listed above should be posted in a conspicuous place on the inside and outside of all chambers.

F. BOATS AND FLOATS

681. USE OF SMALL CRAFT FOR DIVING PURPOSES

While the diving equipment and diving personnel are generally assigned to tenders, repair ships, salvage vessels, etc., there are a great many diving operations where it is not feasible to dive directly from the deck of the vessel, or the work may be inaccessible to a large vessel. In these cases the practice is to convert a motor launch or other small craft for diving purposes. Small boats are generally used where the diving jobs are of relatively short duration and are performed at different points over a wide area. In cases where a diving job entails perhaps months of diving in a small area, such as in harbor clearance work, it may be convenient to build a diving float.

682. CONVERSION OF SMALL CRAFT FOR DIVING OPERATIONS

(1) Many types of small craft are suitable for converting to a diving boat. However, before any attempt is made to rig a boat for diving, it should meet the following basic requirements:

(*a*) Minimum over-all length, 40 feet.
(*b*) Minimum beam, 10 feet.
(*c*) Freeboard, 3–5 feet.
(*d*) Engine in good condition and hull seaworthy.

With these basic characteristics, the boat can be rigged for diving operations with ample space for a diving platform, storage of equipment, and for the diving crew.

(2) The 50-foot motor launch which is carried by most large ships and tenders will be used to illustrate the method of conversion to a diving boat. Figures 95 and 96 show a typical layout of a converted 50-footer and several other types of boats. To convert this type of boat for diving, it is necessary, first, to remove all thwarts to make enough space available for diving gear. A portable partial

deck should be placed over the midship section to be used as a platform from which all diving operations are conducted. This deck should be flush with the gunwale so that the diver can step from the deck directly on to the ladder. The deck should be of sufficient size so that there will be enough room for two divers (one diver—one stand-by diver) and the tenders, plus the equipment to put the divers into the water. The deck must have sufficient railings to protect the diver and other diving personnel from being thrown overboard in rough water. Only personnel that are assisting the diver or his tender should be on the deck during the time that the diver is in the water.

(3) Air compressors should be well secured and away from the diving operations. Unless it is absolutely essential, the compressor should be operated in the open. In the event that it is necessary to operate the compressor below deck, as in a confined area, the intake and exhaust must be outboard.

(4) If torpedo or high-pressure compressed air flasks are to be used in lieu of a compressor, the necessary fittings, chocks, etc., should be fitted so that at least four flasks can be stowed in a readily accessible location. Figure 91 shows a sample air flask installation. This arrangement consists of four 8-cubic-foot high-pressure air flasks leading to a single ⅜-inch line; a ⅜-inch high-pressure strainer; an automatic reducing valve (3,000/100 p. s. i.), which can be bypassed in an emergency; a 1-cubic-foot volume tank; a 1¼-inch line leading to a 3-outlet manifold. There is a gage on the high-pressure side of the reducing valve and a low-pressure gage on the volume tank. There is ⅜-inch copper tubing with the necessary valves for charging the air flasks.

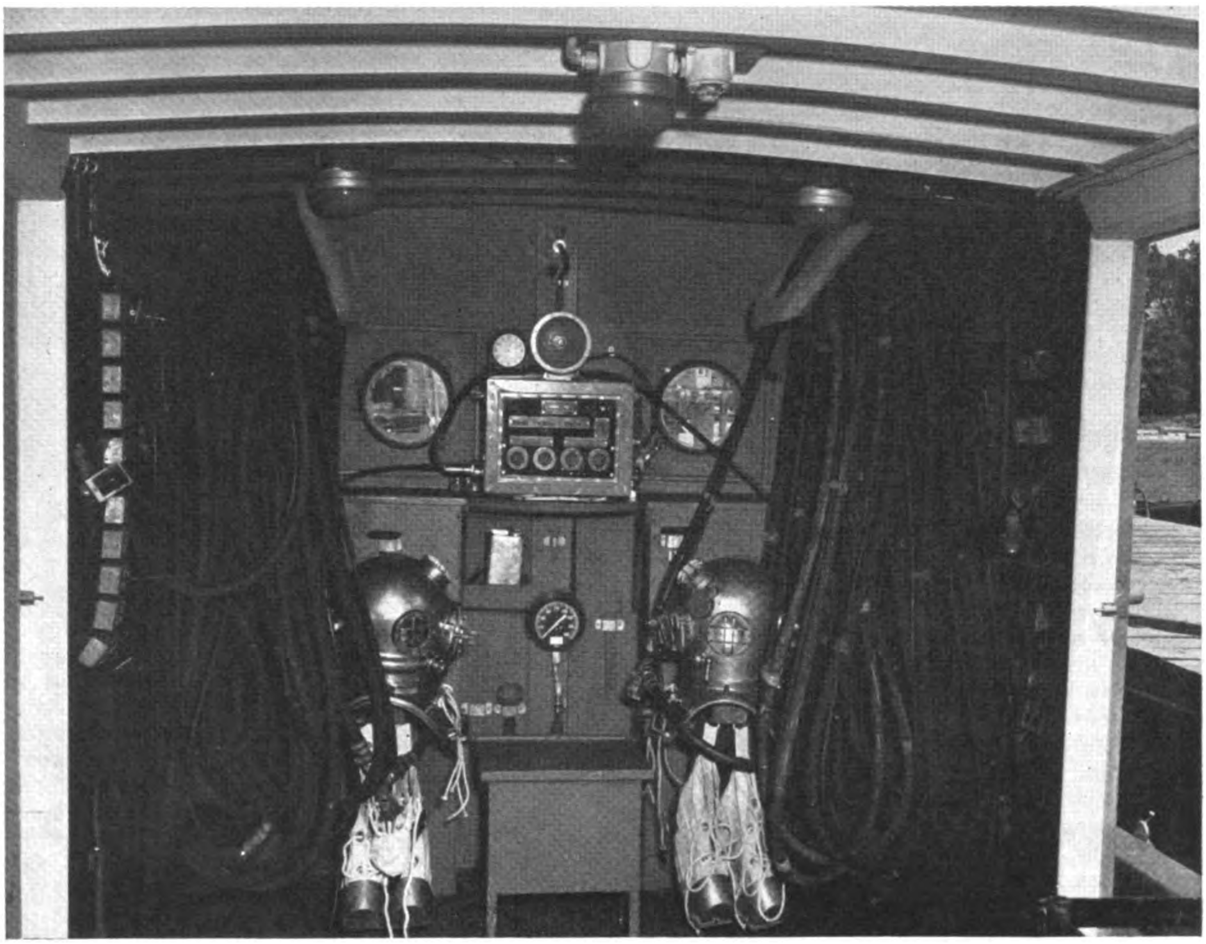


FIGURE 95.

FIGURE 96.

(5) In the event that the motor launch is to be used for general duties, a rack can be made to hold the air flasks and auxiliary equipment which may be lowered or hoisted into the boat for emergency diving jobs. Another feature to make the boat complete for diving is to have either 2- or 4-point moorings with an anchor winch in the bow of the boat. The remainder of the diving equipment that is not being used can be stowed under the portable deck or in the chest in which the outfit was originally furnished.

683. DIVING FLOATS

(1) Diving floats are useful for training divers and for undertaking diving operations in a closed harbor or basin where the water is reasonably calm. Floats used for such purposes may vary in size, but it is quite convenient to have in service one which is large enough to hold a number of divers with a number of sets of diving gear, and on which a large enough deck house could be built so that all necessary diving equipment can be stored in it.

(2) Figure 97 shows a typical diving float used for training purposes. This float has a steel hull with watertight compartments, a wooden deck 60 by 45 feet at the center of which is located a deck house 24 by 18 feet which is used for a storeroom and a place to dress divers in cold weather. This float can accommodate a large number of student divers and is equipped with air winches and booms, phone booths, and electric flood lights for conducting training at night. The float is permanently secured alongside the pier, and receives all the necessary electricity, water, and air from the pier where the compressors are located.

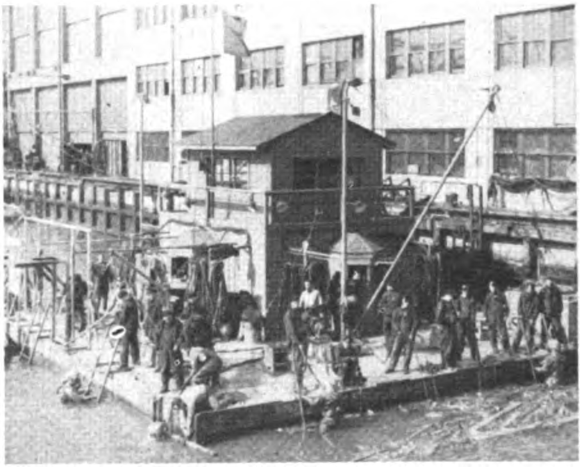


FIGURE 97.

(3) Such a float, even if not as large, could be modified for use in a salvage operation if the compressor and required equipment for the operation were placed on the float. Although it is very awkward to maneuver such floats into position for a task, they can be pressed into service in closed harbors and basins. It is not recommended for work in rough water or the open sea.

684. GENERAL PRECAUTIONS

In general, when diving operations are undertaken from motor launches, the decks, if portable, should be adequately secured. There should be sufficient railings to protect personnel from being thrown overboard, and the air system should be checked to see that it is of sufficient capacity as to volume and pressure and that it is held securely in place. Only personnel tending the diver or assisting the tender should be on the deck from which diving is being done.

Part 4—Diving Procedures

A. PLANNING AND ARRANGING OF DIVING OPERATIONS

701. PLAN OF PROCEDURE

(1) When diving is to be undertaken, the commanding officer of the vessel shall be informed. A general plan of procedure, depending upon the type of work, its location, depth, climatic condition, etc., should be decided upon. The necessary officers, men, quantity and type of equipment, type of vessel or boat to be used, etc., to handle any emergency should be detailed and an effort made to conduct the operations with ease and efficiency. An officer qualified in deep-sea diving is placed in charge of the divers and diving operations. If such an officer or warrant officer is not available, an officer familiar with the principles of diving and the problems encountered by the diver should be placed in charge. Regardless of the magnitude of the diving job, one person shall be placed in charge and assume responsibility for the divers and diving operations.

(2) Diving work is no exception to the general rule that a task is more efficiently performed when the work involved has been properly studied and planned, and preliminary work has been done in advance. In diving operations, the procedure which proves most effective is the one which provides that the maximum amount of work be done on the surface by the surface crew, and that a minimum amount be performed by the diver on the bottom. Accordingly, in planning the work, the procedure decided upon should be that which not only reduces the diver's work to a minimum, but limits his operations to tasks which can be performed within a reasonable period of time under the conditions involved.

702. MANNING AND EQUIPPING DIVING LAUNCH

If a motor launch is to be used as a diving boat, sufficient men should be detailed to man the launch independent of the men required to handle the diving gear. Before permitting the diving launch to leave the shore or immediate vicinity of the ship, the following equipment should be placed aboard:

- Complete diving outfit.
- Stadimeter.
- Boat's diving anchor gear with extra anchor for bow and stern.
- Jacknives.
- 10-X probe made of ¼-inch pipe.
- Steel tape measure and 6-foot rule.
- Boat's compass.
- Hand flags for signaling.
- Boat box.
- Binoculars.
- Long heaving line.
- Several large shackles.
- A coil of small stuff (marline) for lashings.
- A luff tackle.
- Drinking water.
- Other special gear as necessary.
- Bucket of soapy water if dress without gloves is used.
- Blueprint or sketch of job.
- Decompression tables.

703. REPAIRS TO HULLS

In planning for emergency repairs to the hulls of vessels, the following items should be on hand: Collision mats, patent leak stoppers, mattresses, canvas, swabs, cotton waste, caulking, wooden wedges, mild steel plating for small holes, hook-bolts, soft grommets made by tow and tallow kneaded together and parceled round with cloth, rubber gaskets, ample supply of planking for large holes, wire cable, bungs, wooden plugs for closing valve openings, and wire brushes and prickers for use in cleaning valve gratings.

704. SECURITY OF MOORINGS

Upon arrival at the scene of diving operations, the local conditions should be observed to determine whether the vessel or motor launch can be moored and the diver put over the side. Sufficient gear should be carried by the vessel from which diving is to be undertaken to moor the vessel securely. The mooring gear should be given a careful inspection before mooring, and when divers are down, a watch should be placed to insure against any shifting of the moorings or veering of the vessel that would endanger the divers. Usually there is much less tide on the bottom than at the surface. Consequently, although the surface tide may seem strong, it may be advantageous to attempt diving, provided the surface tide is not such as to endanger the moorings. If the velocity of the current is over 1½ knots, the diver should wear additional weights. In sudden squalls, heavy seas, unusual tide, or any other condition which, in the opinion of the commanding officer, jeopardizes the security of the mooring, the divers should be brought up and diving discontinued until more favorable weather conditions prevail.

705. PRELIMINARY PLANNING OF OPERATIONS

(1) The success of diving operations will be considerably enhanced by preliminary planning of operations including the laying out of various phases of the work and the assignment of definite tasks to each diver or group of divers. In general, it is better to arrange the diving task so that the number of divers submerged is kept to a minimum. It should be remembered that the greater the number of divers submerged, the greater the possibility of entangle-

ment of the lines involved, and that for continuous diving the number would be multiplied by the lines of the divers decompressing in the water. The number of divers that can safely be submerged simultaneously will depend upon the depth of water, the nature of the bottom, the ship's facilities for handling divers over each side, and the practicability of this procedure under attendant condition, the freedom of the wreck from debris, and the conditions of the weather and sea. Divers can be used singly, in pairs, or in groups of three or more. It is generally preferable to work divers singly or in pairs. It is sometimes advisable to use divers in relays where one diver acts as another diver's tender, the first diver being tended topside.

(2) With the foregoing as essential requisites, contributions to the satisfactory operation of underwater work is made by application of the following rules:

(*a*) Make inspection dives to ascertain the extent of the work to be done and to determine the method of attacking the problem.

(*b*) The method of accomplishing the job, the type of equipment and personnel, should be considered on the basis of the initial inspection dives. Care should be exercised in evaluating the information obtained during an observation dive because the opportunity for observing conditions below the surface is limited. In addition, the plan decided upon should be flexible enough so that it can be modified to take advantage of information obtained on subsequent dives and on the basis of how the work is progressing.

(*c*) Prepare and assign tasks and give the divers instructions well in advance. This will enable the diver to think over the task with the result that he may offer suggestions or ask questions which may assist in completing the job.

(*d*) A diver may unintentionally overestimate his ability to accomplish underwater work. Suggestions should be thoroughly considered and weighed by the judgment of those in charge.

(*e*) Each diver of a group, in addition to his own specific instructions, should be given a general idea of what tasks the other divers of the group are to perform.

(*f*) Final instructions must be given to each diver and to the group by one person only.

(*g*) If the diver forgets part of his instructions, he must immediately ask advice from the diving supervisor. Therefore, the diving supervisor must be immediately available during diving operations.

(*h*) When a diver is on the bottom, it is inadvisable to alter the diver's prearranged task. It is better to instruct and send down a new diver to replace him.

(*i*) Work night and day, while weather permits, provided sufficient divers are available.

(*j*) In planning the work of divers, arrangements should be such as to preclude any necessity for their stay on the bottom in excess of the optimum time of exposure as shown in the decompression table.

706. STOWAGE OF GEAR

When diving operations are completed, all gear should be cleaned and then stowed in a dry, cool compartment, and kept in good repair and in readiness for immediate use. All chests of diving apparatus shall, when sufficient space is available, be kept habitually stowed under cover, away from steam pipes and excessive heat. When it is necessary to keep them in the open and exposed to the weather, suitable canvas covers should be used to protect the outfit.

B. DRESSING THE DIVER

711. RESPONSIBILITY OF OFFICER IN CHARGE

The officer or diver in charge shall see that the diver is properly dressed, the air hose and all air connections properly made, air system is in satisfactory operating condition, and all gear properly arranged on deck or in the diving launch before the diver begins his descent. The officer or diver in charge is responsible for the condition of the diving gear, and should make sure that all equipment is in good working order before the diver is dressed.

712. DRESSING PROCEDURE

(1) As shown in figure 98, the diver first puts on the woolen shirt, drawers, and socks. The amount of woolens worn will depend on individual preference and climatic conditions. Next, he gets into the dress with the help of the attendants. The legs of the diving dress should be snugly laced. Care should be taken, however, not to draw the lacings so tight that circulation of the blood in the legs is impaired. See figures 99 and 100.

(2) If cuffs are used instead of the gloves, an assistant spreads each cuff by inserting his first and second fingers on each hand, while the diver, taking care to keep his fingers straight, forces his hand through the cuff. Soapsuds rubbed on the inside of the cuffs or dipping the cuffs and diver's hands in fresh soapy water facilitates this operation. If rubber wrist bands are required, they are put on over the edges of the cuff. However, the effect of cold water together with the restriction of the circulation of the blood caused by the rubber wrist bands often results in a loss of the sensation of feeling in the hands so that there is danger of damage or injury to the hands when using tools. Accordingly, for work in cold water, a diver should be dressed in a suit fitted with gloves.

(3) Next, the canvas overalls, if used, are put on. Then the diver sits on the dressing stool, and the assistants place the weighted diving shoes on and secure them to the diver's feet by lacings and buckled straps. Lanyards should be well secured

around the ankles and the straps pulled tight and buckled. Buckles should be outward.

(4) The helmet cushion is put on, followed by the breastplate, figure 101. Care should be exercised to prevent the rubber collar from being torn when it is pulled up and placed over the projecting studs. The bib is drawn well up, and the rubber collar is placed over the front of the breastplate, working it over the remaining studs in succession toward the back studs, alternately pulling up on the bib. Two attendants, one on each side of the diver, are best for this operation. The diver may, by elevating his arms, assist getting the holes in the collar over the shoulder studs. Four copper washers are now placed on the studs where the breastplate straps join. The four removable breastplate straps are placed over the studs. The wing nuts are then run into the studs; those on each side of the strap joints are screwed tight first, and those at the joints last. If a dress with gloves is used, the wrist straps are now applied.

(5) The weighted belt, figure 102, is fastened on, making the leather shoulder straps cross in front of the diver's breastplate and over his shoulders. In back, the shoulder straps again cross before being buckled. The diver then stands and the jockstrap is brought between his legs and, with all the slack taken up, buckled firmly in front.

(6) During the time the diver is being dressed, the helmet should be examined, the valves and intercom tested, the proper decompression tables determined for the depth and anticipated time on bottom, and the necessary lengths of hose coupled, care being taken that a washer is in place in each female coupling. One end of the 50-foot length of air hose should be attached to the inlet of the air control valve and a 3-foot length of hose should be connected between the exhaust of the control valve and the nonreturn valve on air hose gooseneck. The lifeline is secured to the gooseneck on the back of the helmet. The air supply system should be checked thoroughly. If a compressor is to be used, it should be started and warmed up. Air should then be blown through the hose, helmet, etc., to clear the system of any dust or dirt. To reduce the possibility of fouling, the first 50 feet of hose and lifeline are married, and then canvas is sewed on. The remainder of the hose and lifeline should be seized at approximately 10-foot intervals.

(7) The helmet is then screwed onto the breastplate, figures 103 and 104. The ball lever of the safety lock is turned down into its recess and is locked in place by the safety latch and the split cotter pin. The combination amplifier and lifeline cable and air hose are brought up under the right and left arms respectively. The combination amplifier and lifeline cable is secured to the right breastplate eyelet and the hose to the left eyelet. The cable and hose are secured to the eyelet with signal halliard by taking two round turns and a square knot. The air-control valve is then attached to the long stud on the breastplate. The telephone should also be tested by the diver.

(8) The tender should assure himself that the diver is properly dressed, and particular care should be exercised in making sure that the safety catch is secured. When the diver understands the work he is to perform and is ready to dive, he is assisted by an attendant on either side to the diving stage, steps aboard, and grasps the iron bales. When the officer or diver in charge is satisfied that all is in order, the air is started, the helmet faceplate is closed, and the air-regulating exhaust valve closed and reopened the desired number of turns to provide proper ventilation and buoyancy. Usually two and one-half turns provide the proper ventilation and buoyancy. The diver is then hoisted clear of the ship's side and he is ready to begin his descent.

(9) When diving from motor launches, the diver can be completely dressed as described above or he can be partly dressed on deck and partly while on the ladder. In the latter case after the diver is properly dressed, without weights or helmet in place, a manila safety line tended by two men is secured around him, under the arms, and he then climbs over the side and stands on the diving ladder, with his waist on the level of the gunwale on which rests the weighted belt. The diver leans over the gunwale, the weighted belt is fastened, and the jock strap adjusted. Next, the helmet is screwed in place and secured, the air started, the air-regulating exhaust valve properly adjusted, the faceplate closed, and the manila safety line removed. When the officer or diver in charge is satisfied that the gear in the boat is properly arranged and in order, the diver starts the descent. When the lightweight diving equipment is to be used, the diver is dressed in the same manner as that described for the deep sea diving equipment. Care should be taken to insure watertightness at the back opening and where the mask comes in contact with the dress face gasket.

C. THE DESCENT

721. STARTING THE DESCENT

(1) Prior and during time the diver is being dressed, the equipment required for the descent should be arranged. The diving ladder should be secured in position over the side of the boat and to the leeward. Soundings have been taken. The descending line is put abaft of the ladder, leaving room for the decompression stage. The diver remains on the stage or ladder until he is satisfied that the dress is tight, air valves and telephones are in working order, and properly adjusted. After reporting such by signal, he steps off and is hauled by the tenders to the descending line that is usually made fast at the point where the stage is put over.

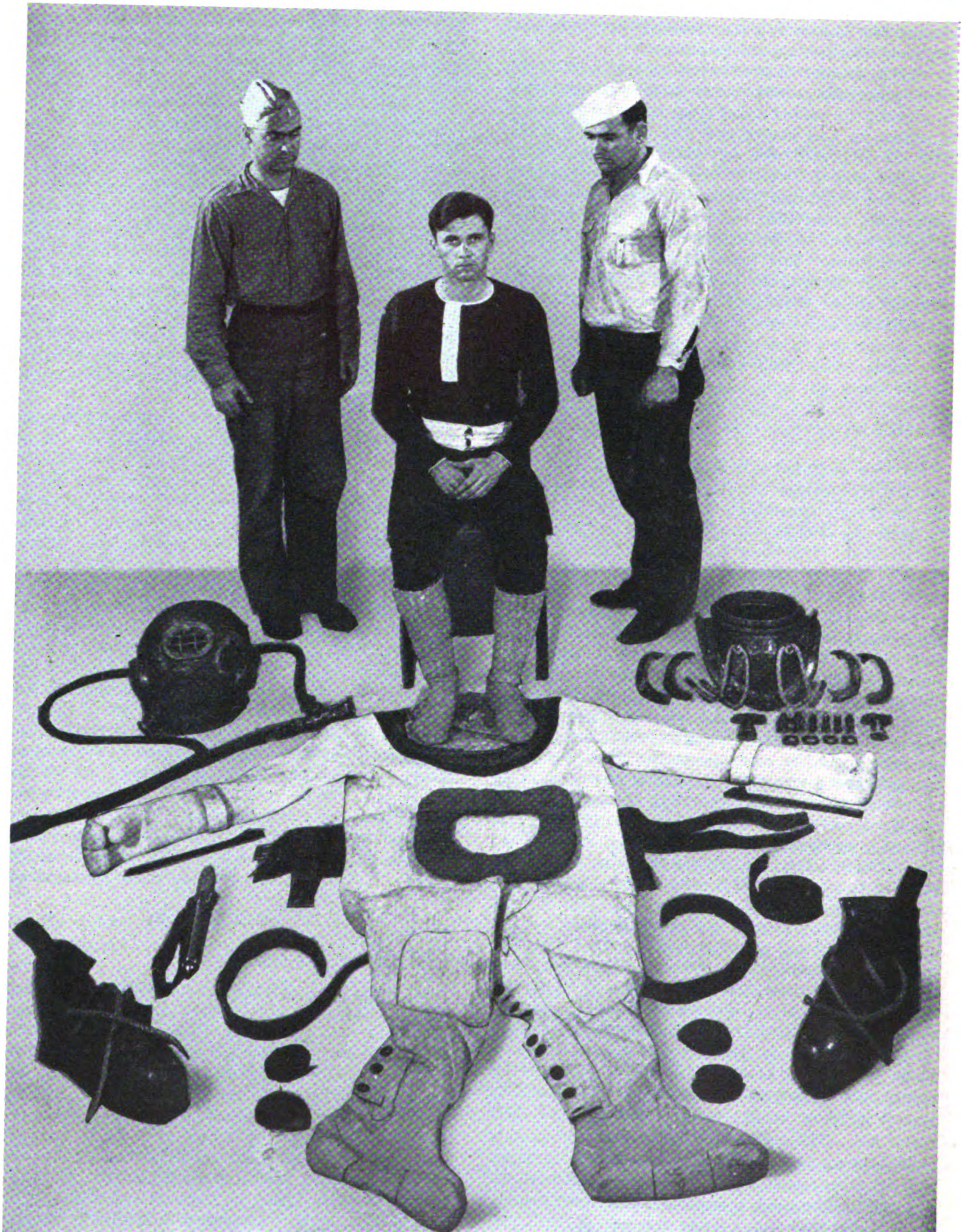


FIGURE 98.

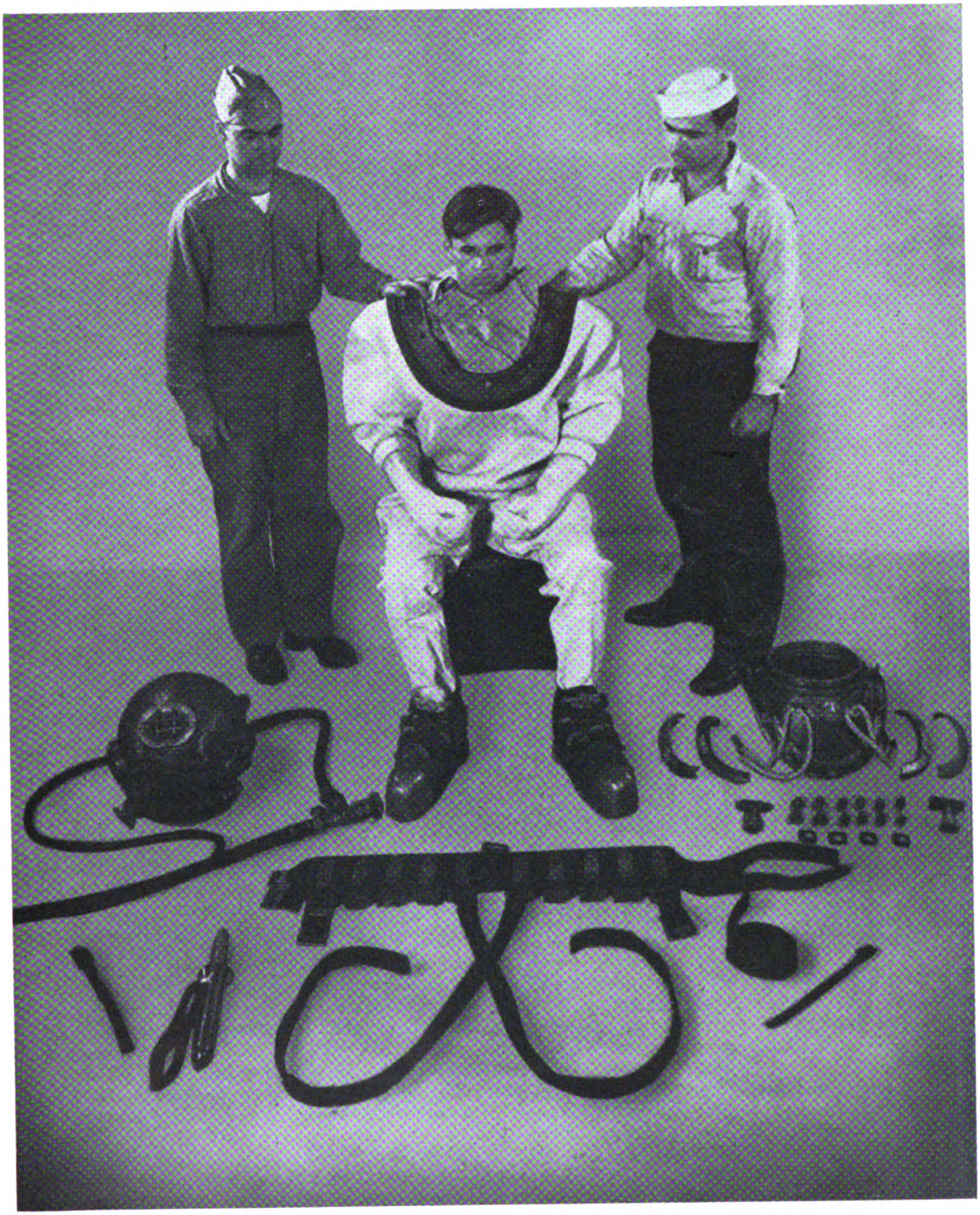


FIGURE 99.

FIGURE 100.

The diver locks his legs around the descending line and holds onto it, while he adjusts his air supply before he starts the descent. Figure 105 shows the diver making an adjustment of the regulating escape valve.

(2) A second method of descending is by means of a decompression stage, figure 106. The diver stands on the middle of the stage and supports himself by bracing his feet against the side and holding on to the stage bails. The stage is then hoisted over the side and the descending line is passed through the shackle on the side of the stage. The diver is lowered until the helmet is awash. At this point the descent is halted until the diver adjusts the flow of air. After the proper signal is given the diver is lowered at a steady rate, allowing sufficient time for the diver to equalize the pressure. When the stage has reached the bottom, the diver steps off the stage from the same side he entered it. This will prevent the diver's line from becoming fouled with the stage.

722. RATE OF DESCENT

(1) The rate of descent should not exceed 75 feet per minute, allowing for the diver's ability to equalize the pressure and "pop his ears," and for checking the descent whenever necessary. The factors limiting the rapidity with which a diver can descend are possibility of a squeeze, inability to equalize the air pressure on both sides of the ear drum, pains in the sinus passages, the tendency toward dizziness, the effect of currents, the necessity of approaching an unknown bottom cautiously, and other variable factors.

723. SWIMMING ON SURFACE

If the diver needs to swim on the surface to reach his descending line, the following procedure should be followed. When the diver enters the water, he closes his exhaust valve and then opens it up about one-quarter of a turn. The spit cock should be opened to allow for a greater flow of air through the suit. The air valve should be adjusted so that when floating in a vertical position, the faceplate will be just out of water. When the diver is ready to begin swimming, he faces the direction in which he wishes to travel and pushes himself free of the ladder or stage. The leg motion used is a circular movement that is similar to pedaling a bicycle. At the same time the arms are used in a dog paddle to help propel the body forward. When the diver begins to move, the tender pays out enough slack in the air hose and life line so that the diver can make headway easily. If the diver has a tendency to fall over frontward when swimming, arching his back and leaning back in the suit will be found helpful. It should be remembered that the swimmer is in a vertical position and that his direction of travel is in the direction he faces.

724. DESCENDING IN TIDEWAY

When descending or ascending in a tideway, the diver should keep his back to the tide so that he will be forced against the descending line and not away from it. It is not difficult for him to maintain this position if he determines which way the tide tends to swing him and pushes the descending line over to one side or the other so as to check the swing.

725. PAIN IN EARS

Pain in the ears during descent is a warning that must not be neglected as rupture of the ear drums is threatened. The remedy is for the diver to stop his descent and yawn, swallow, or press his nose against the wall of the helmet to block the nostrils, and make

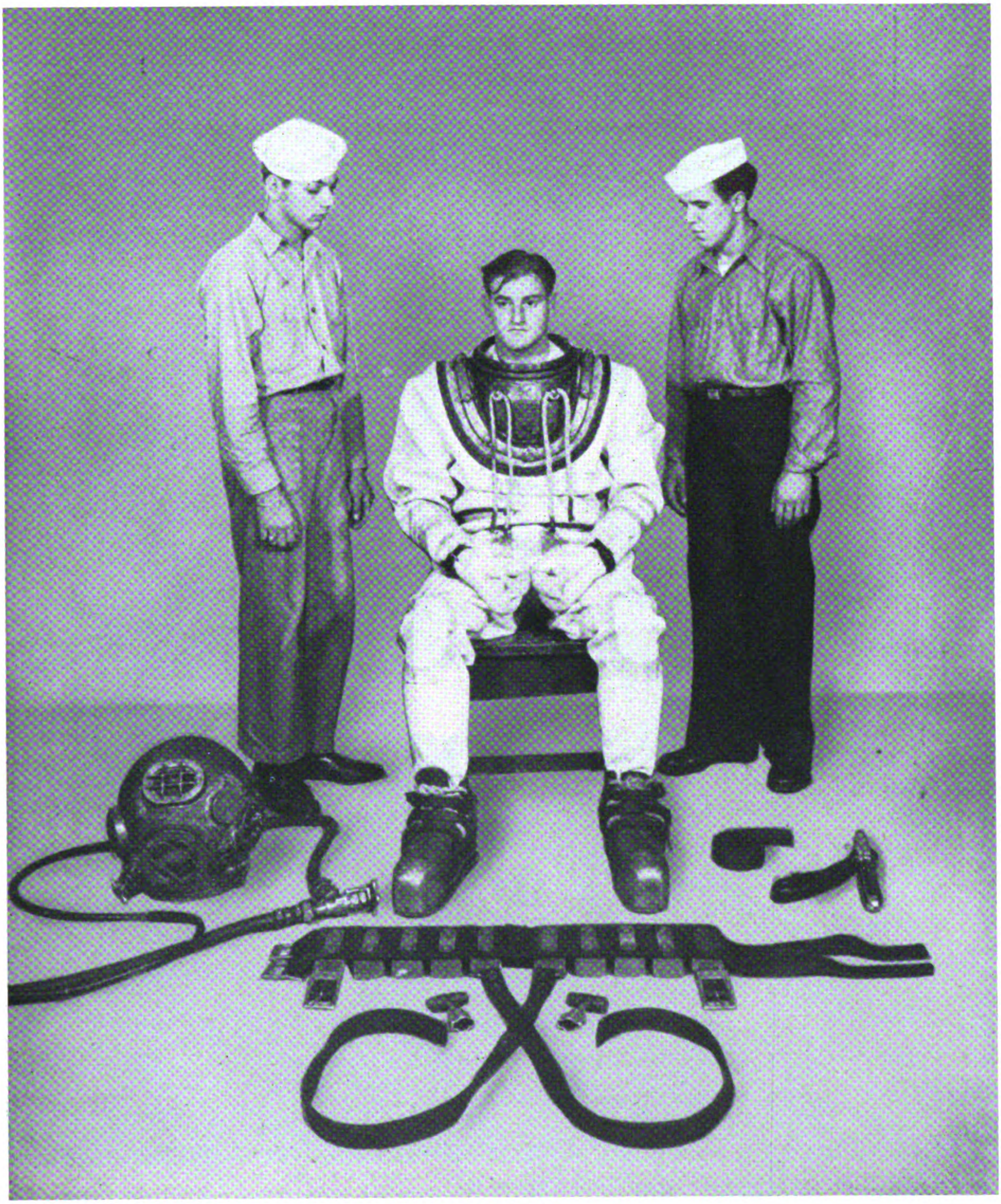


FIGURE 101.

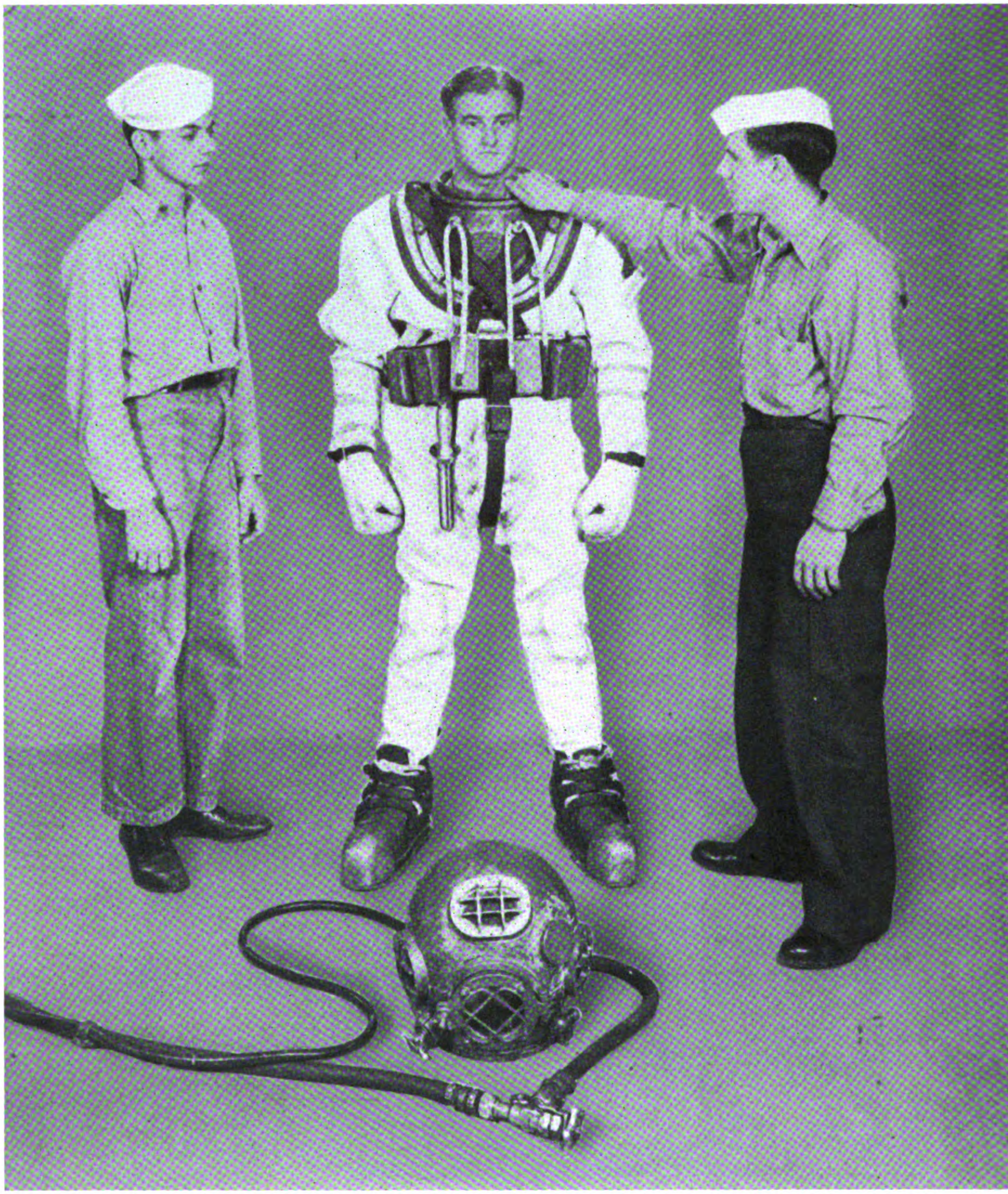


FIGURE 102.

FIGURE 103.

a strong effort at expiration. Ascending 3 or 4 feet usually provides relief, and the descent then may be continued. If the dive is to be made in deep water and the diver has trouble with his ears in getting down to 30 feet, it is advisable to bring him to the surface and not let him dive that day. Pain in the sinuses is usually caused by head colds, and the only remedy is to prohibit the diver from diving until his cold clears up.

726. REGULATING AIR DURING DESCENT

As the diver descends, care must be taken that air is supplied to him in the correct volume and at the pressure corresponding to his increase in depth. Insufficient air supply during descent may force the diver to stop because of a squeeze. As the diver descends, air is forced out through the air-regulating exhaust valve by the pressure of the water, so that the dress becomes closely pressed to the legs, arms, and body up to the breastplate. The experienced diver adjusts the air supply so that he breathes easily and comfortably without endangering his stability.

727. PROCEDURE UPON REACHING BOTTOM

Upon reaching the bottom, the diver holds onto the descending line and adjusts his buoyancy to such a degree that the helmet merely lifts the weight of the apparatus off his shoulders. He also checks his ventilation and should spend about 30 seconds at the descending line to permit his body to adjust itself at the new pressure level.

