Diving and Deep-Sea Operations

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DIVING

AND DEEP-SEA OPERATIONS

Published and Illustrated by the Training Office

PUGET SOUND NAVY YARD

A VOCATIONAL COURSE FOR TRAINING CIVILIAN DIVERS ☆ ☆ ☆

DIVING
and
DEEP-SEA OPERATIONS
(Underwater Welding)

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by
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FOREWORD

The material in this book, based on the latest and most authentic references available, has been compiled and published by the Training Office of the Puget Sound Navy Yard. It is to be used primarily in vocational training of civilian divers, second class, and as a reference for standards for requalifying men with a diver's classification now employed in the Yard and for enlisted personnel being qualified as divers, second class.

In the absence of a test that completely covers Navy standard equipment and operations, this material has been brought together under one cover and the sources of authority are: the Bureau of Navigation Manual; Bureau of Construction and Repair, Diving Manual, 1924; Bureau of Construction and Repair, Submarine Safety, Respiration, and Rescue Devices, 1938; Advanced Mine School Course for Divers, Second Class, Charleston Navy Yard; letters from, and information compiled by Deep-Sea Diving School, Navy Yard, Washington, D. C., and Bureau of Construction and Repair Manual, and Sea Power, magazine of the Navy League of the United States.

Local factors will influence the strict application of the principles involved, but the suggestions given will cover almost any condition. The present emergency emphasizes the necessity of keeping abreast of new developments and changes in the equipment now in use.

Although new techniques and methods have been developed for diving operations, a diver must still take all possible precautions in his work. THERE IS NO SUBSTITUTE FOR SAFETY.

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CHAPTER I

So you want to be a deep-sea diver?

Contrary to public opinion, the dangers and thrills of diving are not what they are popularly supposed to be. Even such perils as the "bends," the "squeeze," or carbon dioxide-oxygen poisoning are being eliminated through training and supervision. But the one implacable enemy of the diver, the enemy more deadly than all the sharks and octopuses in all the oceans, is the lead-weight pressure of the water in which he works. It is a sleepless enemy, waiting only for a moment's carelessness to crush its victim. With his modern equipment the diver can easily match its strength, but he can never conquer it. The pressure is always there, waiting. And when he enters into its territory, he does so under an armed truce; his weapons are the diving suit he wears and the schooling he has received at diving school.

If you plan to attend a diving school, such as the Puget Sound Navy Yard Diving School, you must be between twenty and thirty years of age, neither too tall nor too short, (since diving suits come only in three sizes), and a volunteer. And you can not be more than twelve pounds over the normal weight for your height, for it has been found that overweight men are far more apt to get the "bends" than wiry men, since fatty tissue absorbs more of the dangerous nitrogen bubbles than either muscle or sinew.

If you can qualify and your application is accepted, you will, on reporting to the diving instructor, be given a thorough medical examination, then conducted to the compression chamber for a test of your ability to withstand pressure.

You will see a large gray-painted cylinder, eighteen feet long and six feet wide, with room inside for eight students and an instructor. Stepping through the entrance hatch, you first pass through a small outer lock, then into the main lock where you find benches along either side and an impressive array of valves and dials overhead.

While you are examining the dials, the instructor enters and dogs down both hatches behind him. He phones or knocks once with a mallet against the steel sides of the chamber, as a signal to those outside that everything is in readiness, and then reaches overhead to open a valve.

After you hear the hiss of compressed air, the needle of the pressure gauge moves slowly upward to 3, 4, and 5 pounds. The temperature begins to rise and you perspire. You wonder if you will be able "to take it." The needle goes on--6, 8, 10 pounds--enough pressure so that your ears feel clogged. The instructor tells you to swallow. You do, and your ears "open up" with a pop.

You remark on this to the student sitting next to you. When he answers, you notice that his voice has a curious, high sound and that his face is beaded with perspiration.

When the needle stood at 2, the pressure did not seem to be strong. In fact, it was scarcely noticeable. Yet at two pounds of pressure to the square inch, all of you men inside the chamber could not have opened the entrance hatch so much as a fraction of an inch. To budge it you would have had to exert a pull equal to the weight of the ton of air pressing against it. Now you are beginning to learn what the word "pressure" means.

At last the needle touches 40. Your throat is dry from swallowing to open your ears and you feel a little peculiar, but you have passed your first test with flying colors.

The instructor raps his mallet against the outside wall, three taps. The hiss of the air dies down for a moment till the instructor opens another valve, then starts up again. But now the air is "bleeding" out and the pressure needle is falling rapidly. As it drops, moisture in the air condenses. The glass in the deadlights of the chamber fogs up; the air grows misty and chilly.

Eight More Minutes To Go

At figure 10 the pressure needle halts for what seems like a long wait, perhaps three minutes. Then it drops swiftly to the figure 5 and pauses there for five more minutes before dropping to zero. The hatch, which could not have been budged a few moments earlier, swings open easily on well-oiled hinges now that the needle stands on the zero mark, and you follow the instructor out of the

chamber feeling considerably elated by the knowledge that you have withstood the compression about which you have heard such fearsome tales--tales of how it makes ink squirt from fountain pens, breaks closed bottles, and causes men to become temporarily "slaphappy." You suspect that these tales were exaggerated, and you begin to lose your fear of pressure.

Soon, you learn that to withstand a 40-pound pressure in a lighted chamber in company with a group of others is one thing; to be underwater alone and confined in a diving helmet, dependent for your life on the watchfulness of the men who are pumping air down to you and handling your life-line, is something else again.

Your first dive will be in twelve feet of water. You will make it in full "regalia." After you have become thoroughly accustomed to wearing your diving dress and moving about in it under water, you will dive as deep as ninety feet.

In preparation for your first trip to the "bottom" you pull a pair of heavy woolen tights over your regular underwear and wear heavy wool socks on your feet. These will not only keep you warm but will also prevent chafing from the stiff diving dress.

Next you put on the diving dress which is composed of a layer of India rubber between two layers of heavy twill cloth. Helpers lace up the backs of the legs of your diving outfit to prevent the air pressure from making them "balloon" out, since too much buoyancy in the legs would topple you over. Then you put on your shoes. Soled with lead and copper, they weigh seventeen and a half pounds each. A six-inch belt, weighted with oblong lead slugs and weighing 83 pounds, is strapped around your waist, and a heavy leather harness is placed over your shoulders. The harness has a leather strap that passes under your crotch and buckles in front. Its purpose is to keep the helmet from floating off your head.

You are now carrying 136 pounds of equipment and are ready for the breastplate and 54-pound helmet. You step over to the diving ladder and descend a step or two.

Safety Line Prevents Accidents

A safety line is fastened to you to prevent any such accident as befell a commercial diver who, forgetting that his helmet was not on, stepped off the ladder and nearly drowned before he could be rescued.

The helmet is quickly screwed on and you hear the click of the safety key, designed to keep the helmet from coming unscrewed accidentally. Now there remains only the faceplate to be closed before you are entirely sealed in. But first you test your telephones, air valves, and other instruments to make sure everything is working properly. When everything has been checked, the faceplate is closed and the safety line taken off. You are ready for the descent.

You go down slowly and give yourself plenty of time to get accustomed to everything. In your nose is the smell of metal polish and of rubber; against your eardrums beats a continuous noise, the hiss of air coming into your helmet, the roaring as it escapes through the tiny openings of the exhaust valve.

You descend another rung, then another, and you look at your surroundings curiously. It is as if a piece of very fine gauze hung over the front of your helmet. But even though there is this distortion, you can still see the rungs of the ladder.

On your first dive you will be down in only twelve feet of water. But as soon as you become fully accustomed to your new outfit and feel at ease on the bottom you will go to greater and greater depths.

The instructor is holding a stop-watch in his hand to be sure that you do not stay down long enough to get "pressure happy," for if you are ninety feet down, the water will be pressing against every square inch of your diving dress with a weight of forty pounds, and only the counter-pressure of the air inside your suit keeps you from being crushed. As a result, your senses soon become dulled. You lose some of your normal efficiency. Simple tasks become more strenuous and you have trouble coordinating your movements.

After many weeks of study, of workshop training in using divers' tools, and of diving practice at lesser depths, you will be given assignments to carry out underwater. One of these assignments will be to use an oxy-hydrogen torch.

As you stand on the bottom, completely surrounded by water, your subconscious mind tells you that it is impossible for fire to burn under water.

But the instructor's voice comes over the phone, saying, "On the bottom. Go to work." After adjusting the valve on the torch, you signal for the igniter current to be turned on. Cautiously you strike the arc. Hydrogen bubbles out around the carbon tips of the igniter. A blue-white arc flashes, the torch is lighted, the flame incredibly blossoms into being. You touch the flame to metal and watch the metal curl. It is actually melting--underwater! Of course you know that the air jet creates a bubble about the flame which prevents the water from extinguishing it, but still there is something magical about it.

Other tools you must learn to use underwater are the hammer and chisel, the sledge, hacksaw, and air hammer. And you must learn to calk, patch, and weld. In addition you will learn to fasten loose piling, inspect ship bottoms and propellers, rig pontoons, and retrieve lost articles. You will also learn how to do flange work, how to excavate, and how to fit pipes under water.

CHAPTER II

Qualifications of Divers, Signals Used, Dressing and Tending

The extreme importance of the following material that pertained to diving made it advisable to present the information exactly as it was stated in the Bureau of Navigation Manual.

(Article D-5327, Bureau of Navigation Manual).

D-5327. QUALIFIED DIVERS (C.B.N.M. 3)

(1) Qualified divers are divided into three classes:
- (a) Master Divers.
- (b) Divers, first class.
- (c) Divers, second class.

(2) Master divers are the most competent leading divers. They will be designated "Master Divers" by the Bureau of Navigation. Any diver, first class, may be recommended by his commanding officer to the Bureau of Navigation for the designation of "master diver" who -
- (a) Has served at least one year with the designation of "Diver, first class."
- (b) Meets the following requirements:
  - (1) Has qualifications of diver, first class.
  - (2) Averages 3.5 in efficiency in diving and as leader of men during the preceding year.
  - (3) Is able, while on the bottom, to direct two or more divers in their tasks.
  - (4) Is able to take charge of a diving operation in an efficient manner.
  - (5) Understands all types of air compressors habitually used in diving operations.
  - (6) Has knowledge of what a ship fitted for compressed air diving operations should carry and has a practical knowledge of air system.
  - (7) Understands the principles of Boyle's, Charles's, and Dalton's laws and the theory of saturation and desaturation of body fluids and tissues.
  - (8) Understands the different forms of caisson disease and treatments required and the conditions under which oxygen poisoning occurs.
  - (9) Has a thorough knowledge of the effects of such poisonous gases as may be encountered in diving upon the respiratory system and is familiar with approved methods of treatment.
  - (10) Understands the various factors which contribute to the contraction and severity of caisson disease, and from the basic principles of decompression laid down in the Diving Manual is able to devise proper recompression and decompression tables for the treatment of caisson disease.
  - (11) Is recommended by the faculty of the deep-sea divers' school, Navy Yard, Washington, D. C., for master diver designation.

(3) Divers, first class, trained, qualified, and designated at the deep-sea diving school, Washington, D. C., must have the following qualifications:
- (a) Qualifications of a diver, second class.
- (b) Must have completed satisfactorily the course at the deep-sea diving school, Washington, D. C.
- (c) Be able to withstand pressures equal to 200 feet of water.
- (d) Be able to dive and accomplish work to depths of 150 feet of water.
- (e) Be able to use hand and power tools under water.
- (f) Be able to operate under water the gas and electric underwater cutting torches.
- (g) Understand in detail the operation and care of the machinery and apparatus required for underwater cutting.
- (h) Be able to compute the pressures of gases required to satisfactorily operate the gas underwater cutting torch at various depths.
- (i) Know the dangers that are associated with the use of such gases.
- (j) Know underwater seamanship and how to sling

and lift heavy weights.

(k) Know how to wash and reeve lines and to sweep wires and chains under submerged objects.

(l) Be able to enter a vessel with discrimination as to ability to get out; but only supervising officers will plan and decide on this.

(m) Know how to make air connections to different types of submarines.

(n) Know how to ventilate compartments of submerged vessels and make them habitable.

(l) Be able to recognize the symptoms of caisson disease.

(4) Divers, second class, may be trained, qualified, and designated on board any naval vessel or at any naval station having the proper equipment and competent officer personnel for efficient and safe instruction. They must:

(a) Be physically qualified in accordance with the manual of the Medical Department.

(b) Understand the care, preservation, and use of all equipment, such as pumps, hose, helmets, suits, etc.

(c) Know how to test out, repair, and adjust all equipment, such as hose, pumps, dresses, helmets, breastplates, valves, etc., and determine whether they are safe for use.

(d) Understand the use of and be able to use storage compressed air and air supplied from power-driven compressors.

(e) Be expert in dressing and tending a diver.

(f) Know the diving signals thoroughly.

(g) Be thoroughly familiar with the theory and practice of decompression and have a detailed knowledge of the decompression table and how to use it.

(h) Understand resuscitation and first aid.

(i) Be familiar with the contents of the Diving Manual.

(j) Have knowledge of the physics of diving.

(k) Know the methods employed in recovering objects from the bottom and the precautions to be used in recovering such objects as a charged air flask or a torpedo.

(l) Know how and when to use the recompression chamber.

(m) Be able to equip a boat for diving.

(n) Be able to anchor a diving boat in wind and tide.

(o) Be able to remain at depths of 30 feet for at least 1 hour, 60 feet for at least 30 minutes, 90 feet for at least 20 minutes, and make actual progress along the bottom simulating searching for objects.

(p) Be able to estimate an underwater situation and give an intelligent description of the same.

(q) Be able to care for and operate the Navy standard oxygen breathing apparatus.

(r) Be able to assist a diver, first class, in depths up to 90 feet.

(5) Only master divers and divers, first class, will be permitted to dive to depths greater than 90 feet, except at the deep-sea diving school at Washington, D. C., for requalification, and in emergencies, of which the senior officer present shall be the judge.

(6) In the selection and training of men for divers, commanding officers and examining boards shall be guided strictly by the Navy Regulations, the Diving Manual of the Medical Department, and current instruction.

(7) No man shall be allowed to dive until he has been given the physical examination outlined in the Manual of the Medical Department.

(8) All diving operations shall be under the personal direction of a qualified officer who shall maintain a close contact with the medical officer in order to eliminate accidents.

(9) The designation of any master diver or diver, first class, will lapse upon the expiration of 6 months from date of last qualification, if during these 6 months he has not made four dives in water, each dive to a depth of not less than 150 feet, and remain under water, from the surface to the beginning of the ascent, as follows:

Depth in feet:	Time
150 to 168	15 minutes
168 to 250	10 minutes

If the designation should lapse, an entry to this effect will be made in the service record. A man whose designation has so lapsed shall not be permitted to dive again until requalified, except for requalification or in emergencies, of which the senior officer present shall be the judge. This requalification may be made at the nearest ship or station which is equipped with personnel and equipment to safely conduct same in accordance with subparagraph (3), provided that the designation has not lapsed continuously for more than one year. If more than one year, permission to requalify must be obtained from the Bureau of Navigation, which will designate the place where requalification will be made.

No man shall be redesignated a master diver except by the Bureau of Navigation. No man shall be redesignated a diver, first class, except by the Bureau of Navigation or the deep-sea diving school, Washington, D. C.

(10) The designation of any diver, second class, will lapse upon the expiration of 6 months from date of last qualification, if during these 6 months he has not made 4 dives in water, each dive to a depth between 60 and 90 feet, and remain under water, from the surface to the beginning of the ascent, 20 minutes.

EXTRA COMPENSATION ALLOWED DIVERS OF ALL CLASSES

Article D-5326(3), Bu. Nav. Manual.

An enlisted man, who is designated a master diver, a diver, first class, or a diver, second class, in accordance with article D-5327, shall receive pay, in addition to the pay and allowances of his rating and service, in accordance with the act approved April 9, 1928, as follows:

(a) Master divers, $20 per month as long as designated as such and detailed or assigned to the duty of diving; plus 5 cents per foot of total depth for dives over 120 feet, or equivalent pressure, but not to exceed $10 per month; plus $4 per hour for each hour or fraction thereof while employed in diving in actual salvage operations in depths over 90 feet.

(b) Divers, first class, $15 per month as long as designated as such and detailed or assigned to the duty of diving; plus 5 cents per foot of total depth for dives over 120 feet, or equivalent pressure, but not to exceed $10 per month; plus $5 per hour for each hour or fraction thereof while employed in diving in actual salvage operations in depths over 90 feet.

(c) Divers, second class, $10 per month as long as designated as such and detailed or assigned to the duty of diving; plus $5 an hour for each hour or fraction thereof while employed in diving in actual salvage operations in depths over 90 feet in emergencies, as provided for in article D-5324(5). This extra pay will accrue to divers, second class, only when regularly attached to a ship or station to which divers, second class, are authorized by the Bureau of Navigation circular letter. The number of such divers, second class, drawing this extra pay must not exceed the number of divers, second class, authorized for the particular ship or station. Divers, second class, while employed in diving in actual salvage operations in depths over 90 feet in emergencies, will receive $5 an hour for each hour or fraction thereof while so employed without application of the above restrictions.