D. WORKING ON THE BOTTOM

741. AIR SUPPLY ADJUSTMENT

(1) As the diver descends, it is necessary to adjust the flow of air continually to compensate for the increasing water pressure. As a result, when the diver hits the bottom, the air supply is either too little or too great. Upon reaching the bottom, the diver should remain at the descending line long enough to regulate the flow of air to insure proper dress inflation and become adjusted to the new pressure level. Ordinarily, the dress will be properly inflated when the helmet and breastplate are just lifted from the shoulders and yet does not overcome the negative buoyancy. Next, it should

FIGURE 104.

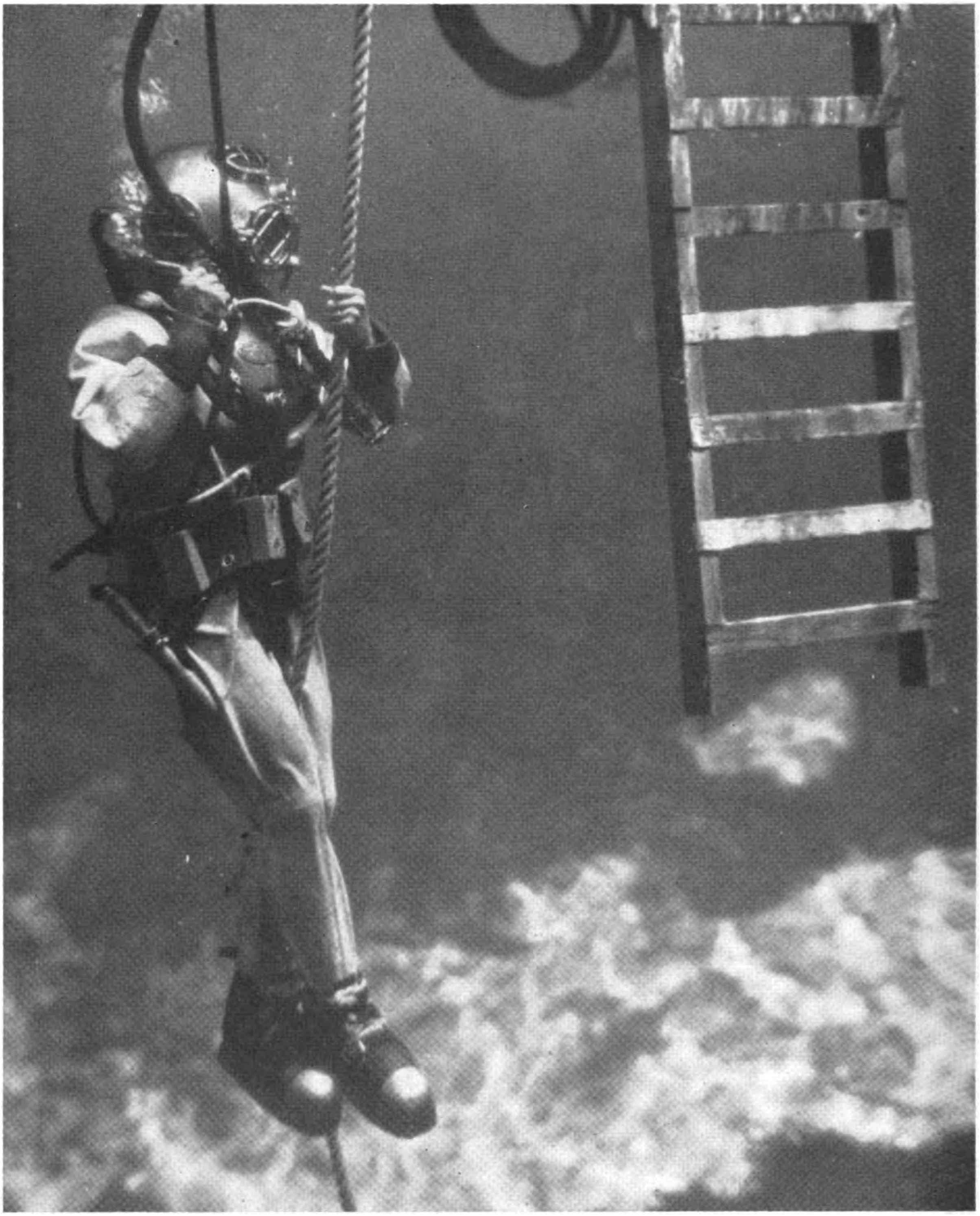


FIGURE 105.

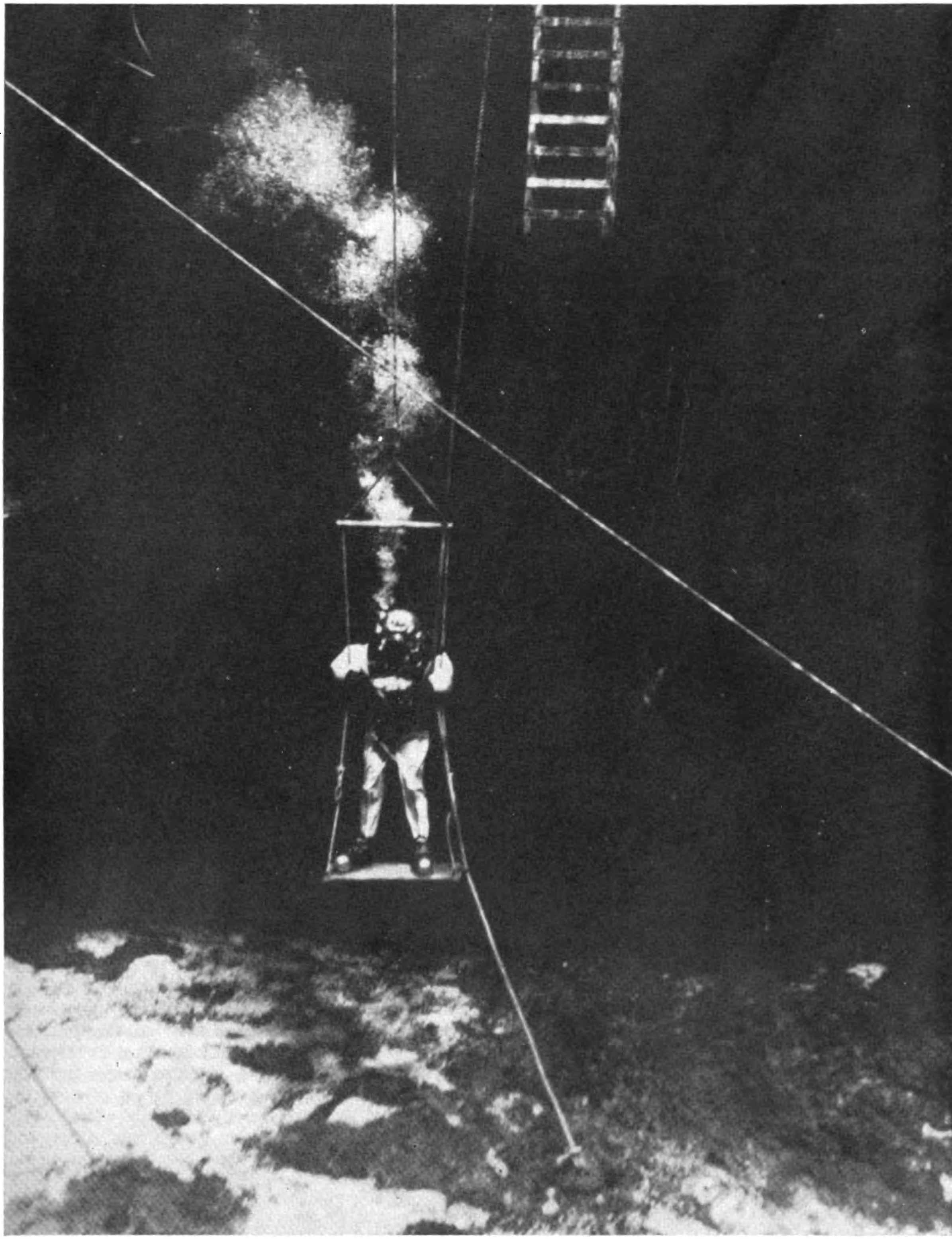


FIGURE 106.

be determined whether there is proper helmet ventilation. While the diver is standing at rest, his physical condition should be comfortable and normal. Should there be rapid breathing, panting for breath, unnatural perspiring, undue sensation of warmth or dizziness, eyesight not clear, or if the helmet windows become cloudy, there is bound to be an accumulation of CO_2 in the helmet and the remedy is "more air." This can be accomplished by increasing the rate of circulation through the helmet. Proper inflation and ventilation can usually be obtained by opening the helmet air-regulating exhaust valve 2½ or 3 turns and then regulating the air flow with the air-control valve. The best practice is to adjust the exhaust valve at the same time as the control valve, i. e., increase air supply, increase exhaust; reduce air supply, reduce exhaust.

(2) There are many occasions where proper control of the air supply can be used advantageously to lessen muscular exertion and assist in completing the job. In addition to the initial settings, it is frequently desirable to obtain a changing inflation or deflation for short periods of time or to accomplish specific tasks without readjusting the regulating escape or control valves. In order to cause a rapid deflation, the exhaust opening is increased by pushing the escape valve chin button outward. If a rapid inflation is required, the chin button should be grasped by the lips shutting off the exhaust. For a further regulation of air flow the "spitcock" may be used.

742. DETERMINING DIRECTION

(1) Before leaving the descending line the diver should note the lead of the hose and life-line cable to insure that they have not fouled the descending line. In order to determine the direction, the diver should also note the bearing of the brightest light (diffusion of sun rays) and the direction of the current. By remembering the direction of the work with reference to the direction of the sun while on the surface, it is easy to proceed in the desired direction. If, for instance, before starting the descent, the sun shone on the left helmet window, the greatest amount of light should still shine in the left window of the helmet when on the bottom if the diver's position is the same as when on the surface with relation to the sun. If there is no light, the diver may depend upon the direction of the current for guidance. The slightest general movement of the water can usually be detected by an experienced diver. However, the current does not always flow in the same direction on the bottom as on the surface and, consequently, if the diver should start off in the wrong direction, the tender should warn the diver.

(2) The most satisfactory method of determining the direction of travel is by tender-diver communication; either by "intercom" or prearranged hand signals—so many pulls means to go to the right, so many means go to the left. A warning or signal to indicate directions means that the diver should first face in the direction from which the lifeline and air hose are tending, and then obey the instructions.

743. MOVEMENT ON THE BOTTOM

(1) Upon leaving the descending line, the diver should proceed slowly and cautiously to conserve his strength. It is advisable for the diver to carry one turn of air hose and telephone cable on his arm in order to prevent sudden pulls from the surface throwing him off balance. The immediate surroundings should be examined and a report made of any wreckage or obstructions encountered. As a general rule, it is advisable to pass over, not under obstructions. In this connection in passing any obstruction, the diver should keep in mind the side on which he passes so as not to become fouled on the way back.

(2) Movement is relatively easy in slack water, but as the side or current increases, it becomes increasingly difficult to advance. This difficulty may be lessened by advancing in a stooping or crawling position, which reduces the area of the body exposed to the sweep of the current. The latter position is the easiest one for navigation under water. However, it should be remembered that every time the diver assumes a new position, consideration must be given to the regulation of the inflation of the dress.

744. WORKING ON ROCKY BOTTOM

When working on a rocky bottom, the diver should guard against tripping and getting legs or arms caught in crevices. If the rocks are sharp, as coral usually is, it will be advisable to wear gloves. Particular attention should be paid to preventing the air hose and life line from catching on the rocks, and the tender should be cautioned about keeping the slack well in hand. In the event the lines do become fouled, the diver should gather up the lines and retrace his steps by following the lead of the air hose and life line. In practically all cases the diver will be able to clear his own lines without requesting the assistance of the standby diver.

745. WORKING ON MUDDY BOTTOM

(1) When working on a muddy bottom, the divers should remember to keep all movement to a minimum in order not to stir up the silt and reduce whatever visibility there may be. In addition the diver should provide more buoyancy by keeping plenty of air in the dress. Sinking deeply into the mud indicates that there is an excess of negative buoyancy. While this condition can be corrected by increasing the inflation of the diving dress, the diver's movements in wiggling out of the mud should be as gradual as possible in order to eliminate the possibility of "blowing up" after breaking loose.

(2) There is nothing to fear about mud, quicksand, and the like. Actually, such substances are a cross between land and water; their density is not

sufficient to support the diver but is great enough to offer more resistance to sinking than water. Divers have been known to work under many feet of mud and silt for relatively long periods without undue discomfort. The hazard involved in diving in muddy water is the inability to see such objects as pilings, stone walls, debris, cans, bottles, etc., that may cause the diver physical harm. One of the primary reasons for using the deep sea diving equipment in water where visibility is very limited is the physical protection offered by this type of equipment.

746. SEARCHING FOR LOST OBJECTS

(1) When searching for lost articles, the diver should explore thoroughly and as expeditiously as possible the whole of the ground within the sweep of the distance line. To accomplish this, the diver takes up the distance line, holding it taut, and starting from some point sweeps around in a circle. After returning to the starting point which must be judged by some object on the bottom—the direction of the tide, a line stretched along the bottom for the purpose, or signal from topside—the diver moves out along the distance line and makes a fresh circle in the opposite direction, thus avoiding the twisting of his air hose and life line around the descending line. It is generally more advantageous to crawl on the bottom when searching, though in exceptionally clear water, a better field of vision may be obtained by walking.

(2) When a diver has explored the whole of the ground in this way without finding the object sought, he may be fairly certain that it is not within the reach of the distance line; hence the next step would be to have the ship or the diving launch moved so that a new area may be searched. Before the ship or the diving launch is moved, the diver is brought up and the position is marked by a buoy so that a systematic search may be accomplished. When a number of buoys have been thus planted over a considerable area, the unimportant ones may be removed by the surface crew. The important ones marking the boundary of the explored area should remain until the search is completed. The diver may be unable to make a complete circle if there is much tide or current. In that case, it is necessary to work back and forth across the tide as far as possible, each time moving out a little farther along the distance line until he reaches the end, and then having the position of the diving boat shifted.

(3) Still another method of searching is to plant two large buoys a considerable distance apart. A surface line of adequate size manila is stretched between the two buoys. The diving launch with diver on bottom is then ferried along, the surface line being taken over the bow and stern rollers of the launch, and the boat being given headway by pulling on the line or stopped by holding onto it, according to signal from the diver. The advantage of this method is that the speed of the boat is always under exact control.

(4) Upon finding the object sought, the diver should, if possible, fasten the distance line to it, after which he may signal for a rope and have it hauled up or go up and make a report, as circumstances may require. An object once found can always be relocated by means of the distance line tied to it.

747. WORKING ABOUT MOORINGS

When working about moorings, a diver should not dip under chains, etc., without having a distance line to show him the way back. As old moorings are often covered with sharp barnacles, gloves should be worn to protect the hands. A diver should not descend on a chain or wire if it is possible to do otherwise, and neither should a chain, wire, line, or weight be veered, lifted, or moved until the diver is clear of them.

748. WORKING WITH SEVERAL LINES

When a diver is required to work with several lines, it is a good plan to have each of them of a different size or material or marked by using colored rags, turns of small stuff, etc., so that he may know their individual purpose. He should never cut a line until he has made certain the purpose for which it is being used. Since a new line when under water shrinks and usually takes several new turns, it should first be lowered in the water by means of a weight and allowed to remain a considerable length of time before it is sent to the diver. Otherwise, if lowered alongside another line, it is sure to become fouled. For underwater work, cable-laid line is the safest and most useful.

749. RECOVERING AN ANCHOR

(1) In recovering an anchor, the line of the watching buoy should be hauled up and down, and the descending line weight dropped close alongside it. The diver can then go down his descending line, keeping the buoy line in hand as he descends, thus preventing his descending line from fouling the buoy line.

(2) If a wire hawser has to be shackled onto an anchor, the task may be accomplished in the following manner:

Prepare the wire by fitting a large shackle to the eye and by stopping another shackle with its crown against the wire a short distance above the eye. The pins of both shackles should be fitted with lanyards to prevent their loss under water. Shackle the wire to the descending line or to the anchor buoy rope (if watching) by the upper shackle, which will act as a traveler, leaving the end of the wire free for the diver to handle. When the diver has found the anchor, he should signal for the wire which should be carefully lowered to him, great care being taken to prevent the wire from being dropped on the diver or too much being paid out, since large bights on the bottom render it difficult to find the end and may foul the diver. After shackling on, the diver must come up before any attempt is made to weigh the anchor. If the anchor is any distance from the descending line, or the buoy is not watching, the diver should bend his descending line on or get another rope bent on so that the lifting wire may come down exactly where it is needed. The same applies for raising other heavy weights such as guns or torpedo tubes from a wreck.

750. WORKING ON SHIP'S BOTTOM

(1) The amount of work which can be accomplished on ships' bottoms by divers depends largely upon the nature of the work and the extent of stable accessibility that can be maintained by the rigging of lines, ladders, and stages to the wreck. Two or more jacob's ladders lashed together side by side and weighted at the lower ends form a convenient arrangement to enable divers to work over the side of a vessel. If the ladder is hung from the ends of spars secured on deck and projected about 2 feet clear of the ship's side, the ladder is hauled under the bottom by hogging lines; the divers will have room to work, be able to move around freely, and be protected from falling, they of course being on the inboard side of the ladder. For working beneath the bilge keels of large vessels where the bottom is usually flat, a good plan is to lace a net between two jacob's ladders. The two ladders are separated by spars lashed in place so as to stretch the net, and the whole is passed under the keel by the aid of hogging and tricing lines. The diver can then lie back in the net and work on the bottom above him with comparative ease. When a diver is working under a ship, all lines, etc., must be carefully attended.

(2) Another method of rigging a stage which is very quickly made and has been found very suitable for the use of divers working on a ship's bottom is as follows:

Two long spars, 20 to 25 feet long, are suspended from each other about 4 feet apart by means of two long ropes, the bights being clove-hitched around the end of each spar, the upper ends forming the tricing lines, and the lower ends the hogging lines. The tricing lines are to take the weight of the stage, and the hogging lines are for holding it down and binding it in to the ship's side. A third spar about 16 feet long is hung to the lower of the two long spars by means of a slung weight, so as to keep it in a horizontal position about 3 feet below the lower long spar, sufficient weight being hung to the stage to overcome its buoyancy. To prevent the stage from being bound too close to the ship's side, crosses of wood can be used, made from any rough pieces about 3½ feet long, and secured in the form of a cross. One of these crosses is secured at each end of the upper spar. A small cleat nailed on the spar prevents the crosses from slipping inward and the clove hitches of the stage ropes prevent them from slipping outward. This stage is suitable for two divers. The stage can be raised or lowered bodily, the diver at each end giving his own signals. When it is desired to fleet the stage, the divers should come to the surface.

751. CLEARING OR REMOVING VALVES

Valves, as a rule, can be easily cleared from the outside by means of a wire brush and a pricker to clear the holes. If barnacles have gathered inside the perforated covering, the grating must be taken off to destroy them. The position of the grating should be marked before removal to facilitate its replacement. In case of the removal of a valve after the securing plate has been taken off, the hole plugged up, and the plug cut off flush with the ship's side, the outside should be covered with wood, lined with greased fearnaught to prevent any leakage inboard. If the valve is only to be kept out a short time, this covering need only be temporarily fastened, as the pressure of the water on the outside keeps it in place.

752. CLEARING PROPELLERS

(1) Propellers usually get fouled by rope or wire hawsers, and at times are most difficult to clear. A stage should be rigged near the fouled part (an iron grating will answer the purpose) to enable the diver to work in comfort.

(2) First, the fouling should be thoroughly examined to see if it is possible to clear an end; if so, and if the turns are jammed, rope ends or tackles from the surface must be rigged and installed to break them out. Back turns can be taken or the propeller turned by the jacking engine to insure the lead of the tackle being at its best. Particular care must be taken to see that the diver and stage are out of the way when the propeller is being turned. The engineer officer and engineering officer-of-the-watch must always be informed whenever a diver is working about the propellers.

(3) If no end can be exposed, then the hawser must be cut. Rope hawsers can be cut with a knife, hack saw, carpenter's chisel, etc. There are several practical methods of cutting fouled wire cables. The first is by use of the powder-actuated cable cutter provided the diameter of the cable does not exceed 1 inch. The second is by burning with underwater gas or electric torches. The third and most tedious method is by cutting the cable with a sharp chisel or saw.

753. WORKING AROUND CORNERS

When a diver is required to drag a long length of life line and air hose, or when it is necessary to work around several corners, an additional diver or divers are of assistance in tending his lines at intervening locations on the bottom or on deck.

Thus, if the intercom should fail, the diver can send signals to one of the divers tending his lines, who, in turn, would transmit them to the surface by intercom or signal over the first diver's lines, using his own lines only for signals affecting himself. However, it should be borne in mind that the greater the number of divers submerged simultaneously, the greater the possibility of fouled lines. Whether the benefits of this procedure justify the acceptance of the greater possibility of fouling depends on the emergency or circumstances involved. This procedure will be at the discretion of the officer or diver in charge.

754. GUARDING AGAINST FALLS

(1) Whenever a diver is working clear of the bottom, as on a rocky ledge, ship's bottom, deck of a vessel, etc., caution should be exercised to prevent falls. The significance of a fall is that there results a sudden increase in external pressure without a corresponding increase in internal pressure, which may result in a serious accident or "squeeze." Falls in shallow depths are more serious than falls in deeper depths. In falling from the surface to a depth of 33 feet, the pressure on the body is doubled and the volume is reduced by one-half while in a fall from 166 feet to 200 feet, the pressure is only increased by one-sixth and the volume is reduced one-seventh.

(2) The diver should always have something substantial to hold on to. However, it is dangerous to hold on to something overhead and climb around in this manner as the air in the dress may escape out of the cuffs or through leaks in a torn glove, in which case the diver may become so heavy as to precipitate a fall. Similarly a diver should never go under the keel of a ship and come up on the other side, for in the event of a fall, it would be extremely difficult for the tender to render the diver assistance in checking the fall.

(3) Should a fall occur, the descent may be checked by the tender if the lines have been held sufficiently taut, or by the diver increasing the flow of air through the control valve and gripping the regulating escape valve chin button between the lips to reduce the exhaust, thereby gaining additional buoyancy by inflating the dress. However, when inflating the dress, it is important that the other extreme, overinflation, does not cause a "blow-up." A "blow-up" can be prevented by reducing the flow of air through the control valve and providing full exhaust by pressing the escape valve chin button.

755. FOULED DIVER

(1) Whenever a diver discovers that he has become fouled, the first thing to do is to stop and think the situation over. It should be remembered that there was a way into the situation, and there is similarly a way out. Under no condition should the diver become excited, but instead should attempt to extricate himself by slow methodical efforts. Topside should be notified, if possible, by "intercom" or hand signal so that arrangement can be made to send a relief diver if required. The diver should then take the distance line together with the life line and air hose and retrace his steps until the point is reached where the lines have become fouled. The necessary steps should then be taken to untangle the lines. After several attempts have been made without success, assistance should be requested and a relief diver will be dispatched.

(2) The relief diver should follow down the fouled diver's air hose and life line in order that he may discover the tangle. However, if, after discovering the tangle, he is unable to release the fouled diver, arrangements should be made to substitute a new air hose and life line. To accomplish this, the relief diver fastens the new life line around the fouled diver's waist. Next, the fouled diver closes his air-regulating exhaust valve and his air-control valve while the relief diver uncouples the nearest free coupling of the fouled air hose and couples the new one. If an air-control valve is not used, it is important that the hose coupling to be broken shall be at or below the level of the fouled diver's feet.

756. LOSS OF DISTANCE LINE

In the event the distance line is lost, the diver should feel carefully on the bottom within his reach for it. But if, after this simple maneuver, he does not find the distance line, he should inform the surface of the loss and that he is coming up. The attendant should guide the diver over to the descending line, and as the diver is hauled toward the surface, it is highly probable that the diver will discover the descending line. As soon as the descending line is located, the surface attendants are advised by means of the signal "lower." The diver descends and with the distance line again in his possession, returns to work.

757. SENDING DOWN TOOLS

Definite arrangements should be made by topside personnel to insure the diver's receiving the necessary tools to do a job with the minimum physical strain. Tools that the diver is to carry down should be fitted with lanyard and slipped over the diver's right arm or placed in the diver's tool bay. When tools are not to be carried down by the diver but are to be sent to the diver, a special descending line of 2½- or 3-inch rope should be secured to the point where the material is to be used. The line should be given an angle of lead that will cause anything sliding down to land so that the diver can easily locate it and guide it into place. When a power tool is to be sent down, it should precede the diver, and should be attached by a piece of 6-thread manila to a sliding shackle on the descending line, and lowered to the bottom by means of the tool's air hose. An electric torch and ground wire or a gas torch and igniter may be sent down in the same manner as the power tool, except the ground wire or torch hose is used as the lowering line. For all other objects, use 15- to 21-thread manila for a lowering line, led from well forward to prevent turns, attached by an eye splice to the sliding shackle on the descending line, the small objects being in turn attached by a short piece of marline to the shackle.

758. SAFETY PRECAUTIONS

In order to work efficiently and safely under water, a diver should keep in mind the following general rules and facts:

(1) The air-regulating exhaust valve adjustment should be set at the desired number of turns open prior to starting the dive.

(2) A diver should adjust his air in such a manner that he is enabled to breathe comfortably.

(3) The helmet air-regulating exhaust valve stem known as the chin button may be used effectively to release quickly the suit pressure when desiring to stoop or crawl on the bottom without changing the air-control valve and the air-regulating exhaust valve adjustment.

(4) The combined discharge of air-regulating exhaust valve and spitcock will not exceed the flow of air that will pass a half-open control valve, hence movement of the control valve wheel must be very small.

(5) Never completely close the air-control valve, except during rupture or replacement of the air hose.

(6) The helmet spitcock offers a secondary method of relieving excess pressure in the helmet.

(7) The safety air nonreturn valve and the air-regulating exhaust valve will seat themselves if the diver's air supply is impaired, but the spitcock, if open, must be closed immediately by hand.

(8) A diver is never in danger from a leaking dress provided he remains in an upright position. Divers have descended to a depth of 274 feet with the helmet only.

(9) Air trapped in the diving helmet will last from 6 to 9 minutes for breathing purposes after diving air is cut off, thus providing ample time for emergency measures to be executed.

(10) If a diver should crack his faceplate, he should keep his faceplate downward and increase his air supply to prevent leakage.

(11) Never become frightened or excited; slow, methodical efforts are always best in an emergency. Inexperienced divers have been known actually to exhaust themselves worrying over very simple circumstances. Such a state of mind is both needless and useless. A diver should never make the foolish mistake of running away from his air supply and consequently from safety; i. e., to become panic-stricken and make violent exertions to escape from a tangle when the proper course is to go slowly and deliberately. When in trouble, he should slow down his exertions and, if relief is not immediate, rest awhile. No matter how serious the situation appears, a diver should remember that there was a way into his predicament, hence there is also a way out of it, and if he cannot solve the problem himself, then the relief diver will.

(12) A diver must have confidence, first in himself, and second in those who are tending him.

(13) In case a diver is fouled and cannot extricate himself, the relief diver that is sent down must be prepared to replace both air hose and life line, a procedure that may be safely executed on the bottom.

E. THE ASCENT

771. PREPARATION FOR ASCENT

After the diver has completed the task or has received instructions from the surface to come up, the necessary preparations for ascent should be made immediately. If a special line has been used for sending down tools, the diver should request that a line be sent down in order that the tool bag or other tools can be sent to the surface prior to starting the ascent. If no special line has been used, the diver should return to the descending line via the distance line and a line is sent down for attaching the tools. In the event the descending line cannot be located and the tools are too heavy to be thrown over the diver's arm, a line should be secured to the life line which the diver then pulls down. The tool bag is then made fast and the tender is signaled to haul the bag up.

772. BEGINNING THE ASCENT

Everything on the surface being in readiness, the tender advises the diver to stand by to "come up." The diver, after making certain that everything is clear and there is nothing to interfere with the ascent, places one leg around the descending line, as in the manner of descending, and lightens his weight as necessary by inflating the dress. In doing this, the diver should be extremely careful not to overinflate the dress, which may result in a "blow up." While the diver can assist the tender by lightening himself, the diver shall be lifted off the bottom by the tender. In this connection, the decompression table, part 3, section (A), is based on the requirement that the diver is brought to the surface at a specified maximum rate which can be more accurately controlled by the tender than the diver.

(1) Everything being ready, topside is then notified, "Ready to come up." When ready, the tender will notify the diver, "Coming up. Report when you leave bottom," and then will lift the diver toward the surface. The diver reports when he leaves the bottom. If the diver feels his dress becoming too buoyant and he is ascending too rapidly, he may check his rise by clamping his legs on the descending line and adjust the inflation of his dress by ad-

justing the air-regulating escape valve. If the dress is not fitted with gloves, reduction in inflation of his dress can be rapidly accomplished by the diver raising his arm which will permit excess air to escape at the cuff.

(2) During the time the diver is preparing to come to the surface or just prior to it, the decompression stage is secured to the descending line by means of a shackle fitted to the stage and is lowered to the desired depth. When the diver is warned by surface attendants that he is nearing the stage, he should keep a sharp watch for the stage. As soon as the diver finds the stage, he should climb upon it and seat himself. When this is done, the topside should be notified, "On the stage," in order that the beginning of the proper decompression at this first stop may be started and timed.

(3) During the time spent on the first and subsequent stops, the diver should see that his lines are clear of the descending line and stage. In case of fouled lines, he should report the fact immediately to the tenders and they will aid the diver to unfoul the lines as much as possible. Similarly, when the fouling of lines is detected by the tenders, the diver should be apprised of the fact. When the lines are clear, the diver shall notify the tenders, and they shall confirm the fact by repeating back the message, before starting to hoist the stage.

(4) When the diver is ascending and is on the stage, he should pay close attention to messages from the surface and in all cases endeavor to answer clearly and distinctly. When word is received from the tenders that the stage is to be hoisted, the diver should assure himself that his hold on the stage is secure before returning the O. K. signal to the surface.

773. ASCENT FROM DIVE MADE FROM MOTOR LAUNCH

The foregoing instructions for ascents cover procedure in diving from vessels such as submarine rescue and salvage vessels, which are properly fitted with hoisting and other diving facilities including a recompression chamber. The instructions are equally applicable to ascents from dives made from motor launches except that the stage must be hauled up by hand instead of a powered winch. Under such conditions, it is impossible to haul the diver to the level of and over the gunwale of the launch. Accordingly, the stage is hauled up until the diver can get aboard the latter which he mounts until his waistline is abreast the gunwale. The diver is then secured to the side with the safety line and helmet faceplate is opened to ascertain his condition. If no adverse symptoms are evidenced, the helmet and belt should be removed and the diver assisted over the gunwale by the attendants. The diver aids by bending his body forward from the waistline at approximately 90°.

774. STAGE DECOMPRESSION

(1) The diver is brought to the surface in stages to prevent contraction of compressed air illness or as it is more commonly called, "bends," "screws," "diver's paralysis," "caisson disease." The table for decompression, and the causes and treatment of compressed air illness are contained in part 3, sections (A), (B). In general, there are two methods of decompression: (1) regular decompression and (2) surface decompression.

(2) *Regular decompression* as used herein consists of bringing the diver to the surface, stopping at successive depths, and maintaining him at these stops for the prescribed period before surfacing him. This method of decompressing the diver is standard and shall be followed in all cases except where emergencies or conditions of tide or weather are such as to warrant surface decompression in the opinion of the officer or diver in charge. When the stage arrives at the surface after regular decompression, it is lifted and swung clear of the gunwale, lowered lightly to the deck, and the diver assisted from the stage. As soon as the diver is seated, the faceplate is opened and the air-supply valve closed. If a recompression chamber is available, the diver can be undressed at once. If a recompression chamber is not available, the diver should remain dressed except for the belt and the helmet for at least 20 minutes and closely observed for symptoms of compressed-air illness. At the end of this period, if the diver's condition appears normal, the remainder of the equipment should be removed.

(3) *In surface decompression*, the stage is lowered to the deck as before. The diver's helmet, belt, and shoes are removed as quickly as possible and he is escorted to the recompression chamber by the attendant, who enters the chamber with him and removes his suit as the pressure is raised to that corresponding to the first decompression stop. Not more than 3 to 4 minutes should elapse from the time that the stage leaves the water until the diver is inside the recompression chamber and is again being subjected to pressure.

(4) Regardless of method of decompression, it is well for the diver to remain in the vicinity of the recompression chamber or facilities for underwater decompression for at least an hour following the completion of a deep dive, even though there has been no indication of compressed-air illness during the 20-minute period mentioned. When extremely deep dives have been made, it is advisable to keep the diver aboard ship where he can be observed for at least 4 to 6 hours.

F. TENDING THE DIVER

781. RESPONSIBILITY OF TENDERS

(1) 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, personnel should be designated as tenders and instructed in the topside duties by the officer in charge of diving.

(2) It is the tender's responsibility and duty to see that the diver receives the proper care while topside and in the water. Before sending the diver down, he must thoroughly check such items as exhaust valve, control valve, intercom, and breastplate nuts. When certain that the diver is properly dressed and ready, a firm grip should be taken on the life line close to the helmet, and with the assistance of another attendant, guide him to the stage or ladder. Care must be taken to prevent the diver from getting off balance, stumbling, or falling. When the diver has adjusted his air and is ready, he should be directed to the descending line. The proper signal will be given when ready to descend. From the time the diver leaves the deck of the ship until he is safe on the bottom, the tender must keep all slack out of the line and be ready to render assistance at a moment's notice.

(3) Generally, the topside duties are divided into handling communications, tending lines, and insuring an adequate flow of air. The primary means of communication between diver and tender is by intercom. However, it is important that the basic hand signals listed in part 1, section (C), plus any supplementary signals originated to fit a particular type of job, should be memorized and practiced so that they will be recognized instantly in the event of intercom failure or when using lightweight gear not fitted with an intercom.

782. SIGNALS

(1) Since signals cannot be received on a slack line, the life line and air hose should be kept well in hand so that the diver can be felt and signals can be made distinctly. The tender, on receiving a signal, shall repeat it only if it is clearly understood. If a signal is not repeated, it indicates to the diver that the signal is not understood and should be repeated. If a wrong reply is received from the diver, the signal should be repeated until it is correctly understood.

(2) When the diver is on the bottom and near the descending line, also watch the latter for signals as the diver may want it lowered or the slack taken up. If at any time there is anything seriously wrong, the diver should ask to be hauled up by signaling four pulls on the air hose and life line. Four pulls on the air hose repeated is the emergency signal and should never be used unless something serious has happened and the tender must not delay in obeying it.

(3) In case the diver does not answer a signal after two or more trials at short intervals, ask him over the intercom if he is all right. Then if he does not answer, haul him up to the first stop of decompression and try again. Should there still be no answer, there is nothing left to do but to bring him to the surface. Should the diver answer the intercom, it may be that there is too much slack in the line or that the line is fouled. Remember that a diver at work may sometimes be in such a position that he cannot answer a signal for several seconds and a reasonable time should be allowed before the signal is repeated.

783. INTERCOMMUNICATION SYSTEM

(1) When using hand signals, the information and instruction exchanged between diver and tender must necessarily be restricted to simple and prearranged words or phrases. To overcome this difficulty, an intercommunication system is provided with the deep-sea diving outfit making it possible to relay and receive detailed instructions. While this system provides a ready means of communication, conversation should be kept to a minimum. It is very annoying and time-consuming for a diver to be continually receiving and answering unessential messages.

(2) In case either the diver or attendant fails to get an answer over the intercom, the hand signal should be made to indicate to the other that he is trying to talk over the intercom. After the diver has repeated the hand signal, the tender should wait a few seconds and try the intercom again. Then if no answer is received, it should be assumed that the intercom is out of order and the hand signals should be restored. If, on the other hand, after answering a message over the intercom, the same message is repeated several times and no attention is paid to the answer, the person receiving the message should acknowledge that he understands it by signals.

(3) In deep water when a strong tide is running, the hand signaling method is very difficult and often impossible. Therefore, diving under these conditions should not be attempted unless the intercom is in good working order. Under these circumstances, if the intercom should fail, the diver should be brought to the surface.

784. DIVING LOG

If personnel are available, one attendant should be assigned to stand by the intercom all the time the diver is down for receiving and relaying instructions. In addition, the intercom attendant may make the entries on the diving log. The time entries on the log should be very accurate, as it is from these entries that the diving officer determines the proper decompression time for the diver. Figure 107 is a typical diving log which will provide a complete record of the diving operations. For depth of dive see Article 836.

PREPARE IN DUPLICATE

Original - Retain for permanent Log
One copy monthly - To Experimental Diving Unit
U.S. Naval Gun Factory
Washington 25, D.C.

DIVING LOG

OF

Naval Shipyards need not submit reports on dives of less than 35 feet.

U.S.S. ______________________ FOR MONTH ENDING ______________ 194__

NAVSHIPS 1000 (REV. 10-48)

1	2	3	4	5	6	7	8	9	10									11	12	13
DATE	NAME OF DIVER	TYPE OF WORK	TYPE OF DRESS	DEPTH OF DIVE	TIME LEFT SURFACE	TIME REACHED BOTTOM	TIME LEFT BOTTOM	TIME ON BOTTOM	DECOMPRESSION SCHEDULE (Clock time and length of stop in minutes)									TIME REACHED SURFACE	MEDIA BREATHED	REMARKS (Include Partial Pressure Percentage of Helium and Oxygen)
									180	170	160	150	140	130	120	110	100			
									90	80	70	60	50	40	30	20	10			

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8-5036

FIGURE 94-107.

785. TENDING THE LINES

(1) In tending the diver's lines, the tender should make certain that the lines are not held too taut, otherwise the diver will find himself being continually pulled away from the work. In attending the life line and air hose, the diver should be given 2 or 3 feet of slack when he is on the bottom, but not so much that he cannot be felt from time to time.

(2) If the combined life line and air hose becomes turned around the descending line, it may become impossible to send or receive signals by this means and the turns must be taken out as soon as they are noticed. If, after a trial, they cannot be cleared, the diver should be hauled up. It may become necessary to haul the diver up along with his descending line and weight. In this event, if the weight is too heavy, the diver must try to cut it adrift and time should be given him for this purpose. Because of the possibility of his lines becoming fouled around another line, a diver should ordinarily not be permitted to descend on a line he cannot cut. However on occasions it may be imperative or highly desirable to use a steel rope or chain. The selection of the descending line to be used is left to the judgment of the officer or diver in charge.

786. CONDITIONS INDICATING DIVER'S LOCATION AND OPERATION

(1) The tender can very definitely use the bubbles rising to the surface to assist in determining how the diver is faring. The bubbles give an indication of the diver's movements on the bottom; and the tender, having a knowledge of the work to be done, can generally tell whether the diver is proceeding satisfactorily. If the diver is searching and the mass of bubbles appearing on the surface seems to be moving in a somewhat definite pattern, or if a job requires the diver to stand in one spot and the bubbles come to the surface in one small area, it is reasonable to assume the diver is proceeding safely.

(2) In addition to the above, it is possible to determine where and how the diver is doing by the following methods which are briefly described.

(*a*) The operation of pneumatic drilling machine can be detected by feeling the supply air hose at almost any point due to the peculiar variation of pressure within the hose when the machine is actually running.

(*b*) The operation of a pneumatic hammer can be detected in the same manner. When divers are working with pneumatic hammers or with hand hammers and chisels of fairly large size, it is also possible by listening in the after hold of the salvage vessel to hear every blow that is made.

(*c*) The operation of an arc torch can be detected by observing the ammeter connected in series with it.

(*d*) The operation of a gas torch may be detected by the flow of gas past the reducing valves that is indicated on adjacent gages. Also when the torch is lit, the noise can almost invariably be heard over the telephone of the diver who is operating it and the large bubbles of gas from the torch break on the surface and emit small bubbles of smoke.

787. PRECAUTIONS TO PREVENT DIVER'S FALLING

Whenever a diver is working clear of the bottom, as on a ship's deck or on a stage under a ship, the attendant should take all necessary precautions to prevent his falling. If under certain conditions it was noted that the bubbles were moving rapidly in a straight line, it would indicate that the diver had fallen. In this event, tightly grip all lines and quickly gather in the slack until the descent is checked, and then determine the diver's condition. In any case where there is danger of a fall, a tight hold should be kept on the diver's lines and a minimum amount of slack left out.