(d) The following men shall, in addition to the extra compensation authorized by (a), (b), and (c) of this paragraph receive such additional compensation as shall bring the total extra compensation to $30 per month.
   1. Divers, any class, assigned to duty with Experimental Diving Unit, Navy Yard, Washington, D. C.
   2. Divers, any class, or qualified submarine men, assigned to duty in connection with the submarine escape training tanks at the submarine bases, New London, Conn., and Pearl Harbor, T. H., not to exceed five men at each of the above training tanks.

SIGNALS FROM TENDER TO DIVER

1-Pull. Are you all right? (or when diver is going down it means STOP).
2-Pulls. You have come up too far; go back down until we stop you.
3-Puuls. Stand by to come up.
4-Pulls. Come up.
2-1 Pulls. I understand you; or answer the telephone.

SIGNALS FROM THE DIVER TO THE 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; or answer the telephone.

SEARCHING SIGNALS

1-Pull.	Stop and search where you are.
2-Pulls.	Go straight ahead.
3-Pulls.	Go to your right.
4-Pulls.	Go to your left.

AIR SIGNALS

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

EMERGENCY SIGNALS

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

SPECIAL SIGNALS FROM THE DIVER

2-1-2 Pulls. Send me a slate.

When the tender receives this signal, he will answer it with 2-1-2 and stop off a slate on the lifeline and air hose; when this is done, he will give the diver 1 Pull. The diver will haul down until he gets the slate; he then gives the tender 1 Pull. When the diver has used the slate, he gives the tender 3 Pulls; and the tender hauls up the slack until he gets 1 Pull from the diver, which will signify that enough slack has been hauled up.

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

When the tender receives this signal, he will answer it with 1-2-3 Pulls. He then stops off a piece of bunting on the life line and air hose about ten feet from water's edge; when this is done, the same routine is carried out as for sending down a slate.

5 Pulls. Send me a line.

NOTE:

All signals will be answered as they are received between tender and diver. When answering or giving signals, all slack shall be taken up in lifeline and air hose until diver can be felt before signal is given. The proper method for giving a signal is to use a gentle, distinct pull.

Special signals in addition to the above signals may be made up between diving officer and diver to take care of any salvage operations which may occur.

DRESSING AND TENDING

Two men are generally detailed to dress and tend each diver. The diver removes his shoes and puts on the heavy woolen socks. He may also don such heavy woolen underwear as he desires. At least the usual uniform trousers and shirt should be worn to prevent chafing the skin by the dress.

The diver sits on a stool near the ladder or stage. The tenders assist him to pull the dress over his legs. When his feet are in the dress, he stands up and puts his arms into the sleeves. The tenders pull the dress over his hands and lift it over the shoulders. The diver then pulls the crotch of the dress up as far as possible when the tenders lace the legs. If the dress has cuffs, the diver should dip his hands in soapsuds before placing his arms in the sleeves so that his hands will slide into the cuffs. It may be necessary to use cuff expanders to get the cuffs over the diver's hands.

Each tender puts on a shoe, with the diver either standing or sitting. The buckles of the shoes should face outward. The shoes are laced tightly and laces buckled under the straps.

With the diver seated, one tender places the breastplate pad on the shoulders and pulls the bib up over it while the other tender slips the breastplate over the diver's head. The collar is pulled up over the breastplate in front and then the holes are slipped over the studs, starting in the middle of the back and working along both sides to the front. The diver assists by raising both arms. To prevent cutting the dress, copper washers are slipped over the studs where the joints in the breastplate straps come. Then put the straps on,

being careful to place each in its proper position. Flanged nuts are put on the studs at the strap joints, a thin nut on the long stud for the control valve link at the lower part of the left front strap, plain nuts on all other studs. The nuts in the middle of the straps are set up with T wrenches first; then the nuts over the strap joints are set up. One tender then tests all nuts with the wrench, finally removing the nut for the control valve link. While working on the breastplate, one tender grasps the breastplate just under the diver's chin to protect the diver's face. Then he puts on the wrist straps if gloves are being used.

The tenders cross the belt shoulder straps and each takes one end of the belt and the middle of a shoulder strap. They place the belt against the diver's abdomen and lead the shoulder straps over the diver's shoulders. The shoulder straps cross above the lower front stud of the breastplate, pass outside of the top stud on each shoulder, cross again above the lowest stud in the back, and buckle to the belt in the rear. The loop in the jock strap is slipped over the belt in the rear and the belt buckled.

The diver stands up and the jock strap is drawn between his legs and buckled to the bolt in front. The jock strap should be tight enough to hold the slack out of the legs of the dress and loose enough so that the diver can just move the breastplate by raising his shoulders slightly. The diver can assist by bending forward and by placing his left hand over the control valve stud on the breastplate to protect the tender. Then snappers are put on if the dress has cuffs.

A life line is placed about the diver's body and belayed conveniently by a tender to prevent the diver falling overboard. The other tender grasps the breastplate under the diver's chin and assists him to the ladder. The diver climbs down the ladder until his head is in a convenient position for putting on the helmet. The pumps should then be started if diving from hand pumps.

The faceplate of the helmet should be closed loosely whenever the helmet is handled. To pick up the helmet, clear the lifeline and air hose, lead lifeline over the left port and the air hose over the right port to the front of the helmet. Then lift the helmet by the side ports, holding the lifeline and hose in place. One tender slips the helmet over the diver's head from the front and

screws the helmet tight, while the other tender holds the breastplate steady on the diver's shoulders. As soon as the helmet is on, he opens the faceplate. The helmet is locked on with a gate over the tumbler. The cotter pin through the gate should be spread sufficiently to prevent its working out. The lifeline is dipped under the diver's right arm and fastened on the right front of the breastplate. The air hose is dipped under the diver's left arm. The control valve link bracket is slipped over the lower left stud on the breastplate and bolted on tight with the bracket extending straight out over the edge of the breastplate. The hose is then fastened on the left front of the breastplate.

As soon as the helmet is on, the diver should test his telephone. He should also test his air supply as soon as the control valve is rigged in place. When the diver indicates that he is ready, the faceplate is closed tightly and the diver is given the signal to enter the water by two taps on the top of his helmet.

After the diver enters the water, he is held just below the surface for a few seconds to insure that his equipment is working properly. When he is ready to descend, he gives the signal and the tender allows him to go down.

In tending a diver, keep the slack out of his lifeline and air hose, but avoid pulling on him. During the descent, give him line as he takes it, being prepared to hold him if he stops, or to pull him up if he so signals. Be prepared to catch and hold him if he falls. The tender next to the rail should keep careful watch of the diver and his bubbles, and he should make all signals. At least one other tender should hold on to the lifeline and air hose to back up the first tender.

Tenders must keep themselves in position to pull on the lifeline and air hose instantly and therefore should stand inside the rail where they can brace themselves. Where the rail is wide or high, it may be necessary for the tender next to the rail to sit straddle of it in order to see the diver. He should always keep his leg locked under the inside of the rail and his outside foot braced so that he is in position to take as much strain as possible without danger of being jerked overboard.

All signals must be answered with the same signal to indicate that the signal has been received and is understood. The telephone is a very valuable means of communication, but pulls on the lifeline and air hose are the primary means of communication. Signals on the lifeline and air hose should always be given in addition to the word passed on the telephone.

Transmit signals on the lifeline and air hose carefully. A heavy jerk may bang the diver's head or face against the helmet, pull him about, cause him to lose his hold, or throw him off balance. In hauling a diver to the surface, start him up slowly. A sudden upward pull might cause him to blow up, since the air in his dress will expand as his depth decreases.

When the diver blows up, take in the slack as quickly as possible, deflate the dress by closing the control valve and by opening the exhaust valve if necessary, then send him back down at once if he is all right. It is necessary to take in his slack immediately because if the dress should burst, or the diver manage to deflate his dress, he will drop and get a squeeze. In blowing up, the diver will frequently break his jock strap or lose a shoe. If he breaks the jock strap, the helmet and breastplate will be forced over his head. If he loses a shoe, he may be forced to remain head down in the water, in which position he will drown if there is any water in the dress.

Keep kinks and turns out of the lifeline and air hose. Flake them down in figures of eight as the slack comes in and keep everything clear. Avoid chafing or pinching the life line and air hose. The attention of the tenders must be concentrated on the diver, and they should not be distracted from watching the diver and his bubbles and tending his lifeline and air hose by performing other duties. Other men in the vicinity must be quiet and avoid interfering with the tenders.

Lack of bubbles coming from the diver or a sudden, large quantity of air coming up may indicate something wrong with the diver. Under such circumstances it is proper to exchange signals to ascertain whether or not the diver is all right. If no answer is received, give the emergency signal and haul him up.

Except in an emergency, do not haul the diver up unless he answers the signal to come up. He may be fouled and to pull on him may make the situation worse.

Always give the diver the decompression required by the standard decompression table. If he has been working hard under water, or if the conditions under which he has been diving have been adverse, regard the time underwater as being increased proportionally and decompress him accordingly. If the diver has been under pressure previously during the same day, his decompression should be for the total time under pressure for that day.

A diving stage, a boatswain's chair, or a bowline should be provided for the diver to sit or stand on at the first decompression stop. It may have to be weighted to make it sink and should be shackled to the descending line so that it can be run up and down the line; while the diver is being decompressed, the lifeline and air hose must be tended carefully and with practically no slack in order to catch him if he should lose his hold or fall.

When the diver comes up the ladder a convenient distance, put the lifeline around him and secure it. Open the faceplate; then cast loose the lifeline, air hose, and control valve from the breastplate, and dip them out from under the diver's arms, one at a time. Remove the helmet and assist the diver to the stool. Remove the lifeline and snappers if they are used and then unfasten the jock strap and remove the belt. Remove the shoes and wrist straps if they are used. Unbolt the breastplate and remove by pulling collar over the studs in front and then off the other studs, working along both sides together to the back. Remove the pad and unlace the legs of the dress. Pull the diver's arms from the sleeves of the dress before removing the dress from the diver's shoulders. One tender then stands behind the diver, passes his arms around the diver's body and holds him while the other tender pulls the dress off his legs.

Where it is necessary to decompress the diver in a recompression chamber, only the helmet, belt, and shoes are removed as quickly as possible and the diver rushed into the chamber.

When the diver is lowered into the water and hoisted out with a diving stage, he is fully dressed before he steps on the stage and none of his equipment is removed until after he steps off the stage. It is not necessary to use a lifeline to prevent the diver falling overboard and drowning, but his lifeline and air hose must be carefully tended to prevent his falling. The stage must be kept level and should not be permitted to bump against the side or anything else, since the diver may be thrown and injured, at least to the extent of wrenched muscles and bruises.

DIVING

The diver himself should observe all the details of the operations performed by the tenders who dress him and check their work in order to assure himself that he is properly dressed and assisted.

The diver must not attempt to walk about with the breastplate on unless he is assisted by a tender grasping the front of the breatplate under the chin. It is very easy for him to fall, especially with shoes and belt on and this help from a tender may prevent the diver cutting his face on the breastplate or otherwise injuring himself.

As soon as the helmet is placed on the breastplate, test the air supply by opening the air control valve. The pumps should be started before the helmet is put on if diving from pumps. Before the faceplate is closed, test the telephone by talking to the telephone tender and having him reply.

Close the exhaust valve all the way and then open it 3 times. This should give proper ventilation at all depths.

When the faceplate is closed, crack the air control valve to ventilate the dress slightly. While the faceplate is closed, never shut off the air control valve tightly. If the exhaust valve is a trifle stiff, the dress may inflate so much that the diver's movements are hampered, in which case he presses the chin valve as much as necessary to exhaust the excess air.

The control valve is operated with the left hand. To have more air come to you, turn the valve toward you; to take excess air away from you, turn the valve away from you. "More air - to me, less air - away." Never close the control valve completely.

Two taps on the helmet tell the diver to enter the water.

As his body is lowered into the water, the diver will notice that his dress is pressed tightly against his body by the weight of the water. When the water level reaches the helmet, the diver will find it difficult to breathe because he must expand his ribs against the water pressure around his chest. If he then opens the control valve to increase the air pressure in his helmet until it equals the water pressure at the depth of his lower ribs, he will be able to breathe easily and normally because the air pressure in his lungs will be equal to the water pressure around his chest. The upper portion of his dress will then be inflated just enough to buoy the weight of the breastplate, helmet, and belt off his shoulders. If the dress is inflated too much, the resulting excess buoyancy will make it very difficult for the diver to handle himself underwater and may cause him to float to the surface.

When the control valve is not opened far enough, the breastplate will press down on the shoulders and the dress will press on the ribs, making it difficult to breathe. If the air pressure in the helmet falls below the water pressure, the water pressure on his body may force a little blood from the diver's ears and nose. This is a common occurrence with inexperienced divers. The lack of sufficient buoyancy in the dress will force the diver to carry more of the weight of his equipment, tiring him out quickly. The lack of air flowing through his helmet will also cause insufficient ventilation.

After entering the water, the diver should stop for a minute or two with his helmet just below the surface and check his equipment. He should adjust his air control valve so that the dress is sufficiently inflated to just take the weight of the helmet and breastplate off his shoulders. This adjustment of the control valve with the helmet exhaust valve open 3 turns should give sufficient ventilation at all depths.

When the diver is satisfied that he is ready and has given the signal to descend, he grips the control valve with his left hand and slides down the line, adjusting his air supply with his left hand as he descends. He should avoid swinging around the descending line, thus getting turns of his lifeline and air hose around it.

It is desirable to get to the bottom as quickly as possible. More time is then available to do the work on the bottom and the decompression time is shortened. The speed of descent is controlled by clinging to the descending line.

Speed of descent should be controlled by the diver at all times. For various reasons it may be necessary to slow up the descent or even to stop on the descending line. The air supply may not increase quickly enough to keep up with a too rapid increase in the dress, the diver may have trouble clearing his ears and sinuses, he may become dizzy, an obstruction may be encountered, and the danger of a fall is always present. Going down too fast will cause dizziness and if a diver arrives on the bottom in that condition, he can do nothing efficiently until his reactions are again normal. The deeper the depth, the longer it will take for the dizziness to wear off.

It is usually easier to clear the ears going down on a descending line than it is in a recompression chamber or diving tank. It may be necessary to stop or climb back up a few feet to equalize the pressure in the ears.

The diver should always endeavor to keep his sense of direction. Observation of the light, the current, objects in the vicinity, the tend of his lifeline and air hose, the slope and characteristics of the bottom, the position of his descending weight and circling line will help.

Keeping the lifeline and air hose clear at all times will prevent fouling. By remembering his movements on the bottom, the diver can frequently readily clear himself if he should become foul. The most common instances of fouling are due to getting turns of the lifeline and air hose around the descending line, the lifeline and hose of another diver, or the decompression stage.

Under heavy exertion, 3 turns' opening on the exhaust valve may not prove sufficient ventilation. Under such conditions, the diver may find it desirable to open the exhaust valve more and increase his air supply accordingly. A diver working in other than an upright position may find it necessary to decrease the amount of air in his dress. To close the control valve too much will reduce the ventilation in the helmet. Under such conditions, the exhaust valve should be opened more than 3 turns.

The spit cock serves two purposes. It can be opened to supplement the exhaust valve in releasing air from the dress. By inclining the helmet so that the spit cock is down, thus slightly building up the air in the dress, water can be blown out of the helmet when the cock is opened.

Lack of ventilation will be manifested by fogging of the windows in the helmet and by the diver tiring easily and breathing heavily.

A leak in a dress below the helmet is not normally serious. The diver may find it uncomfortable, but as long as he can keep the water out of the helmet by keeping upright, he is in no danger. At any time that a diver finds it impossible to get upright, such as from loss of a shoe, he should come up.

Next to a fall, a diver is endangered most by blowing up. Under such circumstances, he comes to the surface with no decompression. As his dress inflates, the diver's arms and legs will be extended rigidly by the dress so that he is unable to help himself. The jock strap may carry away, shooting the helmet and breastplate over the diver's head. The shoes and belt may come off. If the dress bursts from the air pressure, the diver will drop to the bottom again, with an excellent chance of drowning or of being squeezed. Blowing up is most apt to occur when working either prone or in a strong current.

A diver must practice the close regulation of his air supply and his buoyancy at every opportunity. He must learn to avoid using more air than necessary; yet he must use enough to insure proper ventilation. Very expert divers can accomplish an amazing amount of work with a minimum of air. They can regulate it so that they can float on the side of a hull.

In diving, go to the job as quickly as possible, get the work done rapidly, and take care of yourself. No one but the diver knows exactly what conditions are confronting him so he can depend on no one but himself.

After landing on the bottom, the diver should remain at the descending line for a moment to regulate his air supply, to get his bearings, and to accustom himself to the pressure in case he has become at all dizzy during the descent. Some men have a tendency to become dizzy during the descent, others at certain depths, and a few men grow gradually dizzy after they are on the bottom.

A diver should conserve his strength and avoid getting into difficulties by making all his movements deliberate. By planning each move in advance, he can accomplish more work with greater safety to himself. The diver should avoid getting frightened or excited, since useless struggling or rushing about will exhaust him and may make a bad situation worse. "In a tight spot, stop to rest, and try to figure an easy way out." A diver must first be sure of his own ability to do the work and to take care of himself. Secondly, he must have confidence in the ability of his tenders to assist him.

The control valve should never be closed tightly by the diver. This valve has a rather coarse adjustment and should be opened or closed slowly. In diving from a hand pump, the control valve may be left fully opened. It should turn rather stiffly so that it will not move easily if the hand-wheel rubs against an object.

The exhaust valve may become fouled by silt so that it does not operate properly. In this case, use the spit cock as an exhaust valve. Chin valves of old type exhaust valves without the nonbow-up feature can be pushed only as far open as the exhaust valve is already open.

If the air supply fails, the diver should close his exhaust (and spit cock, if open) and signal to be taken up. There is enough air in the dress to supply his needs for at least eight minutes. The safety valve will prevent the air from leaving via the hose.

A diver having his lifeline and air hose badly fouled can be freed by having a second diver remove the fouled hose from the first diver and connecting a clear hose to the control valve of the first diver. A manila lifeline is then attached to the fouled diver and his old lifeline cut. It is, of course, better for the second diver to clear the fouled diver if he can.

If the helmet leaks, no water will enter if the diver can get in such a position that the leak is at the lowest part of the helmet. With a broken faceplate, the diver should lean over forward or lie down, so that the air in his helmet will keep out the water.

In diving in shallow water where there is no current, divers sometimes find it easier to work with a "half-belt," which is made by removing some of the weights from a regular belt, taking the same number from each side. Not over four weights of a 10 weight belt are removed as a rule.

The diver should always carry a knife. It is often valuable for cutting lines and the diver may need it to clear himself.

By cutting off his shoes or his belt, a diver can float himself to the surface, even though his air supply has failed. The resulting loss of weight will float him to the surface. In slipping the belt, get clear of the belly band first and then the shoulder straps. As soon as the shoulder straps are clear, the helmet is apt to shoot over the diver's head.

While going down, the diver may be affected by pain in the ears, in the sinuses, hollow spaces in the bones around the eyes, and sometimes in the teeth. Normally the air passes from the throat to the inner ears via the Eustachian tubes, equalizing the pressure on the ear drums. These tubes can be opened by swallowing, by yawning, or by holding the nose shut and blowing except when they are closed from inflammation. If the pressure is increased sufficiently in spite of the pain, the ear drums will be ruptured. They usually heal readily without affecting the hearing but the inner ear may become infected, which will be harmful to the hearing. When the passages from the sinuses to the nose are closed, they may sometimes be opened by snorting or blowing the nose. Excess pressure on the outside of the sinuses may cause a hemorrhage into the cavities, or even collapse the wall of the sinus, causing danger of infection. Teeth which ache under pressure indicate loose fillings or other defects and should be repaired by a dentist.

CHAPTER III

TESTS AND CARE OF DIVING EQUIPMENT
(Bu. C. & R. Manual, paragraph 3633).

All outfits of diving apparatus furnished to a vessel shall be kept ready for immediate use.

Spare parts of diving apparatus not required for probable immediate use shall be kept in a suitable storeroom and when drawn for use shall be replaced by new ones at the earliest practicable opportunity.

All diving apparatus on board ship shall be critically inspected once each month. At this inspection the efficiency of the diving air pumps shall be proved and recorded in the ship's diving log book; the amplifiers shall be tested by connecting the cables to batteries and helmets and talking over them; each outfit shall be inspected as to its completeness and serviceable condition, and the condition and quantity of the spare parts shall be looked after.

All diving apparatus, except spare parts, shall be inspected once each week for cleanliness, condition of stowage, etc. In connection with this inspection, the diving air pumps shall be hove round several times; helmet valves, faceplates, and fittings looked after; amplifiers tested; diving dresses inspected for dampness, and aired; dirty woolens washed and dried; oil separators cleaned, if necessary, and the lufer 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, and the washers looked after; the interior of all chests cleaned of any oil, grease, or dirt and if the apparatus has been in use, the contents of each shall be checked over to see that they are complete.

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 shall be conveniently arranged for his inspection; all chests shall be unlocked, the covers opened, and men standing by to exhibit the contents as he may require.

APPROXIMATE WEIGHT OF
U. S. NAVY STANDARD DIVING EQUIPMENT

Weight of helmet	54	lbs.
Weight of shoes (each)	17½	"
Weight of belt	83	"
Weight of dress	18½	"
Weight of gear on diver	190	"
Weight of 50 foot length of air hose	22	"
Weight per foot of lifeline, sennit	¼	"
Weight per foot of lifeline, rubber	½	"
Weight of Mark III, Navy Standard Pump	600	"
Weight of Test Tank	175	"
Telephone outfit, new style	110	"

CHARACTERISTICS (OF 2-CYL. DOUBLE-ACTING AIR PUMPS)

Mk.	Type	Bore in in.	Stroke in in.	Cyl. Cap. 1 rev. in cu. inches	Theor. revs. for 1.5 cu. ft. at 1° atmos.	Cistern	Front door	Valves
I	Morse	3 7/8	6	277.7	9.33	low	low	Morse
I-I	Morse	4	6	296.3	8.75	low	low	Morse
I-2	Morse	4	6	296.3	8.75	raised	high	Standard
II	Schrader	4	6	296.3	8.75	low	low	Schrader
II-I	Schrader	4	6	296.3	8.75	raised	high	Standard
III	Navy Stand.	4 1/2	7¼	405	6.4	Standard	Standard	Standard

Capacity of connections and fittings is 83 cu. in. except Mk. II and Mk. II, Mod. 1, which are 43 cu. in.

Capacity of 50 ft. length of hose, 1/2" inside diameter, is 117 cu. inches.

Specifications for a new Mk. III pump:
80% efficient at 100 lbs./sq. in. and 30 r.p.m.
Pump for 1 hour at 100 lbs./sq. in. and 30 r.p.m.

$$\text{Efficiency in per cent} = 100 \times \frac{\text{Theoretical number revolutions to build up test pressure.}}{\text{Actual number revolutions to build up test pressure.}}$$

Except in an emergency, diving to depths in excess of 72 ft. should not be attempted with a Mark hand pump.

Maximum practical speed for a hand pump is about 30 r.p.m. This figure decreases as the depth increases.

FORMULA FROM DIVING MANUAL

Minimum Air Supply Required by Diver.

$S = 1.5 \times (1 + (F \times .0303))$
S is the required minimum air supply measured in cu. ft. per minute at atmospheric pressure.
F = depth in feet.

Note: Pressure per foot depth in salt water is $\frac{.445}{14.7} =$ .0303 atmosphere.

DIVER'S AIR SUPPLY FROM FLASKS:

Allow 1 atmosphere from flask to charge volume tank, hose, etc.
Furnish 4.5 cu. ft. per min. air to each diver.
Keep a reserve of 200 lbs. sq. in. of 15 atmospheres over pressure at depth.
Minimum of 3 flasks to be used; one not to be used except in emergency.
In depths over 120 ft., a stand by boat equipped with at least 3 flasks to be at hand.
Duration of air supply in one flask$=\frac{C(A-(15+E+1)}{4.5\,D\quad E+1}$
C is capacity of one flask in cu. ft.
A is atmosphere's excess pressure in air flask.
D is number of divers.
E is atmosphere's excess pressure to which dive is made.

EFFICIENCY OF DIVING AIR PUMP

$$R = \frac{\frac{CP}{14.7}}{T}$$

Per cent efficiency = $100 \frac{R}{X}$

T is theoretical capacity of pump in cu. in. per revolution.
P is test pressure in lbs. per sq. in. gauge.
C is capacity of test tank, air hose, and pump fittings in cu. in.
R is theoretical number of revolutions required to charge test tank to P.
X is number of revolutions actually required to charge test tank to P, found by averaging results of at least 3 trials.

OPERATION OF A PUMP TO FURNISH MINIMUM AIR SUPPLY

$R = \frac{2592}{N}$
$X = \frac{100 \times R \times (1 + D \times (.0303))}{E}$

D is depth in feet.
E is efficiency of pump.
N is capacity of air pump per revolution at atmospheric pressure in cu. in.
R is number of revolutions per minute required to furnish 1.5 cu. ft. per min., or 2592 cu. in. per min., at atmospheric pressure.
X is number of revolutions per minute required to furnish 1.5 cu. ft. per min. at D

POWER-DRIVEN COMPRESSORS

The air must be as pure as possible.
Use smallest quantity of oil with highest possible flash point to lubricate cylinders.
Air supply must be adequate for a relief diver.
Auxiliary means of air supply must be instantly available in case compressor fails. Either an accumulator of adequate capacity or a separately powered compressor must be available.
Supply each diver with 4.5 cu. ft. air at a pressure 30 to 50 lbs. in excess of pressure at depth.

Power-driven compressors usually have the capacity stamped on the nameplate. If not, it may be computed from cylinder dimensions and r.p.m. In multistage compressors, the volume will be the capacity of first stage cylinders.

DEEP-SEA DIVING SCHOOL
NAVY YARD, WASHINGTON, D. C.

PRECAUTIONS TO BE OBSERVED IN THE OPERATION OF THE DIVING PUMP MANUFACTURED BY A. SCHRADER'S SON, INC.

1. When the air pump is to be laid by or lifted about, unscrew the nut beneath the name plate marked "WATER DRAWOFF" and draw off the water from cistern to prevent corrosion.

2. Should it become necessary to take any part of the air pump apart, care must be taken to replace the parts according to the marks.

3. Use neatsfoot oil in the pistons (supplied by means of the pet cock on top of the cylinder cover). Care must be taken that this cock is kept closed after oiling.

4. A. The bottom valves can be examined or repaired by laying wing nuts.
B. Remove the air chamber covers which are held by hexagon cap screws.
C. The suction and outlet valves can then be removed with a monkey wrench. The operating parts of both valves are interchangeable. When the operating part is used on the suction valve, the brass spring is reversed and a nut and pin added.

5. To keep the cylinders cool, water must be occasionally supplied to the cistern, which is done by pouring it into the funnel on the back of the pump box, with the nameplate marked on the door of the funnel "water supply." The best results can be obtained from the pump by keeping the water at 60 degrees F.

6. If the air pump has been laid by and works hard, pour into the cistern some warm water which will warm the cylinders and soften the oil around the piston.

7. The cylinder covers must be removed when repairing the packings or plunger cups. A "piston tool" accompanies each outfit and is used in putting the piston back into the cylinder after repairing.

8. When the air pump is required for two divers, the control lever should be placed to the left-hand side, marked "one cylinder." When one diver is to be supplied with air in deep water, the lever should be placed on the right-hand side marked "two cylinders."

9. Before starting to use the pump on any occasion, see that each and every bearing is properly oiled before starting; the oil cups on the main bearings and crank shaft bearings must also be inspected carefully before using the pump.

10. When the pump is to be laid by, the steel parts should be rubbed well with vaseline or other heavy oil to prevent rusting.

11. The pump is so arranged that the oil which is not absorbed by the various packings will gather in the drain plate in the bottom of the pump box. This box is supplied with a special plug through which the oil should occasionally be drawn off. The top of this plug is so arranged that it can be entirely screwed out of the plate. After drawing off the oil, be sure to screw the plug in tight.

12. The pump should be started before the diver's faceplate is closed. The speed of the pump should not be permitted to drop below the speed calculated to furnish the minimum air supply for the diver. Keep the pump running until the diver is out of the water.

13. Make certain that all parts of the pump are tight and can not come loose. The handles and flywheels must be well secured.

14. Keep all loose gear clear of the pump so that it cannot foul the mechanism and stop the pump.

15. The pump must always be lashed down before it is used. Turnbuckles are the best means of securing the pump.

NOTES ON PATCHING DIVING DRESS AND ATTACHING CUFFS AND GLOVES

To apply a patch. Cut a patch of the desired size and shape from a piece of patch cloth, rounding off all corners. Remove loose fabric or other material and old rubber cement from the area of the dress to be covered by the patch. Use an abrasive, such as sandpaper, to roughen this area; then clean it with gasoline or carbon tetrachloride. Strip protective cloth from patch and clamp patch flat to a board with heads of thumb tacks in such a way that tacks do not pierce the patch. Apply at least three coats of rubber cement (Goodrich No. 4 cement is recommended) to both dress and patch, allowing each coat to dry until it is tacky before applying the succeeding coat. Use a brush and do not touch the cement with fingers. When the last coat of cement is dry enough, lay the patch on the dress and press it down firmly or tap with a wooden mallet, working from the center to the edges to remove all air bubbles and wrinkles.

To attach gloves. With the dress right side out, tightly place a wooden plug in the sleeve. Loosen the lower part of the elbow patch and fold it back. Measuring from the bottom of the sleeve, prepare a 2-1/2" surface for patching. Cut off the gauntlet of the new glove as follows: Remove the heavy edge only for No. 3 dress, cut off 1 inch for No. 2 dress, cut off 2 inches for No. 1 dress. Turn back 1-3/4 inches of top of glove over the outside of the gauntlet. Slip the glove over the small end of the wooden plug until it touches the sleeve. Have the thumb of the glove lined up with the sleeve so that the glove hangs in the natural position of the diver's hand. Roughen the turned down portion of the gauntlet; then apply cement as for patching. Roll the turned-down portion of the gauntlet up over the sleeve and press down firmly. Cut enough to encircle the sleeve and have the ends overlap 2 inches. Apply one strip evenly over the joint between the glove and the sleeve and replace the elbow patch. Turn the sleeve wrong side out and apply the other strip to the inside of the sleeve in the same manner. If possible, the dress should not be used for twenty-four hours to permit the rubber cement to dry thoroughly.

To attach cuffs. Clean, and prepare the sleeve of the dress the same as for gloves, but on the inside. In other words, have the diving dress sleeve turned inside out. Proceed the same as for gloves except that cuffs are universal and there is no right or left hand.

Factory-attached cuffs are also sewed on, but it has been found that sewing is unnecessary, and a three-cornered sail needle will cut the rubber and fabric of

the dress.

If the rubber collar becomes torn, it should be vulcanized by an experienced man. Care should be exercised so as not to overheat when vulcanizing, as this will cause the rubber to deteriorate.

When applying cement to rubber, a thin coat is sufficient, but it should be put on thick when used on the fabric since this material absorbs a great deal.

Dresses are now issued with the collars already punched. Stud holes will almost never be torn out because of the exactness of the punching and the strength of the ridge added to the inside of the new style collar.

In an emergency, torn collars may be repaired by sewing sides of tear with small herringbone stitches and applying rubber cement liberally.

When a new dress is received, it is recommended that the sleeve lacing flaps be cut off close to the sleeve, taking care not to injure the material of the sleeves. These lacings are of no benefit and may interfere with the diver's movements. Since the crotch and the knees of the dress receive the most wear, it is suggested that additional patches be placed at these points on all new dresses.

DIVER'S AIR HOSE

Extracts from Bu. C. & R. letter, file L2/JJ-33119(ME) 6/19 of 20 May, 1937.

It will be noted from the specifications that before the hose is accepted, representative samples are subjected to hydrostatic pressure tests of 1,000 pounds per square inch. The bursting pressure tests are not made on each length of hose. Even if the hose withstands such tests without bursting, the strains set up weaken the hose and develop permanent defects which render it unsafe for use as diving air hose. Present instructions prohibit the issue of diving air hose over three years old. Irrespective of whether the hose is in service or in store during this period, a gradual reduction in its initial strength is expected.

Attention is invited to the fact that Article 3611 (1) of the Diving Manual does not direct that diving air hose be retested with this pressure but merely states in effect that 1,200 pounds was the bursting pressure to which diving air hose is subjected before its acceptance from the manufacturer. Subsequent to the printing of the Navy Diving Manual, this test pressure was reduced in actual practice and in the specifications to 1,000 pounds.

Ordinarily any diving hose manufactured within the two years of the date of use should not require retest before its use, unless it has been cut or damaged in storage. If it is over three years old, it should not be used at all. If it is tested, the test pressures should be not higher than those necessary to insure the strength of the hose for the maximum depth of dive to be made plus a reasonable factor of safety. Under ordinary circumstances test pressures equivalent to seventy-five per cent of the original proof pressure (250 lbs.) would be sufficient.

NOTE:

Diver's air hose should be tested each time before it is used. It is believed that this test pressure should be 1-1/4 times the pressure at which the hose is to be used, or 1-1/4 times (pressure of depth of dive ≠ 50 lbs. per sq. in.). Air hose must be kept free of oil, paint, and grease, since these materials will rot the rubber. Hose that has been cut or chafed should be discarded. Diver's air hose should not be used for any other purpose.

HELMET

Before using a diving helmet check the following:

1. The non-return, or safety valve, should be checked for defects and for tightness. One method to check for tightness is to invert the valve in a low pressure air line and hold the end in water to check for leaks. A simpler method is to attempt to blow smoke back through the valve. If the valve stem works smoothly and the spring is strong enough to return it to its seat and holds the smoke with the low pressure a man is able to exert with his lungs, the safety valve is working perfectly. This valve is an extremely important feature of the helmet as any interruption of the air supply will cause the diver to be squeezed unless the valve is working properly.

2. The exhaust valve and exhaust tube should be checked for being clean and the springs for proper tension. The valve seat should be clean so that the valve will seat tightly.

3. The windows should be checked to see that they are firmly embedded in their litharge seats and the lenses not cracked. Putty may be used in place of litharge.