788. EMERGENCY ASCENT

(1) In bringing the diver to the surface, the tender shall make certain that the rate of ascent does not exceed 25 feet per minute. In case of accident or emergency, it may be necessary to get a diver to the surface as rapidly as possible despite the possibility of compressed air illness. Under these conditions the speed of the ascent will depend on:

(*a*) Nature of the accident or emergency.

(*b*) Depth and length of exposure at which the diver has been working.

(*c*) The proximity of a recompression chamber ready for immediate use.

(2) In any case when a diver fails to answer his intercom or hand signal, he shall be started toward the surface immediately. A pause should be made at the first stage of decompression and another attempt made to communicate with him. If no answer is received, the remainder of the ascent must be made according to the judgment of the officer or diver in charge. If there is reason to suppose that the diver can be sent down again immediately, or a recompression chamber is ready for immediate use, a chance should be taken on a fairly rapid ascent for the remaining distance.

(3) If a diver loses his distance line and cannot locate his descending line, it becomes necessary for his attendant to pull him up and not waste time searching for the descending line. The attendants should always keep the diver ascending very slowly until he reaches the decompression stage. The tender should cease hauling in the line if it is found that the diver is becoming too light, but continue to take in all slack of the life line. Trouble in this respect may be experienced when the diver is unconscious or helpless. The diver should not be brought up beyond his first stop as indicated by the decompression tables. As the diver reaches this stop, he may be worked over to the decompression stage, and if he is conscious no trouble will be experienced in landing him on it. If it is impossible for the diver to find his descending line at any depth, he should be brought to the surface and

taken over to the descending line, his lines cleared, and again lowered to the decompression stage. In case the diver is helpless, decompression should be carried out as described for surface decompression.

789. MAINTENANCE OF AIR SUPPLY EQUIPMENT

(1) One of the most important duties of the tender is to insure that the machinery used for furnishing compressed air is maintained in satisfactory operating condition. Personnel having a knowledge of air compressors or similar equipment shall be placed in charge of the air system.

(2) The portable gas-driven air compressor is the most widely used means of furnishing air for diving operations. While gas-driven compressors have replaced the hand-operated pump due to the limited pump capacity and the large number of men required for its operation, it should be remembered that the compressors are subject to a greater degree of mechanical failure than the hand pump. It shall be the tender's responsibility to see that the compressor is prepared properly for use—check lubrication, insure that the compressor and engine are properly cooled, that the exhaust fumes are not carried over to the compressor intake, secure the unit to the deck in as near a horizontal plane as possible, make connection between air hose and compressor, etc. After the compressor has been prepared, it should be started and running smoothly before any attempt is made to put a diver over the side. If for any reason the compressor will not operate satisfactorily or should the compressor give any indication of developing trouble, diving operations should cease immediately.

(3) In cases where air flasks are used, the tender shall check the valves, gages, reducers, pipe connections, and air hose connections to determine that everything is in satisfactory condition. Before diving is undertaken, calculation shall be made to determine whether there is adequate air in the flasks for the diver and to provide for emergencies that may arise.

790. NUMBER OF TENDERS REQUIRED

It is preferable to have a minimum of three tenders; one to be assigned to each of the following jobs: intercom, diver's lines, and the air system. If personnel are not available, the tender handling the diver's lines may also take over the intercom. However, only in cases of emergency shall diving be undertaken with fewer than two tenders, one for the lines and one for the air system.

Part 5—Medical Aspect of Diving

A. PHYSIOLOGY OF DIVING

801. GENERAL

The purpose of this chapter 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 of and release from excess partial pressures of various gases. The effects of increased pressures on the body can be divided into primary and secondary phenomena; the former include the mechanical effects of pressure upon the body cells and spaces, the latter cover the physiological effects of gases diffusing into and out of the body fluids and tissues.

PRIMARY PRESSURE PHENOMENA

802. EFFECTS OF PRESSURE APPLIED EQUALLY TO ALL PARTS OF THE BODY

It is a remarkable phenomenon that the body can stand a pressure in excess of 16 atmospheres (equivalent to a diving depth of about 500 feet) without any apparent change, provided the air has free access to all surfaces of the body which include the linings of the natural air spaces in the body—lungs, middle ear spaces, and sinuses. One would think that this tremendous pressure (about 235 p. s. i. absolute) would produce an adverse effect upon the heart and blood circulatory system by interfering with the maintenance of normal blood pressure. Actually the relative blood-pressure readings measured at absolute pressures are merely increased by 16 atmospheres. One might also wonder why the brain is not crushed by a collapse of the protective skull around it. This accident would happen if the brain were inclosed 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 any sealed air spaces) is completely made up of fluids and solids which, according to physical laws, are considered incompressible.

803. EFFECTS OF PRESSURE APPLIED UNEQUALLY TO ALL PARTS OF THE BODY

If, for any reason, air pressure is not equally applied upon all body surfaces, even a pressure difference of one-sixteenth of an atmosphere (about one pound per square inch) will alter the normal shape of tissue by causing congestion and swelling within and bleeding from such tissue. These changes in turn cause symptoms of pain, shock, and cell destruction. The following are the effects upon individual organs or tissues of the body.

804. THE LUNG

(1) The effects of unequal air pressure on the lungs is illustrated by the pearl diver or swimmer who makes a dive by merely holding his breath. In this case the diver or swimmer is subjected to an additional compressive force of one atmosphere for every 33 feet of descent. At a depth of 100 feet, for example, the total pressure acting on his body amounts to about four atmospheres. At this depth, the amount of air which was present in the diver's

chest on the surface, approximately twelve pints, is compressed to one-fourth its original amount or three pints. This amount approximates the volume of the residual air of the lung—normally the amount of air left in the lungs after the most forceful expiration. The depth, therefore, to which the unprotected diver can descend is limited by the ratio of total lung volume to residual air volume.

(2) Should the diver now descend further, the additional pressure, unable to compress the chest walls or elevate the diaphragm further without injury, will bring about a condition known as a "squeeze." The effect of the "squeeze" is to force blood and tissue fluids into the lung air sacs and passages where the residual air is under less pressure than the tissues surrounding the chest. Thus an attempt is made to relieve the negative pressure within the lungs by partly filling the air space with swollen tissue, fluid, and blood. Considerable lung damage, therefore, results which, if severe enough, may prove fatal. If still further descent takes place, immediate death will result by the crushing in of the chest walls similar to the collapse of a sealed tin can which is lowered into deep water.

805. THE EARS, SINUSES, AND TEETH

In a similar manner, the lining membranes of the middle ear and sinus spaces are injured by a "squeeze" if the natural openings (OSTIA) of these spaces are blocked and do not permit equalization of pressure by free entrance of air. The prevalence of obstruction of the eustachian tubes can be seen by the fact that at any given time 10 percent of any group will have trouble adjusting themselves to rapid pressure changes for this reason, while about 1.5 percent are affected by obstruction of the sinus passages and another 1.5 percent are subjected to pain in one or more teeth. The involvement of a tooth suggests the presence of a small gas pocket in the pulp or in a part of the tooth where soft tissue can be "squeezed."

806. FACE OR BODY SQUEEZE

The most common type of "squeeze" encountered in diving is that produced upon the face or upper part of a diver's body when the air pressure within the face mask or helmet suddenly drops below the equivalent 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 air supply or by the cutting or parting of the air lines, (2) when a sudden drop in the depth of the diver is not compensated for by an increased air supply. In either case, the results produced are similar to those caused by a vacuum being suddenly created within the face mask or helmet. If such an accident occurs while using a face mask with rigid eyeglass mountings, the severe suction upon the eyes may forcibly pull them from their sockets. 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 lines is so essential in all diving procedures.

807. OVEREXPANSION OF THE LUNGS (TRAUMATIC AIR EMBOLISM)

(1) Traumatic air embolism is a serious complication which can occur in diving and is caused by an excess of air pressure within the lungs. The conditions which bring about this accident are directly opposite to those which produce lung "squeeze." It occurs most frequently with the use of the submarine escape appliance or by "ducking" the mask or shallow diving helmet and making a free ascent to the surface while holding the breath. To escape from a sunken submarine, an individual may breathe compressed air, helium-oxygen mixtures, or oxygen by means of a rebreathing "lung." The speed of his ascent can be regulated by means of a buoy line previously released from the submarine. In this manner, ascents have been made routinely in submarine escape training tanks from depths of 100 feet and in the open sea by specially trained personnel from depths of 200 feet.

(2) During such ascents, the expanding gas in the lungs exhausts into the breathing bag and then through a relief valve on the bottom of the bag. In this manner the air pressure within the lungs closely approximates the equivalent water pressure surrounding the chest. If the individual, instead of breathing freely, holds his breath and ascends to the surface from 100 feet, the air within the lungs will tend to expand to four times its original volume and, since there is no exit for this excess air, 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 just as though it were an over-inflated balloon. Air is further forced into these ruptured tissues and blood vessels causing bubbles to enter into the pulmonary capillary bed. From there they are carried to the left chambers of the heart and into the arterial blood vessels where they produce the various symptoms of circulatory blockage in the heart, brain, spinal cord, or other vital organs. A description of the symptoms encountered in this type of accident is given in Part 8 under Diving Accidents.

(3) 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 force 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 over-expansion of the lungs. Under these circumstances, death has occurred in ascent from depths of only 15 feet. On the other hand safe ascents can

be made by experienced swimmers from depths of 100 feet without an escape appliance provided the individual exhales continuously during his ascent.

808. SPONTANEOUS PNEUMOTHORAX (PNEUMO-AIR+THORAX-CHEST)

Spontaneous pneumothorax can also result from over-expansion of the lungs, either with or without the occurrence of air embolism, and is produced under similar conditions. 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 the collapsed lung and the heart which are pushed toward the opposite side of the chest. The lung collapse and shifting of the heart's position cause symptoms of shock and if severe enough will produce death. The only remedy for this condition is a surgical procedure whereby the air pocket is removed by a suction apparatus such as a syringe with attached needle inserted through the chest wall and into the pocket. Further discussion of this rare type of accident with an illustrating case history is presented in the Part 8 under Diving Accidents.

809. OVER-EXPANSION OF STOMACH AND INTESTINAL ORGANS

Occasionally while under pressure, gas formation may take place within the diver's intestines or considerable quantities of air may be swallowed and trapped in his stomach. On ascent this trapped gas expands and may constitute not only a serious impediment to further decompression, but may also expand the bowel to such a degree as to impair its muscular strength and function. Gas within the stomach or bowel, however, causes a greater problem with aviators than it does with divers who are exposed to increased pressure for relatively short periods of time. In the case of the aviator, all gas which is present in his intestinal tract while on the surface suddenly expands during his rapid ascent to decreased pressures. In order to prevent air swallowing in a diver while under pressure, the practice of gum chewing should be discouraged.

SECONDARY PRESSURE PHENOMENA

810. SOLUTION AND DISSOLUTION OF GASES IN BODY TISSUES

The phenomena described above arise primarily from differences in pressure which have acted to expand and rupture the spaces, membranes, and blood vessels of the body. The secondary pressure phenomena are associated with disturbances in gaseous equilibria, i. e., the solution and dissolution of gases in the body tissues.

811. NARCOTIC EFFECT OF NITROGEN

(1) When the body is exposed to air pressures of four atmospheres or higher, the gaseous nitrogen breathed induces a narcotic (anesthetic) effect evidenced by the decreased ability to work and changes in mood. A slowing up of mental activity and fixation of ideas are characteristic responses. Recollection of what has been done or is to be done requires greater effort of the mind and concentration is difficult. Frequent errors may be made in simple arithmetical calculations and in the recording of data. The body responses may be similar to those associated with anoxia (lack of sufficient oxygen) or alcoholic intoxication. Although all individuals are to some extent narcotized at deep diving depths, stable individuals react to the stress by increased effort and carry out their task with greater vigor until consciousness is finally lost. The unstable individual, on the other hand, is incapable of purposeful effort throughout his dive.

(2) If air breathing under pressure is replaced by a helium-oxygen atmosphere, these reactions are minimized or eliminated and the previously unstable individual becomes an efficient worker. Why helium, in contrast to nitrogen, is not narcotic is not entirely clear. The physical properties of the gas may be of great importance since argon, although chemically inert like helium, has the same narcotic effect as nitrogen. The solubility of these gases in water and oil and the ratio of these two solubilities (oil-water solubility ratio) plus their molecular weight may be the responsible factors. These physical data are shown in the accompanying table.

Nitrogen, argon, helium, and oxygen molecular weights, solubility in water and in olive oil at 38° C., and their respective oil-water solubility ratios are as follows:

	Nitrogen	Argon	Helium	Oxygen
Molecular weight	28.02	39.94	4.0	32
Solubility in oil	0.0667	0.1395	0.0148	0.112
Solubility in water	0.0127	0.0262	0.0087	0.023
Oil-water solubility ratio	5.24:1	5.32:1	1.7:1	4.9:1

(3) According to a physiological concept known as the Meyer-Overton Theory, the narcotic action of certain gases is directly related to their comparative solubility in fat and water. From this table it will be seen that helium possesses an oil-water solubility ratio which is one-third that of either nitrogen or argon—hence, its action should be less. Furthermore, the molecular weight of helium is only one-seventh that of nitrogen and one-tenth that of argon. The consideration that the molecular weights may be a deciding factor in determining the narcotic effect of the various gases has not yet been supported by experimental data. The employment of hydrogen which has a lower molecular weight than helium but a higher solubility coeffi-

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cient in oil may lead to the solution of the problem, or at least to an evaluation of the role that fat solubility, in comparison with molecular weight, assumes in the cause of this type of narcosis. Whatever the physiologic basis of action, the intriguing fact is that atmospheric nitrogen, an elementary and inert gas as it exists in the body at normal pressure, will induce narcosis or unconsciousness under high pressure.

(4) The accumulation of carbon dioxide within the body, due to the decreased ventilation which is produced by the heavier gases, is another factor which must be considered in the explanation of the narcotic phenomena.

812. TOXIC EFFECT OF OXYGEN

(1) The toxic symptoms that may be encountered while breathing pure oxygen under increased pressure and the tolerance of various individuals to this toxic effect is discussed in Part 8 under Diving Accidents. From a physiological viewpoint, it might be mentioned that in the normal individual breathing air at atmospheric pressure, the partial pressure of oxygen in the alveolar air is sufficient to saturate the hemoglobin contained in our red blood cells to within 95.5 percent of full saturation. On reaching the tissues a portion of this chemically combined oxygen is liberated and given up to the tissues. On return of the venous blood to the heart and lungs, the hemoglobin is thus partly desaturated and is again ready to take up its full load of oxygen as it passes through the lung.

(2) Breathing pure oxygen at a pressure of three atmospheres, however, causes such a high partial pressure of this gas in the alveoli that besides fully saturating the hemoglobin, a large portion dissolves itself within the fluids of the blood. This dissolved oxygen is sufficient to meet tissue requirements as it passes through the body capillaries and that portion which is chemically combined with hemoglobin is not used as it normally would be. The result is that the hemoglobin is not reduced, remaining fully saturated in the venous blood and the body requirements for oxygen are met entirely by that portion which is held in physical solution by the blood fluids.

(3) Why living organisms present toxic symptoms when exposed to oxygen under pressure is still a highly controversial subject and many theories have been propounded to explain the physiological mechanism involved. A discussion of these theories cannot be included in this manual. It is sufficient to say that high oxygen concentrations within the body cause strychnine-like effects upon the nervous and muscular systems and may also act as an irritant to the delicate lung membranes.

813. TOXIC EFFECT OF CARBON DIOXIDE

(1) A review of part 2 will reveal that the partial pressure of carbon dioxide in the alveolar air is about 40 mm. in an individual at rest and breathing normally. The partial pressure of carbon dioxide present in arterial blood was shown to be in equilibrium with that of the alveolar air. However, venous blood, on its return from the tissues, has a carbon dioxide partial pressure of about 46 mm. This slight excess is sufficient to allow rapid elimination by diffusion into the alveoli when the blood reaches the lung and equilibrium is reached as the blood becomes arterialized. Forty millimeter pressure of carbon dioxide in the alveoli at atmospheric conditions will be found to be exerted by about 5.6 percent carbon dioxide; $40 \div (760-47$ (vapor pressure)). This percentage is actually present in the alveolar air under normal conditions.

(2) If we analyzed the alveolar air of a diver having adequate air supply and exposed to 3 atmospheres of pressure (66 feet gage), we would find a carbon dioxide percentage of about 1.8 percent. By calculation, it will be found that this percentage will exert a partial pressure identical to that present on the surface; $0.018 \times ((760 \times 3) - 47) = 40$. This example is cited to convey the importance of keeping the carbon dioxide content of the inspired air down to an absolute minimum. To accomplish this, the air within a diver's helmet must be constantly cleared of the carbon dioxide given off by the diver; in other words, adequate ventilation by abundant air supply must be maintained. If, for instance, some carbon dioxide were allowed to accumulate in the helmet, the result would be a higher percentage of carbon dioxide in the air breathed, and consequently its partial pressure in the alveoli is correspondingly increased. The diver will attempt to remove this carbon dioxide by rapid or labored breathing; but if more contaminated air is inspired, his efforts will be useless. Under such conditions, the diver will become exhausted, not only from his labored breathing but from the toxic effects of carbon dioxide accumulated within his body tissues. Any attempt to work under such conditions will only aggravate the diver's condition because more carbon dioxide is produced by the exercise involved.

(3) When the inspired air at normal atmospheric pressure contains 3 percent carbon dioxide, the breathing begins to be noticeably increased; 6 percent causes distress and 10 percent or more, unconsciousness. Since 3 percent carbon dioxide at surface pressure is about the maximum that can be tolerated without distress, it is essential that the equivalent of this percentage at the pressures in the helmet should not be exceeded. To keep the carbon dioxide content of the helmet within this maximum permissible percentage, a minimum air supply of 1.5 cubic feet per minute (measured at the absolute pressure to which the dive is made) is necessary. According to Boyle's law, the air supply measured at the surface must be increased in proportion to the absolute pressure if adequate ventilation is to be provided.

(4) Since each 33 feet of sea water exercises a pressure of one atmosphere, the air supply measured at the surface must be increased one thirty-third for each foot of dive. Using the reciprocal 0.0303, the minimum air supply for any depth can be calculated by the equation $S=1.5\ (1+F\ (0.0303))$, in which S is the required air supply in cubic feet measured at the surface, and F is the number of feet the diver is below the surface. Better ventilation than this is imperative, particularly if hard work is performed by the diver, and allowances should be made to supply three times this quantity of air per minute. An attempt is always made to keep the carbon dioxide concentration within the diver's helmet to a value equivalent to 0.1 or 0.2 percent of one atmosphere.

(5) In addition to the toxic effects of carbon dioxide alone, it has also been found that carbon dioxide accumulation within the body enhances the toxicity of oxygen and the narcotic effect of nitrogen. With respect to work under compressed air, a higher incidence of "bends" has also been associated with a rise in the carbon dioxide level.

814. NITROGEN ABSORPTION AND ELIMINATION

(1) It was explained in part 2 that the air present in the lung alveoli of a person at atmospheric pressure contained nitrogen which exerted a partial pressure of about 570 mm. Arterial blood exposed to the alveolar air is in equilibrium with this nitrogen tension and necessarily contains the same partial pressure. As the blood passes through the body capillaries, all tissues exposed to it also assume the same partial pressure of nitrogen. In contrast to oxygen and carbon dioxide where the values of their partial pressure vary in arterial and venous blood, nitrogen, being inert, passes through the body capillaries unchanged and its partial pressure in venous blood is identical with that of arterial blood. In other words, all of our tissues and blood are in a state of equilibrium with the nitrogen pressure of the alveolar air. Because of this pressure, and following Dalton's and Henry's laws of partial pressure, a definite amount of nitrogen is always present in a dissolved state throughout all body tissues, varying among individuals according to their body weight and fat content.

(2) With this state of complete saturation by nitrogen at atmospheric pressure let us consider what happens if a person were suddenly placed in an atmosphere of pure oxygen. The nitrogen partial pressure of the alveolar air becomes zero, the carbon dioxide and water vapor partial pressures remain at their normal values of 40 and 47 mm. respectively, and the oxygen partial pressure increases from 100 mm. to 673 mm. As a result of the partial pressure differences between the altered alveolar air and the blood exposed to it, oxygen is driven into the blood and the dissolved nitrogen diffuses from the blood into the alveoli. When this denitrogenated blood leaves the lungs and becomes exposed to the various body tissues containing dissolved nitrogen at a normal partial pressure of 570 mm., there is a similar escape of this gas from the tissues into the blood whence it is carried to the lungs and eliminated. With each round of circulation, more dissolved nitrogen is extracted from the tissues and expelled via the lungs. Because fat is capable of holding over 5 times as much dissolved nitrogen as the water of our blood and tissues (oil-water solubility ratio for nitrogen), it naturally will require a longer period of time to desaturate this type of tissue.

(3) There are also tissues within our body which are supplied by a meager flow of blood for normal sustenance. These tissues will also require a prolonged period of time to rid themselves of their nitrogen since the sluggish rate of blood flow through them offers sluggish gas diffusion. Experiments conducted on man reveal that a period of 9 to 12 hours is required to rid the human body of its dissolved nitrogen. Figure 108 shows the manner in which nitrogen is normally eliminated from the body when pure oxygen is breathed. Total N_2 (curve "A") represents the average of the values for nitrogen elimination from 3 men (average weight 140 pounds) who breathed pure oxygen at atmospheric pressure. "Water" N_2 (curve "B") and "Fat" N_2 (curve "C") are hypothetical curves showing the absorption or elimination of nitrogen by the body solvents. The values for nitrogen on A are approximately the sum of corresponding values of B and C. (From Behnke, U. S. Navy Medical Bulletin, 1937, 35, 219.)

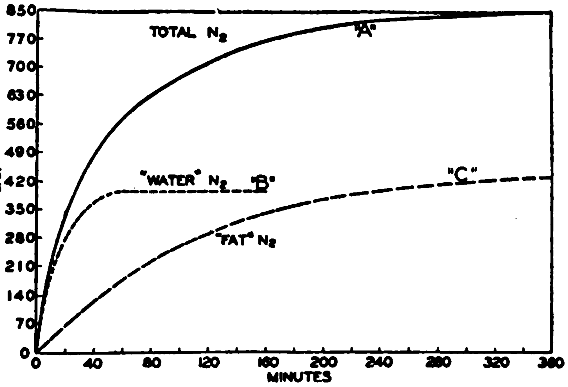


FIGURE 108.

(4) Let us now suppose that all nitrogen has been eliminated from the body and the subject again put on air breathing. The nitrogen partial pressure in the aveolar air would then be restored to 570 mm. and the oxygen partial pressure would assume its normal value of 100 mm. The carbon dioxide and partial pressure of the vapor pressure would remain unchanged. Since the blood exposed to this air has a higher partial pressure of oxygen and no nitrogen,

a new process of equilibrium will take place exactly in reverse of that which occurred at the beginning of the experiment. The blood will rid itself of its excess O_2 and will again saturate with nitrogen to the value of 570 mm. The arterial blood leaving the lungs then gives up its dissolved nitrogen to the denitrogenized tissues and the venous blood returning to the lungs is ready to take another load of nitrogen from the alveolar air. The process continues until the entire body once more is in equilibrium. This process of nitrogen saturation, like nitrogen elimination, is prolonged over a period of 9–12 hours before equilibrium is reached—the prolongation being due to the fatty tissues which take up five times more nitrogen than the other body tissues and also to the normal sluggish circulation of certain body tissues. In other words, the saturation curve is identical to the desaturation curve.

815. EFFECT OF PRESSURES IN EXCESS OF ONE ATMOSPHERE ON BODY TISSUES

(1) We are now ready to consider the physiological response of the body tissues on exposure to pressures in excess of one atmosphere. When compressed air is breathed, the partial pressures of the atmospheric gases increase according to the total pressure applied. Hence at two atmospheres absolute pressure (equivalent to 14.7 p. s. i. gage or a depth of 33 feet of sea water) the total atmospheric pressure is 1,520 mm. (760 x 2). The partial pressures exerted by nitrogen and oxygen within the lung will be approximately double their values at surface pressure. The carbon dioxide and water vapor partial pressures remain unchanged. If an absolute pressure of three atmospheres is applied (equivalent to 29.4 p. s. i. gage or a depth of 66 feet of sea water) the total atmospheric pressure is 2,280 (760 x 3) and the nitrogen and oxygen partial pressures within the lung will be approximately trebled, while the carbon dioxide and water vapor partial pressures remain unchanged. If either of these pressures is maintained for a period of 9–12 hours, the entire body tissues will eventually come in equilibrium with the increased partial pressures as the body tissues become saturated. The body tends to saturate in the same length of time regardless of what initial amount of pressure is applied. An equal length of time will be required to desaturate from any of these pressures provided the decompression rate does not exceed a critical ratio that will produce supersaturation of the tissues with consequent bubble evolution. The degree of body saturation by various gases is thus dependent upon three main factors—depth of dive (pressure head), length of dive (exposure time), and circulatory efficiency.

(2) That body saturation by any particular gas is dependent upon the partial pressure exerted by this gas, in contrast to the total pressure exerted by the gas mixture, can be cited by another example. Suppose an individual were exposed to an absolute pressure of two atmospheres (33 feet) breathing a mixture of 60 percent oxygen and 40 percent nitrogen. Since the nitrogen percentage in the above example is one-half that of atmospheric air, its partial pressure at two atmospheres would be equivalent to that present while breathing air on the surface. There will, therefore, be no absorption or elimination of nitrogen by the body. The oxygen percentage of the mixture on the other hand is approximately three times that of normal air and at a pressure of two atmospheres, its partial pressure will be sixfold that of air at atmospheric pressure. The body will thus saturate with this excess partial pressure of oxygen.

816. PRINCIPLES INVOLVING PREVENTION OF CAISSON DISEASE

(1) The principles underlying the prevention of Caisson Disease can now be undertaken. Whether or not a diver develops bends depends upon the ability of his circulatory system to eliminate what nitrogen was absorbed by his blood and tissues during the exposure to compressed air and to do so before the initiation of excessive bubble formation. If the decompression is too rapid, the blood and tissues approach a state of supersaturation; i. e., they contain more dissolved gas than they are capable of holding in solution. Since this load of dissolved gas cannot be carried to and removed by the lungs in sufficient time, the gas liberates itself in the form of bubbles which appear within the blood and tissues. A similar phenomenon occurs when a soda bottle is uncapped and a charge of small bubbles is released from solution. The bubbles of gas liberated within the body bring about a condition of circulation blockage or local tissue destruction and, depending upon the site, produce symptoms of asphyxia and chokes (bubbles trapped in blood vessels of the lungs or heart), pain or paralysis (bubbles trapped in brain, spinal cord, or nerves), stiffness and soreness of joints and muscles, and itch or rash of the skin.

(2) From figure 108 it will be observed that about 75 percent of the total body nitrogen is eliminated at a comparatively rapid rate and hence does not usually contribute to the formation of bends. There appears to be a relatively small amount of dissolved gas in the fatty tissues (bone marrow contains 90 percent fat, spinal cord substance contains 27 percent fat, and the fat deposits of the body) and those tissues having a poor blood supply (bones, tendons, ligaments) which require many hours for proper elimination. At a depth of 90 feet, for example, 10.5 hours of air decompression were required following a 9-hour exposure. On the other hand, a 2-hour exposure (75 percent body saturation) at the same depth required only 59 minutes of decompression. Nine and one-half hours were, therefore, required for the dissipation of the remaining excess

gas amounting to but 25 percent of the total present in the body.

(3) As an illustrative example, the body may be compared with a mixture of water and fatty material contained in an open flask. Of the fat an important fraction is surrounded by bone representing bone marrow and spinal cord substance. This bone-contained fat may be considered as lying on the bottom of the flask. If the contents of the flask are now exposed to a high nitrogen pressure for a short period of time and then quickly returned to atmospheric pressure, diffusion of nitrogen will take place from the water into the surrounding air and also into the partially saturated water and fat below. In other words, the water (fast tissue) can be desaturating while the fatty material (slow tissue) momentarily continues to saturate. Thus, following short exposures, the partially saturated fat appears to act as a buffer agent against bubble evolution in the overlying water. By contrast, after long exposures, the large reservoir of nitrogen in the saturated fat constitutes the predisposing cause to bubble formation since its excess gas can escape into the air only via the desaturating water that lies above it. Many hours of gradual decompression are thus required if liberation of bubbles is not to take place.

(4) The saturating or desaturating capabilities of tissues with good and poor blood supply can be exemplified by figures 109, 110, 111, and 112. Each figure represents the circulatory system with its two main capillary beds, that of the lungs and those of the body. For illustrative convenience, the body capillaries are divided into those providing a liberal (A), moderate (B), and meager (C) flow of blood and are so indicated by the caliber of the sup-

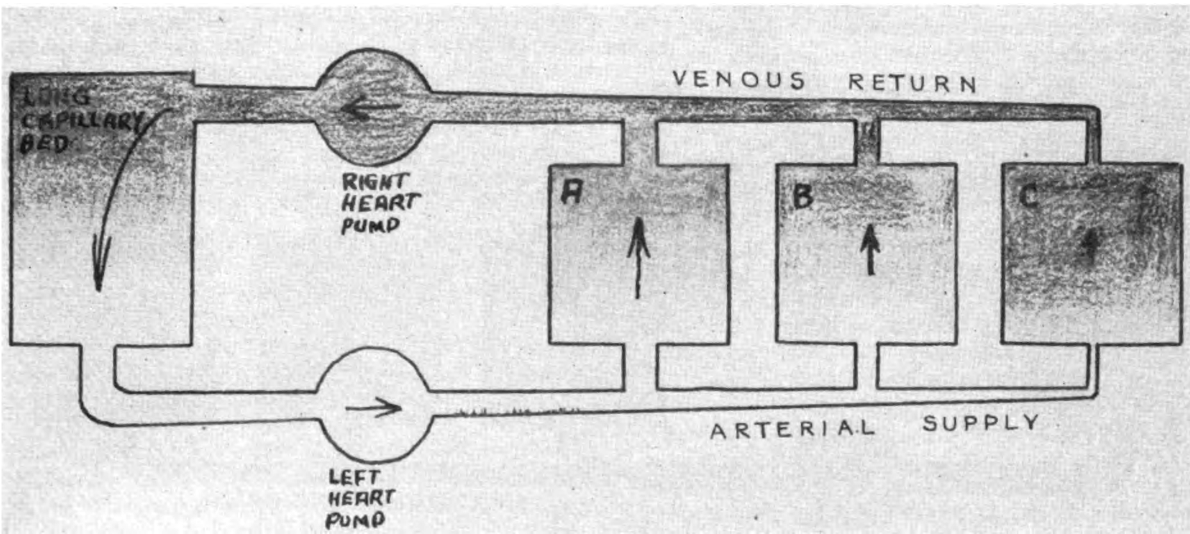


FIGURE 109.

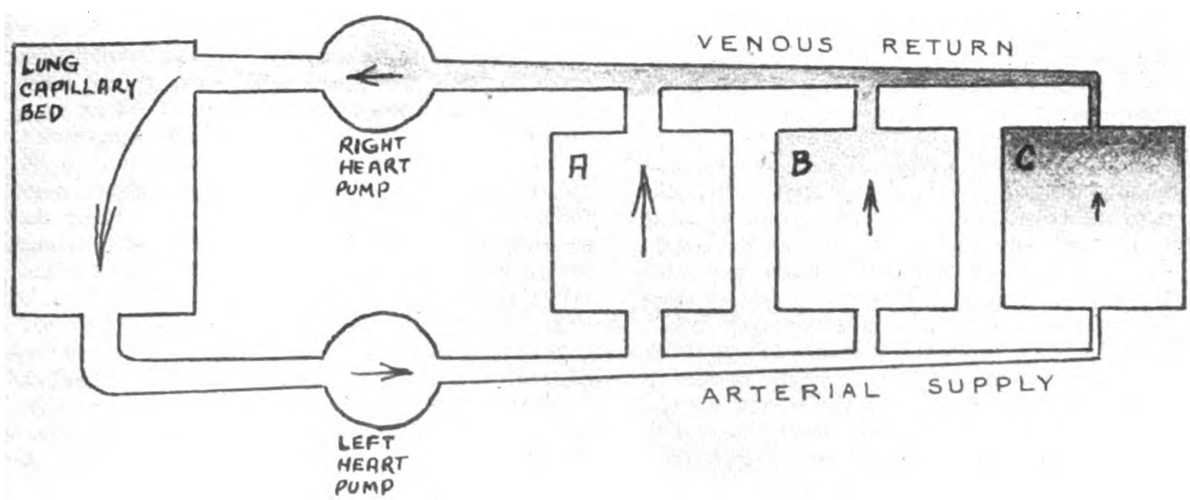


FIGURE 110.

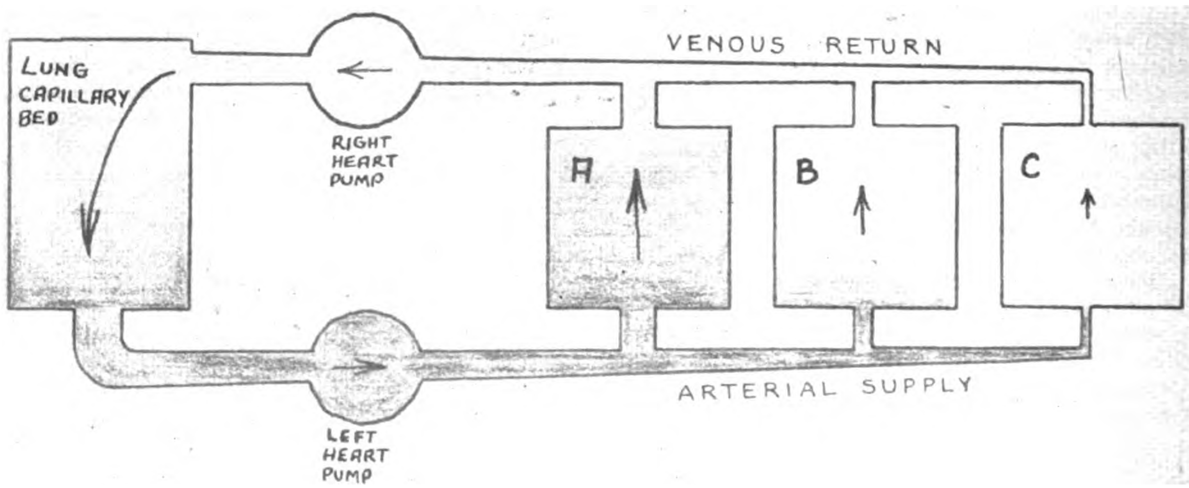


FIGURE 111.

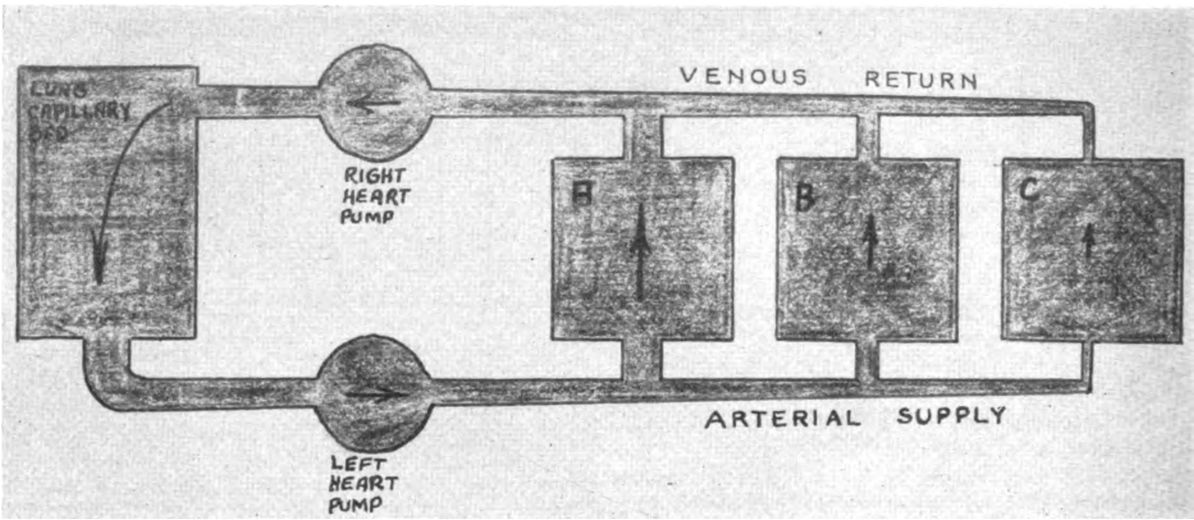


FIGURE 112.

plying vessels. The varying shades indicate the degree of saturation or desaturation that takes place on application of or release from increased barometric pressure.

(5) Figure 109 shows how blood becomes saturated on passing through the lung capillaries when exposed to increased pressure. The arterial blood is fully saturated and supplies tissues A, B, and C. Tissue A, having a good flow of blood, saturates quickly with each heart beat whereas tissue C does so at an extremely slow rate. Eventually after 9 to 12 hours, the blood and tissue of all parts of the body will be in equilibrium with the increased pressure to which the lung was exposed. Saturation of the entire body has taken place as portrayed in figure 110. Figure 111 shows how the blood desaturates when the pressure is again decreased to its original pressure. As the saturated blood passes through the lung capillaries, the excess gas diffuses out into the alveoli and the arterial blood becomes desaturated. When this desaturated blood reaches tissues A, B, and C, it takes up another load of gas from them. Depending upon its rate of flow through these tissues, the blood is returned to the lungs with a more or less degree of saturation. As the cycle of circulation repeats, tissue A with its abundant flow of blood rids itself of the excess gas quickly. Tissue B does so less rapidly and tissue C with its sluggish circulation holds on to its gas content for long periods of time. If the critical ratio has been exceeded, i. e., if the blood and tissues of C become supersaturated by the release of pressure, then bubbles of un-

dissolved gas will appear and produce their symptoms of circulatory obstruction and cell destruction as illustrated in figure 112.

(6) From this figure it can also be understood that if partial saturation of the body takes place to a high degree (as in figure 109) and then a sudden and rapid release of pressure takes place, bubbles can appear in tissue A even before tissue C has had an opportunity to begin its saturation. Such a condition can arise during a "blow up" from a deep dive. This type of accident produces the acute and serious symptoms of "chokes" and asphyxia, and abundant bubbles will be found to be present in the venous side of the circulatory system. Furthermore, explosive decompression is capable of producing bubbles within the arterial side of the circulatory system and symptoms similar to those of air embolism may be encountered.

(7) A glance at the standard decompression tables which follow will show that an optimum time is expressed for each type of dive. The optimum time limits the degree of saturation of the slowly desaturating tissues (as those of group C) and permits reasonable decompression time for the dives made. If these slow tissues are allowed to saturate more fully, the decompression time necessary for safe desaturation not only rapidly increases beyond practical limits but the discomforts of the diver on the stage are immeasurably increased.

(8) The effect that exercise has on body saturation can also be explained by the foregoing figures. Because exercise produces excess carbon dioxide within the tissues, the body normally increases its circulation and respiration to rid itself of this gas via the lungs as quickly as possible. The same physiological response takes place when a diver does heavy work on the bottom. However, the increased respiration and circulation that result from exercise also produce the undesirable effect of more complete saturation of the diver's tissues with nitrogen. In other words, tissues A, B, and C will all have a greater flow of blood and, therefore, a greater saturation of nitrogen.

(9) Likewise, during decompression, the faster rate of flow brings about faster nitrogen elimination. This was shown experimentally by a series of tests where the amount of nitrogen eliminated by breathing oxygen at atmospheric pressure was measured over a 30-minute period with one group of divers at rest and the other group pedaling a stationary bicycle. Exercise produced a 39-percent increase in nitrogen elimination within the 30-minute period for the exercised group. Beyond this period of time, exercise had little effect in hastening further nitrogen elimination thereby indicating that most of the nitrogen thus eliminated was derived from the body fluids. It is doubtful whether exercise appreciably affects the elimination of nitrogen from the bones or from tissues having a poor blood supply, the real source of bubble formation leading to bends. As a matter of fact, further experiments showed that if these slow tissues are supersaturated and on the verge of bubble formation, the agitation and turbulence produced by the exercise can initiate bubble formation and produce bends.

817. PHYSIOLOGICAL ASPECTS OF HELIUM DIVING

(1) The high diffusability and low oil-water solubility ratio of helium renders this gas ideal for diving since it is rapidly eliminated from the body and produces practically no narcotic action as does nitrogen. Essentially practical diving operations have been increased from the physiologist's point of view from a depth of 150 feet to a depth of 500 feet. In diving tests, following short exposures in a compressed helium-oxygen or air atmosphere, the body fluids are well saturated with either gas and no particular advantage in decompression accrues from the use of helium. However, following long exposures, the decompression time for helium-oxygen dives may be reduced as much as 75 percent. Part of this reduction of decompression time is brought about by the inhalation of oxygen at the lower decompression stops, but the important factor is the lessened uptake of helium by fat and its greater diffusion from those tissues having a poor blood supply.

(2) Experimental results with helium-oxygen breathing show that only 3 to 5 hours are required for the complete elimination of helium from the body after being saturated with this gas. This stands in contrast with the time required for the complete elimination of nitrogen (9 to 12 hours). It was also found experimentally that the helium content of saturated body tissues is only about 40 percent of their nitrogen capacity (8 cc of helium as compared with about 18 cc of nitrogen per kilogram of body weight), largely by reason of the lower solubility of helium in fat. Exercise increases helium elimination about 60 percent during the first 15 minutes but the acceleration effect is not appreciable after the first 30 minutes. A 30-minute exercise period increases helium elimination 40 percent compared with resting levels, a finding which is similar for that of nitrogen. This fact also illustrates that it is that portion of helium or nitrogen held by the body fluids whose elimination is hastened by exercise. After this portion is eliminated, exercise has little effect in removing the residual portions of both types of gases.

B. DECOMPRESSION TABLES

831. DEFINITION OF DECOMPRESSION

The degree of body saturation by various gases is dependent upon three influencing factors—time of exposure, depth of dive, and circulatory efficiency. In order to bring a diver safely to the surface, time for this gas to escape without bubble formation in the body tissues must be allowed. The escape of this gas is called decompression, and the time required for the process is known as decompression time. It is manifest that the deeper the dive or the more time spent on the bottom, the greater is the amount of gas absorbed by the body. Therefore, if more gas is taken up by the diver's body tissues, there will be more to get rid of and this takes time.

832. STAGE DECOMPRESSION

(1) Some time ago, Dr. Haldane of England stated that if the human body contained dissolved gas at a pressure more than twice the outside pressure, bubbles would form. On the basis of Dr. Haldane's investigation, the first practical decompression tables were calculated. Extensive work has been undertaken in an attempt to reduce this ratio of 2 to 1, and consequently the decompression time.

(2) The most practical method of bringing the diver to the surface in order to prevent the formation of bubbles is "stage decompression," that is, bringing the diver up to a given depth and holding him there for a stated length of time, then bringing him up to the next stop and repeating the process until he reaches the surface. These stops can be made at any intervals but, for convenience, they are made at 10-foot intervals. Stage decompression can be accomplished by one of two methods: (*a*) Regular decompression or (*b*) surface decompression.

833. REGULAR DECOMPRESSION

(1) Regular decompression consists of decompressing the diver in the water by keeping him at the stops listed in the Navy Standard Decompression Table for the times tabulated. This method of decompression is standard, and should be followed in all cases except where emergencies or conditions of tide or weather are such as to warrant using surface decompression.

(2) The Navy Standard Decompression Table lists required recompression to depths of 300 feet for various times of exposure, and consists of five columns:

Column 1: Depth of dive. (Article 836.)

Column 2: Time on bottom. This is the time between leaving the surface and beginning the ascent. It is the sum of the time spent in descending and the time actually spent on the bottom.

Where the duration of the dive exceeds the time shown on the table, the next greater time should be used. For example, when diving to 130 feet for 40 minutes, the decompression used would be for a dive to 130 feet for 52 minutes. Similarly, where the exact depth of the dive is not tabulated, use the next greater depth. For example, if the depth of a dive is 215 feet for 20 minutes, the decompression schedules listed under 225 feet for 27 minutes will be used. No interpolation of the tables is permitted.

Optimum times are indicated for all tabulated depths. Only in cases of emergencies when specially trained supervisors and recompression chambers are available, as on submarine rescue vessels, and when a high incidence of bends is acceptable, shall the optimum times be exceeded.

A diver should not, except in emergencies, make more than one dive in 12 hours. However, should such an emergency exist, his decompression on each succeeding dive shall be determined by the following rule: Use the combined times on bottom for all exposures and the depth of the latest dive in determining the decompression schedule to use. For example: If a man has made a dive to 100 feet for 60 minutes, and a second dive is made within 12 hours to 80 feet for 70 minutes, the decompression for the second dive would be determined on the basis of an 80-foot dive for 130 minutes.

Column 3: Stops—feet and minutes. This column gives the time and depth of each stop. The full tabulated time should be spent at each stop, and when using a stage should be spent on the stage. Total decompression time consists of time of ascent plus times spent at each stop. Rate of ascent from the bottom to the first stop should not exceed 25 feet per minute. Use 1 minute between stops and 1 minute from the 10-foot stop to the surface.

Column 4: Sum of times at various stops.

Column 5: Approximate total decompression time. This is the sum of column 4, plus time of ascent at not over 25 feet per minute from bottom to first stop, plus 1 minute between stops, plus 1 minute from last stop to surface.

As an example, the following times and decompression are required for a dive to 180 feet, with a time of dive of 20 minutes. Enter the Standard Navy Decompression Table with depth of dive, column 1, of 185 feet, and time of dive, column 2, of 26 minutes.

Event	*Time*
Diver left surface	0
On the bottom	3
Left bottom	20 "Time on bottom."
At first stop and stage (20 feet) *	27
On stage (20 feet)	29
Leave first stop	53
At second stop	54
Leave second stop	1 hr. 31 min.
At surface	1 hr. 32 min.

*Time to first stop: $\frac{180-20}{25}=6+$ Use 7 minutes.

In extremely cold water, or following dives in strong tides or where heavy work is done, decompression should be for the next greater tabulated depth or for the next greater tabulated time. For example, after a hard working dive at 150 feet for 30 minutes, decompression should be in accordance with the schedule given for a dive of 150 feet for 38 minutes, or for 160 feet for 34 minutes.

NAVY STANDARD DECOMPRESSION TABLE

[Using compressed air]

1	2	3									4	5
Depth of dive (feet)	Time on bottom (minutes)	Stops (feet and minutes)									Sum of times at various stops (minutes)	Approximate total decompression time (minutes)
		Feet 90	Feet 80	Feet 70	Feet 60	Feet 50	Feet 40	Feet 30	Feet 20	Feet 10		
40	120									0	0	2
40	180									2	2	4
40	Opt.* *240*									4	4	6
40	300									6	6	8
50	78									0	0	2
50	120									2	2	5
50	150									5	5	8
50	Opt.* *190*									9	9	12
50	300									12	12	15
60	55									0	0	3
60	75									2	2	5
60	110									13	13	16
60	Opt.* *150*								5	15	20	24
60	180								7	16	23	27
60	210								8	18	26	30
70	43									0	0	3
70	60									4	4	8
70	75									13	13	17
70	90								4	16	20	24
70	Opt.* *120*								13	16	29	33
70	150								18	21	39	43
70	180								21	32	53	57
80	35									0	0	3
80	50									6	6	10
80	70								6	16	22	27
80	100								20	16	36	41
80	Opt.* *115*								22	26	48	53
80	150								28	29	57	62
90	30									0	0	4
90	45									6	6	10
90	60								9	16	25	30
90	75								18	14	32	37
90	Opt.* *95*							2	27	21	50	56
90	130							9	27	29	65	71
100	25									0	0	4
100	40									12	12	17
100	60								18	16	34	39
100	75								27	21	48	53
100	Opt.* *85*							6	28	21	55	61
100	90							8	27	24	59	65
100	120							17	28	48	93	99
110	20									0	0	5
110	35									12	12	17
110	55								22	21	43	49
110	Opt.* *75*							14	27	37	78	84
110	105						2	22	29	50	103	110
120	18									0	0	5
120	30									11	11	17
120	45								18	21	39	45
120	Opt.* *65*							13	28	32	73	80
120	100						5	22	27	69	123	130
130	15									0	0	5
130	35								11	15	26	32
130	52							6	28	28	62	69
130	Opt.* *60*							13	28	28	69	76
130	90						9	22	28	69	128	136
140	15									4	4	10
140	30								8	21	29	36
140	45							5	27	27	59	67
140	Opt.* *55*							15	28	32	75	82
140	85						14	22	32	69	137	145
150	15									7	7	14
150	30								13	21	34	41
150	38								28	30	58	65
150	Opt.* *50*							16	28	32	76	84
150	80						18	23	32	69	141	150
160	15									9	9	16
160	34								27	28	55	63
160	Opt.* *45*							17	28	43	88	96
160	75					3	19	23	34	68	147	156
170	15									11	11	18
170	30								24	27	51	59
170	Opt.* *40*							19	28	46	93	102
170	75					9	19	23	38	68	157	167
185	15									25	25	33
185	26								24	37	61	70
185	Opt.* *35*							19	28	46	93	102
185	65				18	18	23	37	65	51	212	223
200	15									32	32	41
200	23								23	37	60	69
200	Opt.* *35*							22	28	46	96	106
200	60			5	18	18	23	37	65	51	217	229
210	15									35	35	44
210	Opt.* *30*						5	16	28	40	89	100
210	55			6	18	18	23	37	65	51	218	231
225	15								6	35	41	51
225	Opt.* *27*						22	26	35	48	131	143
225	60			13	18	18	23	47	65	83	267	280
250	15								17	37	54	66
250	Opt.* *25*					2	23	26	35	51	137	150
250	50		12	14	17	19	29	49	65	83	288	303
300	12								20	37	57	70
300	Opt.* *20*					9	23	26	35	51	144	159
300	45	6	14	15	17	18	31	49	65	83	298	315

*These are the optimum exposure times for each depth which represent the best balance between length of work period and amount of useful work for the average diver. Exposure beyond these times is permitted only under special conditions.

834. SURFACE DECOMPRESSION

(1) If a recompression chamber is available and is equipped with oxygen and inhalators for administering oxygen, then surface decompression using oxygen in accordance with table can be used in a routine manner.

The advantage of decompression on pure oxygen is in the saving of time. For dives in the greater depths, savings from approximately 25 to 30 percent of total decompression time may be realized in comparison with that required for straight air decompression. It must be borne in mind, however, that the results achieved by oxygen surface decompression depend on the accuracy exercised in following the tables and the precautions taken to insure that only pure oxygen is breathed. Oxygen breathing equipment must be maintained in perfect working condition at all times to insure successful results from these tables. In event of oxygen toxicity symptoms, or failure of oxygen supply, decompression should be given in accordance with air tables. In such cases the time spent on oxygen should be disregarded and complete decompression on the standard air tables for the depth and time of dive should be given.

(2) In cases where a recompression chamber is available and emergency conditions make it necessary to use surface decompression when oxygen is not available, air may be substituted by using the following procedure:

The limits of depth and exposure should not exceed the following table:

Feet	*Minutes*
100	85
110	75
120	60
130	55
140	45
150	40
170	30

835. DUTIES OF TIMEKEEPER

The timekeeper shall keep an accurate record of time required for the diver to reach the bottom, the time of exposure on the bottom, the time of ascent to the first stop, and the time spent at each stop during the subsequent ascent. If there is any doubt as to the time that the diver has spent on any phase of the ascent, the time allowance should be made in the diver's favor. These times shall be carefully kept and recorded in the diving log. See figure 107.

The diver is brought up to the first stop as shown on Navy Standard Decompression Table and is decompressed at this stop as indicated in the table. He is then brought to the surface at a rate of 25 feet per minute and the stage is hoisted aboard. The helmet, belt, and shoes are removed and the diver placed in the recompression chamber in the shortest possible time interval. The air pressure is raised at once to the equivalent of the first stop. The decompression time of the first stop is repeated and the remainder of the decompression completed as indicated in the Navy Standard Decompression Table.

Several factors must be kept in mind when using emergency air surface decompression:

(a) The time of exposure must be within the time limit listed in the second table.

(b) The rate of ascent of the stage should not exceed 25 feet per minute.

(c) When on deck, the diver must be placed as rapidly as possible under pressure corresponding to the first decompression stop listed in the first table for the particular depth at which he was working.

SURFACE DECOMPRESSION TABLE USING OXYGEN

1** Depth in feet	2** Time	3** Time (min.) at water stops breathing air at				4**	5** Time (min.) at 40′ chamber stop oxygen	6**	7** 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
70	90	0	0	0	0		15		24
*70	120	0	0	0	0		23		32
70	150	0	0	0	0		31		40
70	180	0	0	0	0		39		48
80	40	0	0	0	0		0		3
80	70	0	0	0	0		14		23
80	85	0	0	0	0		20		29
80	100	0	0	0	0		26		35
*80	115	0	0	0	0		31		40
80	130	0	0	0	0		37		46
80	150	0	0	0	0		44		53
90	32	0	0	0	0		0		4
90	60	0	0	0	0		14		24
90	70	0	0	0	0		20		30
90	80	0	0	0	0		25		35
*90	90	0	0	0	0		30		40
90	100	0	0	0	0		34		44
90	110	0	0	0	0		39		49
90	120	0	0	0	0		43		53
90	130	0	0	0	0		48		58
100	26	0	0	0	0		0		4
100	50	0	0	0	0		14		24
100	60	0	0	0	0		20		30
100	70	0	0	0	0		26		36
*100	80	0	0	0	0		32		42
100	90	0	0	0	0		38		48
100	100	0	0	0	0		44		54
100	110	0	0	0	0		49		59
100	120	0	0	0	3		53		66
110	22	0	0	0	0		0		5
110	40	0	0	0	0		12		23
110	50	0	0	0	0		19		30
110	60	0	0	0	0		26		37
*110	70	0	0	0	0		33		44
110	80	0	0	0	1		40		52
110	90	0	0	0	2		46		59
110	100	0	0	0	5		51		67
110	110	0	0	0	12		54		77
120	18	0	0	0	0		0		5
120	30	0	0	0	0		9		20
120	40	0	0	0	0		16		27
120	50	0	0	0	0		24		35
*120	60	0	0	0	2		32		45

SURFACE DECOMPRESSION TABLE USING OXYGEN

1** Depth in feet	2** Time	3** Time (min.) at water stops breathing air at				4**	5** Time (min.) at 40′ chamber stop oxygen	6**	7** 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
120	80	0	0	0	5		46		62
120	90	0	0	3	7		51		72
120	100	0	0	6	15		54		86
130	15	0	0	0	0		0		5
130	30	0	0	0	0		12		23
130	40	0	0	0	0		21		32
130	50	0	0	0	3		29		43
*130	60	0	0	0	5		37		53
130	70	0	0	0	7		45		63
130	80	0	0	6	7		51		76
130	90	0	0	10	12		56		90
140	13	0	0	0	0		0		6
140	25	0	0	0	0		11		23
140	30	0	0	0	0		15		27
140	35	0	0	0	0		20		32
140	40	0	0	0	2		24		38
140	45	0	0	0	4		29		45
140	50	0	0	0	6		33		51
*140	55	0	0	0	7		38		57
140	60	0	0	0	8		43		63
140	65	0	0	3	7		48		70
140	70	0	2	7	7		51		80
150	11	0	0	0	0		0		6
150	25	0	0	0	0		13		25
150	30	0	0	0	0		18		30
150	35	0	0	0	4		23		39
150	40	0	0	3	6		27		49
150	45	0	0	5	7		33		58
*150	50	0	2	5	8		38		66
150	55	2	5	9	4		44		78
160	9	0	0	0	0		0		7
160	20	0	0	0	0		11		24
160	25	0	0	0	0		16		29
160	30	0	0	0	2		21		35
160	35	0	0	4	6		26		49
160	40	0	3	5	8		32		62
*160	45	3	4	8	6		38		73
170	7	0	0	0	0		0		7
170	20	0	0	0	0		13		26
170	25	0	0	0	0		19		32
170	30	0	0	3	5		23		44
170	35	0	4	4	7		29		58
*170	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 (article 836).

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 as outlined in article 674.

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.

836. INSTRUCTIONS TO TENDERS

(1) The tender shall always keep himself informed as to the depth of the diver. Inasmuch as fathometers, lead lines, descending lines, stage lines, or payed out life line and air hose cannot be used to determine depth with accuracy, a simple and accurate method has been devised. Depth is determined by means of an air supply, a depth gage calibrated in feet of sea water, and an oxygen hose. The oxygen hose is made up with the diver's life line and air hose, the open end terminating at about the breast plate level. 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 the ascent when the diver has been swept from the descending line. See Article 925 (1) also.

(2) The tender shall frequently contact the diver by intercom or signal while on the bottom and on the stage to ascertain if all is well. The tender shall give the diver a few minutes' notice before the expiration of the diver's time 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 bottom.

837. COMPLETION OF ASCENT

In regular decompression, the ascent is completed by hoisting and stopping the stage to and at the successive stops prescribed in Navy Standard Decompression Table. Prior to hoisting of the stage between the first and successive stops, the timekeeper shall notify the diving officer sufficiently in advance of the termination of the prescribed time at the respective stop to permit necessary preparation for the hoisting. For example, if the diver has been decompressed at the first stop and the time spent on the stage at the first stop is within 1 minute of the total time prescribed for that stop, the timekeeper shall indicate it by distinct announcement of "1 minute to go." The diver is then notified by the tender to stand by for hoisting to the next stop. The timekeeper shall announce the termination of the proper time at the various stops, and before starting the stage upward, the diver shall be informed by the tender of the intended hoisting by the message "coming up." On confirmation reply from the diver, the diving officer or diver-in-charge will order the diver brought to the next stop.

C. COMPRESSED AIR ILLNESS AND TREATMENT TABLES

851. CAUSE OF COMPRESSED AIR ILLNESS

(1) Compressed air illness, commonly called the bends, decompression sickness, or caisson disease, is a condition resulting from inadequate decompression following exposure to pressure. Bubbles of nitrogen are formed in the tissues and blood stream and by their mechanical obstruction cause pain, paralysis, asphyxia, and, if large or numerous enough, death. As a diver descends, his body is subject to the increasing pressure of the water. In the case of a diver working in a full suit, this pressure is exerted directly on the suit and helmet and indirectly on the body through the air in his suit and helmet. In a satisfactory dive the pressure is transferred through the air in the helmet to the air in the lungs and thence to the blood. Air is forced into solution in the blood and this dissolved air is carried to each cell of all parts of the body and to the spaces between the cells.

(2) As the diver ascends, the pressure of the water becomes progressively less. Along with this drop in pressure, there is a fall in the pressure of the air in the helmet and the air in the lungs. In accordance with physical laws, the air dissolved in the blood and tissues comes out of solution in the form of gas and is expelled through the lungs, thereby decreasing its partial pressure inside the body until a new equilibrium is established with the outside pressure. If the diver ascends too rapidly or, expressed another way, if he receives inadequate decompression, the gas dissolved in the blood and tissues will come out of solution so rapidly as to produce bubbles of undissolved gas in these tissues. Bubbles will cause symptoms directly in the cells by their pressure on nerve cells or indirectly by interfering with circulation. In the latter case, the bubbles either join together to form one or more large bubbles which block the blood vessels or there are so many present that they replace the blood in a portion of the body.

852. SYMPTOMS OF COMPRESSED AIR ILLNESS

(1) Compressed air illness usually causes symptoms within a short period of time following a dive. If a diver comes to the surface quickly without any stops, he may be suffering from the bends when he reaches the surface. If he makes a stop or two of greatly insufficient duration, he may have symptoms before he reaches the surface. In general, however, most cases develop after a short period of time and almost always before 12 hours. A review of several sets of statistics gives the following figures:

50 percent occurred within 30 minutes.
85 percent occurred within 1 hour.
95 percent occurred within 3 hours.
1 percent delayed over 6 hours.

(2) The symptoms of compressed air illness have been found to occur with the following frequency:

	Percent
Local pain	89
Leg	70
Arm	30

	Percent
Dizziness ("The Staggers")	5.3
Paralysis	2.3
Shortness of breath ("The Chokes")	1.6
Extreme fatigue and pain	1.3
Collapse with unconsciousness	.5

The typical case may begin with itching or burning of a localized area. This may become generalized and then finally localize again. Rarely, the man may have a sensation as of ants crawling all over him. There may be a feeling of tingling of the skin or numbness. There may be a rash, the skin appearing blotchy and mottled. Occasionally, there will be small red spots which vary from the size of a pin head to the size of a dime.

(3) Pain, which is the predominating symptom, is of a deep, boring character. Divers describe it as being felt in the bone or in the joint. Frequently the pain is slight, but becomes progressively worse until it is unbearable. The pain usually is not affected by motion of the area, but frequently may be temporarily relieved by vigorous massage or hot applications.

(4) When dizziness occurs, the diver feels that the world is revolving around him and that he is falling to one side. Usually he experiences ringing in the ears at the same time.

(5) Paralysis, shortness of breath, with pain on deep breathing ("chokes"), extreme fatigue asphyxia, and collapse, though very unusual, are so dramatic in onset that they are immediately recognized.

(6) In all cases where there is any doubt, the diver should be treated as though he is suffering from compressed air illness. Any delay is dangerous.

853. PREVENTION OF COMPRESSED AIR ILLNESS

The prevention of compressed air illness is accomplished through the observance of a few simple rules:

(*a*) Careful selection of personnel. This is the problem of the medical officer.

(*b*) Careful observation and evaluation of each man before he makes any dive. Recent over-indulgence in alcohol, excessive fatigue, or a general "run-down" condition should be sufficient cause to restrict a man from diving. It is the duty of the diving officer and the senior divers present to prohibit any man from diving when his physical condition on that day is not satisfactory. If any doubt exists as to the diver's physical fitness, the medical officer's opinion must be the deciding factor.

(*c*) Constant meticulous attention to the details of the dive. Diving officers and divers should see to it that at all times a record is kept of the exact time of the dive, the depth of the dive, the duration of the dive, and all details of the decompression given the diver. This record should be easily available at all times as the knowledge of these facts is of the utmost importance in diagnosis and treatment.

(*d*) Strict observance of the decompression tables with due consideration for modifying factors. The tables should be followed at all times unless there is definite evidence from past experience that the decompression time given for a dive is inadequate. In that case the diver should be decompressed as if he had made a dive 10 feet deeper than he actually did.

(*e*) The incorporation of a safety factor in all dives. For example, if a dive is 85 feet for 70 minutes, the diver should be decompressed in accordance with the table for a dive to 90 feet for 75 minutes. (See Decompression Table.)

(*f*) Immediate reporting of all symptoms to the medical or diving officer. Serious cases of bends often begin as a slight itch or pain. All too often men fail to report their symptoms early and as a result their treatment is much more prolonged and their chances of suffering permanent damage greatly increased.

854. TREATMENT OF COMPRESSED AIR ILLNESS

(1) As soon as a diver experiences any unusual sensation in his skin or any pain or other symptoms mentioned above, he should report at once to a medical officer and/or to the diving officer. The treatment of compressed air illness is by compression in accordance with the Treatment Tables. These tables shall be strictly adhered to, and may be modified only by medical officers experienced in deep-sea diving when, in their opinion, deviations therefrom are indicated. The tables shall not, except in emergencies, be shortened for reasons of convenience or to save time.

(2) If only pain is present, treat in accordance with tables, 1, 1-A, 2, or 2-A, as shown in figure 113

TREATMENT TABLES FOR COMPRESSED AIR ILLNESS

Stops		Bends—Pain only			
Rate of descent, 25 feet per minute	Rate of ascent, 1 minute between stops	Pain relieved at depths less than 66 feet. Use table 1-A if O_2 is not available.		Pain relieved at depths greater than 66 feet. Use table 2-A if O_2 is not available. If pain does not improve within 30 minutes at 165 feet, the case is probably not bends. Decompress on table 2 or 2-A.	
Lbs.	Feet	Table 1	Table 1-A	Table 2	Table 2-A
73.4	165	----------	----------	30 (Air)	30 (Air).
62.3	140	----------	----------	12 (Air)	12 (Air).
53.4	120	----------	----------	12 (Air)	12 (Air).
44.5	100	30 (Air)	30 (Air)	12 (Air)	12 (Air).
35.6	80	12 (Air)	12 (Air)	12 (Air)	12 (Air).
26.7	60	30 (O_2)	30 (Air)	30 (O_2)	30 (Air).
22.3	50	30 (O_2)	30 (Air)	30 (O_2)	30 (Air).
17.8	40	30 (O_2)	30 (Air)	30 (O_2)	30 (Air).
13.4	30		60 (Air)	60 (O_2)	2 hours (Air).
8.9	20		60 (Air)		2 hours (Air).
4.5	10	5 (O_2)	2 hours (Air)	5 (O_2)	4 hours (Air).
Surface			1 minute (Air)		1minute(Air).

Time at all stops in minutes unless otherwise indicated.

FIGURE 113.

(3) If serious symptoms occur, treat in accordance with tables 3 and 4 as shown in figure 114. The symptoms requiring this treatment are:

1. Unconsciousness.
2. Convulsions.
3. Weakness or inability to use arms or legs.
4. Visual disturbances.
5. Dizziness.
6. Loss of speech or hearing.
7. Shortness of breath.

(4) If dizziness, nausea, muscular twitchings, or blurring of vision occurs while breathing oxygen, remove the mask and proceed as follows:

(*a*) If using table 1, complete remaining stops on table 1–A.

(*b*) If using table 2, complete remaining stops on table 2–A.

(*c*) If using table 3, complete remaining stops on table 3, breathing air.

At the discretion of the medical officer, oxygen breathing may be resumed at the 40- and 30-foot stops for a total of 90 minutes if using tables 1 or 3, or for 150 minutes if using table 2 in figure 113.

TREATMENT TABLES FOR COMPRESSED AIR ILLNESS

Stops		Serious symptoms	
Rate of descent, 25 feet per minute	Rate of ascent, 1 minute between stops	Symptoms relieved within 30 minutes at 165 feet. Use table 3.	Symptoms not relieved within 30 minutes at 165 feet. Use table 4.
Pounds	Feet	Table 3	Table 4
73.4	165	30 (Air)	30 to 120 (Air).
62.3	140	12 (Air)	30 (Air).
53.4	120	12 (Air)	30 (Air).
44.5	100	12 (Air)	30 (Air).
35.6	80	12 (Air)	30 (Air).
26.7	60	30 (O_2) or (Air)	6 hours (Air).
22.3	50	30 (O_2) or (Air)	6 hours (Air).
17.8	40	30 (O_2) or (Air)	6 hours (Air).
13,4	30	12 hours (Air)	First 11 hours (Air). Then 1 hour (O_2) or (Air).
8.9	20	2 hours (Air)	First 1 hour (Air). Then 1 hour (O_2) or (Air).
4.5	10	2 hours (Air)	First 1 hour (Air). Then 1 hour (O_2) or (Air).
Surface		1 minute (Air)	1 minute (O_2).
Time at all stops in minutes unless otherwise indicated.			

FIGURE 114.

(5) In the treatment of compressed air illness, certain techniques must be followed:

(*a*) Symptoms occasionally become temporarily worse if pressure is applied too rapidly. The descent should be made at a rate of 25 feet a minute. If the symptoms become worse, stop momentarily and then slowly raise the pressure at a rate tolerated by the diver.

(*b*) In all cases, particularly serious cases with paralysis, the ability of the diver to stand up and walk the length of the chamber should be tested. This test should be made routinely before leaving the bottom and upon completion of the 30-foot stop.

(*c*) Treatment includes first-aid measures. These are discussed below.

(*d*) Always keep the patient near the chamber for at least 24 hours in order to be able to treat any recurrences immediately.

855. RECURRENCES

Occasionally, because of the severity of the conditions or the inadequacy of the treatment, recurrences of symptoms will occur.

(1) If symptoms recur during treatment with any of the above tables, recompress to the depth at which relief is obtained, but never less than 30 feet, and then complete decompression from this depth according to table 4.

(2) Should symptoms recur following treatment with any of the above tables, recompress the diver to a depth giving relief.

(*a*) If relief occurs at a depth less than 30 feet, take diver to 30 feet and decompress from the 30-foot stop according to table 3.

(*b*) If relief occurs deeper than 30 feet, remain at the depth of relief for 30 minutes and then complete remaining stops of table 3, using air throughout.

856. USE OF OXYGEN

When using oxygen, certain precautions are to be followed:

(1) Observe all fire precautions as listed in part 1 (E). The electric fan and heater outside disconnect-switch should be open. The chamber should be frequently ventilated in order to keep the oxygen concentration in the chamber at a low level.

(2) A very high concentration of oxygen, preferably above 95 percent, should be delivered to the patient. The mask used should be as tight fitting and as leakproof as possible in order to make the treatment tables effective.

(3) If possible, the oxygen should be humidified to avoid dryness of the nose and throat.

(4) The tender should be acquainted with the symptoms and treatment of oxygen poisoning.

857. APPLYING FIRST AID

In the treatment of compressed air illness, certain first aid and supportive methods should be used. The patient should be kept warm by the use of fire-resistant blankets, hot-water bottles, and the feeding of hot coffee or soup. Never give fluids by mouth to an unconscious man. When the patient is in shock, he should be placed flat, with his feet slightly elevated. In the hands of a medical officer or an experienced pharmacist's mate, intravenous and subcutaneous injections of blood, plasma, or saline solution may be administered if the patient's condition so warrants. Adrenalin and other heart and respiratory stimulants should be on hand and used if heart failure is present or imminent.

858. USE OF HELIUM-OXYGEN

Helium-oxygen mixtures, in about an 80:20 ratio, may be used instead of air in all types of treatment at any depth.

859. TREATMENT WITHOUT CHAMBER

(1) Frequently, diving operations are carried out without a recompression chamber being available. Should a diver develop compressed air illness, the attending personnel may be hard put to administer adequate recompression. If the man is conscious and able to care for himself, he should be put in a suit and recompressed in the water. If he is partially paralyzed, another diver should be put down with him to operate his valve and help him. This is a particularly difficult and dangerous procedure which should not be undertaken unless absolutely necessary.

(2) In certain instances, especially in emergency harbor clearance work, a man may develop compressed air illness and there will be no chamber available and an insufficient depth of water in which to recompress him in accordance with the tables given above. In such cases, the diver should be taken to 30 feet and there treated in accordance with table 3, figure 109.

860. TENDER ALWAYS PRESENT IN CHAMBER

(1) A tender must always be present in the chamber with a diver breathing oxygen. If possible, this tender should be a pharmacist's mate trained in diving. If one is not available, the tender should be one who has had experience in the use of oxygen.

(2) While using table 1, 30 minutes of oxygen breathing is adequate for the tender; while using table 2, 60 minutes of oxygen breathing is required. If the diver is treated as outlined in tables 3 and 4 (figure 114), the tender will necessarily be subjected to the same treatment. The tender should not make an attempt to calculate and follow his own decompression. Several cases of compressed air illness have occurred as a result of such action. Decompression for additional tenders who may subsequently enter the recompression chamber for short periods will be carried out in accordance with standard diving tables.

861. PREPAREDNESS

At all diving activities, the personnel should be prepared at all times to deal with cases of compressed air illness.

(*a*) The chamber should be tested regularly and kept in a state of repair and readiness. It should not be used as a stowage space, as a private locker, or as sleeping quarters.

(*b*) The oxygen masks shall be operable and clean and the oxygen banks filled at all times.

(*c*) The air lock should be tested at frequent intervals and personnel instructed in its use.

(*d*) A fire-resistant mattress and blankets should be kept in the chamber at all times, along with a bucket for body wastes.

(*e*) A medical kit containing first-aid equipment should be in the chamber. It should be well stocked with fresh supplies and contain, in addition to the usual items, adrenalin and other stimulants, sterile syringes, and needles.

(*f*) All personnel should be assigned definite tasks to perform in the treatment of a case of compressed air illness, and training runs should be directed by a medical or diving officer.

862. SUMMARY

Compressed air illness is a disease peculiar to those who have been exposed to increased air pressures. It results from inadequate decompression which causes the formation of bubbles of gas in the blood stream and tissues. It manifests itself as a rash, pain, paralysis, asphyxia, or death. Most cases of compressed air illness can be prevented. If it does occur, it should be reported to the medical or diving officer at once. Treatment is by recompression given in accordance with the tables appearing above. Diving activities must always be in a state of readiness to handle any cases that arise.

Part 6—Diving With Helium-Oxygen Mixtures

A. DEVELOPMENT AND PRINCIPLES

871. EARLY EXPERIMENTS

(1) It has been established that oxygen in high concentration and pressure becomes toxic and that the nitrogen under high pressure produces a narcotic effect. In order to overcome the limitation of these two gases it was necessary to produce a new artificial atmosphere having a variable oxygen percentage and to reduce the narcotic effect of nitrogen. As early as 1921, it was suggested that a lighter inert gas could be beneficially substituted for nitrogen in the breathing medium for the deep sea diver.

(2) In the latter part of 1924 the Bureau of Construction and Repair in conjunction with the Bureau of Mines established an experimental diving project at the Bureau of Mines Laboratory in Pittsburgh to investigate the use of helium-oxygen mixtures as a substitute for air. After two years' work which definitely indicated that the narcotic effect of helium was much less than that of nitrogen and that a synthetic atmosphere with a reduced oxygen proportion was possible, the Experimental Diving Unit was transferred to the U. S. Naval Gun Factory, Washington, D. C., as an activity under the cognizance of the Bureau of Construction and Repair. The Experimental Diving Unit was provided with pressure tanks, laboratory facilities, and personnel to carry on the work started at Pittsburgh. Research done by this activity has developed the original preliminary ideas into effective and economical methods of utilizing the superior qualities of helium-oxygen mixtures. Test work in pressure tanks plus practical experience in salvage operations on the U.S.S. *Squalus* have culminated in an accurate set

of gas mixtures and decompression tables which have proven satisfactory to depths as great as 500 feet in the open sea.

872. RESULTS OF TESTS

During the years of experimentation with the use of helium-oxygen mixtures, a great many tests have been made. In general, the result of this work indicated that:

(1) The breathing of helium when mixed with the proper amount of oxygen is harmless.

(2) The rate of absorption of helium by the body tissues and its elimination by dissolution from these tissues is more rapid than that of nitrogen.

(3) All body tissues when fully saturated contain less dissolved helium than they do nitrogen. For instance, the watery tissues, such as blood or lean muscle, will hold about 1½ times more nitrogen than they will helium. In addition, the proportions of gas held by the different types of body tissues vary with nitrogen and helium. Thus, tissues that are high in fat content, such as fat, bone marrow, and spinal-cord substance, will absorb more than 5 times as much nitrogen as will the watery tissues. For helium the proportion of gas held by these respective tissues is only about 1.7 to 1. By simple calculation, the fatty tissues would, therefore, hold about 4½ times more nitrogen than they would helium.

(4) As the rate of absorption for helium is more rapid than that of nitrogen, some tissues will take up more helium during a short exposure at a given depth. However, on decompression, the rate of elimination of helium from these tissues will also be more rapid than that of nitrogen. Both phases promote the formation of bubbles which can cause bends. While the ratio of the pressure of the gas within the diver's body to the external pressure can be 2.0 or 2.25 to 1 safely with nitrogen, this ratio is about 1.7 to 1 with helium. Therefore, this lower safe ratio of pressures with helium requires the first decompression stop to be deeper than that following dives on nitrogen. Accordingly, it is desired to emphasize that a diver can contract bends when using helium-oxygen mixtures as readily as with normal air and that decompression in accordance with the tables herein is essential.

(5) Oxygen and helium must be mixed in proper proportions to suit the depth of the particular dive involved. The oxygen and helium should be obtained in separate cylinders and mixed as required. Oxygen concentration must be kept within the safe limits of about 2.3 atmospheres absolute pressure of pure oxygen. During decompression, the diver can be shifted to pure oxygen at 50 feet to hasten helium elimination from his body.

(6) Divers are more mentally alert when breathing helium-oxygen mixtures under pressure than when breathing normal air. The sense of depth commonly experienced when breathing air is greatly reduced. Also divers can work considerably harder and for longer periods since better ventilation of the diver's lungs takes place with the lighter helium atmosphere.

(7) The advantages of using helium-oxygen mixtures in lieu of normal air are applicable mainly to diving in depths in excess of 150 feet. For the shallower depths, the time saved in decompression and improved physiological reactions are not commensurate with the elaborate special equipment which has to be provided. Consequently, this equipment is furnished only to submarine rescue vessels.

873. REMOVAL OF CARBON DIOXIDE

(1) Due to the characteristics of helium and the fact that the helium-oxygen mixtures have to be furnished in bottles, it was necessary to provide special equipment and to modify the standard deep sea diving equipment. Early experiments with helium-oxygen mixtures were carried out using open circuit helmets in the same manner as for air diving. Experience soon showed that consumption was excessive; small salvage craft could hardly carry enough gas aboard for a day's diving.

(2) Consideration of the gas laws discussed in part 2 shows the cause of this difficulty. It has been found necessary to maintain a circulation of at least 3 cubic feet per minute through the helmet of a working diver in order to keep the CO_2 content at a safely low level. This ventilation, being simply a mechanical sweeping-out process, must be maintained regardless of pressure—and *measured at the depth of the diver*. At 365 feet (12 atmospheres absolute), the necessary supply will be increased

to 12×3=36 c. f. m. if measured at the surface. Now an average flask of helium-oxygen mixture contains only about 75 cubic feet of usable gas when account is taken of the last 200 to 300 p. s. i. pressure which is necessarily wasted. Therefore the gas is being used at a rate of one cylinder every two minutes, or 30 per hour.

(3) In order to reduce this excessive figure, attempts were made to use various arrangements of mouthpieces and one-way valves to circulate exhaled air through an absorbent which removed the CO_2 chemically. This apparatus was exceedingly clumsy and inconvenient to the diver, and increased density of the gas under pressure caused so much breathing resistance that the idea was discarded as impractical. Therefore, further application of physical laws was made to let the incoming gas do the work of recirculating itself by a well-known principle (Venturi's), a rapidly moving jet of gas tends to drag surrounding gases along with it creating a suction pump effect. By proper design, this jet arrangement has been made to recirculate approximately 11 times its own input volume, so that only about ½ cubic foot per minute within the helmet is needed for adequate ventilation and absorption of the CO_2. By this means, helium-oxygen diving has been made practical.

874. SPECIAL TRAINING REQUIRED

Since technique of preparing and using helium-oxygen mixtures is entirely different and more complicated than in air diving, a special program of training has been added to the instruction courses of the Deep Sea Diving School. Here each student before being designated a diver first class is taught the principles and practical applications of mixing and use, including qualifying dives at depths of 320 feet.

B. EQUIPMENT

881. SPECIAL EQUIPMENT

In addition to the standard diving equipment, the following special equipment is carried by the Submarine Rescue Vessels for doing helium-oxygen diving.