4. On the faceplate: (a) Check the hinge, hinge pin, and cotter pins for defects. (b) The rubber gasket and knife edge should be checked. (c) Concerning the butterfly nut and stud (if rim is not of the countersunk type), wire the butterfly nut bolt to the faceplate to prevent the nut from sliding off the rim of the faceplate.

5. The spit cock should work stiff enough so that it will not accidentally open. Check it for its stop pin and hole being clear when open.

6. On the amplifier connection, check washers and see that the connections are made up tight and will not leak.

7. Check the helmet lock for defects. See that the safety gate is in place.

8. Be sure that the leather gasket seats evenly all around and that it is treated with neatsfoot oil occasionally.

9. Check the bayonet joint screw threads for burrs and defects.

10. Examine the breastplate studs for proper fit and see that they have no defects. See that the nuts turn freely on them. Loose studs should be sweated in tightly.

11. Check the straps for proper fit and see that their serial number corresponds with the helmet.

12. Be sure to closely check the control valve for defects and tightness. Carefully adjust the valve packing so that the valve will not be turned accidentally. All experienced divers insist that the control valve work stiffly.

13. See that the diving hose is free of soapstone; check the leather washers; examine the joints for firmness and see that they are properly clamped. Note date of

manufacture and if more than two years old or if it shows much use, test it in accordance with instructions. Wash out the soapstone with fresh water. See that the leather washers do not restrict the flow of air.

14. Check the amplifier for operation by testing it.

15. See that the lanyards are in good condition.

16. See that all metal parts are free of verdigris and corrosion.

17. If it is necessary to use oil for cleaning purposes, remove the oil and rub the surface with a clean rag. After using the helmet, disassemble the exhaust valve, clean all parts, dry and reassemble them with a light coat of vaseline on the springs. When not being used, put the straps and nuts on the breastplate studs. Keep the helmets on the breastplates and the breastplates on the racks.

THE DIVER'S COMMUNICATION SYSTEM

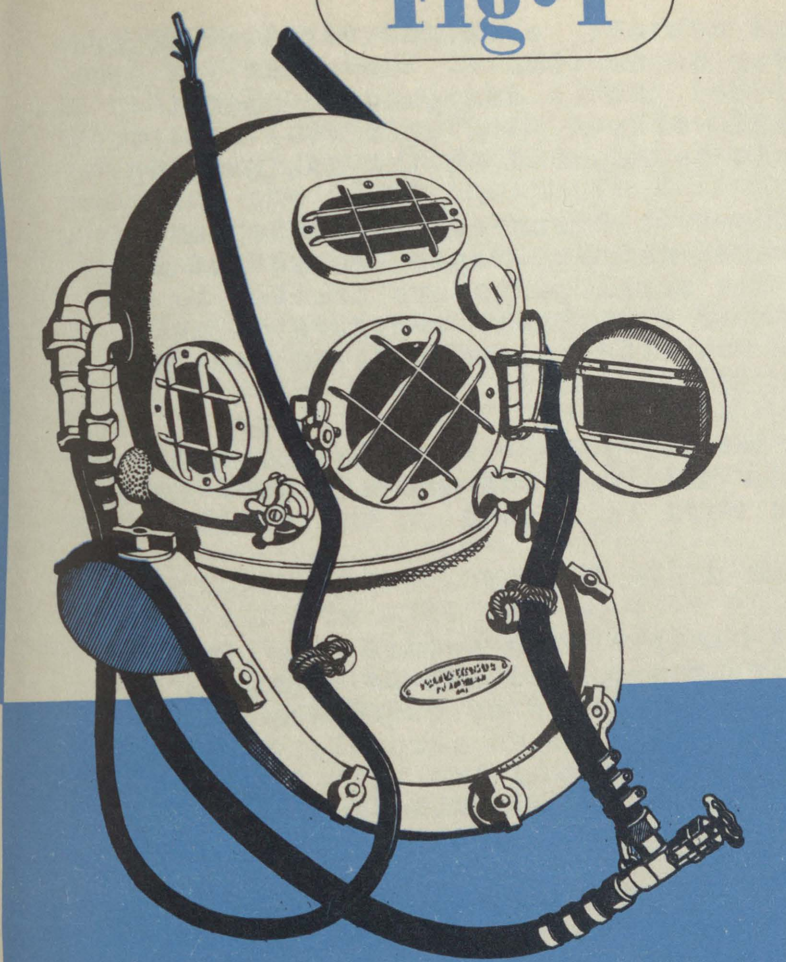
The present type of communication system now being used successfully is the Diving Amplifier Equipment made by the Guided Radio Corporation. The use of the two-way trans-ceiver is of great importance because it eliminates the old style head set worn by the diver and makes intercommunication possible without necessitating the diver's cutting off his air supply in order to hear. The Diving Amplifier Equipment is designed to provide for two-way communication between the tender station on the surface and from one to three divers on the bottom. In all cases speech pick-up and reproduction are obtained on the reproducers, these units being used in both their normal capacity as reproducers and as microphones. The system is normally set up for transmission of speech between all connected divers and the tender. The control panel has switching facilities that permit the tender to converse with any one particular diver. Tone and volume controls make the speech more intelligible since it is picked up under varying pressure conditions.

The amplifier is housed in a heavy steel case plated and painted to resist corrosion. The control panel is located on the front of the case and connection to the three divers' cables is made through three receptacles along the bottom of one side of the amplifier cabinet.

Fig·1

THE DEEP SEA DIVING HELMET

The air hose which is stopped (i.e., secured, fastened) to a small pad eye on the left side of the breastplate furnishes the diver with air. The air control valve, connected to the air line and within easy reach of the left hand, is stopped to a long stud on the left side of the breastplate by means of a link bracket. Passing under the diver's left arm, the air hose is attached to the safety or non-return valve placed on the right rear side of the helmet. The safety valve prevents air from going back up the hose in case of an accident that punctures or severs the air hose. The only other line to the diver is the communication cable which, being tested to 2,250 lbs., is sufficiently strong to be used as the life line. The life line is stopped to a small pad eye on the right side of the breastplate; after it passes under the diver's right arm it crosses the air hose in the back and enters the helmet on the left rear side. For regulating his buoyancy, the diver has, in addition to the air control valve, a valve on each side of the face plate, viz., the non-blow-up exhaust valve on the right side, and the supplementary relief valve or "spit-cock" on the left side. To prevent the helmet from being unintentionally detached from the breastplate, a safety lock is placed at the rear of the helmet in the position shown in detail. The diver's double-twill-and-India-rubber suit is fastened to the headgear by clamps around the outside of the breastplate and is made airtight by eight small and four large wing nuts with the aid of a "T" wrench. In order to do underwater welding and burning, the protective bronze grating is removed and a special welder's supplementary face plate is mounted over the usual glass face plate.



NON-BLOW-UP EXHAUST VALVE

HELMET SAFETY LOCK

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

On the other side of the cabinet, arranged vertically, are the three receptacles for connection to the power for operation of the amplifier. It is designed to operate from 115 volts D. C., 155 volts A. C., or 12 volts D. C. The tender's speaker unit is mounted on the cabinet top.

The divers' reproducer or trans-ceiver, which mounts in the recess of the diving helmet, has a protective grill that covers it and all the metal parts are treated to resist corrosion. Because of the highly complicated and restricted nature of a detailed explanation, address all queries to the Bureau of Ships.

Although the trans-ceiver is a very valuable means of communication, signals on the lifeline and air hose should always be given when the word is passed on the trans-ceiver.

THE DIVER'S AIR SUPPLY

The manually driven air pump has become obsolete by the development of easily transported six to eight horsepower compressor units which readily maintain about 120 lbs. of pressure per square inch in an accumulator tank. They are equipped with a governor and two relief or pop-off valves. The high-pressure gauge indicates the amount of pressure the divers have in reserve in the volume tank, and the air regulator is used to regulate the amount of air being sent to the divers. The amount of air is shown on the low-pressure gauge which immediately follows the regulator on an air manifold used for diving. After leaving the air regulator and passing through the low-pressure gauge, the air then passes through an oil separator and thence to the divers. The so-called oil separator is a filter that keeps oil and water from reaching the diver through his air supply line. This is necessary because when air is compressed, the change in temperature causes a condensation on the inside of the volume tank and since moving mechanical parts need to be lubricated, the diver should not be further handicapped by being forced to work under any more unfavorable conditions than are necessary, i.e., with oil and water inside his helmet.

DIVING HELMET EXHAUST VALVE

One of the principal dangers that the diver must guard against is the possibility that the over-inflation of his dress will cause him to blow up. It is most apt to occur when the diver is frequently changing his position and remaining for several minutes at a time on a stooped or bent position. This brings his exhaust valve lower than his back and shoulders. Air will accumulate in the back of the dress. When the diver straightens up, the accumulated air flows to the upper part of the dress and expands, thus inflating the arms of the dress and rendering the diver incapable of reaching his air control or helmet exhaust valves, and blow-up results, with the attending dangers explained elsewhere in this work.

In the past, blow-ups have occurred to even our most skilled and experienced divers, and the ever-present thought of the possibility of blow-up causes the average diver to spend much of his time on the bottom regulating his air supply. This knowledge ever present in the mind of the diver at work must necessarily have an adverse moral effect.

With the non-blow-up type of valve in use the diver can inflate his suit and blow up only if he so desires, but at no time will the pressure inside his dress be so great that he cannot reach his air-control or helmet valves. Therefore, unintentional blow-up is somewhat controlled.

The operation of the non-blow-up type, helmet exhaust valve is essentially the same and adjustments are made in the same manner as in the old type. The major difference is in the introduction of a secondary spring which permits further opening of the valve, regardless of the setting, when the air pressure of the helmet exceeds two pounds pressure per square inch.

The valve is shown in figure one and the parts are designated as follows:

A----------Chin Button.
B----------Exhaust valve stem.
C----------Exhaust valve body.
D----------Bonnet guard.
E----------Bonnet.
F----------Adjusting screw.
G----------Adjusting hand-wheel.
H----------Exhaust valve disc.
I----------Exhaust air escape channel.
J----------Valve stem adjusting sleeve.
K----------Primary valve spring.
L----------Retainer ring.
M----------Valve stem adjusting sleeve set screw.
N----------Secondary valve spring follower disc.
O----------Secondary valve spring.

GENERAL NOTES ON DIVING

Before going down, the diver should understand the exact conditions under which he is to work. He must know exactly what he is to do. It is best to illustrate his work on a drawing or sketch if possible.

If the diver finds that he cannot proceed according to his instructions, he should stop where he is and inform the supervisor of the circumstances. The supervisor can then inform the diver as to what he is to do under the new circumstances.

Because a diver works under handicaps, as much of his work as possible should be done before he goes down. He should not be expected to exert himself to move heavy objects or to walk long distances on the bottom. His tools and gear should be selected with care to insure that they are the most effective and efficient for the work to be done underwater. It is dangerous for the diver to work on a long scope of lifeline and air hose. The tenders can then be of little assistance to him. If he blows up, a very large amount of slack must be taken in quickly.

Skill and judgment in rigging will assist the diver to a very great extent. His descending line should land him as close to his work as possible. Heavy weights should be moved by lines from the surface. In working on a ship, one or more hogging lines will enable the diver to stay against the bilge or to stay around the propellers. Work on a ship's hull will be facilitated if a stage of some sort is rigged for the diver. Wooden stages must be weighted so that they will sink. Ladders sometimes make excellent stages since the diver can keep himself on them by thrusting his legs through the rungs, leaving both hands free for his work.

When it is necessary to heave on any lines from topside, bring the diver to the surface first. This will avoid any possibility of injuring or fouling him. While a diver is down, mooring lines and anchors should be kept secured under all circumstances.

Divers have been injured while working suspended from a crane. At no time should a diver work with any rigging led to power machinery. Either a misunderstood signal or the accidental operation of such machinery could easily result in a serious accident. Divers should never be required to work around any lines which by any possibility might shift or become taut. It is also dangerous to be around heavy material which may move.

Care must be taken that tools, lines, and other objects are not dropped on the diver or across his lifeline and air hose. When sawing off piling, or under any other circumstances where objects might topple over on the diver, such objects should first be secured from topside. Make certain that the propellers and rudder of a ship can not possibly be moved while the diver is down. It is best to bring the diver to the surface when ships or boats approach the locality of diving operations. Be prepared for heavy swells and washes from passing vessels.

An excellent general thumb rule for working under water is "Do not try to do more than one thing at a time." While a diver is under water, no activities should be permitted in the vicinity except those necessary to assist the diver with whatever he is doing at the time and these should be under the diver's control.

A diver should never pass under an obstruction, but he should go over or around it. If he blows up or has to be pulled up, he may be hung up part way between the bottom and the surface if his lifeline and air hose lead under an object. Therefore, a diver should not cross under the keel when diving on a ship.

If the diver loses his distance line or cannot find his descending line, he should signal to his tenders to pull him up. It would be a waste of time to search for either line. By leading the lifeline and hose close to the descending line, the diver may find the descending line again.

DIVING IN CURRENTS

A slight current can sometimes be used to advantage by a diver. Its flow will give him direction. If he stays on the downstream side of his work, the sediment which he stirs up will be swept clear, permitting him to see. A judicious lead to the descending line and other rigging may gain some advantage from the current.

Strong currents will probably prevent the diver from even reaching the bottom. The bight swept into the descending line will make it difficult to follow the line down. The bight of the lifeline and air hose will drag heavily on the diver, and he may be unable to even pull himself down. The pull of the lifeline and air hose may sweep the diver off the bottom, causing him to blow up. Because the current may be less toward the bottom than at the surface, the diver should always attempt to get down and get the work done.

The lifeline and air hose can sometimes be used by the diver to anchor himself on the bottom. The weight of a few feet carried along in his hand, or the bight from the surface resting on the bottom may help. Under no circumstances should the lifeline and air hose be made fast to anything, nor should the diver attempt to lash himself down. Additional weights on the belt or a second belt may weight the diver down. A weight carried by hand might help the diver to move about.

When working in a current, the diver should make himself heavier than normal. The exhaust valve should be opened more than the usual amount instead of cutting down on the air supply with the control valve. Diving in a current is hard work and the diver will need plenty of ventilation.

The effect of the current on the diver's body will be in proportion to the area which he presents to the force of the flow. By lying down or turning his side to the stream the smallest possible area will be presented to the current. To move along the bottom, it is best to crawl.

SEARCHING

Searching for lost articles on the bottom constitutes a large portion of diving work. The position of the lost object should be estimated as closely as possible and the descending line put down at this spot. If an area of any size must be searched, several buoys will be needed to mark off the ground covered.

The diver should move away from the descending line against the current, then circle to the right or left, moving with the current. When the current is very strong, it may be impossible for the diver to move against the current to any extent. In this case, the diver must make half circles on the downstream side of the descending line.

Even when weighted with small strips of sheet lead wrapped around the line, the circling line will not catch objects lying close to the bottom. Such material can be found only when the diver himself makes contact with them. Objects buried in mud or sand can sometimes be found by the marks which they have left on the bottom. A lance can be made to probe in the mud for large objects. It should have a lanyard six or eight feet long, bent on to the butt end.

It is occasionally suggested that the diver be towed from a boat when covering large areas to be searched. This obviously would be a very dangerous procedure under the most favorable circumstances. It is much better to shift the boat and the descending line, bringing the diver up for each shift.

With a hard smooth bottom, no current, and depth of water about 150 feet or less, a good diver should have no trouble making a complete circle with 150 ft. of distance line. Less advantageous conditions will require the diver to use a shorter scope. When the diver finds the object of his search, he should always bend his distance line to it at once to prevent losing it again.

When the bottom is soft, the diver should call for a little slack in the descending line and then turn the descending line weight upside down to hold his distance line as far down in the bottom as possible.

After the distance line is bent to the object, the diver may find it easier to pull the descending line weight to him. Necessary tools and lines can then be sent down the descending line directly to the object.

Experienced divers sometimes use a bight of their descending line for a distance line. The diver calls for slack in the descending line after he reaches bottom. The tenders slack away and then tend the descending line by hand. The diver moves away from the descending line weight, holding the bight of the descending line. When at the proper distance from the weight, he circles. When the object being searched for is found, the diver takes a turn around it with the descending line and then tells the tenders to take up the slack. The hook rope is then sent down the descending line to the diver. After the hook rope is attached to the object, the diver throws his descending line clear, the tenders take up the slack, and the diver returns to the surface on the hook rope.

It is recommended that the lost object be located by dragging for it if there is any possibility of finding it by this means. A drag can cover a much larger area than a diver can in the same time. With a limited number of divers available, it is better to save them until they must be used rather than to exhaust them in extensive search operations. Under no circumstances should drags be used within a very wide distance of the diver; the farther away the better. Divers can be very easily fouled by a drag line with dangerous consequences.

It is necessary to use plenty of scope on the drag line; roughly three times the depth of water is generally about right. The arms of the grapnel should be long enough to insure that they will hook over the lost object. Weights on the drag line ahead of the grapnel will help to hold the drag on the bottom. The boat should run as slowly as possible or drift with the current because too much headway will cause the bight of the drag line to lift the drag from the bottom. Buoys should be used to mark the area to be searched and the ground that is covered. When the object is hooked, its location must be buoyed for the diver.