Item	Number	Unit
Helmet: Complete with breastplate, canister, injector, 3′9″ length of standard diver's air hose, control valve with adapter, and Hoke valve and recirculator supply hose	3	No.
Helmet spares:		
Exhaust valve, secondary, complete	1	No.
Valves, rubber	6	No.
Screws, for rubber valves	6	No.
Gaskets for exhaust valve, secondary	3	No.
Hoke valve	5	No.
Injector spares:		
Nozzle, high pressure	3	No.
Nozzle, discharge, Venturi	3	No.
No. 72 drill	3	No.
Pin vise for 72 drill	1	No.
Manifold: Complete	2	No.
Spare parts for manifold:		
Petcocks	5	No.
Globe valve, ½-in., high pressure, 5,000 lbs	4	No.
Globe valve, ¾-in., high pressure, 300 lbs	2	No.
Valve, relief, 1-in	1	No.
Gas-mixing equipment:		
Tee for spliting gas flasks, ¼-in. high-pressure, equipped with 0–3,000-p.s.i. gage and 2 left-hand nuts to fit helium flasks	2	No.
Tee for mixing gas, ¼-in. high pressure, equipped with 0–3,000-p.s.i. gage, left-hand nut to fit helium flasks, and right-hand nut to fit oxygen flasks	2	No.
Electrically-heated underwear:		
Large size	2	No.
Small size	2	No.
Panel, complete with switches, ammeter, ammeter shunt, and voltmeter	2	No.
Storage batteries, 6-volt, 200 ampere-hour	6	No.
Helium, 200-cubic-foot flasks	100	No.
Oxygen, 200-cubic-foot flasks	20	No.
Gas analysis outfit:		
Beckman Model "C" Oxygen Analyzer	2	No.
Haldane-Henderson	2	No.
Potassium hydroxide, 1-lb. bottles	6	No.
Pyrogallic acid, purified, 1-lb. bottle	1	No.
Mercury, in 10-lb. bottles	5	No.
Leveling bulbs, 2½-in	6	No.
Rubber tubing, 3/16 x 5/64-in	50	Feet.
Rubber tubing, ¼ x 3/16-in	10	Feet.
Lubriseal (stopcock grease)	10	Tube.
Mineral oil, 1-pint bottles	1	Pt.
Support lift ring, medium	4	No.
Support lift ring, large	2	No.
Ring supports	6	No.
Gas collecting tubes	6	No.
Clamp holders, ¾-in	6	No.
Clamps, Bunsen	6	No.
Micrometric control valves, for bleeding sample from helium flask	2	No.
Shell Natron, in approximately 2¾-lb. containers, 12 containers in box	450	Pounds.
Cable for heating electric underwear in 600-ft. lengths with male fittings	3	Lengths.
Report on the Use of Helium-Oxygen Mixtures for Diving (pamphlet)	6	No.

The ship's recompression chamber should be equipped to supply helium-oxygen mixtures to divers undergoing surface decompression. Ten face masks are supplied each vessel for this purpose.

In addition to the above, submarine rescue vessels should provide and maintain satisfactory forms for recording helium-oxygen mixtures and results of dives made with same. Figures 115 and 116 are samples.

Manifold No.--------- Date---------------

	Bank 1 per cent O_2	Bank 2 per cent O_2	Bank 3 per cent O_2	Bank 4 per cent O_2
Flask 1				
2				
3				
4				
5				
Sum				
Average				
Pressure				

O_2 pressure
Bottle No. 1---------
Bottle No. 2---------

FIGURE 115.

U. S. S. ____

Date ________________________ Diver ________________________ Currents ____________________________

Depth Gage Line ____ ____________________________

Fathometer ____ ____________________________

____ O. B. ________________________

Bank No. ____________ % O_2 ____________ P ________ S. B. No. ______________ % O_2 ____________ P ______

Depth ABS. ____________________ ACG ___________ PP _______________ Table ______________ Mins______

	Time	*Bank P*
L. S.	____________	____________
R. B.	____________	____________
L. B.	____________	____________
R 50	____________	____________

Feet	*Minutes*	*Time*
TO ______	______	______
AT ______	______	______
TO ______	______	______
AT ______	______	______
AT ______	______	______
AT ______	______	______
AT ______	______	______

For Surface Decompression:

L 40 ____

RS ____

LS ____

R 40 ____

PO_2 __________________ SBO_2 ____________________

	Time	*Pressure*
Begin Vent 50	____________	____________
L 50	____________	
L 40	____________	
R. S.	____________	____________
O_2 Used		____________

Feet	*Minutes*	*Time*
AT ______	______	______
AT ______	______	______
AT ______	______	______
AT ______	______	______
AT ______	______	______
AT ______	______	______

____________________________ Bottles O_2

	Time	Pressure
Initial		____________
L 40	____________	
RS	____________	____________
O_2 Used		____________

REMARKS:

FIGURE 116.

882. HELIUM-OXYGEN DIVING HELMET

The helmet, figure 117, used in helium-oxygen diving is a modified standard diving helmet. The principal changes involved the installation of a means of conserving the helium-oxygen mixture by recirculating it through a carbon dioxide absorbent. This is necessary due to the fact that at deep depths, the effect of carbon dioxide is so marked that it becomes important to have a minimum amount of this gas present in the helmet. Essentially the recirculating device draws the carbon dioxide laden atmosphere from the helmet, forces it through a chemical absorbent, and returns it to the helmet with the carbon dioxide removed. In this way, normal expenditure of helium-oxygen mixture is reduced to about ½ cubic foot per minute at the pressure of the dive. In addition, the helmet has been modified to take the special goosenecks for the carbon dioxide absorbent canister and electrically heated underware. A check valve has been installed on the exhaust channel to prevent accidental flooding and a duct from the canister discharge opening improves gas circulation within the helmet. The modified helmet with breastplate and canister weighs about 103 pounds against 56 for the standard helmet and breastplate.

883. RECIRCULATORY DEVICE

(1) The recirculatory device is show in figure 118. The connection to the aspirator or circulator consists of an extra strong nipple, a ¼-inch pipe elbow, and an oxygen hose adapter to which the helium-oxygen supply hose connects. A fine wire gage strainer is fitted into the oxygen hose adapter. It is important that this strainer be kept in good condition to prevent solid matter blown along the hose from plugging the high-pressure nozzle. The high-pressure nozzle fitting is threaded into the aspirator body with a metal-to-metal joint, no packing being used. It can be removed for cleaning with a ¾-inch wrench.

(2) The high-pressure nozzle is secured into the aspirator body and projects into the throat of the venturi. The orifice of the nozzle is so proportioned that with 100 p. s. i. differential pressure, a volume of gas which contains sufficient oxygen to replace that consumed by the diver is introduced into the helmet in a given time. Simultaneously the movement of the gas mixture through the nozzle draws the atmosphere from the helmet and forces it

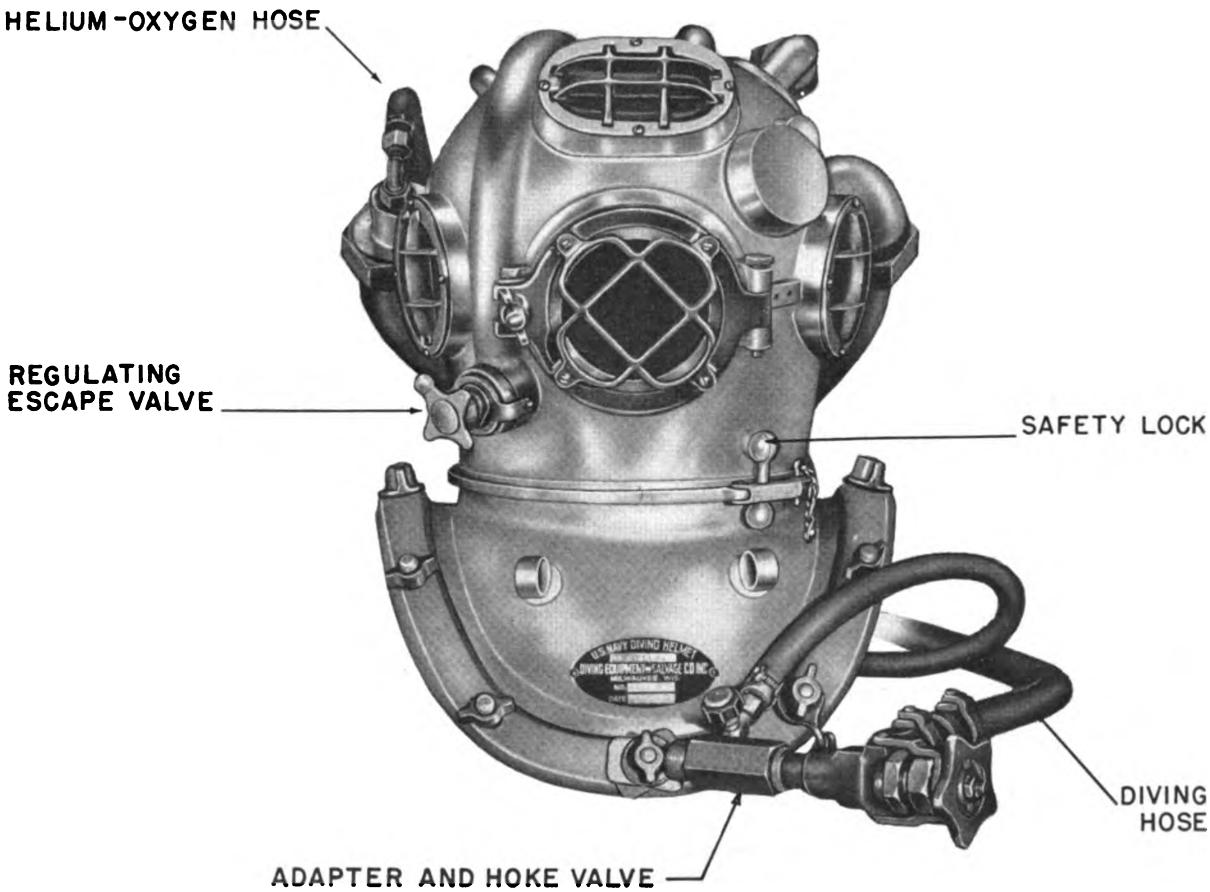


FIGURE 117.—H. O. HELMET (FRONT).

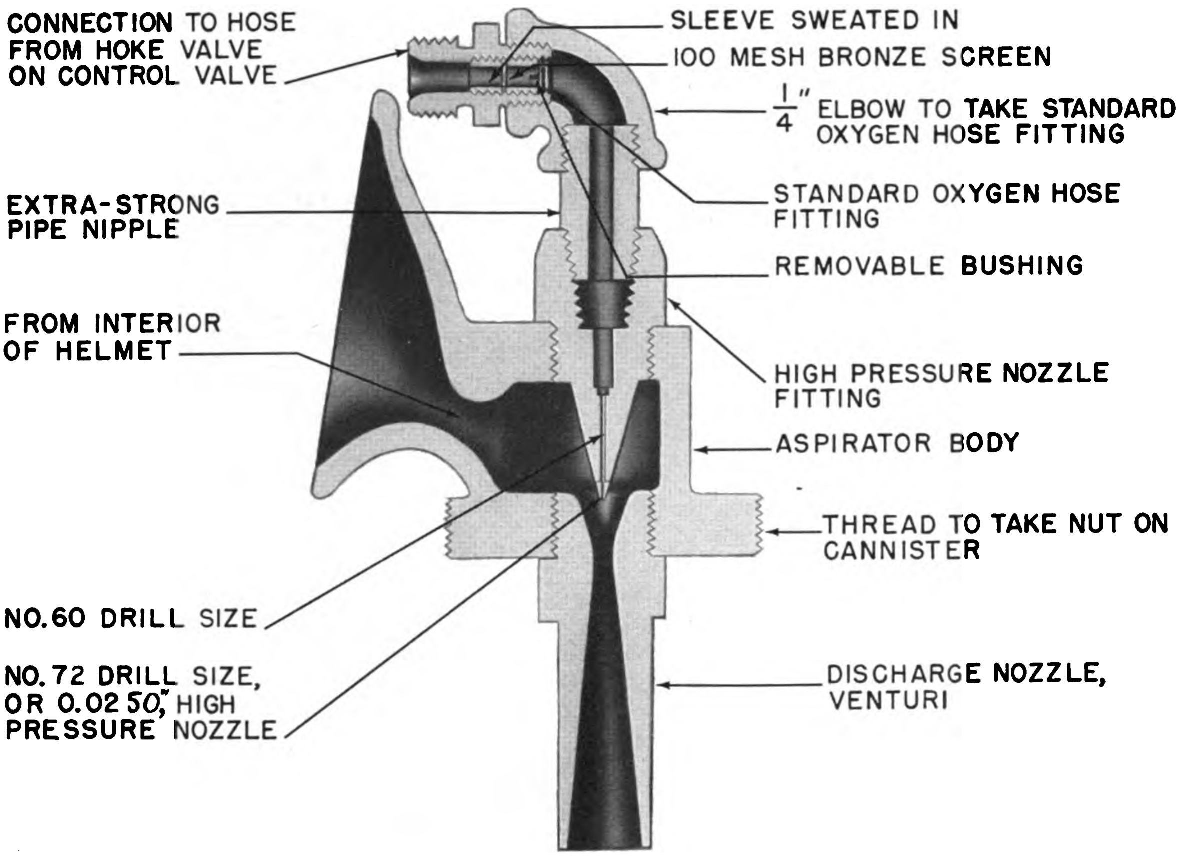


FIGURE 118.—NIPPLES RECIRCULATING DEVICE.

through the carbon dioxide absorbent in the canister and then back to the helmet after purification. Any excess gas that tends to accumulate escapes through the exhaust valve. By this means, the helmet is given sufficient ventilation and the amount of gas which is required is only about one-fifth of that used in the standard method of ventilation. At depths less than 200 feet, 50 p. s. i. over bottom pressure will provide adequate recirculation and gas supply and may be used with safety. The decrease in total recirculation will be about 25 percent, and the decrease in gas supply will be about 3 percent.

(3) As the nozzles are machined to extremely accurate dimensions, they must be handled very carefully. The relative position of the nozzles must also be exactly as designed. A nearly invisible scratch or a tiny bit of foreign matter around the nozzles will alter the flow of the gas and will result in inadequate ventilation of the helmet. The dimension of the jet orifice is 0.025 inch, or No. 72 drill size. Each time a helmet is used, inspect the strainer and nozzles. Make sure the high pressure nozzle is clean by running a No. 72 drill through it from the high-pressure side. If a drill is soldered to the end of a small brass rod about 4 inches long, it can be inserted into the nozzle easily.

(4) The jet produces a low rumbling noise. Any change in this sound may indicate that the recirculating system has failed. The discharge nozzle is a venturi tube. The jet of gas from the high-pressure nozzle rushing through the throat of the venturi sucks the atmosphere from the helmet and forces it through the canister. The discharge nozzle is screwed into the lower side of the aspirator body and projects down into the canister. It can be removed with a ¾-inch wrench.

(5) The carbon-dioxide absorbent is a compound known commercially as Shell-Natron. The particles are molded to permit easy flow of gas through the material. Shell-Natron has a very high affinity for carbon dioxide and moisture. It is extremely caustic and will produce active burns if it comes in contact with the skin. It is packed in 2¾-pound containers, 12 containers to a drum. Shell-Natron must be kept completely dry and air tight to prevent absorption of moisture and carbon dioxide from the air.

(6) The canister, figure 119, holds a little more than a container of Shell-Natron or about three pounds of absorbent. This quantity probably will continue to absorb carbon dioxide effectively for about 7 hours. However, it should be changed after approximately three hours of use. The discharge

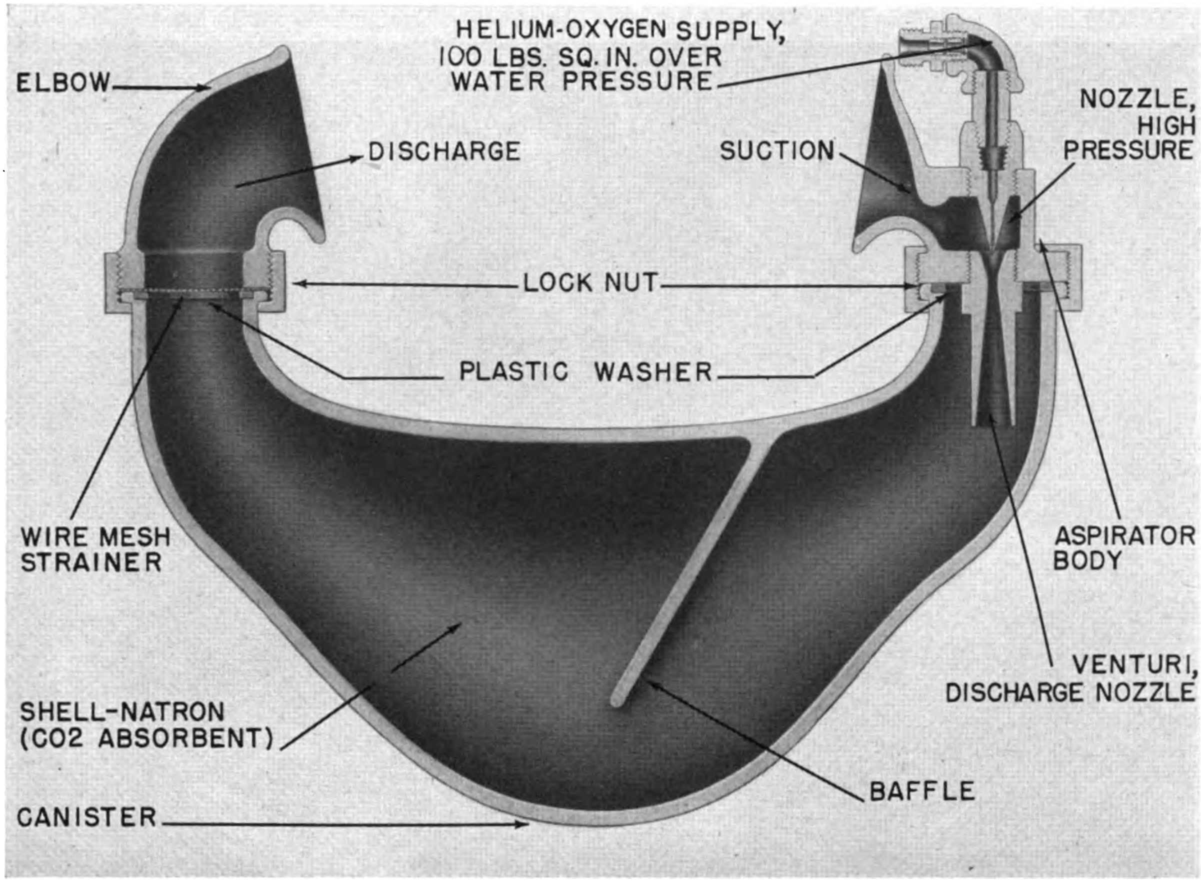


FIGURE 119.

(left) end of the canister is fitted with a removable screen to prevent the absorbent from entering the helmet. Shell-Natron which has powdered should not be used because the caustic dust will be blown into the helmet. The canister is attached to the helmet with two large nuts which can be turned with a 3-inch wrench. Plastic washers inside the nuts make the connection watertight. In assembling the recirculating system, it is essential that all connections be completely tight to avoid loss of gas and to prevent water from reaching the Shell-Natron.

(7) With the canister removed from the helmet, fill it carefully with Shell-Natron from both ends. Leave an empty space in the aspirator end of the canister to accommodate the discharge nozzle. Shake the absorbent down enough to insure that the canister is otherwise filled completely. A baffle, figure 119, is installed in the canister to prevent the gas from channeling or by-passing the absorbent. After use, remove the Shell-Natron from the canister and wash out thoroughly with fresh water. Any absorbent left in the canister will produce heavy corrosion.

(8) The exhaust valve, figure 117, is the standard air-regulating exhaust valve of the "non-blow-up" type. The exhaust channel is led over the top of the helmet and terminates by the secondary exhaust check valve, figure 120. During the dive, the exhaust valve is normally kept closed, the diver using the chin valve as necessary to regulate his buoyancy. When ordered to "ventilate," the diver holds the chin valve open. If it is necessary to "go on open circuit," the exhaust valve is used in the ordinary way and is opened as necessary to regulate ventilation.

(9) The helmet safety lock, figure 117, has been shifted to the left front of the helmet so as not to interfere with the carbon dioxide absorbent canister. The spit-cock, common to the standard helmet, has been removed to provide space for the helmet locking device and to prevent possible loss of gas from leakage.

(10) The helium-oxygen supply line (aspirator supply hose), figure 117, is a 2½-foot section of standard oxygen hose and is led from the Hoke valve on the control valve adaptor to the aspirator. With this arrangement, the breathing medium is led to the aspirator jet with the control valve closed. Should a sudden additional supply of gas be required,

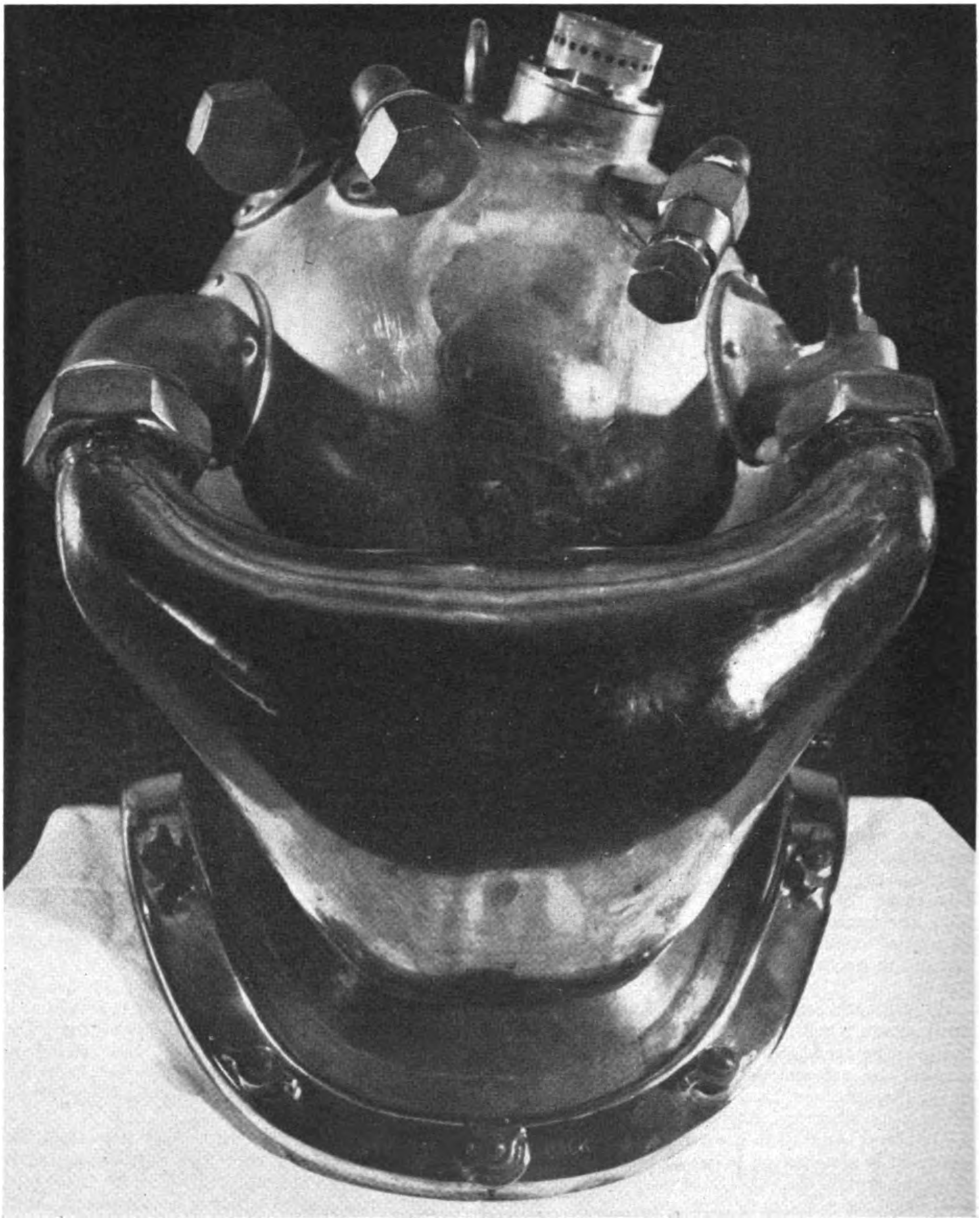


FIGURE 120.

as for instance during the descent, the control valve can be opened to obtain an open circuit flow of air. The working pressure in the aspirator supply hose is maintained at 100 pounds per square inch over bottom pressure. The aspirator hose is secured to the 3-foot 9-inch length of regular diving hose. During the dive, the Hoke valve is kept fully open at all times to supply the helium-oxygen mixture to the recirculator nozzle. It should never be closed unless the aspirator supply hose breaks or becomes disconnected.

(11) The control valve, figure 117, is the standard type control valve with a hexagonal adapter carrying the Hoke valve, attached to the supply side. During the dive, the control valve is kept closed except under the following conditions:

(*a*) To build up the pressure and volume of gas in his suit during the diver's descent.

(*b*) Whenever the diver suddenly requires more gas in his suit to regulate his buoyancy.

(*c*) To supply gas or air to the helmet in the conventional way in case the recirculating apparatus fails. Use of the control valve in this manner is called "going on open circuit."

(*d*) To ventilate the helmet by replacing the gas in the dress with a fresh quantity of gas. The control valve and the exhaust valve are opened on the order "Ventilate" and closed on the order "Circulate."

(12) The air hose is the regular diver's air hose. The control valve and hose are attached to the breastplate in the usual way. The 3-foot, 9-inch length of hose is led under the diver's left arm and to the right gooseneck through a standard safety non-return valve.

884. HELIUM-OXYGEN MANIFOLD

(1) The helium-oxygen manifold, shown on figures 121 to 124, is used to control the supply of gas to the diver and to hold the flasks containing the gas mixtures. The manifold is designed so that one of three breathing mediums, helium-oxygen mixtures, pure oxygen, or compressed air, can be supplied as required. It holds 20 flasks of helium-oxy-

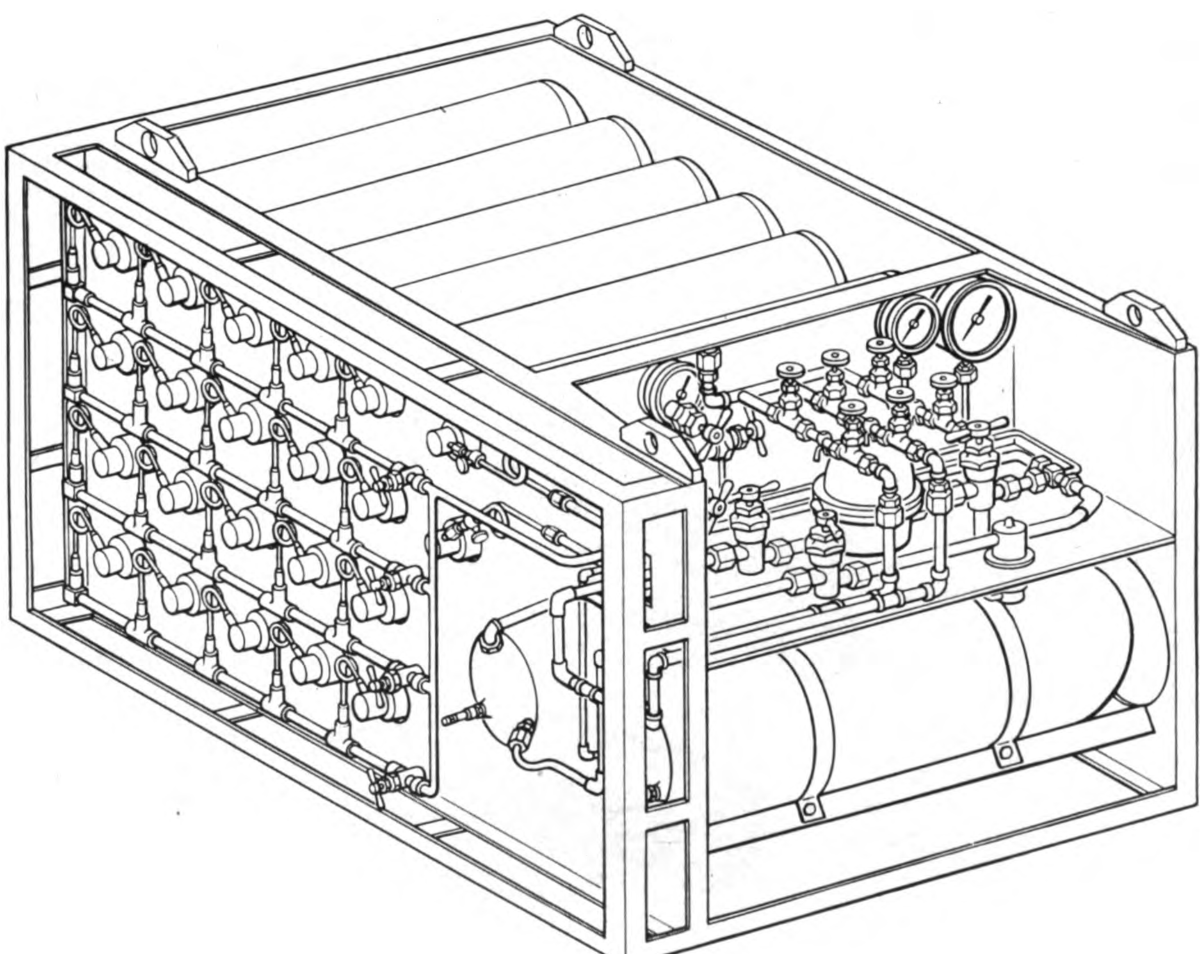


FIGURE 121.

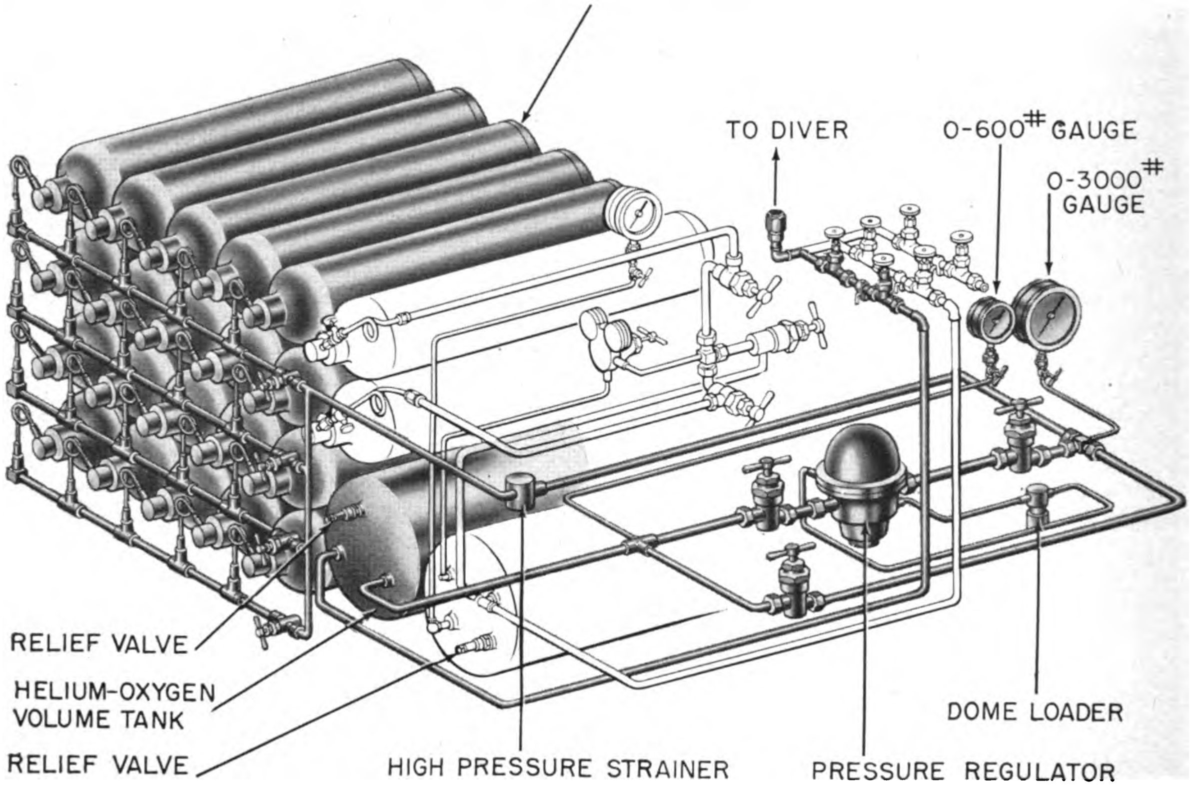


FIGURE 122.—HELIUM-OXYGEN.

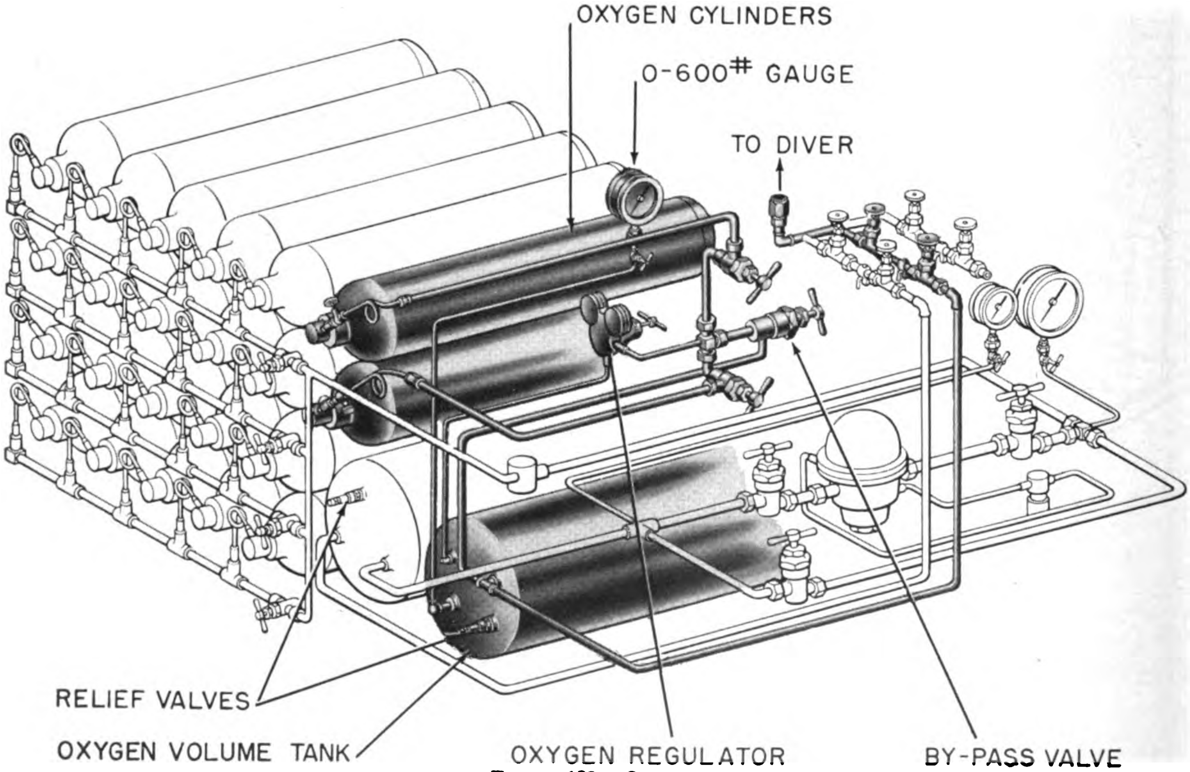


FIGURE 123.—OXYGEN.

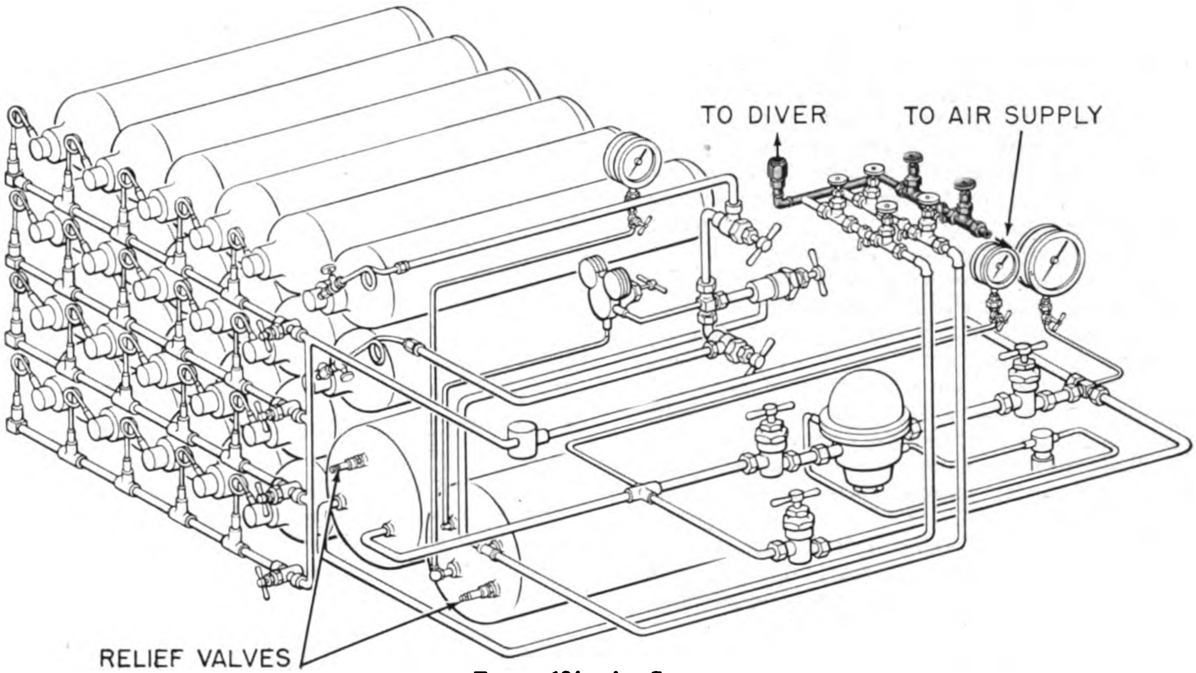


FIGURE 124.—AIR-SYSTEM.

gen mixtures, two oxygen flasks, one helium-oxygen volume tank, and one oxygen volume tank.

(2) The flasks containing the helium-oxygen mixture are arranged in four banks, with five flasks to the bank. Only helium flasks which have left hand threads will fit the flask connections on the manifold. All flask valves are opened and one bank is used at a time. Flasks in an exhausted bank can be replaced with full flasks without interrupting the supply to the diver.

(3) Referring to the manifold, figure 122, the flow of helium-oxygen mixtures is from the helium-oxygen banks into the high pressure strainer, then to the high pressure globe valve through the pressure regulator where the pressure is reduced to 100 p. s. i. over bottom pressure. The gas then goes to the helium-oxygen volume tank, then through the line to the diver. There are the necessary connections to the high and low pressure gages, and a suitable way of by-passing the pressure regulator, if necessary.

(4) Two flasks of pure oxygen are placed in the rack above the oxygen-helium volume tank, figure 123. The valves on each flask should be opened wide. The piping from each flask is equipped with a stop valve on the control panel which connects the flasks to an ordinary oxygen pressure regulator having high and low pressure gages. The regulator reduces the oxygen pressure to that required by the diver, 50 p. s. i. over bottom pressure, and discharges it to the diver's hose via the oxygen volume tank. A valve is provided for by-passing the oxygen regulator in case of failure.

(5) If the helium-oxygen or oxygen system fail, the diver can be shifted to compressed air, figure 124. A length of standard diver's air hose from a regular diver's air supply is attached to the air hose connection at the control panel. When the diver is shifted to compressed air, he would continue to "Circulate" for 20 minutes without "Ventilating" before he goes on "open circuit." This will prevent his suddenly becoming dizzy from the decreased lung ventilation produced by the denser gas and also the narcotic effect of the nitrogen. It should be remembered that pressure regulation of the compressed air is at the source and not at the manifold.

(6) The maximum working pressure of the low pressure helium-oxygen system is 300, 400, or 500 p. s. i., depending upon the setting of the relief valve. The maximum working pressure of the low pressure oxygen systems approximate 100 p. s. i. This is obtained when ventilating a diver at 60 feet with an 800-foot length of life line and air hose in use.

(7) The helium-oxygen volume tank, figure 122, has a capacity of about 3.75 cubic feet. It is equipped with a relief valve having a 300 p. s. i. spring installed and set to lift at 275 p. s. i. Spare springs of 400 to 500 p. s. i. are also supplied. The test pressure of the tank is 1,000 p. s. i.

(8) The oxygen volume tank, figure 123, is of the same size as the helium-oxygen volume tank and has an identical relief valve with spare springs.

885. PRESSURE REGULATOR

(1) A Grove type pressure regulator, figure 122, is used to reduce automatically the flask pressure of

the helium-oxygen mixture to that required by the diver. It is similar in construction to other diaphragm-operated regulators except that instead of a spring against the diaphragm being used to control the discharge pressure, a dome over the diaphragm is charged to a suitable pressure. As installed, the dome pressure is adjusted from the high pressure side of the line to give the desired discharge pressure by turning the handle on a dome loader, figure 122. In case the dome loader does not operate, use the bypass valve and close the cut-out valves in the supply and discharge lines of the regulator. The pressure delivered by the regulator must be carefully adjusted to 100 p. s. i. over the water pressure corresponding to the actual depth of the diver. A pressure lower than this amount will prevent proper functioning of the diver's recirculating system. This requires continuous changing of the dome loader setting while the diver is going down and coming up.

(2) The most likely causes of derangement of the regulator are failure of diaphragm and worn or damaged valve parts. New parts may be obtained upon requisition to the Bureau of Ships.

886. HEATING ELEMENTS

(1) Helium-oxygen mixtures when compared with air have poor insulating qualities. To increase the diver's comfort, electrically heated diver's underwear was developed.

(2) The heating elements consist of fine interwoven wires arranged in multiple series-parallel circuits. Each wire is insulated with spun glass cloth and are sewn to one layer with glass thread. The inside and outside of the garment is knitted wool, dyed blue and impregnated to make it fire-resistant. The high concentration of oxygen in the dress increases the possibility of igniting materials which ordinarily will not burn readily, hence the glass insulation and fire-resistant impregnation.

(3) Nine 6-volt, 200-ampere-hour storage batteries are supplied to furnish the current for the underwear. The leads from the batteries are led to switches on the panel so that any number of batteries can be used at one time in series, giving 6 to 36 volts on the leads to the underwear in 6-volt steps. Only one switch at a time should be in the "On" position, otherwise one or more of the batteries will be short-circuited. It is necessary to have the batteries and all parts of the circuit well insulated from grounds to avoid giving the diver a possible shock that will be uncomfortable, but not dangerous.

(4) 500 feet of No. 12 twin-conductor portable wire is supplied for the underwear conductor. It is led into the helmet through a goosenesk, using the old style battery type telephone connections. Connection to the underwear is made inside the helmet with a small bakelite plug and jack placed on the left side of the diver's face clear of his telephone.

(5) The resistance of the dress is about 2 ohms and it is designed to operate on a maximum current of 15 amperes. The resistance of the cable must be considered in calculating the voltage required to obtain the desired current. For example: No. 12 wire has a resistance of 0.00162 ohms per foot. 500 feet of twin conductor cable will have 1,000 feet of No. 12 wire with a resistance of 1.62 ohms. To obtain a current of 15 amperes, a potential of about 54 volts is required. The actual current through the underwear is read directly from the ammeter on the panel. Divers report being comfortable in water of 46° F., using 11.5 amperes. Figure 125 shows a layout of the storage batteries, control panel, cable, and electrically heated underware.

887. HOW TO OBTAIN EQUIPMENT

All items of the helium-oxygen equipment, with the exception of the gases, are special and can be obtained by submitting a request to the Bureau of Ships. The gases are standard stock and can be obtained from the Bureau of Supplies and Accounts. The stock numbers are:

Helium	51-G-148-70
Helium cylinder	51-C-2083-100
Oxygen	51-G-203
Oxygen cylinder	51-C-2165-50

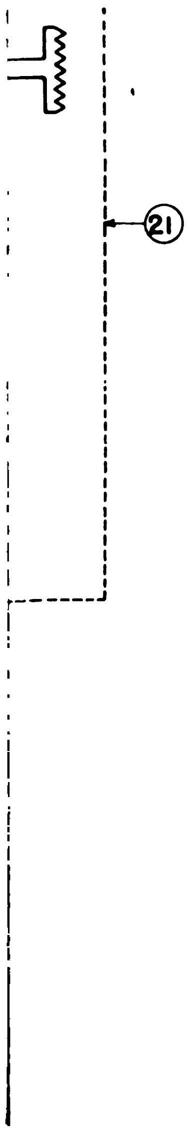
C. APPLICATION AND PROCEDURE

901. PREPARING HELIUM-OXYGEN MIXTURES

(1) Before diving operations can be undertaken, the required helium-oxygen mixtures must be prepared in adequate quantities. In order to obtain the proper mixture, start with a full helium flask (about 1,800 p. s. i.) and bleed it into an empty helium flask. The two cylinders are connected by means of the gas mixing T which has two left-hand nuts threaded to take the fittings on the helium flasks. Open the stop valve on the full flask and read the pressure gage on the T fitting. Open the valve on the empty flask and allow the pressure in the flasks to equalize. The gage reading should then be half its original value. Close the valves on the flasks.

(2) In order to add oxygen to the helium, a fully charged oxygen flask is "bled" into the helium flask containing helium at the reduced pressure mentioned above. This requires a T fitting provided at one end with a right-hand threaded nut and at the other with a left-hand threaded nut. Using the T fitting, connect a split helium flask (about 900 p. s. i.) to a full oxygen flask (about 1,800 p. s. i.). Open the stop valve on the helium flask, read the pressure on the gage on the T connection, then close the valve again. Open the stop valve on the oxygen flask and read the gage.

(3) Compute the pressures which each flask will contain when enough oxygen has flowed into the



3. UNDER SERVICE CONDITIONS TWO CONTROL PANELS LOCATED ON OPPOSITE SIDES OF A VESSEL WILL BE CONNECTED TO ONE SET OF BATTERIES. THE SECOND CONTROL PANEL IS NOT SHOWN ON THIS PLAN BUT IS INDICATED BY THE SECOND COMPOSITE TEN-WIRE CABLE FROM THE BATTERIES.

4. THE CONTROL PANELS SHOULD BE INSTALLED IN A SHELTERED LOCATION ON THE VESSEL AND NOT ON THE OPEN OR WEATHER DECK.

5. ANY WIRE TERMINALS THAT IT MAY BE DEEMED NECESSARY TO USE CAN BE SECURED FROM BUREAU DWG. 9-S-1841-L.

6. EACH COMPOSITE 10-WIRE CABLE TO BE MADE UP OF 5 DCP-6 CABLES.

7. UNDER ORDINARY SERVICE CONDITIONS SIX BATTERIES WILL BE USED. PROVISION IS MADE FOR NINE BATTERIES IF NEEDED.

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ALTERATIONS

POWER SUPPLY & CONTROL PANEL FOR ELECTRICALLY HEATED DIVERS SUIT

SCALE. AS SHOWN

BUREAU OF SHIPS
NAVY DEPARTMENT
WASHINGTON, D.C. APR. 15, 1942

FOR CHIEF OF BUREAU

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DRAWN BY. / TRACED BY. / INSPECTED BY. / PRINC'L ENG. / HEAD OF DIV.	9	S	5374-L-ALT. 1

helium flask to give the desired percentage as follows: Assume that an 80 percent helium and 20 percent oxygen mixture is required. The total pressure in the flask, after mixing the two gases, is obtained by dividing the pressure in the split helium flask by the percentage (expressed in decimals) of helium in the final mixture.

For example:

$$\text{Final pressure in mixed gas cylinder} = \frac{\text{Pressure in split helium flask}}{\text{Percentage of helium in final mixture}} = \frac{900}{.80} = 1{,}125 \text{ p. s. i.}$$

Pressure exerted by oxygen =1,125—900=225 p. s. i.=pressure drop in oxygen cylinder.

If an 84 percent helium and 16 percent oxygen mixture is desired and the split helium cylinder pressure is 860 p. s. i. then:

$$\text{Final pressure in cylinder will be} = \frac{860}{.84} = 1{,}024$$

Pressure drops in oxygen flask will be=1,024—860 =164 p. s. i.

902. TEMPERATURE OF GASES DURING MIXING

The helium flask will heat up and the oxygen flask will become cold due to their respective pressure changes (Charles' law). If the flow between the two flasks is stopped under these conditions and the temperatures of the two flasks allowed to equalize again, the pressure in the oxygen flask will have increased slightly and that in the helium flask will have dropped (Charles' law also). No way of controlling the temperature of the gases during mixing has been devised, so this temperature effect must be compensated for by running over a slight excess oxygen pressure, or by adjusting the pressures two or three times at intervals after the flasks have been allowed to return to approximately the same temperature. To compensate for the temperature changes which occur during mixing, more accurate results will be obtained if the oxygen is bled into the helium bottle at a uniform rate of about 70 pounds per minute and in an amount equal to 1 percent more oxygen than is desired in the final mix.

903. PROCEDURE BEFORE USING HELIUM-OXYGEN MIXTURES

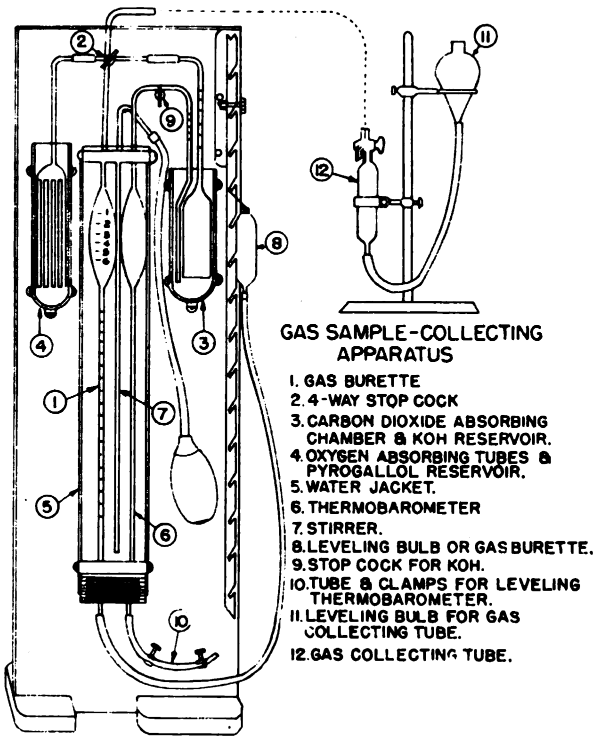
After the gases are mixed the flasks should be correctly analyzed for oxygen percentage. This analysis may be accomplished either with the Haldane-Henderson apparatus or Beckman Model "C" Oxygen Analyzer. The operation of this apparatus is discussed in detail in article 904. Mark each flask with a label tag securely attached to show what gases and the percentages it contains. Serial numbers of all flasks and the analysis of the contents of each should be recorded on a form provided for that purpose. A second analysis should be made immediately prior to use if the flasks have been stored for any length of time. Inasmuch as this situation will invariably arise aboard ship it will be necessary to conduct this analysis using the Beckman Model "C" Oxygen Analyzer.

(3) When loading the helium-oxygen manifold, the oxygen content of the individual flasks in any one bank should not vary by more than 2 percent. Flasks are placed in the manifold so that the average of the flasks in each bank is as close as possible to the oxygen percentage desired.

904. TESTING MIXTURE

(1) The Haldane-Henderson apparatus shown on figure 126 is very accurate and will give oxygen and carbon dioxide to within 0.03 percent when operated by a diving hospital corpsman. The gas burette is calibrated to 0.01 cc. However, it may be read to 0.001 cc. by reading between the calibrated lines.

(2) The apparatus is shipped unassembled. Great care must be exercised in the assembly of the parts since they are of a fragile nature. Most of the working parts are made of glass to be mounted on a wooden frame or board. A light source, usually an incandescent lamp, is mounted behind the frame to aid in reading the burette. The cardinal principle in operating this apparatus accurately is in assembly, and care in keeping the glass parts free from stain, the glass stopcock properly lubricated, and the assembly installed on a sturdy table



HALDANE-HENDERSON GAS ANALYSIS APPARATUS.

FIGURE 126.

or bench as free as possible from vibration, motion, and sudden temperature changes. A convenient place ashore should be maintained to house and operate the Haldane-Henderson apparatus. It is impossible to operate the apparatus on board ship even in calm water alongside the dock, because it is fluid-operated and the motion of the ship, which normally seems negligible, will create erroneous results. For shipboard analysis of helium-oxygen mixtures, the Beckman Model "C" Oxygen Analyzer is provided, the operation of which is discussed in art. 904 (6).

(3) The stirring tube, figure 126, may be connected to a source of compressed air instead of to the rubber bulb. All joints should be made up glass-to-glass using sulphur-free rubber tubing. Lubricate and seal stopcocks with a minimum amount of Lubriseal. Stopcocks must be kept clean. The carbon dioxide absorbent is potassium hydroxide (KOH), 20 percent. 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 grams 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 grams of pyrogallic acid (Merck). Both reagents must be kept from contact with the air to prevent their absorbing carbon dioxide and oxygen, thus losing their strength. Both are very caustic. The potassium pyrogallol should be kept in a bottle with a greased stopper.

(4) The following method should be used 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 short length of rubber tubing about 4 inches long. At the extreme end place a clamp and screw down tightly. With a 10 cc. hypodermic syringe, inject into the tubing about four or five cc. of water in order to reach the level of the bottom of the enlarged section of the thermobarometer. Now inject enough mercury into tubing to force the water half way up the enlarged section. If bubbles form in the thermobarometer, force water up by injecting more mercury into the tubing until bubbles escape out through one-way stopcock. Then draw mercury back into syringe until level of water is half way up enlarged. Now withdraw needle and place a second clamp about halfway between end of tube and thermobarometer.

(*c*) Pour potassium hydroxide (KOH) into its reservoir.

(*d*) Open one-way stopcock and squeeze tubing, thus forcing air out of thermobarometer outlet tube into the KOH reservoir. Release pressure on tubing causing the KOH solution to rise to the graduated portion of the thermobarometer outlet.

(*e*) Set the four-way cock, (2) to connect the burette, (1) to the carbon dioxide absorbing chamber (3).

(*f*) Raise the mercury almost to the top of the burette by elevating the mercury bulb (8). Then lower the mercury bulb drawing 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 burette, then pour pyrogallol solution into its reservoir and draw it up into the oxygen absorbing chamber by lowering the mercury in the burette. Pour some liquid petrolatum into the pyrogallol reservoir to protect the solution from the air.

(*i*) Adjust the level of KOH in the thermobarometer connection to the KOH reservoir to one of the marks on the glass tubes by means of the clamps on leveling tube at the bottom of thermobarometer.

(*j*) Adjust the level of the liquid to one of the marks on the carbon dioxide absorbing chamber by changing the mercury level in the burette.

(5) Gas samples must be sealed with mercury and are taken with the gas collecting tube (12). To take and analyze a gas sample:

(*a*) Open the collecting tube stopcock and fill tube and cock with mercury from the leveling bulb, (11) then close cock.

(*b*) Gas flows from the helium-oxygen flask through a regulator or needle valve to reduce the pressure. Before taking a sample of the gas, it should be allowed to flow through the regulating valve and tube to the gas collecting bottle for approximately a minute to expel all the air.

(*c*) The hose running from the flask should be connected with the top of the sample tube and allowed to flush out through the discharge hole. When the line has been flushed, turn the stopcock so that the gas pressure will force the sample into the collecting tube. When the tube is ¾ full, turn cock to discharge hole and disconnect tube.

(*d*) Connect gas collecting bottle to apparatus and open four-way cock to sample connection.

(*e*) Elevate burette leveling bulb to run mercury to sample bottle stopcock, expelling previous sample, then open sample bottle stopcock to withdraw sample.

(*f*) Draw in sample by running mercury down to just above the 8.2 cc. mark, allowing for pressure of sample.

(*g*) Shift four-way cock clockwise so that it is not connected to anything. (All holes in cock are closed.) Lower leveling bulb until both the columns of mercury in the burette and the leveling bulb meet. Hang leveling bulb up and then turn stopcock to carbon dioxide absorbing chamber and read quickly.

(*h*) Run mercury in burette up and down with the leveling bulb about 5 times.

(*i*) Return level of KOH in absorbing chamber tube to the previous mark by adjusting height of mercury in burette. Read burette again.

(j) The carbon-dioxide content in percent of volume is:

$$\frac{\text{Difference between burette reading} \times 100}{\text{First burette reading}}$$

(k) Turn four-way cock clockwise to connect burrette to oxygen absorption chamber. Run level of pyrogallol up and down in chamber twenty times to absorb oxygen.

(l) Return pyrogallol level to original mark on absorption chamber tube, then shift four-way cock counterclockwise to connect burette to carbon dioxide absorption chamber again.

(m) The gas sample is washed in the KOH solution again, then in pyrogallol. Adjust the level of the liquid each time in the absorbing chambers just before shifting the stopcock.

(n) At the conclusion of the second washing with pyrogallol, shift back to the carbon-dioxide absorbing chamber, adjust level of KOH solution, and read burette. Repeat washings until burette scale reading remains constant within 0.04. This is usually the third burette reading.

The oxygen content of the sample in percent of volume is:

$$\frac{\text{Difference between second and last readings} \times 100}{\text{First reading}}$$

(6) Instructions for the operation of the Beckman Model "C" Oxygen Analyzer are as follows:

(a) Use a 50–60 cycle, 115-volt alternating current source.

(b) Allow the instrument to warm up for a minimum of 30 minutes prior to use.

(c) Check the calibration of the instrument prior an analyzing helium-oxygen mixtures by analyzing samples of normal diving air supply. The instrument is calibrated to account for a nitrogen background gas, therefore, no background gas correction is required. Apply necessary barometric pressure correction to determine O_2 percentage; approximately 21% should be the resulting figure.

(d) Use a continuous flow of gas sample between 60 and 250 cc. per minute. *Never exceed a flow of 250 cc. per minute.* A Hoke reducer or oxygen regulator connected by one-eighth inch diameter rubber tubing to the left sample intake works very well. The flow can be estimated by pinching off the end until the gas can barely be heard escaping. For more accurate determinations the Hospital Corpsman can test the flow by measuring into a sample container for one minute or by inserting the tube into a container of water and adjusting the flow until it just barely bubbles out. If too much pressure is used in the flow of sample gas, the calibration will be thrown off and the instrument will require re-calibration by the manufacturer. *Never connect the tubing to the instrument before the gas flow has been regulated.*

(e) Correction equation for barometric pressure and background gas:

$$[\text{Instrument reading in percent} - \text{Correction factor from table}] \times \frac{\text{Normal barometer}}{\text{Actual barometer}} = O_2\%$$

NOTE.—Normal barometer may be expressed as either 760 mm. or 29.92 inches mercury to correspond with calibration of instrument used to measure actual barometric pressure.

Example.—Test O_2 percentage in mixture of HeO_2.

Beckman reading=20.8.

Barometer reading=30.84 inches or 783.08 mm. mercury.

Correction factor from table=.240.

$$(20.8-.240) \times \frac{29.92}{30.84} = O_2\%$$

$$20.56 \times 0.97 = 19.94\%\ O_2$$

The same result would be obtained by using correction for barometric pressure $= \frac{760}{783.08}$

CORRECTION FACTORS FOR HELIUM-OXYGEN MIXTURES

(For instrument readings of 10 to 25 percent)

10 percent=0.272	18 percent=0.248
11 percent= .269	19 percent= .245
12 percent= .266	20 percent= .242
13 percent= .263	21 percent= .239
14 percent= .260	22 percent= .236
15 percent= .257	23 percent= .233
16 percent= .254	24 percent= .230
17 percent= .251	25 percent= .227

(f) Additional information relative to the operation of this instrument may be obtained from the manufacturer's bulletin furnished with each unit.

905. CARE OF TESTING APPARATUS

(1) All carbon dioxide and oxygen must be removed from the Haldane-Henderson apparatus, leaving only inert gas in it. This is done by analyzing at least two samples of atmospheric air, which also checks the accuracy of the set-up. The clearing process and the check analysis must be repeated whenever the apparatus stands unused for any length of time. Keep the lamp turned off except while actually taking reading. The heat from the lamp will cause temperature changes and errors. By careful manipulation and practice, bubbles of gas and drops of liquid can be kept out of the apparatus.

(2) If either of the solutions is run over into the burette, it must be drained out and the burette washed out with a 1 percent solution of sulphuric acid. The length of time required to complete the absorption processes is a measure of the strength of the reagents. When potassium pyrogallol becomes old and thick, it may clog the small tubes in the oxygen absorption chamber, causing errors due to bubbles and slowing the reaction. When a

test on a sample is finished, leave the levels of the liquids in the connecting tubes at their reference marks to save time. The level of KOH in the thermobarometer connection of the KOH reservoir should not vary more than a perceptible extent during a test. It does not matter which lines are chosen as the levels in both chambers. However, both chambers and thermobarometer should be the same level and the solutions must always return to the same levels.

(3) Once a sample has been taken into the apparatus the blue end of the four-way stopcock handle must not be moved through the upper half of its arc until the analysis is finished. Bubble air through water jacket with stirrer every 3 to 5 minutes to keep it at same temperature throughout. Do not agitate water enough to make it splash on burette and thermobarometer tubes. Keep the apparatus and the mercury clean to prevent introduction of errors. When apparatus is to be left unattended for a time, open stopcock on thermobarometer connection to KOH reservoir to avoid having liquids run over. Consult standard reference works and textbooks on analytical chemistry for details of technique.

906. PREPARATION FOR DESCENT

(1) The diver puts on the electrically heated underwear which replaces all of the diver's underwear usually worn. If desired, the diver may protect his head by wearing a leather aviator's helmet buckled securely under his chin with holes cut in the ear flaps to permit him to hear. A standard rubber diving dress in good condition and equipped with gloves is worn. Place the electric plug on the left side of diver's neck. The breastplate nuts must be well set up to avoid any leaks. A full belt and standard shoes are used. Inspect the connections to the helmet to see that they are tight and properly made up. A safety nonreturn valve must be used. See that the aspirator high-pressure nozzle is clear and clean. Screw helmet on the breastplate, open faceplate, attach control valve to breastplate, then stop lifeline and heating cable to right side of breastplate and hose to left side. Connect underwear heating plug and jack on the left side of the diver's face. Test the underwear by turning on the lowest voltage available and noting the ammeter reading. Test the intercom. In temperate waters, the electrically heated underwear is not necessary, and either cuffed or gloved diving dresses may be worn.

(2) Prior to securing the canister to the helmet, it should be checked to insure that it is properly filled and that the screen has been placed in the left (discharge) connection and that a plastic washer is in each connecting nut. Then attach canister to the helmet, setting up on the nuts with a wrench. Next turn on the helium-oxygen supply with a pressure of 100 points per square inch and listen to the sound of aspirator. The diver then opens and closes the control valve to test it and the safety nonreturn valve. As soon as the exhaust valve and faceplate are closed, the diver will be ready to enter the water.

(3) There should be no leaks anywhere in the dress and there must be none at all in the recirculating system, particularly the canister. The entire operation of dressing is done more conveniently with the diver seated on a stool. He should be lowered into the water on a stage because the weight and balance of the dress make it very difficult for the diver to handle himself out of the water.

(4) Prior to descent, it is imperative that the tender knows that the diver's supply lines have been flushed of all other gases by the mixture to be used and that the diver is actually breathing the HeO_2 mixture. This can be detected quite accurately by both the diver and his tender, since a change of voice pitch occurs when breathing helium. This precautionary measure is particularly important when several hundred feet of diving hose are used. In the case of the initial dive of the day, the length of hose will probably contain air. For subsequent dives, the line will contain pure oxygen left over from the previous diver's decompression. A case of oxygen poisoning which occurred recently at 300 feet is on record where this procedure was not followed. It was calculated that the oxygen left in 600 feet of hose from a previous dive momentarily furnished the affected diver with a 40% oxygen mixture when bottom was reached.

907. PROCEDURE DURING DESCENT

(1) During the descent, the diver uses his control valve to keep the dress properly inflated. After he reaches the bottom, the control valve is closed. The recirculating system then replenishes the oxygen and provides the necessary ventilation. The exhaust valve is kept closed, the diver using his chin valve occasionally to regulate his buoyancy. The control valve may be opened if the diver needs a sudden increase of gas in his dress.

(2) When he receives the order "Ventilate," the diver opens his control valve about one-quarter turn and holds the chin valve open. This is done either to renew the atmosphere in the dress completely, or to remove the helium-oxygen mixture from the dress when shifting to pure oxygen during the decompression. The diver may ventilate his dress at intervals on the bottom if he is working hard, or if he is not satisfied with the adequacy of the recirculating system.

(3) At the order "Circulate," the diver closes his control valve and releases the chin valve, permitting the recirculating system to supply him.

(4) The order "Go on open circuit" means to open both the control valve and the exhaust valve, operating the dress in the same way that the conventional compressed-air dress is used. This must be done if the recirculating system fails. If the diver

notices from the sound of the aspirator jet that the circulating system is not working, he should shift at once to "open circuit," reporting his action via intercom and by signal.

908. CONVERSATION IN HELIUM ATMOSPHERE

The acoustical properties of diver's intercommunication have generally been poor. When diving with helium-oxygen, the density of the mixture being different from air, a peculiar quality is imparted to the sound of the voice. It is almost impossible to understand the diver. Experimental types of intercom with tonal control built into the amplifier have given better results. With experience, men learn to adapt their voices somewhat to the helium atmosphere. It is an excellent practice for the diver to speak over the intercom about once a minute during the dive. A continuous description of the conditions he encounters and a report of what he is doing will give him something to talk about and may be extremely useful information.

909. HAND SIGNALS

The following special hand signals with lifeline and air hose seized together are recommended for use in case the telephone fails:

1–2 pulls—Reduce current to underwear.
1–3 pulls—Increase current to underwear.
3–2 pulls—"Ventilate" or "Go on open circuit."
4–3 pulls—"Circulate."

When made by the diver, these signals indicate that the diver is carrying out the operation indicated.

910. PROCEDURE DURING ASCENT

(1) During the diver's ascent, the speed of ascent to the first stop and the time spent at the subsequent stops, breathing helium-oxygen mixture or oxygen, are specified in the decompression tables. These must be rigidly adhered to in order to prevent the occurrence of bends.

(2) Undressing is done most easily with the diver seated on a stool. Open the faceplate, remove the canister, unfasten lifeline, air hose, and control valve from breastplate. Disconnect underwear cable plug from helmet and remove helmet. Proceed with undressing in same manner as with compressed air outfit.

D. MEDICAL ASPECTS AND DECOMPRESSION PROCEDURES OF DIVING WITH HELIUM-OXYGEN MIXTURES

921. EARLY EXPERIMENTS IN HELIUM DIVING

The use of an artificial atmosphere composed of helium and oxygen mixtures was first proposed about 1921. But it was not until 1924 that serious studies were undertaken by the U. S. Navy. Some of the ideas regarding the use of helium in diving as a substitute for the nitrogen of normal air were found, on application by early investigators, to be misleading and resulted in very discouraging results. Subsequently much experimental work went into the formulation of the present technique of helium-oxygen diving.

922. EFFECT OF HELIUM UPON THE BODY

In order to understand why such a complicated technique as helium diving is used in place of the simpler "air" diving, the physiological effects of this gas upon the body while under increased pressure must be known. The most pronounced subjective symptom occurring during a normal dive while breathing air at any considerable depth is the mental confusion and muscular incoordination that the diver experiences as he descends. Essentially, greater effort on the part of the diver is necessary to perform useful work on the bottom. This narcosis or alcoholic-like intoxication is caused most probably by the abundant amount of nitrogen and slight amount of argon present in atmospheric air. If these gases are replaced by helium, as in a helium-oxygen mixture, the adverse effects of air under pressure are abolished or rendered negligible, and an ideal atmosphere is created which is compatible with efficient work and mental clearance at depths up to 565 feet. Breathing air at such a pressure would produce unconsciousness. By contrast, when argon is substituted for atmospheric nitrogen, the inhaled mixture at high pressures elicits symptoms similar in type but even more intense than those produced by compressed air. The elementary gases of the normal atmosphere which are innocuous at normal pressures are, therefore, capable of rendering an individual completely helpless in a high-pressure atmosphere.

The explanation of the action of nitrogen and argon is to be sought in some physical property since argon, like helium, is chemically inert and is incapable of entering into any stable chemical combination. Of the obvious physical properties, their solubility in oil or fat and molecular weight may be the important factors. These have been discussed in Parts 2 and 4.

923. DECOMPRESSION WITH HELIUM-OXYGEN MIXTURES

The characteristics of decompression with helium-oxygen mixtures are different from those of air. With the former a larger volume of gas is concentrated in the faster saturating parts of the body, and the rapid diffusion of gas from one part of the body to another on reduction of pressure requires the keeping of the body at high pressures for a longer time during the primary period of decompression. Also, the normal procedure for decompression after a helium-oxygen dive is to have the diver breathe pure oxygen beginning at the 50-foot stop. Since pure oxygen should not be used at depths greater than 50 feet, the decompression must be made on helium-oxygen mixtures up to that point. In case of necessity, however, the diver can be decompressed on helium-oxygen mixture throughout, or shifted to compressed air, subject to a separate and distinct procedure for use in these two cases. In shifting to compressed air, it has been found that the human body cannot stand a direct change from helium to nitrogen at depths beyond 6 atmospheres' pressure without discomfort unless the air is supplied gradually at an increase in volume of about 3 percent per minute. In actual practice, gradual shift from helium to air is accomplished through use of the recirculation system for 20 minutes of decompression time. The helium-oxygen decompression tables which follow are accordingly different from those used for ordinary compressed-air diving. The tables are somewhat complicated but at this time further simplification has been impracticable due to the many factors and conditions affecting the decompression.

924. OXYGEN CONCENTRATIONS TO BE USED

The maximum tension of oxygen that may be used is 2.3 atmospheres effective. The maximum percentage for any given dive may be obtained from the following formula:

$$\text{Maximum \% } O_2 = \frac{(2.3\times 33)}{(D\ \text{gage}+33)}$$

The minimum oxygen to be used with partial pressures to and including 410 feet is 16 percent. This limitation is necessary as decompression table stops are computed for a 16 percent oxygen content. During decompression, the diver can be shifted to a low pressure bank on the manifold without regard to its oxygen content. Considerable saving of gas is effected. The partial pressure table does not change, as it is based on depth and percentage of oxygen while on the bottom.

925. USE OF HELIUM-OXYGEN DECOMPRESSION TABLES

Helium-oxygen decompression tables differ from the air tables in the following major respects:

1. The partial pressure of the inert gas and not the depth of the dive determine the particular table to be used.
2. The rate of ascent from the bottom to the first stop is given in the particular table used.
3. The rate of ascent from stops subsequent to the first is determined from table I.
4. The time of ascent from one stop to the next is included in the time of the subsequent stop.

The procedure for using helium-oxygen decompression tables is as follows:

Procedure

(1) Determination of depth:

Assume a depth of 300 feet. This is most accurately measured by means of an air supply, a depth gage, and a length of oxygen hose. The hose is attached to a weighted line and lowered to the bottom. Air is blown through the oxygen hose until it escapes from the open end. The air is then secured and the air pressure remaining in the hose is read on the depth gage. This value gives the depth to the accuracy of the gage calibration. It is recommended that a similar hose be made up with the diver's life line and air hose in order that the depth of the diver may be determined with accuracy during the phase of the dive. Depth readings by fathometer, lead line, stage line, and descending line are subject to large and varying errors. See article 836 also.

(2) Oxygen percentage to be used:

Determine the maximum percentage of oxygen permissible by the formula given in 924:

$$\text{Max. } O_2 = \frac{2.3\times 33}{300+33} = \frac{76}{333} = 22.8\%$$

Load the helium-oxygen manifold, observing the provisions of 903 (3).

(3) Selection of decompression table:

Determine the partial pressure of all other gases (*AOG*), except oxygen for the depth of the dive. Assume that the bank to be used averages 21.6 percent oxygen.

$$PP \text{ of } AOG = (D+33)\times 100-(O_2\% - 2)\ \%$$

A loss of 2 percent oxygen in the helmet is assumed.

Thus, for a depth of 300 feet and an average of 21.6 percent oxygen in the bank, the partial pressure will be:

$$\begin{aligned} PP\ AOG &= (300+33)\times 100-(21.6-2)\ \% \\ &= 333\times(100-19.6)\ \% \\ &= 333\times 80.4 \\ &= 267.7 \end{aligned}$$

As no interpolation of the decompression tables is permitted, use the next higher tabulated decompression table, which is for a *PP* of 270. Table II gives the *PP* of *AOG* for various depths and for various percentages of oxygen. To use, enter the table with the depth by gage and the average oxygen percentage of the bank to be used. By interpolating both arguments, the *PP* of *AOG* may be determined.

(4) The descent:

When the diver is dressed with the faceplate closed and the hoke valve open, have him start counting and ventilating in order to flush the air hose and helmet. The characteristic voice change will show when the diver is on helium-oxygen. The diver is then hoisted over the rail and lowered in the water while on the stage. A careful visual check of the helmet and suit is made for leaks. When satisfied that conditions are normal, the diver gets on the descending line and is started down. The rate of descent should not exceed 65 feet per minute. Frequent short ventilation should be made during descent upon reaching bottom. The frequency of ventilation while on the bottom depends upon the conditions of work and currents.

(5) The ascent:

(*a*) The time of dive is the total time from leaving the surface to leaving the bottom. Assume 9 minutes as time of dive. The correct decompression schedule (table III) is Partial Pressure 270, time of dive 10 minutes.

(*b*) The first stop:

The rate of ascent from bottom to first stop is determined as follows: Time to first stop—4 minutes (from Decompression Table, Partial Pressure 270) first stop—110 feet (from Decompression Table) Distance to first stop equals depth of dive minus depth of first stop, or 300 minus 110, or 190 feet; 190 divided by 4 equals 47.5 feet per minute.
Bring the diver up to 110 feet at the uniform rate of about 50 feet per minute, and keep him at the first stop for 7 minutes. During decompression, beginning at depths of about 120 feet, the pressure of the diver's gas supply may be reduced to 50 pounds over bottom pressure. Adequate high pressure jet flow and recirculation are maintained, and the noise level of the jet operation is greatly reduced. This results in greater comfort for the diver and in better intercom communication.

(*c*) The second stop:

The second stop, at 70 feet, is for 3 minutes with a note "Take 1 extra minute from first stop to next stop." This means to add 1 minute to the second stop. Mathematically, 3 minutes at 70 feet is sufficient time to reduce the quantity of inert gas in the controlling tissue to a 1.7-to-1 ratio. However, with a helium-oxygen mixture of low oxygen content, over 3 minutes are required for the ascent from 110 to 70 feet without exceeding the rate of ascent given in table 1. The rate of ascent from the first stop to the second as determined from table 1 is as follows:

From	Distance	Rate of ascent (interpolating)	Time
			Minutes
110–100	10	44	0.2
100–70	30	34	.88
Sum			1.08

Use 1 minute for the ascent. Keep the diver at 70 feet for 3 minutes.

(*d*) The third stop:

Four minutes from the time of leaving 110 feet, the first stop, proceed to 60 feet, the third stop. From Table I, the rate of ascent is 34 feet per minute. Bring the diver to 60 feet in about half a minute.

(*e*) The fourth stop:

Four minutes from the time of leaving the 70-foot stop, bring the diver to 50 feet. Shift the diver's gas supply to oxygen on the manifold. Ventilate the diver with 25 cubic feet of oxygen, and then have him circulate for the remaining time of the stop. The total time of the 50-foot stop is the sum of the individual times of the following three distinct times:

1. Time of ascent from previous stop.
2. Time of ventilating the diver with 25 cubic feet of oxygen.
3. Time of circulating on oxygen.

Do not exceed the time as given in the decompression tables. In the computation of this stop, 3 minutes are allowed for the time of ascent and the time of ventilation.

(*f*) The fifth stop:

Ten minutes from the time of leaving the 60-foot stop, bring the diver to 40 feet.

(*g*) Surfacing:

Forty minutes from the time of leaving the 50-foot stop, the decompression is complete. Surface the diver at a rate of about 50 feet per minute.

Be familiar with the safety precautions as summarized in part 7, and be ready to take prompt action in the event of oxygen poisoning.

TABLE I.—RATE OF ASCENT IN FEET PER MINUTE

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.

TABLE II.—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% O2.
20														*ND to 100% O2.
30														*ND to 100% O2.
40	65	64	62	61	59	58	56							*ND to 100% O2.
50	74	72	71	69	67	66	64	60	56					*ND to 100% O2.
60	83	81	79	77	75	73	72	67	62	58	53			*ND to 90% O2.
70	92	90	88	85	83	81	79	74	69	64	59	54		*ND to 80% O2.
80	101	98	96	94	92	89	87	81	76	70	64	59	53	*ND to 73% O2.
90	109	107	105	102	100	97	95	89	82	76	70	64	58	*ND to 67% O2.
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												
405	510	499												
550	519	507												
560	528	516												
570	537	525												
580	546													
590	554													
600	563													

*(ND)—No Decompression.

Table III.—DECOMPRESSION TABLES

PARTIAL PRESSURE 60

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	4	0	4	80	2	6	8
20	4	0	4	100	2	7	9
30	4	0	4	120	2	9	11
40	4	0	4	240	2	13	15
60	4	0	4				

PARTIAL PRESSURE 70

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	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

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

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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

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

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

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: 80	70	60	50	40	Total time	Time of dive	To first stop	Feet and minutes: 80	70	60	50	40	Total time
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

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: 90	80	70	60	50	40	Total time	Time of dive	To first stop	Feet and minutes: 90	80	70	60	50	40	Total time
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

PARTIAL PRESSURE 210

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: 100	90	80	70	60	50	40	Total time
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

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.

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.

PARTIAL PRESSURE 330

*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.

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	4	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 210	200	190	180	170	160	150	140	130	120	110	100	90	80	70	60	50	40	Total Time
*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.

PARTIAL PRESSURE 410

*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.

926. EMERGENCY TABLE FOR USE OF HELIUM-OXYGEN ONLY FOR DECOMPRESSION

In an emergency it may be that oxygen cannot be used for decompression, owing to failure of oxygen supply, or to symptoms of oxygen poisoning. Either air or helium-oxygen mixtures may be used. In order to have a table that may be available immediately, the decompression provided in regular tables should be given up to the first oxygen stop, and from that point on, using HeO_2 for decompression, table IV should be used.

TABLE IV

50 feet	40 feet	30 feet	20 feet	10 feet
Minutes 26	*Minutes* 30	*Minutes* 35	*Minutes* 42	*Minutes* 44

927. EMERGENCY USE OF AIR FOR DECOMPRESSION

In emergencies when it is not possible to use helium-oxygen mixtures or oxygen during decompression, it is necessary to use air. Decompression for each case can be calculated. 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. Therefore, a table (table V) for maximum saturation is provided and this table may be used for any emergency. When it is possible to do so, the air should be administered or furnished through the recirculator for the first twenty minutes of these tables. Otherwise the diver may experience uncomfortable symptoms, dizziness, weakness, loss of consciousness, etc., as a result of a sudden shift to air. The schedules given in table V are provided for each 50 feet, and the table selected should be one next deeper than the actual depth, unless the depth is at an even 50-foot figure.

TABLE V

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

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928. SURFACE DECOMPRESSION PROCEDURE

(1) Surface decompression following helium-oxygen dives was used during the SQUALUS salvage operations, and has been successful following exposures of one hour at 250 feet, 20 minutes at 300 feet, and 10 minutes at 350 feet, 440 feet, 485 feet, and 500 feet.

(2) 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

(3) 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

929. PROCEDURE FOR BLOW-UP

In event of a blow-up, the emergency procedures outlined in Part 8 for blow-ups from air dives should be followed, the exception being the substitution of the helium decompression tables in lieu of the standard air decompression tables. The treatment tables outlined in part 5–C are equally as effective for helium bends or helium embolism as they are for air bends or air embolism.

Part 7—Summary of Safety Precautions

941. DIVER MUST BE QUALIFIED

(1) Don't put a man down who is not a qualified diver.

(2) Don't put a diver down whose qualification has lapsed except in case of an emergency or to requalify under adequate supervision.

(3) Don't exceed depth to which diver is qualified.

(4) Do not send a diver down who has been physically disqualified.

(5) Don't dive a man until he has been given the physical examination outlined in the manual of the Medical Department.

(6) Don't dive a man unless he is schooled properly in operating the type of diving outfit he is to wear.

(7) Don't dive a man if he does not know the diving hand signals.

(8) Don't dive a man if he has consumed excessive alcohol in the preceding 24 hours.

(9) Don't dive a man if he is suffering from a severe cold, sinus, or ear trouble or an acute illness.

(10) Don't dive a man who is subject to fatigue from loss of sleep or previous severe physical or emotional strain.

942. DIVING EQUIPMENT

(1) All equipment must be in first-class operating condition.

(2) The control, nonreturn, and regulating escape valves should be inspected frequently and must operate satisfactorily at all times.

(3) The leather items should be checked and oiled to prevent deterioration.