An electric drag can be used effectively to locate metallic objects, especially iron or steel. It can be trailed behind a single boat over a rough bottom or towed in a span between two boats over a smooth bottom.

DIVING FOR WRECKED PLANES

The wreckage of a plane presents special hazards and difficulties to a diver. The debris may be badly twisted, tangled, and scattered over a wide area. Pieces of ragged metal and the ends of wire and metal parts can entangle and produce severe cuts on the diver.

Hacksaws and heavy wire cutters are convenient tools to have available when working on plane wrecks.

The structure of a plane makes it difficult to attach lifting lines to bring the wreck to the surface. If hoisting slings or eyes are accessible to the diver, they are generally the most satisfactory for attaching lines. Next best are the engines or the heavy parts of the engine mountings. It may be necessary to use the heavier members of the landing gear and wings next to the fuselage. Since the weight of a plane in the water is less than the weight of the same plane out of the water, it may be possible to bring the plane up to the surface of the water with a light rig, where heavier slings can be put on to hoist it clear of the water.

The diver should lose no opportunity to recover papers, books, bomb sights, and other material which may be of confidential nature or of great monetary value. Notebooks and papers from the wreck may also be of value in determining the cause of the wreck.

If gasoline is floating on the water, no open flames, no smoking, or anything else which may ignite it should be permitted in the vicinity.

TORPEDO RECOVERY

A diver should always approach a submerged torpedo with caution. Sometimes a slight jar or movement of the torpedo will start it running again, or moving the starting lever may have the same effect.

The propeller lock should be put on and lashed. If no lock is at hand, a piece of small size manila may be used. The stop valve should be closed with the torpedo tool made for that purpose.

Since the after part of a torpedo is easily damaged, torpedoes should always be handled so that the afterbodies and tails suffer no strains or bumps.

After leaving the descending line, the diver should proceed slowly, examine his immediate surroundings as he proceeds, and report any wreckage or obstruction encountered, or parts damaged or carried away, particularly wreckage that should be removed in order to safeguard the diver. He must always pass over lines or obstructions, never under them. He ought to carry a few turns of air hose and telephone cable on his arm to prevent a sudden pull from the deck causing him to lose his balance. It is best to allow the hose and cable to touch the deck or bottom behind him, but he must not allow it to pile up; this portion of hose and cable should be sighted frequently. In passing any standing object such as a gun, mast, stanchion, etc., the underwater worker must keep in mind the side passed on, i.e., if on his left-hand side proceeding, it must be on his right-hand side returning. When entering a wreck, or passing through doors, he must always proceed feet first and should never attempt to force shoulders and breastplate through first.

A team of three divers has proved to be the most effective while working inside a submarine. No. 1 man carries the tool bag; No. 2 man carries the light and assists No. 1 man; No. 3 man remains outside at the hatch to tend No. 1 and No. 2's hose and cable.

A diver should always be sure that he thoroughly understands his task before making the dive. He should never deviate from his instructions without first obtaining permission from the deck.

SENDING MATERIAL DOWN TO THE DIVER

In salvage work, too much attention cannot be given to the subject of sending material, tools, etc., down to the diver. His stay on the bottom is limited and his vision is never better than fair. The use of his hands is often restricted by their being encased in gloves.

His ability to move about is greatly restricted due to his small negative buoyancy, the cumbersomeness of the diving dress, the resistance offered by the water, and disadvantages increased in direct proportion to the force of the current. His buoyancy allows him only a few pounds of pull. In fact, about 50 per cent of the diver's energy is required to maintain him on the bottom. Therefore careful planning is necessary on the part of those supervising the work of the divers. Each phase of the work should be studied in advance in order to devise methods and rigs which will permit the divers to work with the greatest efficiency.

In general, a special descending line of 2½-to 3-inch manila should always be secured at the point where the material is to be used or the fitting to be installed. This descending line is led to the ship's rail, hauled taut, and the ship moved to give an angle of lead that will guide it into place with little physical effort.

Hand tools should be fitted with lanyards having an eye sufficiently large to slip easily on the diver's forearm. They should be put on his right arm when he is on the stage. If several tools are needed, they are placed in a canvas tool bag.

In sending down small tools, bolts, nuts, small fittings, etc., secure each article to the holes (eyelets) in the upper rim of the tool bag with about three feet of marline. Nuts, bolts, etc., can be tied in one string so

that they may be cut off one at a time.

While the diver is being dressed, his tool bag should be made up. The diver can then observe just how each article is placed. Special items (i.e. the principal tool or fitting) should be secured with manila yarn or 6-thread manila. Securing small tools and fittings to the tool bag insures the diver being able to recover them in case of dropping. The following are the normal contents of the diver's tool bag:

1 six-pound hammer.
1 eight-inch Stillson wrench.
1 fourteen-inch monkey wrench.
1 fourteen-inch Stillson wrench.
1 hack saw.
2 hack saw blades.
1 pair of large pliers.
1 marline spike.
1 combination jimmy heaver and prier.
2 cold chisels.

A good practice is to give the diving light to the first diver down; the second diver takes the tool bag.

When small fittings, valves, shackles, etc., are to be sent down, it is a better plan to put them in a tool bag, and if too heavy for the diver to carry down on his arm, the bag can be sent down on a descending line. The mouth of the bag should be tied shut.

Power tools should be sent down ahead of the diver. Use a piece of 6-thread manila for the guy line attaching the tool to the shackle sliding on the descending line. The guy line should be attached to the tool with a sliding noose. The air hose of the tool is used as a lowering line.

Send down the electric torch in its box and the ground wire, the gas torch, and the igniter in the same manner, i.e., the sliding noose over the torch and igniter or torch and ground wire, as the case may be.

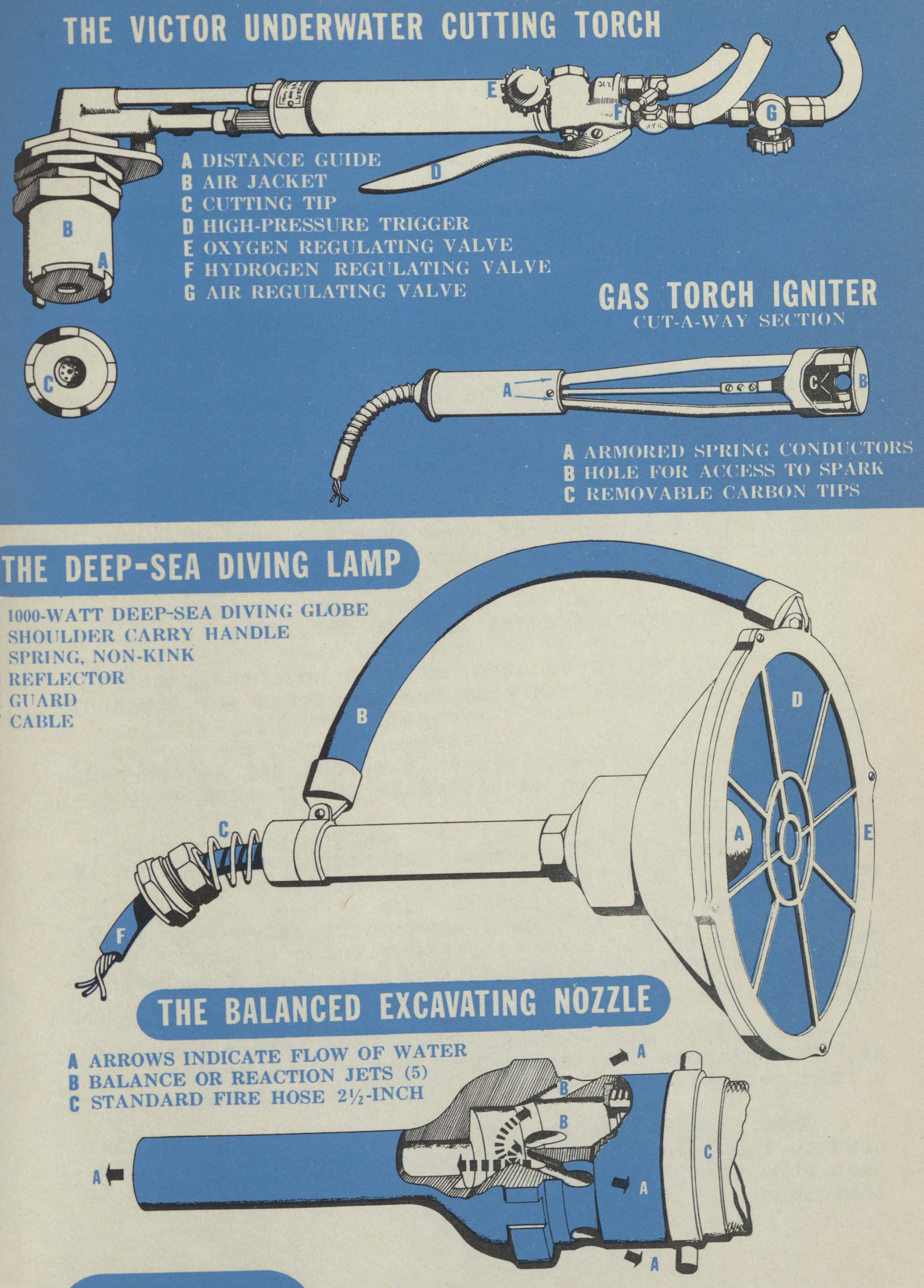
For all other objects use 15-or 21-thread manila for a lowering line, fitted with an eye splice, or short bowline. Secure the distance line from the sliding shackle on the descending line to the eye on the lowering line. Then fasten the object to the eye of the lowering line with material no longer than necessary, (marline, 6-thread, 12-thread, etc.), with about 1 foot of play. The diver then takes the object off with one cut of his knife.

The lowering line can then haul the shackle back. The best results will be obtained by having one man, preferably an officer, make up all the material going below. He will then be in a position to plan ahead. A uniform system should be followed and those assisting will soon become acquainted with his method, which will cause the work to progress smoothly.

To illustrate the advantages to be gained in having plans ready, it was desired to reinforce the upper conning tower hatch on the S-4 by placing 40 lead pigs, each weighing 100 lbs., over this hatch. To prevent the pigs from shifting due to the motion of the hull, the pigs were to be placed in a wooden box and cement poured around them. The box was to have a canvas lining to hold the cement. The hatch cover was not sufficiently wide to permit stacking all of the 40 pigs directly over it so two flat bars of steel were to be laid over the hatch first.

The material was prepared in advance. A traveler ring for the descending line was made with a 1" screw shackle welded to it. Each pig was drilled to provide an eye for a small becket strap of 15-thread manila. The bars were cut and drilled for the guy line and lowering line. The box was made, weighted with sheet lead on the bottom edges to give it negative buoyancy, knocked down, and then stoppered up with the canvas lining on top. When ready for this job and all preparations were completed, two divers carried down a 3" manila line. They were instructed to catch a turn on the far side of the chariot bridge rail about midships, this line to be hauled taut from the topside and the divers to then observe objects sliding down the line to fall fair in the chariot bridge.

The first trial position proved correct. The descending line was set up, the first pair of divers received the two flat iron bars, placed them, received the box, set it up in place with its canvas lining, and received and placed ten pigs of lead in 50 minutes. The second pair of divers received and placed thirty pigs in 42 minutes. Another pair of divers received and placed 10 pigs in 16 minutes.



THE VICTOR UNDERWATER CUTTING TORCH

A DISTANCE GUIDE
B AIR JACKET
C CUTTING TIP
D HIGH-PRESSURE TRIGGER
E OXYGEN REGULATING VALVE
F HYDROGEN REGULATING VALVE
G AIR REGULATING VALVE

GAS TORCH IGNITER
CUT-A-WAY SECTION

A ARMORED SPRING CONDUCTORS
B HOLE FOR ACCESS TO SPARK
C REMOVABLE CARBON TIPS

THE DEEP-SEA DIVING LAMP

A 1000-WATT DEEP-SEA DIVING GLOBE
B SHOULDER CARRY HANDLE
C SPRING, NON-KINK
D REFLECTOR
E GUARD
F CABLE

THE BALANCED EXCAVATING NOZZLE

A ARROWS INDICATE FLOW OF WATER
B BALANCE OR REACTION JETS (5)
C STANDARD FIRE HOSE $2\frac{1}{2}$-INCH

Fig. 2

Placing the flat iron bars would have been considered and was, of course, a simple matter. The box proved to be quite as easy for the divers to cut six thread beckets to free the box from the guide and lowering line; then it was easy to cut two six-thread stops that bound the several parts together, lay the canvas cover aside, place the forward and after sides, slide the port and starboard side into position, insert the bolts which had been secured by short lanyards, and then place the canvas lining which had been folded sides and end to bottom and then rolled. The lead pigs were sent down as follows: the becket inserted in the shackle of traveler ring. The shackle bolt being inserted from up-down, it was only necessary to catch a turn or so of the threads to secure it. A turn was taken on the belaying pin with the lowering line, the pig slid off the rail, and lowered on the run until the square mark on the lowering line was at the rail. The pig was now about 10 feet above the divers. It was held at this position until the diver signaled "Let it come." When the diver cut the pig becket, the slack of the lowering line being immediately apparent, the traveler and shackle were hauled back hand over hand, and then the next pig sent down to the square mark and held until the signal "Let it come," etc.

SENDING MATERIAL DOWN TO THE DIVER

Use small stuff to stop material to shackle and as few turns as possible so that the diver can cut the stop easily.

Put small tools and parts in a tool bag before sending them down. It may be desirable to tie them to the bag with marline.

The descending line should be rigged as close as is practical to the point where the diver is to work.

Pay out lowering line from a point far enough away from the descending line to prevent turns of lowering line from fouling the descending line. Keep the descending line taut.

When diver must untie a large line rather than cut it, half hitches are the easiest for him to handle. As a rule, shackles are easier to unfasten than knots.

Good rigging is extremely important to get material down to the diver quickly so that his dive is no longer than absolutely necessary and his exertion is reduced to a minimum.

CHAPTER IV

RIGGING BOATS FOR DIVING

See Articles 3627 to 3637, 3641 to 3642 of Bureau of C. & R. Manual.

A motor launch must always be used for diving, if practicable. All motor launches are required to be fitted with padeyes for receiving hand-operated air pumps for divers. Chocks and fittings for securing torpedo air flasks in the boat and for using them to supply diver's air should be made up and kept ready also.

It is preferable to dive from a boat with air furnished from torpedo air flasks. They should be thoroughly cleaned of any rust, dirt, oil, or grease. Place them on chocks on the floor boards and secure them so they cannot move.

At least three flasks must be in the boat, connected and ready for instant use. One air flask must be held in reserve and not used except in case of emergency, such as a fouled diver. The pressure in the working flasks shall not be permitted to fall below 220 lbs. per sq. in., (15 atmospheres) over the pressure at which the diver is working while on the bottom. When the diver is clear of the bottom and safely on his way up so that no emergency can possibly arise, the reserve flask may be cut in. Not over two divers may be permitted to dive at the same time from the same boat. The air supply to the divers must be maintained at least 25 lbs. over bottom pressure.

When working depths over 120 feet, a second boat must be rigged with at least three fully charged flasks. It shall remain within easy signaling distance of the diving boat so that it can be brought up quickly and its air supply connected to the diving boat.

A dinghy, or other small boat, shall always be assigned as tender to the diving boat.

The boat crew must be adequate and in addition to the men required to manage the air supply and to handle and tend the divers.

The following equipment is required to be in the diving boat if it leaves the vicinity of the ship:

The requisite number of torpedo air flasks, and all necessary connections and special tools, or, if a diving pump is to be used, it must be complete, in working order and properly secured.
Complete apparatus for two divers.
Sufficient air hose for two divers.
Two lifelines.
Two amplifier outfits (if supplied).
Tool box with air-hose spanners, wing nuts, etc.
Spare washers for air hose.
Spare rubber wrist rings.
Fitted descending line and distance line.
A length of rope for sending down to diver.
Diving ladder.
Decompression stage.
Slate with pencil attached.
Red diving flag on staff.
Lead line.
Stadimeter.
Boat's diving anchor gear.
Boat's compass.
Hand flags for signaling.
Boat box.
Boat medical outfit.
Binoculars.
A watch for timing divers.
Long heaving line.
Large shackle.
Coil of small stuff for lashings.
A luff tackle.
Drinking water.
Other special gear as necessary.

To prevent dragging the diver over the bottom and to avoid getting him fouled, the diving boat should be moored securely. The easiest method of mooring is to stand over the spot where diving is to be done, let go a stern anchor with plenty of line on it, go ahead until well past the spot then let go the bow anchor and drop back, taking in the slack on the stern anchor. If the wind is strong, it will be best to head into it since the wind will probably have more effect on the boat than the current. Mooring with either wind or a strong current across the boat will put a heavy strain on the anchors.

At the slightest sign that the moorings may not hold, start the divers to the surface. The mooring lines should not be touched while the divers are down, either to take in slack or to veer them.

The heaviest, maneuverable boat anchors available should be used. If heavy anchors are not available, at least two anchors must be used on each mooring line, leaving a few fathoms of line between anchors. An additional mooring on the beam or bow may be necessary to hold the boat from yawing back and forth with the wind or current.