(4) The helmet fittings—safety lock, windows, goosenecks, air passages, gaskets—should be securely in place and free from all obstructions or verdigris.

(5) The diver's air compressor must be properly lubricated, cooled, and cleaned, both during use and stowage. If the compressor is not used, it should be broken out every 30 days and operated, and again prepared for stowage.

(6) The recompression chamber must be ready for use at all times.

(7) All inflammable material possible should be removed from the chamber.

(8) Only fire-retarding paint should be used in the chamber.

(9) No open flames, matches, cigarette lighters,

lighted cigarettes or pipes shall be taken in or used in the chamber during its use.

(10) Open the heater and fan disconnect switch located outside the recompression chamber before using oxygen. Close the switch only after the doors are open and the chamber has been well ventilated.

(11) Decompression tables and treatment tables should be located on the inside and outside of the chamber.

943. PLANNING DIVING OPERATIONS

(1) Do not start any diving operations without an officer qualified in diving being present. If such an officer is not available, a qualified diver should be placed in charge.

(2) Do not send a diver down without having immediately available the means of sending down a relief diver and being able to maintain both divers on the bottom for a reasonable length of time.

(3) Don't rely on charts or hearsay as to depth of water when diving, but have a qualified man take soundings with a lead line. If an area is being searched, soundings should be repeated from time to time.

(4) Don't undertake diving operations without having a decompression table on hand. If decompression is contemplated, a stage should be rigged and stage line marked at 10-foot intervals.

(5) In all cases where diving operations are to be undertaken, the depth of water and fatigue of the diver should determine the diver's time on bottom instead of the amount of work to be done.

(6) A diver should never be allowed to descend without first determining his decompression time for his expected time on bottom.

(7) Foresight used in the sound planning of a diving or salvage operation is half the job. Emphasis is often laid on the emergency of the job resulting in men and equipment arriving at the scene of operation unprepared.

(8) Too often inexperienced diving supervisors, impelled with the urge to do something, put a diver over on that long chance he will stumble over the object. Exhaust your means of search with all available equipment before you exhaust your divers and their patience. Again, planning is paramount if systematic locating operations are to be undertaken from the surface, but in most cases it is easier, quicker, and more accurate than the diver with his circling line.

(9) No diving locker is considered complete without equipment for performance of the following in a manner commensurate with the capacity of the men available:

(*a*) Location and search equipment adequate to search a given area properly, including buoys and anchors for marking such areas.

(*b*) Adequate and safe diving equipment for two divers.

(10) Don't send a diver down unless he thoroughly understands what he has to do when on the bottom. This is important. Use sketches, blueprints, or a sister ship of the sunken vessel if available. If the diver does not fully understand his task, it is useless to send him down.

(11) Don't dive over 120 feet from a diving launch unless there is a stand-by boat with an extra air supply near by.

(12) Don't put a diver down unless the boat or ship is in at least a two-point moor.

(13) Don't send a diver down unless Baker flag is flying.

(14) Never attempt to shift moor while a diver is down.

(15) Never turn the propeller or get under way while a diver is down.

(16) Never send a diver down on the propeller of a ship without first informing the duty engineer and receiving acknowledgment.

(17) Never send a diver down around the hull of a submarine until the duty officer has been notified not to operate bow planes, stern planes, sound heads, or propellers.

(18) Never set off an explosive charge with a diver down.

(19) Never let a diver work around corners or inside a wreck without the help of another diver to tend his lines from the point of entry.

(20) A diver should never cut a line until he has made certain of the purpose for which it is being used.

944. DRESSING THE DRIVER

(1) Don't dive without a safety nonreturn valve on helmet or mask; always check this valve for proper working order.

(2) Don't dive with a helmet without first checking the safety non-blow-up type exhaust valve.

(3) Don't dive with a hand pump without knowing its efficiency or without overhauling it if the efficiency has dropped too low.

(4) Do not attempt any diving operations if the compressor is not operating satisfactorily or gives any indication that it will not continue to operate satisfactorily.

(5) Never connect a diver's air hose directly to the delivery nozzle of a diving compressor or diving pump; an oil separator and volume tank are required.

(6) Don't dive without first checking jock strap for possible breakage.

(7) In diving operations where the helmet is put on and taken off at the ship's side, always secure the diver with a life line.

945. THE DESCENT

(1) Don't allow a diver to descend without first making these final checks:

(*a*) The helmet is tightened securely and the helmet lock is locked in place.

(*b*) The air hose and life line are securely tied to the breastplate.

(*c*) The exhaust valve is set.

(*d*) The control valve is opened and air is passing through the suit.

(*e*) The diver makes a sound test of the nonreturn valve seating.

(*f*) Telephone communications are in good order.

(*g*) The jock strap is tightened properly.

(*h*) The faceplate is securely closed.

(*i*) The diver has a ready, pure, and adequate supply of air at the proper overbottom pressure, and that this pressure is maintained.

(*j*) The descending line is properly placed.

(*k*) Finally, that the diver gives his signal to descend.

(2) In going down, never get ahead of your air supply. To do so may result in serious injury.

946. WORKING ON THE BOTTOM

(1) In order to work efficiently and safely under water, a diver must keep in mind the following:

(*a*) Never completely close the air-control valve, except in case of rupture or replacement of air hose.

(*b*) The helmet air-regulating exhaust valve stem, known as the chin valve, may be used effectively to release quickly the suit pressure when desiring to stoop or crawl on the bottom without changing the air-control valve and the air-regulating exhaust valve adjustment.

(*c*) The helmet spitcock offers another method of relieving excess pressure in the helmet.

(*d*) The safety nonreturn valve in the helmet gooseneck and the helmet air-regulating exhaust valve will seat themselves if the diver's air supply is impaired, but the spitcock, if open, must be closed immediately by hand.

(*e*) A diver is never in danger from a leaking dress provided he remains in an upright position.

(*f*) Air trapped in the diving helmet will last from 6 to 9 minutes for breathing purposes after the diving air is cut off, thus providing ample time for emergency measures to be executed provided the diver does not get excited.

(2) Never leave a diver on the bottom in sudden squalls, heavy seas, strong tides, or any other conditions which, in the opinion of the commanding officer, jeopardize the security of the moorings.

(3) Don't burn or weld under water with electricity without gloves.

(4) Don't weld or burn under water with alternating current where direct current is available. See Manual for Underwater Welding (NavShips 250–692–3) and Summary of Recent Advances in Underwater Cutting (NavShips 250–692–4) for full information.

(5) Don't weld or burn under water without a complete suit.

(6) When working about moorings, or wreckage, a diver should be especially careful not to get fouled. He should not dip under chains or lines. He should, if possible, always go over obstacles instead of under them. This is especially important in case of a blow-up. A diver should not descend on a chain or wire if it is possible to do otherwise, and neither should a chain, wire, line, or weight be veered, lifted, or moved until the diver has been brought up.

(7) Whenever a diver discovers that he is fouled, he should not get excited but should attempt to extricate himself by slow methodical steps. The distance line should never be released, as it is a safe guide and should show the way out of a tangle. He should inform the surface crew to take up slowly the slack in his air hose and life line. After resting and again attempting unsuccessfully to free himself, he should ask for help.

(8) In case a diver is fouled and cannot extricate himself, a relief diver who is sent down must be prepared to replace both air hose and life line—a procedure that may be safely executed on the bottom.

(9) When a diver is working on the bottom of a ship, he should never run the risk of falling off, but should always have something substantial to hold on to, and have the tenders keep the life line and air hose well in hand. It is dangerous for a diver to hold on to something overhead and climb around in that manner; all the air in the dress may escape out of the cuffs or through leaks in a torn glove, in which case he may become so heavy that it will precipitate a fall. He should never go under the keel of a ship and up the other side. If it is necessary to work on the other side, he should ask to have the diving boat shifted.

947. TENDING THE DIVER

(1) Never allow a dressed diver to walk on topside, unattended.

(2) Never let a man who does not know his signals tend a diver.

(3) When a diver is going down a ladder, the tender must keep both hands on life line and air hose, and be backed up by another man.

(4) Do not allow air hose and life line to run free when diver is descending.

(5) Do not give diver too much slack while he is on the bottom. To do so increases the chances of fouling.

(6) Do not try to send hand signals to diver without first taking up all the slack.

(7) Do not give signals with long heavy jerks; diver may be hurt in doing so. Signals are to be short and distinct pulls. Never belay a diver's life line and air hose to a cleat or a stanchion.

(8) Never give a diver too much slack where there is any danger of a fall; keep a tight hold on the diver's lines and do not give out any more slack than necessary.

(9) "Fish" diver occasionally taking in all slack easily and paying out as before. This is a good way of telling if the diver has shifted his position. An expert tender can do this without the diver's knowledge.

(10) In case a diver is blowing up, the tender should take in his slack as fast as he ascends and haul him in upon reaching the surface. A check of diver and equipment must be made before descending again.

(11) A good tender can help a diver considerably. A poor one is a menace.

(12) Don't use a man as a tender who does not understand the dangers of a squeeze or blow-up and what to do under the circumstances.

(13) The tender should be continuously on the alert. Don't stand where there is a chance of the tender being pulled into the water. When the diver is going down or coming up, make sure the tender is backed up by someone.

948. MASK DIVING

(1) Don't duck the mask while on the bottom except in an emergency, and then remember to exhale continuously while ascending.

(2) In shallow water diving, don't send a man down who is not a qualified diver and a first-class swimmer.

(3) Don't put shoes or any extra weight on a diver while using a mask or helmet alone for diving.

(4) Don't dive without a lifeline attached around the diver's waist. This line must be securely fastened above the belt.

(5) Don't exceed depth limits as set forth in current instructions when using shallow water diving equipment, i. e., helmet diving, mask, lightweight suits, pumps, and compressors intended to be used with this equipment.

(6) In helmet and mask diving, i. e., "skin" diving, the diver must be able to rid himself instantly of all equipment except his lifeline in case it becomes necessary to swim to the surface. Only a belt with a quick release shall be used.

(7) It is well to remember that mask, helmet, and "soft" suit diving can, because of its simplicity, become the most dangerous type of diving if not properly supervised.

949. MEDICAL ASPECTS OF DIVING

(1) The rate of ascent for air diving shall not exceed 25 feet per minute. Decompression shall be strictly in accordance with the decompression tables.

(2) The compressed air illness treatment tables shall be strictly adhered to. There shall be no deviation from the tables for reasons of convenience or to save time where time is not of a vital nature.

950. HELIUM-OXYGEN DIVING

(1) The safety precautions covering procedures, equipment, methods of working on the bottom, etc., when using standard equipment applies to helium-oxygen diving.

(2) Do not undertake diving operations until a sufficient quantity of gas has been prepared, and has been checked to determine that it is of proper composition.

(3) Make certain that the aspirator and canister are functioning properly.

(4) Maintain 100 pounds gas supply pressure over bottom pressure.

(5) If the diver while on the bottom develops symptoms of inadequate ventilation, there should be no hesitation on his part to by-pass the venturi supply by periodically opening his control valve as conditions warrant. To compensate for this excess supply, the chin button will have to be used more frequently to prevent blow-up. Upon reaching the surface an investigation for the cause of the inadequate ventilation should be immediately undertaken.

(6) While breathing oxygen at the 50- and 40-foot stops, the diver must keep any form of exertion or exercise to an absolute minimum since increased activity increases susceptibility to oxygen toxicity.

(7) Prior to putting the diver down, ventilate the hose to insure that the diver is actually breathing a helium-oxygen mixture. The change in tone of the diver's voice as he begins to breathe helium is distinct and easily recognized.

(8) Divers must be alert to recognize the symptoms of oxygen poisoning while at the oxygen stop. At the first indication of trouble, notify topside and stand by to ventilate. The diving supervisor should immediately order the manifold to shift to air or helium-oxygen and the diver to ventilate. The symptoms of oxygen poisoning include nausea, twitching of muscles, ringing of ears, visual disturbances, and dizziness.

Part 8—Diving Accidents

961. TYPES OF DIVING ACCIDENTS

(1) Accidents which may occur during diving operations are listed alphabetically as follows:

(*a*) Air embolism.
(*b*) Asphyxia (carbon dioxide poisoning).
(*c*) Bleeding from the nose and lungs.
(*d*) Blowing up.
(*e*) Compressed-air illness (caisson disease).
(*f*) Drowning.
(*g*) Ear pains (bleeding from ears).
(*h*) Exhaustion.
(*i*) Fouling.
(*j*) Mechanical injuries from external violence.
(*k*) Oxygen poisoning.
(*l*) Spontaneous pneumothorax.
(*m*) Squeeze.

(2) In the treatment of accidents occurring in deep water, it must be remembered that, while the diver can be brought up immediately to the first stop or stage of decompression, he cannot be brought immediately to the surface without danger of serious compressed-air illness unless a recompres-

sion chamber is available or the diver can be sent down again in his suit; in addition, the depth and exposure times must not be greater than those prescribed as safe for Surface Decompression (see Part 5) except in extreme emergencies.

962. AIR EMBOLISM

(1) Air embolism refers to the entrance of air bubbles into the left side of the heart and arterial circulation as a result of air being forced into the small blood vessels of the lungs. The detailed discussion of air embolism has been covered in Part 5.

(2) *Prevention.*—(*a*) Avoid ascent to the surface at a rate in excess of the prescribed rate.

(*b*) Never "hold the breath" during ascent.

(3) *Treatment.*—Air embolism is considered as a serious case and should be treated according to the treatment table outlined in part 5. All cases of air embolism will fall under table 3 for treatment.

(4) *Case history.*—(*a*) Lt. ____________________ on 10–2–33 was making a 100-foot ascent during submarine escape training using a submarine escape "lung." The mouthpiece of the apparatus slipped out of his mouth at 30 feet below the surface, making it necessary for him to ascend without the use of the "lung." He exhaled some before surfacing, climbed from the tank, and stood by the railing. His nose was bleeding slightly and there was questionable bloody froth coming from his mouth. Because of his balance becoming unsteady, he was immediately put into the recompression chamber. During the period of time elapsed in doing so, his legs and arms became rigid, his speech became thick and mushy, and he began to lose consciousness.

(*b*) *Treatment.*—Recompression—

20 p. s. i. gage (45 ft.) patient became fully conscious with normal speech.

30 p. s. i. gage (67 ft.) rigidity of arms disappeared. Still complained of numbness and inability to move legs which were being massaged.

40 p. s. i. gage (90 ft.) able to move his left leg, and as massage continued the movements and skin sensations of both legs improved.

After 10 minutes at 40 p. s. i. the feeling of pins and needles, numbness and coldness disappeared and his sensations became normal.

Decompression—A short decompression schedule was given as follows:

20 p. s. i. (45 ft.) 2 minutes.
15 p. s. i. (34 ft.) 5 minutes.
10 p. s. i. (23 ft.) 8 minutes.
5 p. s. i. (12 ft.) 10 minutes.

(*c*) *Recurrence of symptoms.*—Approximately 2 hours later while walking back to duty, he again fell to the ground unconscious and became rigid, while frothing at the mouth and biting his tongue. His respirations stopped and he became cyanotic (bluish).

(*d*) *Treatment.*—Artificial respiration was begun immediately and he was recompressed.

Recompression.—

66 p. s. i. (148 ft.): Normal respirations returned but his rigidness remained and his head and eyes were turned to the left.

77 p. s. i. (175 ft.) for 10 minutes during which time patient revived and spoke in a weak voice.

Decompression.—A relatively short decompression schedule was again given as follows:

75 p. s. i. (171 ft.) 2 minutes.
22 p. s. i. (50 ft.) 5 minutes.
18 p. s. i. (40 ft.) 6 minutes.
13½ p. s. i. (30 ft.) 15 minutes.
9 p. s. i. (20 ft.) 20 minutes.
4½ p. s. i. (10 ft.) 30 minutes.

During this decompression he became alert and his muscle rigidity disappeared. He complained of abdominal pain which was relieved at 20 feet by vomiting copiously which included expelling a large bubble of air. Recovery was uneventful except for a headache which persisted 12 hours.

Comment.—A major error was made in the treatment of this case in that recompression was not initially applied to an equivalent depth of 165 feet. The inadequacy of a short decompression schedule is clearly demonstrated.

(5) *Case history.*—Flc __________ on 11–29–44 was qualifying for pressure in a chamber and with the usual method of clearing his ears reached 50 p. s. i. without difficulty. During decompression he believed he held his breath a short time. Upon reaching 5 p. s. i. pressure he complained of dizziness, disturbance of vision, and immediately became nauseated and vomited. The pressure was held at 5 p. s. i. for 5 minutes, then reduced to surface pressure. Upon reaching the surface and attempting to get out of the chamber this man again vomited and fell over unconscious. A medical officer immediately examined him and noted his shallow rapid respirations, flexed and rigid left arm, and paralyzed legs and right arm.

(*a*) *Treatment.*—Recompression.—

20 p. s. i. gage (45 ft.). He was able to move his head and left arm.

20–40 p. s. i. gage (45 to 90 ft.). He became conscious but still was unable to move his right arm or legs.

60 p. s. i. (135 ft.). He could move his feet and right hand. He vomited twice and expectorated a small amount of blood-streaked sputum.

73.4 p. s. i. (165 ft.) for 30 minutes during which time he regained motion of legs and right arm but had residual weakness.

Decompression.—Accomplished according to 165 ft. treatment table breathing oxygen for a 90-minute period, from the 60-foot to 40-foot levels and then to the surface within 5 minutes. Recovery was uneventful except for findings of minor nerve injury.

(b). *Comment.*—The effectiveness of immediate recompression to 165 feet is shown in this case history. The administration of oxygen under pressure in the treatment of air embolism is not advised because of its irritating effect upon lung tissue which has already been previously damaged in the original accident.

963. ASPHYXIA (CARBON DIOXIDE POISONING)

(1) Asphyxia or suffocation of the diver may be caused by one or more of the following conditions:

(a) Increase of carbon dioxide or carbon monoxide.

(b) Insufficient respiratory movement of the diver's chest and lungs due to underinflation of his suit or "squeeze."

(c) Deficiency of oxygen.

(2) Carbon dioxide (CO_2) and carbon monoxide (CO), from oil flashing in the compressor or pump cylinders, rarely will be encountered, especially if precaution is observed in using good oil of a high flashing point for lubrication. Carbon monoxide may contaminate the diver's air supply from a gasoline-driven compressor if the exhaust fumes of the compressor enter into the diver's air intake manifold. Excess of carbon dioxide in the diver's air is usually caused, however, by inadequate ventilation of the helmet. In helium-oxygen diving, where the gas in the helmet is recirculated through a canister containing absorbent for the purpose of removing the CO_2 produced by the diver, improper functioning of the aspirator, canister, or absorbent will allow an accumulation of this gas in toxic concentrations. When diving on air, this may occur while the diver is attempting to keep himself "heavy" on the bottom by cutting down on his air supply, or when he is not ventilating enough while engaged in heavy work. Such an excess of CO_2 is readily recognized by fogging or sweating of the faceplate and by the subjective symptoms of shortness of breath, sweating, headache, fatigue, and a general feeling of discomfort. These symptoms occur before consciousness is lost, and death does not follow for some time.

(3 Asphyxia may be caused by the squeeze accompanying the improper inflation of the diving dress. Except in case of an accident, this occurs only to inexperienced or careless divers who do not use a sufficient amount of air to prevent the dress from squeezing their chests, thereby preventing adequate chest movement for proper breathing. Divers should learn to remedy this fault long before they are allowed to dive to any appreciable depth.

(4) Oxygen deficiency, also known as anoxia, will seldom occur unless there is a complete stoppage of the air supply caused by a failure of the pump or a break in the air line. Anoxia seldom evidences itself by warning symptoms before unconsciousness occurs.

(5) A diver suffering from asphyxia usually presents the following signs:

(a) Respiration entirely absent or only as an occasional gasp.

(b) Muscles either limp or rigidly contracted.

(c) Face blue or deep red.

(d) Eyes, as a rule, bloodshot.

(e) Rapid or irregular pulse or both.

(f) Body cold and clammy.

(g) Unconscious or semiconscious.

(h) Following asphyxia the patient usually complains of headache and fatigue.

(6) *Prevention*—(a) With an inadequate or bad air supply a diver should immediately stop his work, restrict his movements to a minimum, inflate his suit, and prepare to ascend.

(b) The diver should keep his dress sufficiently inflated to allow free respiratory movement of his chest.

(c) When exercising or working hard, a diver should increase the circulation of air through his helmet by opening his air-control valve and adjusting his exhaust valve.

(d) The tender should be able to detect inadequate ventilation by the decrease in the number of bubbles coming to the surface, and by the decreased audibility, over the telephone, of the diver's air escaping through the air-regulating exhaust valve.

(e) Special consideration should be given to the possibility of the diver being in distress from asphyxia if he ceases to answer his telephone or send signals after calling for more air.

(7) *Treatment.*—If asphyxia is suspected by the tender, the diver should be started immediately toward the surface. If the depth and time of exposure are not greater than those limits prescribed for Surface Decompression (Part 5), he may be brought directly to the surface (at a rate not in excess of 25 feet per minute) and placed in the recompression chamber. If not within such limits, the diver should be brought to the first stop governing stage decompression for the depth of the dive and further attempts made to communicate with him. If there is still no response, the diver should then be brought to the surface (at a rate not in excess of 25 feet per minute) regardless of the depth and time of exposure, placed in the recompression chamber, recompressed immediately, and then decompressed. In mild cases of asphyxia this is all that is necessary but in cases where unconsciousness and lack of spontaneous breathing occur, artificial respiration (see drowning) must be resorted to. Such treatment should be carried out in the recompression chamber during recompression and decompression. It must be remembered that the main treatment of asphyxia is the restoration of an adequate supply of fresh air. If a recompression chamber is not available, supply the diver with fresh

air from natural sources, i. e., open the helmet face plate as soon as he has reached the surface and remove the helmet and suit as quickly as possible, cutting the latter off if necessary. If he is not breathing, start artificial respiration immediately. Administration of oxygen will hasten recovery and should be used in conjunction with artificial respiration. The latter may be accomplished with an inhalator or with the Navy standard oxygen rescue breathing apparatus which is furnished with adaptors for this purpose.

(8) On recovery from asphyxia, the diver must be closely observed not only for further cessation of breathing but also for the occurrence of "bends." At the slightest symptoms of "bends", he should be given treatment in the chamber, or if the latter is not available, he should be sent down again in the company of another diver for recompression and decompression.

(9) *Case history.*—CGM(AA) ______ on 7–10–42 was working at 106–120 feet in a one-knot tide. He became separated from his distance line and, in making himself heavy in his attempt to prevent being swept by the tide, he cut his air supply down. After a 14-minute exposure he was brought to the surface unconscious. While his helmet was being removed he regained consciousness. He was recompressed to 150 feet in the chamber and given adequate decompression with uneventful recovery.

(10) *Case history.*—On 11–24–41 a diver aboard the U. S. S. *Ortolan* was in 152 feet of water during a helium-oxygen training dive. After a 3-minute descent and 2 minutes on the bottom, he reported his faceplate fogging. The order was given to bring the diver up. He ventilated but did so inadequately. During the ascent to the stage of 60 feet, he called out, "Something is wrong;" and later he reported weakly that he could see the stage and was holding onto it with one hand. No further communication was received from the diver on questioning. He screamed once and his tender reported him as "light." The diver blew to the surface and was brought aboard unconscious, salivating, but not cyanotic. The control and exhaust valves were fully closed.

Treatment.—Recompression.—

23 p. s. i. (52 ft.). He was struggling and maniacal but became quiet and cooperative as the pressure increased.

73.4 p. s. i. (165 ft.) for 30 minutes during which time he was slightly disoriented.

Decompression.—An air-oxygen treatment table was scheduled beginning oxygen administration at 60 feet and continued as follows:

60 feet	20 minutes.
50 feet	120 minutes.
50–30 feet	22 minutes.

A prolonged stop at 30 feet for 11 hours was then given following which the diver was brought to the surface in a period of 75 minutes. Recovery was uneventful except for a persistent headache relieved slightly by further oxygen breathing. The patient was mentally clear the next day except for remembering the circumstances of his dive.

(11) *Comment.*—The first case history (9) probably represents a case of inadequate ventilation of the helmet and perhaps some embarrassed respiration from slight squeeze. The second case history (10) probably represents accumulation of CO_2 in the helmet due to failure of the recirculating apparatus or to failure of the CO_2 absorbent to function properly.

964. BLEEDING FROM THE NOSE AND LUNGS.

(1) *Bleeding from the nose* usually originates from the middle ear spaces or the nasal sinuses and is often caused by too rapid a descent or by strenuous efforts in clearing the ears or sinuses.

(2) *Bleeding from the lungs* is usually caused from the effects of a "squeeze" or from rupture of the lung tissue incident to air embolism. However, it can also occur as the result of great respiratory efforts when the dress is insufficiently inflated and squeezing of the chest takes place.

(3) *Prevention.*—Bleeding from the nose and lungs will be avoided if one observes the proper method and rate of descent and avoids taking pressure until the ears and sinuses can be cleared freely.

(4) *Treatment.*—The nose and Eustachian canals should be kept clear with nose sprays and the diver should report to a medical officer for examination. The treatment for bleeding from the lungs is the same as that outlined for "squeeze."

965. BLOWING UP

(1) Blowing up is caused by over-inflation of the dress, too strong or rapid a pull by the tenders, or by the drag of the tide causing the diver to lose his hold on the bottom or descending line and thus sweeping him to the surface.

(2) Accidental "blowing up" may be injurious in various ways such as the following:

(*a*) Air embolism. This may occur when "blowing-up" from any depth in excess of 7 feet (depth of water above diver's helmet).

(*b*) Compressed air illness may result when blowing up from depths greater than 36 feet.

(*c*) Mechanical injury may result from the diver's striking some object such as the ship's side, bottom, etc.

(*d*) "Squeeze" may result from falling back into deeper water after reaching surface and exhausting the air from the dress.

(3) *Prevention.*—(*a*). Attention should be given to the proper functioning of the exhaust valve before descending.

(*b*) "Controlled blow-ups" commonly employed by some divers should not be allowed.

(*c*) A diver who has blown up should never exhaust air from his helmet or dress while on the surface until he is certain that his tenders have secured a hold on his lines and have taken in all slack so that he is protected from a fall into deeper water.

(*d*) The diver should never hold his breath during ascent.

(4) *Treatment.*—The treatment of "blow-up" cases depends largely upon the depth and time to which the diver was exposed before his accident. If a dive is terminated by blow-up and the time spent on the bottom for the particular depth was of such duration as not to require any decompression according to the standard tables, the diver should be watched closely on arrival to the surface and if no symptoms of bends or air embolism develop, no further recompression is necessary. Should symptoms develop, he should be immediately recompressed in a chamber and treated according to the tables outlined in part 6. On the other hand, if the time spent on the bottom for the particular depth was of such duration as to require decompression according to the standard table, the diver must necessarily be recompressed either in the chamber or in his suit if no chamber is available. If no symptoms of bends or air embolism have developed during his time on the surface, he should be recompressed to the depth of the first stop required by the Standard Decompression Tables and decompression completed according to the remaining stops for the dive. If symptoms do develop during his time on the surface, he should be immediately recompressed and treated according to the treatment tables outlined in part 6.

(5) Treating cases of blow-up without having a chamber on hand is an embarrassing procedure. The only alternative to follow, if recompression is necessary, is to lower the diver back into the water and treat him as above in his suit. His valves should be regulated for him until he can handle them himself. A second diver as his tender should, if possible, always be sent down with him.

(6) *Case history.*—S2c ____________________ was making a searching dive at 40 feet on a mud bottom. At the end of 50 minutes, he "blew" himself to the surface and climbed the ladder. While walking to the tending stool, he had a sudden blurring of vision, became very weak, and was unable to stand during the removal of his dress. A medical officer's examination revealed exaggerated knee and ankle jerks. Four hours later the diver could walk but he staggered as though drunk. Seven hours after his dive he complained of coldness and numbness of his lower limbs. Nine hours after his dive he developed abdominal pain, was unable to walk, and had evidence of spinal cord damage.

Treatment.—Recompression:—

22 p. s. i. (50 feet) abdominal pain was relieved.

40 p. s. i. (90 feet) some voluntary motion of his legs returned.

50 p. s. i. (113 feet) was able to get out of stretcher and stand.

80 p. s. i. (180 feet) maintained for 48 minutes.

Decompression.—Accomplished according to the 300-foot air treatment table of the old Diving Manual. Because of unbearable abdominal pain at 44.5 p. s. i. (100 ft.) he was recompressed to 75 p. s. i. and decompression was again started according to the 300-foot treatment table. On further examination he was found to have a full bladder, the emptying of which gave him relief of pain. At 13.5 p. s. i. (30 ft.) he was given an "overnight-soak." Brought to the surface after breathing oxygen for 2 hours. Patient had some residual muscle weakness and was transferred to the hospital for further treatment.

(7) *Comments.*—Since this "blow up" occurred from a shallow depth after an exposure insufficient to produce bends, the case was undoubtedly one of air embolism. The symptoms were typical of the accident and a major error was made in not treating this case by immediate recompression. Allowing a diver with such symptoms to remain at surface pressure for a period of 9 hours before recompression therapy was begun is inexcusable and evidence of ignorance. It will also be noted that the diver developed abdominal pain during decompression while being treated. A bladder full of urine often produces confusing symptoms when a diver is treated over long periods of time or when he has developed evidence of spinal cord damage, and its presence as a producer of abdominal pain should always be borne in mind. Frequently the diver is unable to pass his urine voluntarily in which case catheterization (drainage of urine by a soft rubber tube inserted into the bladder) by a medical officer must be resorted to.

966. COMPRESSED-AIR ILLNESS

Compressed-air illness is the most frequent accident encountered during diving operations and is fully discussed in part 6.

967. DROWNING

(1) Drowning in a full diving dress is uncommon. There are two cases on record of drowning in a standard diving dress in which the helmet became detached from the breastplate. This accident cannot happen if the safety catch at the back of the helmet is properly turned down and locked in place. Even though the dress may rupture, water cannot enter the helmet as long as the air pressure within the helmet is maintained and the diver remains in the erect position. By simply closing the exhaust valve, air is forced down into the dress and will escape through the tear.

(2) Drowning may easily occur when using shallow water diving gear if the diver becomes fouled beneath the surface with his mask or helmet knocked off or if he attempts to swim to the surface

after "ducking" his mask without sufficient air reserve in his lungs.

(3) *Prevention.*—(*a*) The diver's helmet should be carefully inspected before descent.

(*b*) Shallow water divers should make certain they are not fouled before ascending.

(*c*) "Ducking" a shallow water mask should not be done unless this procedure is absolutely necessary as a last resort.

(*d*) Tenders must take up slack and haul the diver in as soon as he reaches surface to prevent him from submerging in case he is injured or unconscious.

(4) *Treatment.*—In case of apparent drowning the diver should immediately be given the benefit of treatment. Water should be allowed to drain from his mouth and windpipe by lifting the diver with the hands under his abdomen so that his head hangs downward. Then artificial respiration should be applied as quickly as possible. If the diver has been exposed to depths requiring decompression, he should be placed in the recompression chamber and compressed to the pressure of the first stop required by the standard decompression tables. Artificial respiration procedures should not be delayed during this recompression period. They should be applied while the diver is being taken down and continued during decompression as long as is necessary.

(5) *Back-pressure arm-lift* method of manual artificial respiration should be administered as follows:

(*a*) Turning Victim Over.—Victims are sometimes found in a face-up position. It is necessary to turn them over before beginning artificial respiration. Here's a good way to do it: Stand to the side of the victim. Bending slightly, grasp the patient's wrist nearest to you with your hand which is closest to the patient's head. In grasping, the palm of your hand should grip the back (or hairy) side of his wrist. Then reach across the body and grasp the far wrist with your other hand. (See Fig. 127.)

Figure 127.

Step back, pivoting on the foot nearest the victim's head, and pull the far arm across the body, at the same time pull the near arm up above patient's shoulder. (See Fig. 128.)

Figure 128.

As the victim's body turns to a semiprone position, bend the arms and move the victim's face so that the cheek rests on his hands. At this point the operator should be kneeling in front of the victim and ready to begin artificial respiration. (See Fig. 129.)

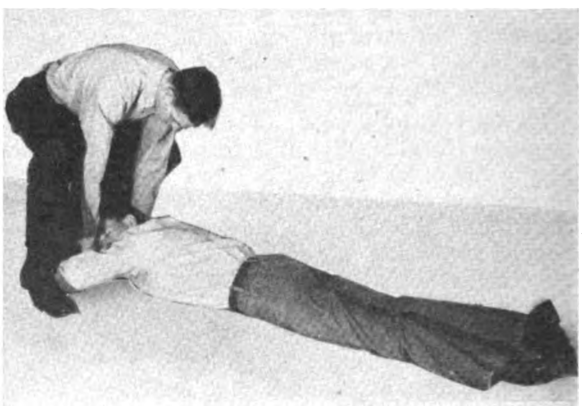

Figure 129.

(*b*) Manual Artificial Respiration Procedure.—Place the patient in the face down, prone position. Bend patient's elbows and place the hands one upon the other. Turn patient's face to one side, placing the cheek upon hands. Remove froth, debris, and other foreign objects from the patient's mouth which might block respiratory system; pull tongue forward. There should be a slight inclination of the body, with the head lower than the feet, so that fluids will drain better from the respiratory passage. The head of the patient should be extended forward, so that the chin will not sag causing obstruction of the respiratory passage. If possible, cover the patient with blankets or other material to keep him warm and reduce shock, but do not delay beginning artificial respiration to accomplish these measures. The operator kneels on either the right or left knee at the head of the patient, facing him. Place the knee at the side of the patient's head, close to the forearm. Place the opposite foot near the elbow. (It may be preferred to kneel on both knees, one on either side of the patient's head.) (See Fig. 131.)

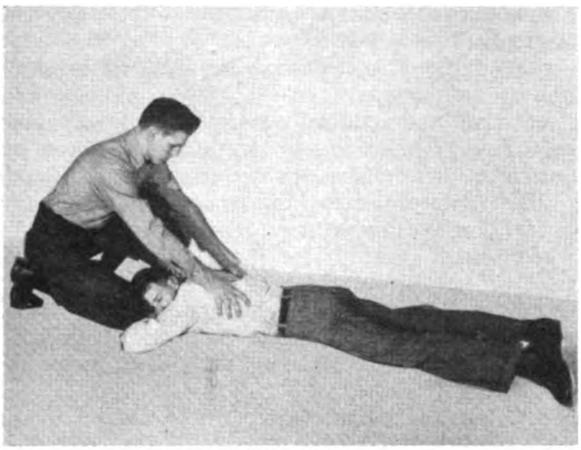

FIGURE 130.

(*c*) COMPRESSION PHASE.—Place your hands upon the flat of the patient's back in such a way that the heels of the hands lie just below a line running between the arm pits. With the tips of the thumbs just touching, spread the fingers downward and outward. Rock forward until your arms are approximately vertical and allow the weight of the upper

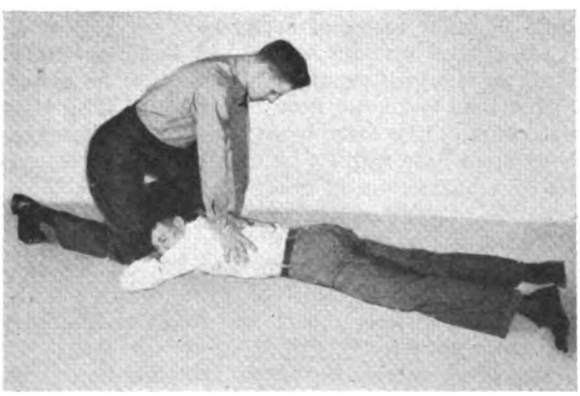

FIGURE 131.

FIGURE 132.

part of your body to exert slow, steady, even pressure downward upon the hands. This forces air out of the lungs. Your elbows should be kept straight and the pressure exerted almost directly downward on the victim's back. (See Fig. 131.)

(*d*) STARTING EXPANSION PHASE.—Release the pressure, avoiding a final thrust, and commence to rock slowly backward, completing the expansion phase. Place your hands upon the patient's arms just above his elbows as you rock back. (See Fig. 132.)

(*e*) COMPLETING EXPANSION PHASE.—With your hands upon the patient's arms just above his elbows, draw patient's arms upward and toward you. Apply just enough lift to feel resistance and tension at the patient's shoulders. Do not bend your elbows and, as you rock backward, the patient's arms will be drawn toward you. Then drop the arms gently to the ground. This completes the full cycle. The arm-lift expands the chest by pulling on the chest muscles, arching the back, and relieving the weight on the chest. (See Fig. 133.)

The cycle should be repeated 12 times per minute

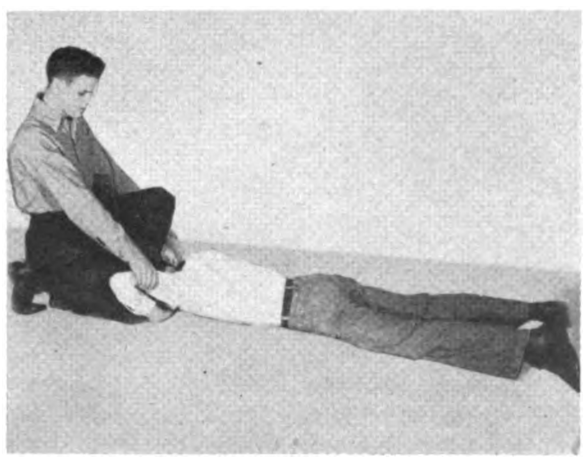

FIGURE 133.

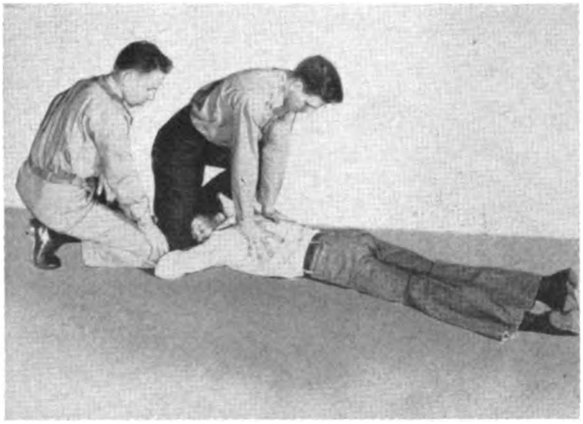

FIGURE 134.

FIGURE 135.

FIGURE 136.

at a steady, uniform rate. The compression and expansion phases should occupy about equal time, the release periods being of minimum duration.

(f) CHANGING OPERATORS.—An important, but sometimes overlooked, technique involved in artificial respiration is that which is used for changing operators. Here's how it's done: The relief operator kneels on one knee as close to the regular operator as possible. The regular operator continues to work, giving necessary instructions to his relief. Split-second timing is not necessary. It is important, however, that the change-over be effected with a minimum of confusion and loss of rhythm. (See Fig. 134.)

The relief operator should go through the motions, along with the regular operator, adjusting his rhythm to that of the regular operator. (See Fig. 135.)

At a predetermined time—and after a cycle has been completed—the regular operator falls to one side and the relief operator pivots on one knee and places his hands on the back of the patient before moving forward to apply pressure. (See Fig. 136.)

Split-second timing is not essential but a smooth, steady rhythm is necessary.

(6) Additional instructions for artificial respiration are as follows:

(a) Continue artificial respiration without interruption for 4 hours unless breathing is restored, or until a medical officer has declared further efforts futile. If natural breathing stops after temporary restoration, resume artificial respiration at once.

(b) Watch carefully for signs indicating the return of natural breathing. Do not block feeble respiratory efforts. Time your movements so that pressure is exerted only while the patient is breathing out. Release pressure instantly when he begins to breathe in.

(c) Keep the patient warm. Unconscious patients lose heat rapidly. Give him fresh air. Without interrupting resuscitation movements, have someone else loosen his clothing about the neck, chest, and waist.

(d) Have some one hold the tongue out if it draws back. If necessary, run a safety pin through the tongue in order to hold it. The small puncture thus caused will injure the tongue less than clamps or forceps which squeeze and crush it. The tongue is more likely to cause trouble in drowning cases than in other forms of asphyxia.

(e) Do not attempt to give any liquid or stimulants by mouth if the patient is unconscious. Ammonia may be placed near the patient's nose after determining how close it may be brought to somebody else's nose without causing irritation. Do not let bystanders shut off fresh air.

(f) Encouraging signs of revival are (1) the presence of a pulse beat—if there is a pulse beat the chances of recovery are excellent, (2) an improvement in the color of the skin, (3) movements of the mouth and nostrils, and (4) spontaneous voluntary breathing efforts.

(g) If the patient revives, do not allow him to get up or to be raised for any purpose. Watch him closely for several hours after he has recovered. Keep him prone until a medical officer arrives.

(*h*) If the patient has received lacerations or injuries during his drowning accident, he should be watched closely for bleeding. As an unconscious person recovers, his blood pressure increases which may be sufficient to cause new bleeding from a non-bleeding wound.

(*i*) The back-pressure arm-lift method of artificial respiration should be applied by persons who have practiced on a voluntary subject.

(7) Oxygen administration may be used in conjunction with these methods at the discretion of the medical officer, but it must never be administered in the chamber at pressures greater than the equivalent of 60 feet.

(8) As soon as possible and practical after recovery, the patient's wet clothes should be removed and he should be wrapped in warm blankets and given a general stimulant (hot coffee or tea).

(9) *Case history.*—GM1c ---------- on 5-17-45 was working on a photographic tower in 41 feet of water using a shallow water diving outfit and face mask. After about 25 minutes' work, he left the bottom without warning and attempted to come to the surface. The tender on taking up the slack noticed his lines were apparently fouled. The diver also seemed to note the same thing for he went down again almost immediately. An observer believed that this diver attempted to remove his mask as he neared the surface. The tender took up slack but got no reply to his signals. Fellow divers almost immediately went to the aid of the diver and found him leaning on the tower with his face mask off and his belt on. When brought to the surface several minutes later, he was unconscious and not breathing.

Treatment.—Artificial respiration with oxygen and recompression were administered, but proved to be of no avail in resuscitating patient. Respiratory passage contained considerable water, as was evidenced by water flowing from mouth during treatment. Patient pronounced dead, death due to drowning.

968. EAR PAINS

(1) Ear pains are caused by inequalities of pressure on either side of the ear drum. The mechanism involved is discussed in part 2-B. Pain is usually experienced while pressure is being increased. This is due to the inability of air to flow through the Eustachian tube into the middle ear thus causing a greater pressure on the outer side of the ear drum. This failure to equalize properly may be due to inexperience on the part of the diver, but usually is due to the inflammation and swelling around the opening of the tube associated with a head cold, sore throat, or excess tissue growth in the throat. Only slight pressures may be sufficient to cause rupture of the drum with bleeding from the ear or nose.

(2) *Prevention.*—This is a matter mainly of keeping the Eustachian tubes open in order to compensate for changes in pressure. Divers with colds or ear conditions should not dive until cured.

(3) *Treatment.*—If bleeding occurs or pain is severe, the diver shall report to the medical officer for examination and necessary treatment.

969. EXHAUSTION

(1) Exhaustion occurs much more readily when working under compressed-air than when working at atmospheric pressure, and due allowance for this should be made when planning the amount or type of work the diver is to do. Exhaustion may be enhanced by poor ventilation, allowing carbon dioxide and water vapor to increase in the helmet, and by purposeless or ineffective muscular efforts such as might be the case when a diver, helplessly fouled, is struggling to escape.

(2) *Prevention.*—Exhaustion is prevented mainly by carefully planned and supervised work and by adequate ventilation. Ineffective muscular efforts should be avoided.

(3) *Treatment.*—(*a*) The diver should "take a blow" and ventilate his helmet freely while his tenders prepare to haul him up.

(*b*) If caught on the bottom, the diver should remain quiet and be reassured frequently while attempts are being made to free him.

(*c*) If unconscious when brought to the surface, he should be given oxygen and intravenous fluids.

(*d*) Adequate air supply, salty fluids, and rest will usually be sufficient treatment.

(4) *Case history.*—Diver ---------- on 2-16-44 was tunneling under a sunken LST during a salvage operation when a "cave-in" occurred. He was thrown off balance and immobilized in a horizontal position by a large metal plate pressing against the front of his chest. His strenuous efforts and those of others were futile in the attempt to free him. He became excited and rapidly exhausted himself in trying to change position and free his limbs. His respirations became labored, rapid, and grunting. Twenty-two hours later, telephone contact was lost and respirations were no longer heard. Twenty-eight hours after contact was lost, his body was brought to the surface and his suit and helmet were found to be intact and to contain air.

(5) *Comment.*—A fellow diver caught in the same cave-in survived after 74 hours at 55 feet. When it was apparent that all muscular effort was futile, this man remained quiet and awaited rescue. He was finally freed, given adequate decompression, and made an uneventful recovery.

970. FOULING

Fouling, which prevents the diver from ascending, occurs when the diver's lines and hose become entangled with some underwater obstruction, when a tunnel caves in, or when the diver is pinned on the bottom by the shifting of heavy objects. It usually requires the assistance of another diver to clear the one fouled. If his lines are fouled with the descending line, it may be necessary to haul up the descending line with the diver. When this is done, great care must be exercised in bringing both the diver and the descending line up at the same rate. Divers should be warned of the dangers associated with fouling. When a diver becomes fouled, he must carefully and systematically attempt to clear himself. If these attempts are futile, he should remain quiet and wait for aid. Continued futile efforts and excitement have resulted in death from exhaustion and shock. Fouled divers should be cleared as rapidly as possible, since prolonged exposure at deep depths can lead to the development of pneumonia.

971. INJURIES

There are many varieties of mechanical injuries from external violence and they call for no special comment. The diver should be brought to the surface as soon as deemed safe, first aid applied as indicated, and the medical officer notified.

972. OXYGEN POISONING

(1) The occurrence of oxygen poisoning in deep sea diving using compressed air as the breathing media is a remote possibility. However, toxic symptoms occasionally are encountered when pure oxygen is breathed during (1) shallow diving using either the face mask (open circuit) or the self-contained unit (closed circuit), (2) decompression following helium-oxygen dives, or (3) the treatment of cases of compressed-air illness. When diving with a mask, oxygen should not be used at depths greater than 30 feet. The time of dive should not exceed 30 minutes.

(2) In contrast to its dangers, oxygen is the most economical gas to use in underwater breathing equipment. In a closed breathing system all of the oxygen supplied from the flask is utilized by the tissues of the body. An individual may remain submerged for prolonged periods of time independent of surface help, and his location may be concealed by the absence of bubbles escaping from the self-contained equipment. Such dives, however, are limited as to depth or time of exposure and must fall within the latent period before toxic symptoms become manifest. This latent period of "tolerance time" determines the practical usefulness of oxygen in actual underwater dives. Oxygen breathing under increased pressure employed during decompression following a helium-oxygen dive, air dive, or treatment dive is extremely effective but its use at certain depths or for certain exposures is also limited by the "tolerance time" of the individual.

(3) Paul Bert in 1878 was the first to observe signs and symptoms of oxygen poisoning in the lungs and nervous system of lower animals. Prolonged exposures to pure oxygen in excess of 24 hours at atmospheric pressure are usually required to produce signs and symptoms of irritation and accumulation of fluid in the lung. The safe concentration for continuous oxygen administration over a period of days at surface pressure is about 60 percent. However, when oxygen is breathed under increased pressures, symptoms in lower animals and man are chiefly indicative of involvement of the nervous system. The convulsion which resembles an epileptic attack is the most striking manifestation of oxygen poisoning. Nausea, recurring periodically, is the symptom most frequently encountered.

(4) The fact that the symptoms of oxygen poisoning, particularly the convulsion, are followed by apparently complete recovery and the fact that a latent period precedes the onset of incapacitating symptoms make possible the inhalation of oxygen at pressure higher than surface pressure for limited periods. In the U. S. Navy, oxygen has been successfully employed for the prevention and treatment of compressed-air illness, i. e., it has been administered with apparent safety to individuals in an inactive state for 2 hours in the dry chamber at 60 feet and to divers during decompression following helium-oxygen dives for 15 minutes at 60 feet and for periods up to 2 hours at 50 feet.

(5) The maximum pressure and exposures to which an individual can be exposed while breathing pure oxygen have been studied by extensive animal and human experimental work conducted at the Experimental Diving Unit, Washington, D. C., and the Naval Medical Research Institute, Bethesda, Md. The results obtained are as follows:

(6) *Divers at rest.*—(a). *Dry chamber* of 20 exposures at a depth of 60 feet for a 2-hour period, no symptoms were encountered. Of 46 exposures at a depth of 80 feet, 26 developed symptoms during the first hour and a total of 36 developed symptoms within a 2-hour exposure. The average time of onset for those developing symptoms was 50 minutes. Of 29 exposures at a depth of 100 feet, 26 developed symptoms during the first hour and none of the remaining 3 tolerated the 2-hour exposure. The average time of onset of symptoms was 27 minutes. Three convulsive seizures occurred in exposures of 16, 23, and 23 minutes.

(b) *Wet chamber.*—Both the open circuit and closed circuit were used in these experiments. One hundred and seven exposures were made at a depth of 60 feet; 92 being of 1-hour duration and 15 continued for an additional hour. Of the 92 1-hour exposures, 33 developed symptoms, the average time of onset of symptoms was 33 minutes, and the shortest exposure was 8 minutes. Two convulsive seizures occurred in exposures of 13 and 24 minutes. Of the 15 exposures continued for an additional hour, 3 developed symptoms after 93,113, and 116 minutes' exposure. The remaining 12 tolerated the 2-hour exposure. Of 54 exposures to 80 feet, 48 developed symptoms during the first hour, the average time of onset of symptoms was 28 minutes, and the shortest exposure was 5 minutes. One convulsive seizure occurred with an exposure of 25 minutes. Of the 6 exposures continued for an additional hour, 5 developed symptoms after 72, 76, 93, 99, and 110 minutes' exposure, the remaining exposure being terminated after 99 minutes without symptoms. Of 20 exposures at a depth of 100 feet, 18 developed symptoms and 1 was terminated after 49 minutes without symptoms during the first hour. The average time of onset of symptoms was 16 minutes and the shortest exposure was 4 minutes. One convulsive seizure occurred with an exposure of 17 minutes. Only one exposure continued beyond the first hour and it terminated with a convulsive seizure after 107 minutes.

(7) *Divers at work in wet chamber using both open and closed circuits.*—At a depth of 30 feet, 2 out of 35 exposures developed symptoms during a 2-hour exposure period, the average onset of symptoms being 100 minutes. At a depth of 40 feet, 19 out of 71 exposures developed symptoms prior to 2 hours, the average onset of symptoms being 57 minutes. At a depth of 50 feet, 3 out of 5 exposures developed symptoms during the 2-hour exposure period with an average time of onset of symptoms being 32 minutes.

(8) A glance at these tolerance times reveals that there are individuals who appear to be highly susceptible and others who are relatively resistant to the toxic effects of oxygen. Furthermore the tolerance of the same individual on different days shows a high degree of variability and does not permit the setting of precise time limits for depths in excess of 30 feet when work is performed. The profound effect of carbon dioxide accumulation within the body in reducing the oxygen tolerance time is clearly shown in the results of the dives where work is performed. An accumulation of carbon dioxide within the breathing apparatus has a similar effect.

(9) The "tolerance time" appears to be of longer duration in dry chamber dives than in wet chamber dives. This may be due in part to slight mask leakage around the face in the dry chamber or to the apprehension of the diver while under water. It appears also that in the case of under-water diving the tolerance time is slightly extended in those subjects using a closed breathing system (carbon dioxide concentration being kept in a minimum by means of efficient absorbent) over those using a free-flowing circuit, such as the face mask with hose supply. This probably is the result of oxygen dilution within the self-contained outfit by the nitrogen which is eliminated from the body and retained in the system. It has been noted also that brief intermittent periods of air breathing interspersed throughout the period of oxygen administration definitely prolongs the "tolerance time."

(10) Of the symptoms which terminated oxygen dives, nausea and dizziness comprised 57 percent. In order of their frequency the symptoms encountered were nausea (40 percent), muscular twitchings (21 percent), dizziness (17 percent), disturbances of vision (6 percent), restlessness and irritability (6 percent), numbness and "pins and needles" sensations (6 percent), and convulsive seizures (4 percent). With the exception of headache, drowsiness, and laziness persisting for several hours following seizures, the symptoms rapidly disappeared when air was substituted for oxygen.

(11) It has been unfortunate that the observations of oxygen tolerance referable to the resting state and its rational application in the treatment of compressed-air illness have been construed to be applicable to men performing work. Dry chamber tests have demonstrated that although oxygen could be inhaled for 2 hours in the resting state of 60 feet, moderate exercise sufficient to increase the body metabolism threefold served to restrict the period of useful work within a range between 10 and 20 minutes.

(12) *Prevention*—(*a*). Tenders must be thoroughly acquainted with the maximum pressures and time limits for which oxygen may be safely tolerated.

(*b*) Both the tender and the diver must recognize the early warning signs and symptoms of oxygen poisoning.

(*c*) It must be remembered that the tolerance time for breathing oxygen is decreased in direct proportion to the amount and degree of work done during the dive.

(*d*) Fresh and efficient carbon dioxide absorbent must always be used when diving with closed circuit outfits.

(13) *Treatment.*—Apparent recovery from oxygen poisoning is rapidly and dramatically brought about by substituting air for oxygen. Thus, when the early warning symptoms occur, simply cutting down the concentration of oxygen, substituting air, or decreasing the pressure will usually bring about prompt recovery.

(14) *Case history.*—Lt. (jg) ---------- on 10–7–42 made three dives to 40 feet using shallow water gear. On his first dive using a helmet with compressed air supply for 5 minutes he became exhausted from heavy physical exertion and an insufficient air supply. After being hauled up and resting in the boat, he suffered from a severe headache which lasted 30 minutes. After resting one-half hour he made a second dive of 20 minutes' duration using a face mask with an oxygen supply.

While performing heavy work he panted strenuously and had recurrent thoughts of a shark seen before descent. Toward the end of this dive he noticed spasmodic, involuntary, jerky spasms of all muscles, especially those of the abdomen. He felt alert rather than fatigued and had a desire for haste in all movements. The spasms became progressively worse toward the end of his work but ceased when he left the bottom. On reaching the surface he experienced unusual fatigue and a dry puckery sensation in his mouth.

After a 15-minute rest he felt normal. Within the next half hour he made another dive of 10 minutes' duration using the mask and oxygen. Again he worked moderately heavily on the bottom. The spasms recommenced in about 5 minutes after he reached the bottom and became more frequent, occurring in rapid cycles. While pulling a cable he had a severe spasm which prevented him from signaling or breathing. This was accompanied by a violent "ringing and buzzing" in his ears until a "black envelope" engulfed him and he passed out. His supply of oxygen was adequate and under a pressure of 120 feet gage. Because he did not answer signals he was hauled up and found to be unconscious and not breathing. The prompt institution of artificial respiration restored his breathing. He then began to froth at the mouth and bite his tongue. He made a powerful lunge following which he gradually quieted down and opened his eyes. During the 30-minute boat trip to shore he had three or four more convulsions and remained groggy. He had become clear mentally and had no more convulsions by the time he reached the hospital approximately 40 to 60 minutes after reaching surface. Subsequent observation in the hospital was uneventful.

(15) *Case history.*—F1c _________ on 10-24-44 was making a "dry-dive" in the chamber during diving experiments employing surface decompression. He had been on air at 100 feet for 85 minutes during which time he rode a stationary bicycle as a form of moderate exercise. Surface decompression was then given and he felt fine upon reaching surface. Twenty-five minutes later, he developed pain in his left elbow which became worse over the next 55 minutes and recompression was instituted where he obtained relief at 50 feet.

Treatment.—Decompression:

100 feet. 30 minutes.
80 feet. 12 minutes.
60 feet. 28 minutes on oxygen.

At the end of 28 minutes on oxygen, he complained of nausea and before his mask could be removed, he had a convulsion. The pressure was lowered to 40 feet and the chamber ventilated. Patient was further decompressed on air. Upon reaching the surface the patient was drowsy and disoriented. Twelve hours later he was without complaints other than a headache.

(16) *Comments*—(*a*). In the first case, the diver showed definite signs of inadequate air supply and CO_2 accumulation in his helmet while making his first dive on air. During his next dive on oxygen, he developed early symptoms of oxygen poisoning. This dive demonstrates that oxygen poisoning occurs at relatively shallow depths and the early appearance of his symptoms was probably due to the previous effects of CO_2 intoxication and the heavy work encountered during his oxygen dive. Had symptoms of oxygen poisoning been recognized by either the diver or his tender, he never would have been exposed to a second oxygen dive with continued hard work. The second oxygen dive required only 5 minutes to precipitate the convulsive attack. That convulsions can occasionally continue even after reaching surface pressures is also shown in this case report.

(*b*) The second case also demonstrates the effect of previous fatigue and body CO_2 production on the "tolerance time" to oxygen breathing. This individual, a second-class diver, was unusually susceptible to oxygen poisoning during many previous experiments conducted at the Experimental Diving Unit, Washington, D. C. Because of his low tolerance to oxygen and also because of the fact that he presented a childhood history of attacks of unconsciousness suggesting epilepsy, he was subsequently disqualified from further diving.

973. SPONTANEOUS PNEUMOTHORAX

(1) Spontaneous pneumothorax (air in the chest cavity) is an accident which rarely happens during diving practice but has occurred on at least one occasion. The mechanism involved in the production of spontaneous pneumothorax and the dangers that result therefrom have been discussed in part 5. The initial symptom developing with the onset of this accident is usually a sharp pain in the chest. If pneumothorax develops while still under pressure, difficulty will be encountered in bringing the patient to the surface. The trapped air in the chest cavity will expand and produce collapse of the lung on the involved side and later displacement of the heart toward the sound side of the chest. Extreme shortness of breath, distention of the neck veins, irregular pulse, bluish discoloration of the skin, and other signs of pulmonary or circulatory embarrassment will take place. The aid of a medical officer is required in such cases as the treatment involves surgical procedures.

(2) *Prevention.*—The precautions to be observed in preventing pneumothorax are essentially the same as those mentioned for air embolism.

(3) *Treatment.*—In addition to following the method of treatment prescribed for air embolism, procedures must be instituted to reduce the pneu-

mothorax. Medical officers will necessarily have to resort to a surgical procedure whereby the positive pressure is relieved by inserting a needle into the chest and allowing the trapped air to escape. The pressure within the pleural cavity can thus be made to equalize with that on the outside of the chest. After the diver reaches atmospheric pressure, any residual pneumothorax will absorb spontaneously.

(4) *Case history.*—FC3c ______ on 1–27–44 during routine submarine escape training had made successful escapes from the 12- and 18-foot levels. While making the 50-foot escape, he experienced some difficulty in breathing and let go of the line, swimming to the surface from approximately 20 to 25 feet. He apparently held his breath while doing so and broke the surface semiconscious and groaning. Three minutes later while being recompressed in the chamber he was unconscious, gasping for air, and bloody froth was coming from his mouth. His pupils were dilated and his eyes were turned to the left.

(5) *Treatment.*—Recompression—

11 p. s. i. (25 ft.)—He recovered consciousness.

22 p. s. i. (50 ft.)—He was fully conscious and felt well, although he complained of slight soreness behind the breast bone.

Decompression.		Ascent.
25 p. s. i. 20 min.	1 pound/min.	(5 min.)
20 p. s. i. 6 min.	1 pound/min.	(5 min.)
15 p. s. i. 5 min.	1 pound/min.	(5 min.)
10 p. s. i. 12 min.	1 pound/min.	(5 min.)
5 p. s. i. 11 min.	5 pounds/6 min.	(5 min.)

(6) Because the patient continued to complain of soreness under his breast bone, he was recompressed and decompressed according to a 100-foot treatment table in the old Diving Manual.

At 100 feet he had no complaints.

At 40 feet he complained of a little soreness in his chest.

At 30 feet his complaints were the same. Physical examination revealed a partial left pneumothorax. Five minutes after reaching 20 feet the patient became very short of breath, his skin appearing bluish, and he became excited. His pulse became irregular and weak and the veins of his neck were dilated. Massive left pneumothorax with shift of the heart to the right of the breast bone was found to be present on examination by a medical officer. He was given oxygen and morphine with resulting improvement. After 50 minutes, the pressure was lowered gradually at 10 feet with no untoward symptoms. He was kept on intermittent oxygen and kept in the chamber overnight at 10 feet. About 4½ pints of air were removed from his left chest as he was brought to the surface. X-ray revealed a complete left pneumothorax. No further difficulty was encountered and the residual pneumothorax remaining was allowed to reabsorb.

974. SQUEEZE

(1) Squeeze is usually a serious accident in diving and great care should be exercised to prevent its occurrence. The mechanism involved in the production of squeeze has been explained in parts 3 and 5.

(2) The following are the most common causes for squeeze:

(*a*) Falling while submerged.

(*b*) Descending ahead of the air supply, i. e., descending before the pressure within the dress is adequate for the water pressure without.

(*c*) Rupture of the air hose with either a leaky nonreturn valve or none at all. This may occur in deep diving as well as when using shallow water gear.

(*d*) Rupture of a cuff or sleeve of the dress with the escape of a large amount of air when the diver raises his arm in his attempt to reach the air regulating valve.

(*e*) Loss of pressure within the suit when the air supply is at a minimum and the exhaust valve is open wide.

(3) Squeeze of the diver's body or lung may occur in all degrees from slight to severe. In case of slight squeeze, the dress becomes flat and presses against the diver's chest because the air within the dress is at a relatively lower pressure than the pressure outside the suit. The diver thus is forced to breathe against this extra pressure. Since the lungs only work comfortably when the external and internal lung pressures are approximately equal, a small additional external pressure materially increases the labor of breathing. Respiratory embarrassment and exhaustion soon result from this exertion. A diver may bleed considerably from the lungs and nose when struggling up the descending line (buoyancy negative) under these conditions. Hemorrhage, in this case, is due to the rupture of small lung capillaries. Squeeze may be so severe as to cause almost immediate death, and cases have been known where the diver has been molded into the helmet to such an extent that it was nearly impossible to remove the body from the helmet. Swelling of the tissues of the head and neck, bleeding from the nose and lungs, signs of asphyxia, and unconsciousness are the common findings in cases of moderate or severe squeeze.

(4) In shallow water diving a local squeeze of the face (in mask diving) may occur. The mechanism involved is essentially the same as that occurring in body or lung squeeze when a full dress is being used. However, in this case, the pressure effects are limited to the face and they are usually caused by a reduction in the air supply when no safety nonreturn valve is used. The effect on the diver may vary from a slight local congestion of the eyes to that of extreme swelling of the face, bluish discoloration of the face, extrusion of the eyes, bleeding from

the nose and lungs, or even death from suffocation. This accident occurs rapidly even before the diver has time to remove his mask.

(5) *Prevention.*—(*a*) Tenders must observe the utmost caution to protect the diver from falling. The air-hose and lifeline must never be permitted to "run" through the tender's hands.

(*b*) If for any reason the diver finds himself

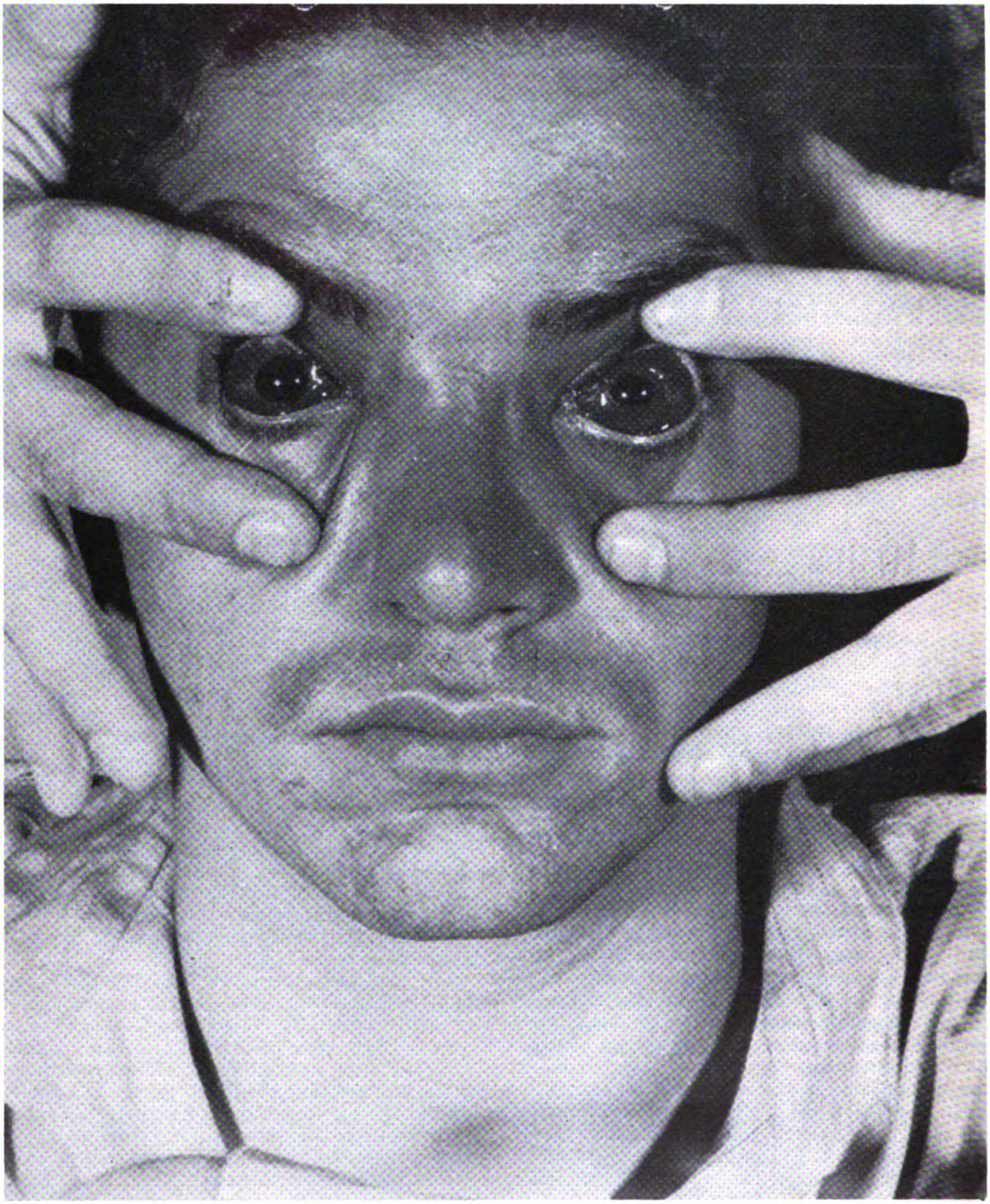

FIGURE 137.

falling or in danger of falling, he should signal for more air, or open wide the air-control valve, throttle the exhaust valve, and notify the surface to "hold on." The moment the danger is over he should re-regulate the air to prevent "blowing up."

NOTE.—The effects of squeeze are much more serious than those of "blowing up." Avoid both, but if it is matter of choosing between the two evils, choose the latter.

(*c*) While descending, the diver should be regulating the air supply so that he maintains sufficient pressure in his dress to breathe comfortably.

(*d*) When it is anticipated on the surface that the air supply will be interfered with unavoidably (compressor trouble, leaky fittings, etc.) the diver should be informed immediately and told to close both the exhaust valve and air-control valve, and to stand by for coming to the surface.

(*e*) In shallow water diving, a safety nonreturn valve should always be used. When, for any reason, the pressure in the mask begins to drop beyond the control of the diver, he should immediately "duck his mask" and his belt, and then surface, being certain to exhale during the ascent.

(6) *Treatment.*—(*a*) Squeeze may be corrected by increasing the air pressure in the dress.

(*b*) When squeeze is moderate or severe, the diver should be brought to the surface as quickly as deemed safe and given first aid treatment and further decompression if indicated.

(*c*) The assistance of a medical officer is required when bleeding occurs from the mouth, nose, or eyes or when the diver appears to be in distress.

(*d*) Artificial respiration may be necessary if respiration has ceased.

(*e*) The patient should be kept in a lying-down position, kept warm and given stimulants or other treatment as necessary.

(*f*) For shallow water squeeze of the face cold packs locally and sedatives will afford relief until the patient can be placed under the care of a medical officer.

(7) *Case history.*—M1c ___________ on 8–8–45 was diving in 50 feet of water with a converted gas mask which had no "safety nonreturn" valve. A fitting on the volume tank parted, allowing all of the air to be exhausted from the diver's lines. This diver pulled off his belt, then his mask. Upon surfacing, the tissues of and around his eyes began to swell and soon completely closed his eyes. Twenty minutes later, he was seen by a medical officer who noted additional hemorrhage under the delicate tissues of the eye coverings and the adjacent tissues. (See fig. 137.)

(8) *Treatment.*—His face was packed in ice. Ten days later he was markedly improved, although the residual hemorrhages in the tissues were still present. A fellow diver in the same predicament supplied with air from the same source first pulled off his mask and then his belt before surfacing. He suffered no injury.

(9) *Case history.*—S2c __________ on 2–5–42 was descending to 36 feet in a regular diving suit when he began to lose consciousness. He signaled his tender who brought him to the surface at once. He was immediately taken by ambulance to the dispensary where he complained mainly of headache and nausea. The skin of his face and neck were of a bluish color and there were small hemorrhages present in the skin of his shoulders, chest, and back. These skin findings were limited to the area covered by the helmet. His nose was bleeding and blood was present in both middle ear spaces although both eardrums were intact.

(10) *Treatment.*—50 cc. of 50 percent glucose by vein relieved his headache slightly and allayed his vomiting so that oxygen could be given. When oxygen was discontinued, his bluish discoloration reappeared. He was transferred to a hospital for further observation and treatment.

(11) *Comment*—(*a*). The first case history clearly shows how quickly the effects of local squeeze can develop. His diving partner would have had a similar outcome had time been taken by him to remove his belt before "ducking" his mask. The dangers of diving without a nonreturn valve in the supply lines is clearly demonstrated in this example.

(*b*) The second case demonstrates what effect squeeze has on the body as a whole. Apparently for some reason, this diver was unable to maintain the air pressure within his suit to balance the additional hydrostatic pressure of the surrounding water as he descended. The result was that he was not only unable to inhale any air into his lungs causing his symptoms of CO_2 intoxication, but the relative vacuum within his helmet brought about suction effects on his upper body with attending hemorrhages. The seriousness of such an accident can be readily appreciated from a study of this case.

Part 9—Component parts of standard diving

981. DEEP SEA DIVING OUTFITS

Item	Article	Unit	Stock No.	Outfit	
				No. 1	No. 3
1	Amplifier, complete [1]	No.	17-A-7755-50 or 17-A-7755-52	1	3
2	Bags, tool 18 inches	No.	24-B-1108	2	6
3	Belts, weighted	No.	37-B-2850	2	8
4	Box, spare parts	No.	23-B-251-50	1	2
5	Cable, combination amplifier and life line 200-foot lengths	No.	17-C-566-500	3	2
6	Cable, combination amplifier and life line 600-foot lengths	No.	17-C-566-520		8
7	Cement, rubber	Qts.	52-C-1206-100	2	12
8	Chest, helmet	No.	23-C-135	1	
9	Chest, outfit	No.	23-C-140	3	
10	Clamps, air hose, spare	No.	33-C-30	12	12
11	Cloth, patching	Yds.	33-C-225	2	4
12	Compressor, gas driven	No.	11-C-130-750	1	1
13	Couplings, air hose, female	No.	33-C-300	2	6
14	Couplings, air hose, male	No.	33-C-301	2	6
15	Couplings, air hose, double female	No.	33-C-305	2	6
16	Couplings, air hose, double male	No.	33-C-306	2	6
17	Coupling, diving cable	No.	(2)	2	3
18	Cuffs, rubber	Pr.	37-C-3200	8	20
19	Cushions, helmet	No.	23-C-210	2	6
20	Dies, rethreading $\frac{1}{2}$ inch—12	No.	41-D-887	1	2
21	Dies, rethreading $1\frac{1}{16}$ inch—17	No.	41-D-889	1	2
22	Drawers, woolen, size 36	Pr.	37-D-280-360	6	4
23	Drawers, woolen, size 38	Pr.	37-D-280-380	6	12
24	Drawers, woolen, size 40	Pr.	37-D-280-400	6	8
25	Dresses, diving, No. 1	No.	37-D-360-100	1	4
26	Dresses, diving, No. 2	No.	37-D-360-200	3	12
27	Dresses, diving, No. 3	No.	37-D-360-300	2	4
28	Faceplate, helmet	No.	23-F-105	1	4
29	Faceplate, welding	No.	23-F-107	1	
30	Filter, oil separator	No.	23-F-280	6	4
31	Flag, baker	No.	5-F-341	1	
32	Gaskets, faceplate, spare	No.	33-G-605	2	6
33	Gaskets, helmet, spare	No.	33-G-610	4	10
34	Gaskets, oil separator	No.	33-G-615	6	4
35	Glasses, helmet, face	No.	23-G-135	2	6
36	Glasses, helmet, side	No.	23-G-140	1	6
37	Glasses, helmet, top	No.	23-G-145	1	6
38	Glycerine	Pts.	51-G-348	1	
39	Gloves, divers-tenders	Pr.	37-G-2170	8	24
40	Gloves, woolen	Pr.	37-G-2150	4	18
41	Halliard, signal	Ft.	21-H-105	20	20
42	Helmet, complete	No.	23-H-153	2	7
43	Hose, air, high pressure, 3 feet	Lgths.	33-H-17	3	12
44	Hose, air, high pressure, 3 feet, 9 inches	Lgths.	33-H-17-50		4
45	Hose, air, high pressure, 50 feet	Lgths.	33-H-18	12	68
46	Jackboxes, amplifier	No.	(3)	3	10
47	Knives, cases	No.	41-K-855	2	10
48	Ladder, iron	No.	23-L-105	1	1
49	Lead, sounding, 7 pounds	No.	23-L-125	1	
50	Lenses, welding, No. 4	No.	23-L-167	12	
51	Lenses, welding, No. 6	No.	23-L-168	3	
52	Lenses, welding, No. 8	No.	23-L-169	3	
53	Light, with 200-foot cable	No.	17-L-11781-50	1	
54	Light, with 1,000-watt bulb	No.	17-L-510		4
55	Light, bulb, 1,000 watt	No.	17-L-2000		6
56	Line, sounding	Ft.	21-L-197	1	
57	Litharge	Lbs.	52-P-11692	2	
58	Lines, descending, 200 feet	Lgths.	21-L-260	2	
59	Lines, distance, 60 feet	Lgths.	21-L-255	3	
60	Manifolds	No.	28-M-105	1	3
61	Manual, diving	No.		1	
62	Nuts, wing, breastplate, large	No.	23-N-110	4	15
63	Nuts, wing, breastplate, small	No.	23-N-115	8	30
64	Oil, neatsfoot	Qts.	14-O-3105	2	
65	Packing, air control, flax	Lbs.	33-P-97	$\frac{1}{2}$	$\frac{1}{2}$
66	Reducer, type S	No.	23-R-105	4	18
67	Reducer, type T	No.	23-R-110	2	6
68	Safety latch, helmet, spare	No.	23-L-107	2	7
69	Screws, machine, brass, 8 by 32 by $\frac{3}{4}$ inches	No.	43-S-8998	1	
70	Sealing compound amplifier gooseneck	Lgs.	52-B-230	2	10
71	Separator, oil	No.	23-S-145	2	8
72	Shoes, lightweight	Pr.	37-S-796	1	3
73	Shoes, weighted	Pr.	37-S-800	2	6
74	Socks, woolen	No.	37-S-2100-110	4	16
75	Socks, woolen	No.	37-S-2100-120	4	16
76	Socks, woolen	No.	37-S-2100-130	4	16
77	Springs, primary and secondary regulating escape valve	Pr.	23-S-223	6	12
78	Stages, decompression (1-man)	No.	23-S-235	1	2
79	Stages, decompression (2-man)	No.	23-S-234		1
80	Straps, leather, with buckle	Pr.	23-S-332	2	4
81	Stop watch	No.	18-W-170	1	1
82	Studs, breastplate, long	No.	23-S-335	4	6
83	Studs, breastplate, short	No.	23-S-340	8	18
84	Taps, rethreading, $1\frac{1}{16}$ inches—17	No.	41-T-338	1	2
85	Taps, rethreading, $\frac{1}{2}$ inch—12	No.	41-T-1039	1	2

See footnotes at end of table.

Item	Article	Unit	Stock No.	Outfit	
				No. 1	No. 3
86	Trousers, overalls	Pr	37-T-300	3	9
87	Tubing, elastic	Yds	33-T-75	2	20
88	Undershirts, woolen, size 38	No	37-U-75-380	6	6
89	Undershirts, woolen, size 42	No	37-U-75-420	6	12
90	Undershirts, woolen, size 44	No	37-U-75-440	6	6
91	Valves, air control	No	23-V-100	2	12
92	Valves, regulating escape	No	23-V-105	2	6
93	Valves, air, nonreturn	No	23-V-116	4	6
94	Washer, copper, for breastplate straps	No	33-W-47	12	50
95	Washer, air hose-oil separator	No	33-W-45	36	60
96	Washer, nonreturn valve seat	No	33-W-49	4	20
97	Washers, amplifier	No	17-M-338-100	20	50
98	Weights, 50 pounds	No	23-W-95	1	12
99	Weights, 100 pounds	No	23-W-100	2	12
100	Wrench, air hose	No	41-W-1311-50	2	6
101	Wrench, nonreturn valve, spanner	No	23-W-145	1	4
102	Wrench, T helmet	No	23-W-150	4	6
103	Wrench, amplifier and life-line couplings	No	17-W-4210	2	6
104	Wrench, diving cable spanner	No	17-W-4220	2	6

[1] Amplifier, complete, consists of the following which may be requisitioned separately as spares:
Amplifier, diving—3 keys or .... 17-A-7755-54.
Amplifier, diving—6 keys .... 17-A-7755-56.
Reproducers, diving .... 17-A-6071-803.
Spare parts set for 3-key amplifier .... 17-A-7755-70.
Spare parts set for 6-key amplifier .... 17-A-7755-72.

[2] Coupling, diving cable, flat spring contact type .... 17-C-37069-60.
Coupling, diving cable, coil spring contact type .... 17-C-37069-50.

[3] Jackbox—for old style helmet gooseneck, flat spring contact type .... 17-J-135-20.
Jackbox—for new style helmet gooseneck, coil spring contact type .... 17-J-135-10.

982. LIGHTWEIGHT DIVING OUTFIT

Item	Article	Unit	Stock No.	Quantity	Item	Article	Unit	Stock No.	Quantity
1	Bag, breathing	No	23-B-75	2	16	Knife and sheath	No	41-K-855	1
2	Belt, cartridge	No		2	17	Mask	No	23-M-108	2
3	Belt, leather	No	37-B-2852	2	18	Shoes, gymnasium, size 10	Pr	37-S-1201-100	1
4	Cement, rubber	Qts	52-C-1296-100	1	19	Shoes, gymnasium, size 12	Pr	37-S-1201-120	1
5	Clamp, dress	No	23-C-171-50	3	20	Shoes, lightweight	Pr	37-S-796	2
6	Cloth, patching	Yds	33-C-225	2	21	Socks, size 12	Pr	37-S-2100-120	4
7	Compressor, gas driven	No	11-C-130-700	1	22	Trousers, overalls	Pr	37-T-300	2
8	Drawers, size 38	Pr	37-D-280-380	2	23	Tubing, elastic	Yds	33-T-75	1
9	Drawers, size 40	Pr	37-D-280-400	2	24	Undershirts, size 38	No	37-U-75-380	2
10	Dress	No	37-D-355	3	25	Undershirts, size 42	No	37-U-75-420	2
11	Gaskets, face dress	No	33-G-625	6	26	Valve, control	No	23-V-100-50	2
12	Gloves, divers-tenders	Pr	37-G-2170	4	27	Valve, flapper, dress, spare	No	23-V-102-25	6
13	Gloves, woolen	Pr	37-G-2150	4	28	Valve, flapper, mask, spare	No	23-V-102-50	6
14	Harness, head, mask	No	23-H-121-50	2	29	Valve, nonreturn	No	23-V-101-50	3
15	Hose, with couplings, 50′ length	Lgth	33-H-453	4					

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