Keep all of the gear in the boat straightened out and clear for use. Coil down or flake all lines, hose, etc. Keep the small boat used as a tender moored astern and ready for use. The air flasks must be cut in all the time that the diver's helmet is worn. The diver's air supply must be drawn from the test tank (or volume tank). The required pressure in the volume tank must be maintained at all times. Do not use an automatic pressure regulating valve to reduce the pressure in the flasks to the required pressure in the volume tank. Station a reliable man on the air supply.

Lash the diving ladder to the side of the boat. Keep gear off the gunwales. The diver's tenders should keep both feet inside the gunwale. If the gunwale is very high or wide, one tender may have to sit straddle of the gunwale, but he must be backed up by a second tender completely inside the boat.

FIRST AID AND HYGIENE

First aid is immediate attention given to the injured and ill in cases of emergency; it should neither supersede nor take the place of proper medical or surgical attention and should consist of furnishing temporary assistance to a sufferer pending the arrival of medical aid. The most important fact to remember in first-aid treatment is to summon a medical officer or some one capable of rendering the proper treatment.

Hygiene, the science of the preservation of health, is the proper care of the body to permit the proper functioning of the various organs and tissues.

PERSONAL CLEANLINESS

Personal cleanliness is a very important fact and especially so in the Navy where a large number of men live together in a relatively small area. Conditions on board the salvage ships throw a greater number of men together in the living compartments than the compartments were originally designed to accommodate. The MALLARD, WIDGEON, and the PIGEON operate almost continually in the tropics and this fact further complicates matters. Much more effort must be expended by the individual to keep up the standard of personal cleanliness in the tropics than in the temperate zone. By the appearance of his hair, face, teeth, clothing, hammock, and his general bearing, it is possible to tell at a glance whether a man observes the rules of personal hygiene.

The following is a list of comparatively simple things that should be done if a man is to follow the rules of good personal hygiene:

(1) Take at least one good bath daily. If you are doing heavy, dirty work, more attention should be paid to bathing than otherwise. Follow the bath by a brisk rub with a coarse turkish towel.

(2) Intemperance in eating and drinking should be avoided. Men who drink alcoholic liquor are more apt to get sick than those who abstain. DIVERS SHOULD NOT DRINK.

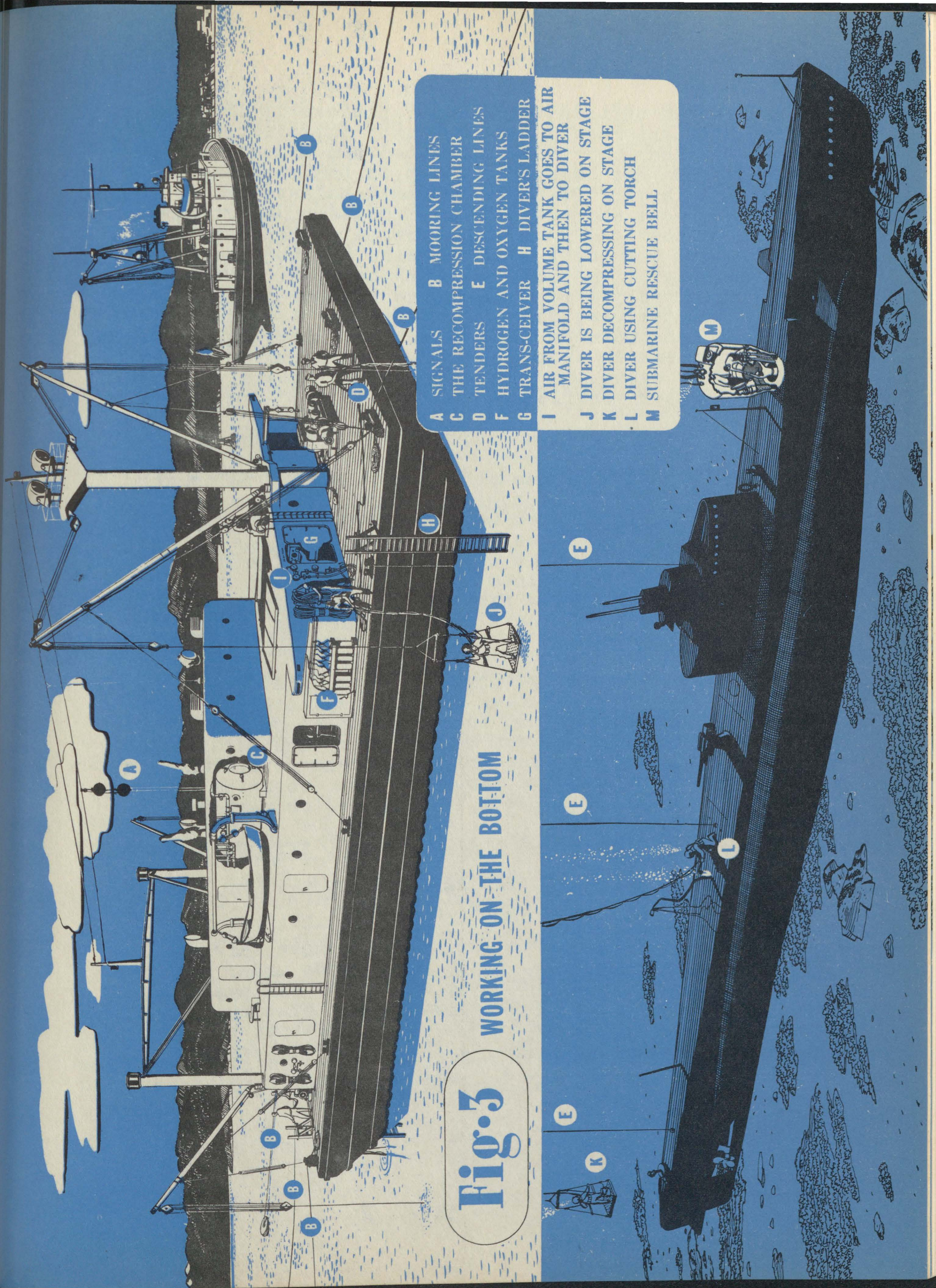
(3) Daily exercise is conducive to good health. On board ship and especially on submarines and small craft it is often impossible for the crew to get sufficient exercise. All hands should take advantage of periods when the ship is tied up at bases and stations to join in all athletic events possible.

(4) If possible, periods of work should be followed by periods of relaxation, rest, or recreation.

(5) Sufficient time should be allowed for meals; the food should be chewed thoroughly. There is a tendency in the Navy for all hands to hurry through their meals.

(6) Plenty of water should be drunk, but do not drink a large amount at any one time, especially when overheated.

(7) Take the proper care of your feet. Feet should be bathed at least once a day; cold water hardens them, while hot water softens them. Clean, dry socks that do not wrinkle should be worn at all times. The nails should be cut straight across and kept trimmed close.



Fig·3 WORKING ON THE BOTTOM

Corns should be treated at once, preferably in the sick bay. Blisters should be treated by the sick bay without delay, as they may become infected and cause you to be laid up. Do not delay reporting to the sick bay for any trouble with your feet. It is well to have two or three pairs of shoes and wear them in rotation, as it gives them a chance to dry out after being dampened by perspiration from the feet. No two pairs of shoes make pressure equally on the same part of the feet; therefore by changing shoes you rest and allow to heal parts of the feet that have been rubbed or subjected to undue pressure. Blisters can often be avoided in this way. Rubber-soled shoes or sneakers should not be worn any more than necessary. They cause the feet to perspire excessively and prevent proper ventilation.

(8) Never sit in a draft to cool off when perspiring, as the evaporation of the perspiration will cause chills and may cause pneumonia to develop. We usually catch colds because we neglect to put on a sweater after being overheated by hard work, or when going from a hot compartment out into the cold air, or when sleeping in a draft without sufficient covering. Take a bath as soon as possible and shift into dry, clean clothes after finishing work. If you work in the rain and get wet, keep moving until you have a chance to take a bath and shift clothes.

(9) The mental attitude has close relationship to health. This fact has been greatly neglected in the past. Many people do not realize that there is a very close relationship between mental worry and bodily ills. Worrying and anxiety over trifles should be avoided. To accomplish this the mind should be kept occupied and interest maintained in work, study, and recreation.

<u>IN GENERAL, KEEP CLEAN AND YOU WILL FEEL HEALTHY</u>.

ARTIFICIAL RESPIRATION
(Schaefer Method)

To remove water from the lungs, remove shirts; lay the patient on his face; clasp your hands under his abdomen and drain water from his lungs and air passages. Be sure that the air passages are clear of foreign objects such as sea weed, false teeth, etc., and that the tongue has not dropped back, thus blocking the air passage.

To apply artificial respiration, place the shocked

person on his belly, with his face turned to one side; straddle him and place the palms on the small of his back just below the ribs; lean forward and gradually bring the weight of the body on the hands, thus forcing the air out of the lungs. <u>AVOID ROUGHNESS</u>. Release the pressure quickly and return to the original position. The first motion should occupy two or three seconds. After returning to the original position there should be a wait of about two seconds before repeating; thus there will be about 12 respirations each minute. Imitation of the natural breathing is the object. These efforts should be kept up for at least two hours, or until natural breathing is restored.

Remove all wet clothing from the body and wrap well with blankets. Never give up hope to restore breathing for many a life has been lost because artificial respiration was stopped too soon. Efforts to restore breathing should be kept up for at least two or three hours.

GASES OF THE AIR AND THEIR EFFECTS ON THE BODY

Air is a physical mixture of the following gases:

Oxygen (O_2)----------------------------------21%
Nitrogen (N)-----------------------------------78%
Carbon Dioxide (CO_2)-----------------------0.03%
Argon and other gases--------------------------Traces
Water vapor, dust, etc., are also present.

All of these gases are odorless, colorless, and tasteless; therefore their presence cannot be detected by the senses.

Oxygen is the only part of the air which is necessary to life. Approximately 5% of the oxygen is consumed from the air when it is breathed. A man burns about 0.7 cu. ft. of oxygen per hour but under heavy exertion he may use 4 to 5 times this amount. Air containing less than 10% oxygen may produce unconsciousness without any preliminary warning symptoms. It is always dangerous to breathe air containing less than 15% oxygen.

Pure oxygen at atmospheric pressure can be breathed for a long time, as is done when working with the oxygen rescue breathing apparatus. When pure oxygen is breathed long enough under pressure of two atmospheres absolute and over, various harmful effects are produced. The tissues of the lungs are irritated and may produce a form of pneumonia. Higher pressures will first cause nausea and blindness, finally unconsciousness and convulsions. Pressures of pure oxygen at about 4 atmospheres absolute will destroy all forms of life.

At 300 ft. depth, the pressure is 133.5 lbs. gauge or 148.2 lbs. absolute, equivalent to 10 atmospheres of pressure. Air is approximately 1/5 oxygen, so that the oxygen concentration at this pressure is the same as 1/5 of 10, or 2 atmospheres absolute of pure oxygen. For this reason, 300 ft. is generally considered the maximum depth to which a diver should go while breathing compressed air.

In the lungs, oxygen combines chemically with the red corpuscles of the blood. The blood then delivers the oxygen to the tissues of the body where it is consumed. Very little oxygen remains in physical solution in the blood and most of that which does will eventually combine chemically with the blood and will be burned in the tissues. CO_2 is a product of combustion. When O_2 is burned in the tissues of the body, carbon dioxide is produced in the tissues and carried by the blood in chemical combination to the lungs where it is exhaled. The rate at which the carbon dioxide leaves the blood will depend on the amount of carbon dioxide already in the lungs. (Dalton's Law)

More oxygen is consumed and more carbon dioxide is generated when a man is working than when he is resting. The amount of dioxide in the blood affects the brain, which in turn regulates the rate and volume of breathing.

Air exhaled from the lungs of a man at rest usually contains about 5% carbon dioxide. If this percentage is increased by exertion, the carbon dioxide remaining in the blood will cause the brain to increase the breathing in an effort to expel the excess quantity. The control of the breathing is so delicate that an increase of 0.02% of carbon dioxide in the lungs will double the volume of breathing. On the other hand, a man's breathing can be stopped completely by sufficiently reducing the percentage of carbon dioxide in his lungs.

The inhalation of air containing carbon dioxide will produce various effects. Their severity will depend on the length of time the carbon dioxide is breathed.

Small percentages of CO_2 will cause tiredness and perhaps headache.

3% CO_2 in the air doubles the breathing.
5% CO_2 causes panting.
8% CO_2 causes marked distress.
10% CO_2 causes unconsciousness very quickly and permanent injuries to the heart and brain may result.

The treatment consists of artificial resuscitation, administering oxygen, keeping the patient warm and quiet, and afterwards giving him plenty of rest.

The effect of a given percentage of carbon dioxide in the air breathed is proportional to the absolute pressure. While 3% CO_2 will hardly be noticed at atmospheric pressure, at 3 atmospheres absolute (66 ft. depth) it will have the same effect on the body as 3 times 3%, or 9%, which is a very dangerous concentration of carbon dioxide. Divers therefore require adequate flow of air through their helmets to keep within safe limits the proportion of CO_2 which they must breathe. Under the most favorable conditions, a diver is considered to require at least 1.5 cu. ft. of air passing through his helmet at the pressure of his depth. Whenever it is possible and always at high pressures, he should receive at least 4.5 cu. ft. of air per minute.

Nitrogen does not combine chemically with the blood as oxygen and carbon dioxide do. Instead it remains in physical solution in the blood and the tissues of the body. The pressure of the nitrogen in solution tends to equalize with the pressure of nitrogen in the lungs. This is in accordance with the laws of Dalton and Henry.

Various parts of the body absorb nitrogen at different rates and in different amounts. The blood holds a moderate amount and will change the quantity of nitrogen very quickly, conveying it between the lungs and the tissues. Fat will absorb about 5 times more nitrogen than other tissues and the rate at which it changes the quantity of nitrogen in solution is much slower. Parts of the body which receive little circulation of blood will be slow to change their amounts of nitrogen in solution also.

The rate at which a tissue absorbs nitrogen is the same as the rate at which it will release the nitrogen. It is believed that 5 to 12 hours are required for the pressure of the nitrogen in solution in the body to equalize with the pressure of the nitrogen in the air being breathed. Since the blood carries the nitrogen to and from the tissues, increased circulation will increase the rate at which the body saturates or desaturates.

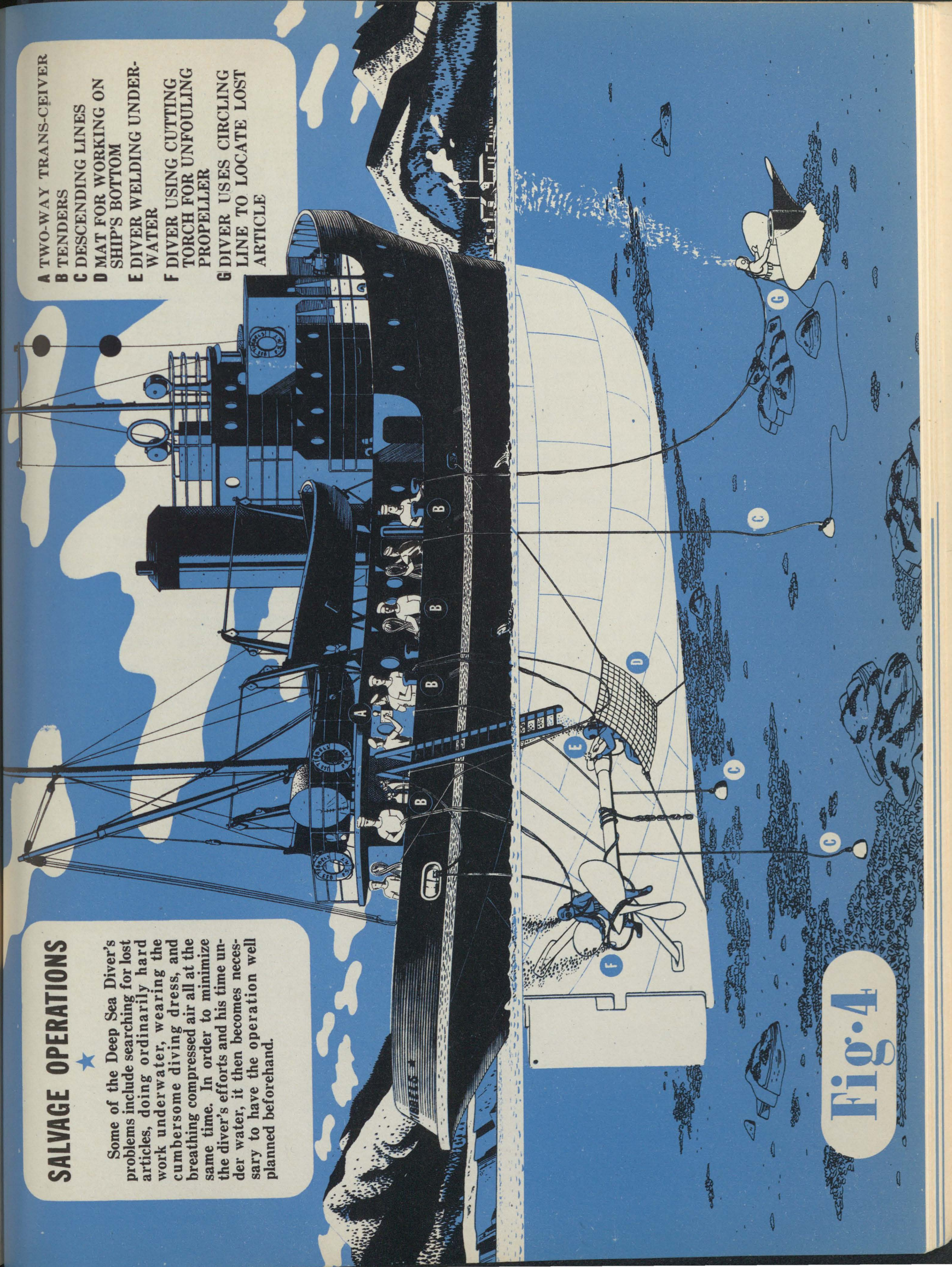
The amount of nitrogen in the body therefore depends on the absolute pressure of the air breathed and the length of time that the body has been exposed to that pressure.

It has been found that if the pressure is suddenly reduced enough, the nitrogen will leave solution so rapidly that the blood can not carry it all to the lungs. Bubbles of nitrogen will then be formed in the blood and some of the tissues. These bubbles may block the flow of blood, burst small blood vessels, cause pressure on the parts surrounding the bubbles, and cause damage to the tissues. Pressure on nerves or damage to nerve tissue will cause pain. Damage to the brain or spinal cord will cause various kinds of paralysis and may be severe enough to cause death. The symptoms produced by the formation of nitrogen bubbles in the body are called bends, caisson disease, diver's palsy or paralysis, compressed air illness, etc.

It has been found that if the pressure is reduced at a rate that will keep the absolute pressure of the nitrogen in the body at less than twice the absolute pressure of the air being breathed, no bubbles will be formed. A diver can come up half his maximum absolute depth at any time without danger of bends. If he has been working at 99 feet (3 atmospheres gauge, 4 atmospheres absolute), he can come safely to a pressure of 2 atmospheres absolute, which is 1 atmosphere gauge or 33 feet.

Decompression of divers is accomplished by bringing them up and keeping them for a time at progressively decreased depths, each time ten feet less, until the surface is reached. The correct procedure is set forth in the decompression tables. The depths and time at each will depend on the depth at which the diver has been working and the duration of his exposure.

A diver who has exerted himself heavily on the bottom may have absorbed more nitrogen than normal due to his increased rate of circulation. A Standard Decompression for his time on the bottom should be regarded as being proportionally greater than it actually is and a decompression selected accordingly. To increase their circulation and eliminate more nitrogen, divers should



SALVAGE OPERATIONS

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Some of the Deep Sea Diver's problems include searching for lost articles, doing ordinarily hard work underwater, wearing the cumbersome diving dress, and breathing compressed air all at the same time. In order to minimize the diver's efforts and his time under water, it then becomes necessary to have the operation well planned beforehand.

Fig·4

exercise during decompression.

When the water is very cold and under other conditions where it is inadvisable to give the diver his decompression in the water, he sometimes takes his first one or two decompression stops in the water, then is brought on board where helmet, belt, and shoes are removed as quickly as possible. The diver is then rushed into the recompression chamber and recompressed to his first stop and brought out on the regular preliminary decompression in the water when the diver has been at deep depth.

Because it takes a long time for all the tissues of the body to desaturate, a diver should not make more than one dive to any considerable depth in the same day. If he is exposed to pressure again, the second decompression should be based on approximately his total time on the bottom and maximum depth during the day.

SYMPTOMS OF CAISSON DISEASE

Symptoms of caisson disease vary widely in degree and effects. They have been known to occur as long as 15 hours after exposure to pressure.

1. Itch, rash, or discoloration of the skin will not require recompression, but the diver should be watched for the development of a more serious condition.

RECOMPRESSION SHOULD BE USED IMMEDIATELY FOR THE FOLLOWING SYMPTOMS:

2. Pain in various parts of the body. Abdominal pains may indicate the onset of a very serious case.

3. Unconsciousness, partial or complete.

4. Abnormal condition of the senses (sight, hearing, taste, touch, and smell) and lack of coordination and control of the body.

5. Parts of the body becoming paralyzed or going to sleep.

6. Marked dizziness.

7. Heavy and labored breathing.

NOTE: 3, 4, 5, & 7 indicate that either the brain or the spinal cord, or both, are affected. Decompression should be prolonged for such cases.

TREATMENT OF CAISSON DISEASE

Extract from Bureau of C. & R. Manual, Paragraph 3679.

(1) In case a diver has made a rapid ascent from deep water, but shows no symptoms of caisson disease, he must be hurried into the chamber as soon as possible and the pressure raised to 60 pounds or less, this pressure being at least half the absolute pressure at which the diver has been working. He must be kept at this pressure for at least 5 minutes, after which, if no symptoms have developed, he can be decompressed according to the tables, corresponding to the time and depth of the dive, with the extra five minutes added to the total of the diving time for the time used in selecting the table. Should symptoms of caisson disease develop during decompression, gradual decompression as outlined below should be resorted to.

(2) If symptoms of caisson disease develop, the patient should be taken immediately into the recompression chamber and pressure run up to 45 pounds with as little delay as possible. In most cases this will be sufficient to revive him. If, however, the patient does not show marked improvement, the pressure must be increased to 60 pounds. In one instance, 75 pounds was necessary after a 300 foot dive. The patient must be kept at this pressure until any symptoms of circulatory embarrassment or dyspnea have disappeared. Such symptoms disappear almost directly, and if no other serious symptoms are present, decompression may be started at once.

(3) If paralysis is present and does not pass off in two hours, it is useless to wait longer at high pressures. It must be remembered that exposure in the chamber exceeding 30 pounds is likely to delay decompression very much.

(4) Decompression should be started as soon as the patient is relieved, pressure being allowed to fall at the following rate:

When pressure in chamber is-	Pressure may be allowed to fall at a rate not faster than-
Above 60 pounds-------------	Rapidly
Between 60 and 45 pounds----	1 pound in 1 minute
Between 45 and 30 pounds----	1 pound in 3 minutes
Between 30 and 15 pounds----	1 pound in 5 minutes
Between 15 pounds-----------	1 pound in 10 minutes

(5) No hard and fast rule can be laid down for a decompression rate, which will depend on the condition of the patient, how he stands decompression, and also the pressure at which he was saturated. If the patient becomes ill again while the pressure is falling, decompression must be stopped, and, if necessary, the pressure raised; when the patient is better, pressure may be allowed to fall again, but at a slower rate. If after decompression the patient again develops symptoms, the process of recompression and subsequent decompression must be reported.

BUREAU OF SHIPS

Pilot letter

L9/P-(14) (8688)
EN28/A2-11
July 30, 1942

From: The Chief of the Bureau of Ships.
To: All Ships and Stations.

Subject: DECOMPRESSION FOR DIVERS.

Enclosure: (A) Two (2) copies Navy Standard Decompression Table (using compressed air).

1. Two (2) copies of the latest approved Navy Standard Decompression Table (using compressed air) are enclosed for use in future diving operations.

J. J. BROSHEK
By direction

Aug. 15, 1942 Navy Department Bulletin BuShips
R-491

NAVY STANDARD DECOMPRESSION TABLE
(using compressed air)

Depth of dive (Feet)	Time from leaving surface to beginning of ascent for regular decompression or to "upstage" for surface decompression (Minutes)	Stops at different depths in minutes						Total time of decompression; sum of times at various stops (Minutes)	Approximate total time for ascent; column 4 plus time between stops (Minutes)
		Ft. 60	Ft. 50	Ft. 40	Ft. 30	Ft. 20	Ft. 10		
40	120	....	....	....	....	....	0	0	1
40	180	....	....	....	....	....	2	2	3
40	Opt.* 240	....	....	....	....	....	4	4	5
40	300	....	....	....	....	....	6	6	7
50	78	....	....	....	....	....	0	0	2
50	120	....	....	....	....	....	2	2	4
50	150	....	....	....	....	....	5	5	7
50	Opt.* 190	....	....	....	....	....	9	9	11
50	300	....	....	....	....	....	12	12	14
60	55	....	....	....	....	....	0	0	2
60	75	....	....	....	....	....	2	2	4
60	110	....	....	....	....	....	13	13	15
60	Opt.* 150	....	....	....	....	5	15	20	22
60	180	....	....	....	....	7	16	23	25
60	210	....	....	....	....	8	18	26	28
70	43	....	....	....	....	....	0	0	3
70	60	....	....	....	....	....	4	4	7
70	75	....	....	....	....	....	13	13	16
70	90	....	....	....	....	4	16	20	23
70	Opt.* 120	....	....	....	....	13	16	29	32

70		150					18	21	39	42
70		180					21	32	53	56
80		35						0	0	3
80		50						6	6	9
80		70					16	14	30	33
80		100					20	16	36	39
80	Opt.*	115					22	26	48	51
80		150					28	29	57	60
90		30						0	0	3
90		45						6	6	9
90		60					4	16	20	24
90		75					18	14	32	36
90	Opt.*	95				2	27	21	50	53
90		130				9	27	29	65	68
100		25						0	0	5
100		40						12	12	17
100		60					16	16	32	37
100		75					27	21	48	53
100	Opt.*	85				6	28	21	55	60
100		90				8	27	24	59	64
100		120				17	28	48	93	98
110		20						0	0	5
110		35						12	12	17
110		55					22	21	43	48
110	Opt.*	75				14	27	37	78	83
110		105			2	22	29	50	103	108
120		18						0	0	5
120		30						11	11	16
120		45					18	21	39	44
120	Opt.*	65				13	28	32	73	78
120		100			5	22	27	69	123	128
130		15						0	0	5
130		35					11	15	26	31

130		52				6	28	28		62	68
130	Opt.*	60				13	28	28		69	75
130		90			9	22	28	69		128	134
140		15						4		4	10
140		30					8	21		29	35
140		45				5	27	27		59	65
140	Opt.*	55				15	28	32		75	81
140		85			14	22	32	69		137	143
150		15						7		7	13
150		30					13	21		34	40
150		38					28	30		58	64
150	Opt.*	50				16	28	32		76	82
150		80			18	23	32	68		141	147

			Ft 90	Ft 80	Ft 70	Ft 60	Ft 50	Ft 40	Ft 30	Ft 20	Ft 10		
160		15									9	9	16
160		34								27	28	55	62
160	Opt.*	45							17	28	43	88	95
160		75					3	19	23	34	68	147	154
170		15									11	11	18
170		30								24	27	51	58
170	Opt.*	40							19	28	46	93	100
170		75					9	19	23	38	68	157	165
185		15									25	25	32
185		26								24	37	61	69
185	Opt.*	35							19	28	46	93	101
185		65				18	18	23	37	65	51	212	220
200		15									32	32	40
200		23								23	37	60	68
200	Opt.*	35							22	28	46	96	104
200		60			5	18	18	23	37	65	51	217	226

210		15									35	35	44
210	Opt.*	30						5	16	28	40	89	98
210		55			6	18	18	23	37	65	51	218	227
225		15								6	35	41	50
225	Opt.*	27						22	26	35	48	131	140
225		60			13	18	18	23	47	65	83	267	276
250		15								17	37	54	64
250	Opt.*	25					2	23	26	35	51	137	147
250		50		12	14	17	19	29	49	65	83	288	299
300		12								20	37	57	69
300	Opt.*	20					9	23	26	35	51	144	156
300		45	6	14	15	17	18	31	49	65	83	298	311

* 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.

OXYGEN TREATMENT FOR CAISSON DISEASE

The Experimental Diving Unit has had great success with the following treatment for caisson disease, using oxygen.

(1) Increase pressure rapidly to one atmosphere more than pressure necessary to relieve the symptoms of the patient. Keep patient at this pressure for 30 minutes.

(2) Lower pressure gradually over a period of 45 minutes to pressure at 60 feet.

(3) Have patient breathe oxygen through a mask throughout the remainder of the decompression which is as follows:

20 minutes at 60 feet.
30 minutes at 50 feet.
40 minutes at 40 feet.
5 minutes at 30 feet, then lower pressure to atmospheric pressure.

Pressure should be reduced at a rate not greater than 25 feet per minute.

(4) If symptoms are not permanently eliminated by the above treatment, recompress patient again until symptoms are relieved. This pressure may be expected to be materially less than 66 feet. The patient is kept at this pressure for 12 to 24 hours, or longer if necessary.

(5) Final decompression is then accomplished in accordance with the table below:

PRESSURE	TIME AT PRESSURE
40 feet	14 minutes
30 feet	42 minutes
20 feet	52 minutes
10 feet	68 minutes

AIR EMBOLISM

If the lungs are filled with air while under pressure and the breath is then held while the pressure around the body is reduced, an excess pressure will develop in the lungs. This pressure may drive a bubble of air from the lungs directly into the blood stream where it will pass at once to the heart. If the bubble is large enough, the heart will be blocked just as a mechanical pump may become air bound. If the bubble is small enough to pass through the heart, it will be carried along with the blood stream until it enters an artery small enough to be blocked by the bubble. This interruption to the flow of blood is called air embolism.

The effects produced by air embolism will depend on the location of the bubble. If the heart or the large arteries supplying the brain are blocked, instantaneous unconsciousness and perhaps almost immediate death will occur. If small arteries supplying the brain are blocked, collapse and spasm may develop. If the bubble lodges in other parts of the body, symptoms like those of bends may show.

Such accidents are most likely to happen when engaged in helmet diving and in using the submarine escape appliance (lung). The diver ducks the helmet and swims to the surface, voluntarily while making an ascent. With the lungs fully inflated, a rise in the water of approximately 2½ feet is sufficient to produce enough pressure in the lungs to cause air embolism. If the injury is received at any depth, the expansion of the air bubble as the man ascends to the surface will intensify the effects. Men have been killed coming from a depth of 10 or 15 feet.

At considerable depths men have become instantly unconscious from this cause. Others who were injured have actually appeared to be all right within ten or fifteen minutes after leaving the water and then started to collapse into convulsions.

In all cases where a man is in distress either after he has been using a "lung" or has been diving with the helmet alone, it should be presumed that he is suffering from air embolism and treated as outlined below. The natural and usual assumption of bystanders is that the man is suffering from drowning.

The patient should be placed under pressure immediately. It is well to keep his feet elevated above his head as high as possible in the hope that circulation of blood to the brain will be facilitated. The bubble may perhaps flow to a location less dangerous that the arteries to the brain. The pressure may have to be quite high in order to first compress the bubble and reduce its size so that it no longer blocks the circulation, then dissolve the bubble into the blood so that it can be eliminated during decompression. If patient's breathing has stopped, artificial resuscitation must be applied. Decompression should be the same as that prescribed for treatment of caisson disease.

If the patient is actually suffering from drowning or bends, the above treatment will do him no harm. To fail to treat a case of air embolism by prompt recompression is likely to cause death although a few mild cases have been known to recover with no treatment at all.

After being decompressed, a man who has suffered from air embolism will usually complain of a dull headache that will persist for about five hours and soreness of the abdomen which will last a day or two.

THE RECOMPRESSION CHAMBER

The primary purpose of a recompression chamber is to recompress victims of the bends. It is also used to decompress divers when it is impossible or dangerous to decompress them in the water. It may be used to compress personnel with the object of accustoming them to pressure and to ascertain their general condition under pressure.

The recompression chamber must be kept ready for instant use at all times while diving is being carried out and for at least 15 hours after the last diver has been secured. It should be tested daily. A diver should be detailed to be ready to operate the chamber.

Men who have been exposed to high pressures should remain in the immediate vicinity of a recompression chamber for one hour afterward and within one hour's distance of the chamber for at least 12 hours.

The following equipment should be kept in the recompression chanber:

(1) A time-keeping instrument, either a clock or a stop watch.
(2) Caisson gauges.
(3) Decompression tables.
(4) Small mattress and blankets.
(5) Apparatus for administering oxygen, ready for use.

The following materials should be immediately available to the chamber:

(1) Sterile syringes and needles with bottle of 1-1,000 adrenaline.
(2) Stethoscope and blood pressure apparatus.
(3) Vessel and towels for hot applications.

Bottles passed in or out of chamber, or stored therein, should have holes through stoppers to equalize pressure. No highly volatile or dangerous liquids should ever be kept in the chamber.

When no recompression chamber is immediately available:

If a diver has been working at great depths or exposed for long periods in shallower depths, he must be kept dressed for at least 20 minutes after being brought on deck. If he develops symptoms of bends, he can then be sent down again for decompression.

SQUEEZE

Squeeze occurs when the water pressure becomes greater than the air pressure in the helmet; the water pressure will then tend to compress the dress, pushing the diver into the helmet. If the diver is not carrying sufficient air in his dress, he will feel the breastplate pushing on his shoulders, and the force of the water pressure on his ribs will make it difficult for him to breathe. Slight bleeding of the nose and ears may be produced by the excess of water pressure over the air pressure in the dress. This is likely to occur if the diver descends faster than his air supply can build up the pressure in his dress. When the safety non-return valve on the helmet is tight, the pressure in the helmet cannot be lost through failure of the air supply. Every precaution must be taken to insure that this valve operates properly. The only other manner in which a squeeze can be suffered is from a fall under water.

Dropping suddenly from the surface to 33 feet increases the absolute pressure from 1 to 2 atmospheres. The air in the dress is thereby reduced to 1/2 its former volume since volume is inversely proportional to pressure (Boyle's Law). To drop from 66 feet to 99 feet changes the absolute pressure from 3 to 4 atmospheres. The volume of air in the dress is then reduced to 3/4 its volume. The diver's body must make up the difference in volume in

the rigid helmet. It follows that a fall in shallow depth will do the diver more harm than a longer fall at deep depths.

In some extreme cases of squeeze, the diver was almost entirely compressed into the helmet, killing him instantly and making it impossible to remove the helmet from the body.

In any situation where there is a choice between risking a squeeze and the bends, choose the bends as a much smaller evil.

Upon blowing up, the diver may have his dress burst or deflated suddenly in some other way. He would then drop to the bottom, suffering a heavy squeeze.

Unless the diver has been working long enough in water deep enough to require decompression, there will be no need to recompress him if he should get a squeeze. Remove the dress as gently as possible. Lay diver prone and try to keep him warm and comfortable. Get the services of a doctor. The patient may be bleeding from nose and mouth, unconscious, eyes popped out, head and features badly swollen and livid in color. The imprint of the breastplate may show on his chest, back and shoulders.

CARBON MONOXIDE

Carbon monoxide (CO) is a product of incomplete combustion of carbon. When carbon burns completely, only carbon dioxide (CO_2) is formed.

Carbon monoxide occurs as a large proportion of the exhaust gases of internal combustion engines. It is found in the smoke from charcoal, coal, or oil. Since it is odorless, colorless, and tasteless, its presence cannot be detected by the senses. It is slightly heavier than air.

The blood combines chemically with carbon monoxide more readily than it does with oxygen. When the blood absorbs carbon monoxide, its oxygen-carrying capacity is reduced accordingly. Once absorbed, it is retained by the blood. Asphyxiation is produced because the blood finally will be unable to carry any oxygen from the lungs to the tissues of the body. Breathing will eventually result in poisoning because the amount of CO in the blood will gradually be built up until the blood can no longer carry sufficient oxygen for the needs of the body.

Improper lubrication of diving air compressors so that oil accumulates in the cylinders, breaks down, or burns, may generate carbon monoxide and pollute the diver's air supply. A volatile oil such as kerosene or fuel oil anywhere in the diving air system may produce the same result. The intake of a diving air pump or compressor should not be close to the exhaust of an internal combustion engine or to the top of a smoke stack.

Unconsciousness from carbon monoxide poisoning may result without any warning symptoms. Generally a person affected has a blush color. Treatment consists of removal to fresh air, artificial respiration, keeping patient warm and quiet, and administering stimulants. Pure oxygen may be administered from a mask while artificial respiration is being given. After the patient regains consciousness, hot black coffee may be given by mouth as a stimulant.

The effect of a given percentage of carbon monoxide will be in proportion to the absolute pressure at which it is breathed.

A few masks (having black canisters) which will give protection from only carbon monoxide are carried in submarines. Carbon monoxide absorbent canisters for attaching to submarine escape appliances (lungs) are also carried.

HYDRAULICS

Weigh a large container having a flat bottom and vertical sides and then fill with water and weigh again. Divide the weight of the water by the volume to obtain the weight of the water per cubic foot. The density of fresh water will be found to be about 62.4 lbs. per cu. ft., that of salt water is generally 64 lbs. per cu. ft.

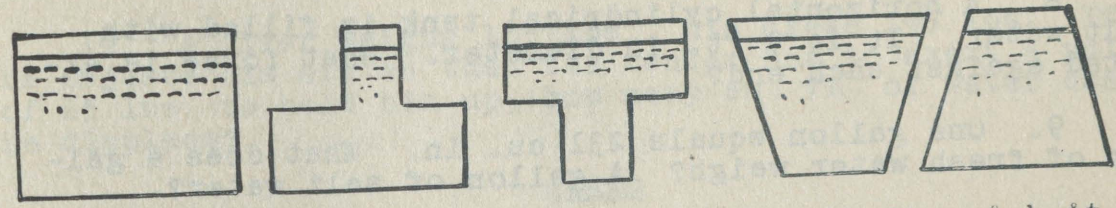
If one end of a piece of tubing is connected to a gauge and the other end is submerged in the water, the gauge will indicate the pressure in the water at the end of the tube. If the pressure is measured at a certain depth and then the end of the tube is lowered to twice this depth, the gauge will show twice as much pressure. Therefore, the pressure in a liquid depends on the depth.

No matter in which direction the end of the tubing points up, down, or toward any side the gauge will read the same as long as the end of the tube remains at the same depth. Thus the pressure at any point in a liquid is exerted equally in all directions.

It is apparent that the weight of all the water in a container having vertical sides rests on the bottom of the container. The force on the bottom is the weight of the water. The pressure can be found by dividing the weight of the water by the number of square inches in the bottom of the container. By measuring the height of the water in the container, the pressure per foot of depth in water can be calculated. It is 0.343 lbs. per sq. in. in fresh water, or 0.445 lbs. per sq. in. in salt water.

The same result may be obtained in another way. Consider a cubic foot of water in a container having the height, length, and width each of 12 inches. The area of the bottom of the container is one square foot. The depth of the water is one foot. A cubic foot of fresh water weighs 62.4 lbs., salt water 64 lbs. The pressure per foot depth of fresh water is therefore 62.4 lbs. per sq. ft., of salt water 64 lbs per sq. ft. There being 144 sq. inches in one sq. ft., the pressure per sq. in. will be the above amounts divided by 144, or 0.434 and 0.445 lbs. per sq. in., respectively.

The pressure on the bottom of the container will have no relation to the shape of the container, since the pressure will depend only on the depth of the liquid. For example, each of the containers below will have the same pressure on the bottom if all are filled to the same height. If the bottoms all have the same area, the force against the bottom will also be the same in each.



Calculate the volume of a block of metal, weigh it, and then weigh it again suspended in water. It will be found to have lost weight in the water and that the loss of weight is exactly equal to the weight of an equal volume of water. Therefore, an object submerged in a fluid is buoyed up by a force equal to the weight of the displaced fluid. A floating object will sink into a liquid until the weight of the volume of liquid displaced is equal to the weight of the object.

PROBLEMS

1. A pressure gauge connected to the sea in a submarine reads 74. At what depth is the submarine?

2. The specific gravity of kerosene is 0.8. What is the pressure on the bottom of a tank filled to a depth of 30 ft.?

3. What pressure is required to supply water to the top of the Washington monument, 550 ft. high, at a pressure of 80 lbs.?

4. A drum 2 feet in diameter, standing on end, is capable of withstanding an internal pressure of 50 lbs. per sq. in. A 2 inch pipe is connected to it vertically. How high will salt water have to be poured into the pipe to burst the drum?

5. A tank is 6 ft. tall, 8 ft. wide, and 12 ft. long. How many pounds of salt water will it hold? What is the pressure on the bottom? How many pounds of force are pushing on the sides?

6. The area of a man's body is about 2,000 sq. in. How many tons of force are pressing on a diver at 90 ft. depth?

7. The Squalus lay in 243 ft. of water. What air pressure is required at that depth to overcome the water pressure?

8. A horizontal cylindrical tank is filled with salt water. It is 9 ft. in diameter. What force is exerted against each end?

9. One gallon equals 231 cu. in. What does a gallon of fresh water weigh? A gallon of salt water?

10. Twenty gallons of salt water per minute must be pumped 60 ft. high into a tank. If the water end of a reciprocating pump has a bore of 10 inches and a stroke of 16 inches, how many strokes per minute does it make?

11. If the steam end has 1/2 the diameter of the bore of the water end of this pump, what is the least steam pressure used?

12. A hydraulic jack has a ram 8 in. in diameter with a lift of 2 feet. How many strokes must be made with the pump if the piston has a 2 inch diameter and a 4 inch stroke?

13. A block of spruce weighs 18 lbs. per cu. ft. It is 8 ft. long, 12 inches thick, and 18 inches wide. How deep will it sink in salt water?

14. A flooded pontoon, 50 ft. long and 18 ft. in diameter, is on the bottom in 200 ft. of water. If the structure of the pontoon weighs 60 tons, how much can it lift when blown dry?

15. A standard sized hatch for a submarine is 22 inches in diameter. If the hatch is three feet under water, could a man exert sufficient force to raise the hatch cover?

16. The density of spruce is 18 lbs. per cu. ft. A block 12 inches by 8 inches will float with what draft? What is its displacement?

17. A tight cylindrical tank 3 ft. in diameter, 6 ft. long, weighing 3,000 lbs., is placed in the water. Will it sink or float and by how many lbs.? What is its specific gravity?

18. A lighter in salt water 30 ft. by 15 ft. sank 5 inches when a truck was loaded on board. What was the weight of the truck? How much would it have sunk in fresh water?

19. A diver weighs 165 lbs., his dress 195 lbs. If he adjusts his air so that the tender has to exert a pull of 15 lbs. to hold him up, how many cu. ft. of water does he displace?

GASES

If all the air is pumped out of a container, and then the container is weighed, it will be found to weigh less than when full of air. An automobile tire weighs more when inflated than flat. It is apparent that air has weight, which has been found to be 1/12 pound per cu. ft. All gases have weight, some more than others.

Being a fluid and having weight, air exerts pressure and buoys up any object submerged in it just as a liquid does. Balloons float in the air because they are buoyed up by a force equal to the weight of the displaced air. If the volume is decreased by allowing the gas lighter than air to escape from the bag, the balloon sinks.

Put a little water in a can and boil the water. Remove from the flame, cover the can tightly, and cool it quickly. The steam will have driven out all of the air in the can and when the can is cooled, the steam will condense. The pressure of the atmosphere on the outside of the can will crush it flat.

If a long tube, closed at one end, is filled with mercury and the open end is inverted in an open dish of mercury, the mercury will run out of the tube until the weight of the column of mercury equals the force of the air at the bottom of the tube. A vacuum will be left in the space at the top of the tube. Measure the height of mercury in the tube and it will be about 29.92 inches at sea level. This arrangement is one form of barometer and is actually used to measure the pressure of the atmosphere. The higher we go from the face of the earth, the less the depth of air above us, and consequently the lower we can expect the air pressure to be. Actually, the mercury within the barometer will fall about 1 inch for each thousand feet we ascend. An altimeter is made exactly the same as a barometer, except that instead of being marked to show the air pressure it is marked to show the height above the surface of the earth just as a depth gauge in a submarine shows the water pressure in feet of depth instead of lbs. per sq. in. The pressure of the earth's atmosphere is measured at sea level, which is zero altitude.

The specific gravity of mercury is 13.6. The height of a column of water which has the same pressure as the mercury will be $13.6 \times \frac{29.92}{12}$ feet, or 33.6 feet of fresh water. It is 33 feet for salt water. The formula is: 33 feet x 0.445 lbs. per ft. = 14.7 lbs. per sq. in. This is the pressure of the earth's atmosphere at sea level.

When a pressure gauge reads zero, it indicates that the pressure is the same as the pressure of the earth's

atmosphere. Actually, zero gauge pressure is 14.7 lbs. per sq. in. By adding 14.7 to the gauge reading we get the true pressure in lbs. per sq. in., called absolute pressure. By dividing lbs. per sq. in. by 14.7 lbs., the pressure of the atmosphere, we have the pressure in atmospheres.

Take a U-shaped glass tube with one arm of the U shorter than the other; seal it up. Pour mercury in the long tube until the mercury stands at the same height in both arms of the U. The air pressure will be one atmosphere and equal in both sides of the tube because if it were not, the mercury would be pushed up in the side having the less pressure. The volume of air in the short side of the tube will be equal to the area of the cross section of the Tube (A), when multiplied by the length of the tube above the mercury (l). Measure l and the volume will be A x l. Then pour more mercury into the tube until the mercury in the long tube stands about 29.92 inches above the mercury in the short tube. The pressure in the short tube is now two atmospheres. Measure l again and it will be 1/2 its former value. The new volume will be A x l/2, or 1/2A x l. It is apparent that if the absolute pressure is doubled, the volume is halved.

Let the first pressure be P_1 and the second P_2. Let the first volume be V_1 and the second V_2. Then

$$\frac{P_1}{P_2} = 1/2 \text{ and } \frac{V_2}{V_1} = 1/2$$

Since $\frac{P_1}{P_2}$ and $\frac{V_2}{V_1}$ are both equal to 1/2, $\frac{P_1}{P_2} = \frac{V_2}{V_1}$

This is called Boyle's Law, which is true for any gas. It may also be expressed as follows: "The volume of a gas is inversely proportional to the absolute pressure."

When a gas is compressed, more molecules occupy the same space. As they fly about they bump into each other more frequently, and the resultant rebounds from these collisions cause the molecules to fly about faster. This increased molecular motion produces more heat. When the gas is allowed to expand, the molecules slow down and the heat is less.

PROBLEMS ON BOYLE'S LAW

1. The capacity of an oxygen flask is 2.2 cu. ft. What is the pressure if it contains 200 cubic feet of oxygen?

2. How much will the air weigh in a torpedo air flask 20 in. in diameter by 15 ft. long, charged to 2800 lbs. per sq. in.?

3. Eight men are trapped in a submarine compartment. They have two 2.2 cu. ft. oxygen cylinders, the gauges of which read 1300 and 1400 lbs. A man requires 1.5 cu. ft. of oxygen per hour. How long will their oxygen supply last?

4. A diver using torpedo air flasks should have at least 25 lbs. above bottom pressure on his control valve; air should be supplied at 4.5 cu. ft. per min.; at least 3 torpedo air flasks must be in the boat, and one must be held in reserve. Pressure in all flasks must not be allowed to drop below 220 lbs. per sq. in. over bottom pressure. How long can you dive to 120 ft., with three 18 cu. ft. torpedo air flasks in a boat, each charged to 1,000 lbs.?

5. Calculate the air supply necessary for a diver to work in 200 ft. for 5 hours. Twenty cu. ft. torpedo air flasks, maximum capacity 2800 lbs. per sq. in., are available. The diver requires 4.5 cu. ft. per minute of air.

Temperature is a measure of heat. The inventor of the Fahrenheit thermometer believed that it was impossible to obtain a temperature lower than the point at which he placed the zero mark on the scale of his thermometer. Today we believe that the heat, and consequently molecular motion, exists down to 460°F. below zero, which is called the absolute zero. The actual amount of heat present in a body must therefore be referred to the absolute zero, and temperatures based on this point are called absolute temperatures. To obtain absolute temperature, add 460° to the Fahrenheit temperature.

If the air in the end of the V-tube used to demonstrate Boyle's Law were heated, it would be necessary to increase the pressure by pouring in more mercury to keep the volume of the air constant. This explains why a charged flask should not be exposed to the sun.

Represent the absolute pressure of the air before heating by P_1 and after heating by P_2. Let T_1 and T_2 be the absolute temperatures of the air before and after heating. It will be found that:

$$\frac{P_1}{P_2} = \frac{T_1}{T_2}$$

This holds good for all gases. It is called Charles' Law, which may also be expressed as follows: "The volume of a gas remaining the same, the absolute pressure is proportional to the absolute temperature."

If the pressure is kept constant and the gas allowed to expand as it is heated, it will be found that:

$$\frac{V_1}{V_2} = \frac{T_1}{T_2}$$

This is Gay-Lussac's Law, which may be stated as follows: "The pressure of a gas remaining the same, the volume is proportional to the absolute temperature."

All three of the above equations can be combined into one, called the Law of Gases.

$$\frac{P_1 V_1}{P_2 V_2} = \frac{T_1}{T_2}$$

If the temperature is the same, $T_1 = T_2$ and both cancel out of the formula, leaving Boyle's Law. When volume is the same, V_1 and V_2 cancel out, leaving Charles' Law. When the pressure does not change, P_1 and P_2 are eliminated, giving Gay-Lussac's Law.

PROBLEMS

1. An 18 cu. ft. torpedo air flask charged to 3,000 lbs. per sq. in. has a temperature of 150° F. What will its pressure be when it has cooled to 75° F.?

2. Two full bottles of oxygen holding 2.2 cu. ft. each at 1500 lbs. per sq. in., and 80° F., are connected to two empty flasks of the same size. The pressure in all four flasks was 700 lbs. at one instant. What was the temperature of the oxygen then?

3. The pressure in a tank is one atmosphere, temperature 72° F. Air is forced in at a temperature equal to the temperature in the tank until the pressure is 66 lbs. per sq. in. by gauge. What is the temperature?

When a gas under pressure is in contact with a liquid, the gas molecules will enter the spaces between the molecules of the liquid, forming a solution. Soda water is made by dissolving carbon dioxide in water. The gas will continue to enter the liquid until the pressure of the gas in the liquid is equal to the pressure of the unabsorbed gas. If the pressure is released from the outside gas, the gas in the liquid will leave the solution until the inside and outside pressures are equal. When these pressures are equal and no gas is entering or leaving the liquid, the solution is said to be saturated for that pressure. This is what occurs when a bottle of ginger ale is opened and the carbon dioxide allowed to escape, making it flat.

When the external pressure of the gas is lower than the internal pressure by a certain amount, the gas may leave the solution so fast that it will form bubbles in the liquid. Such bubbles are apparent in a freshly opened bottle of ginger ale. Bubbles of nitrogen are formed in the body of a diver in this way if he is not properly decompressed. The amount of gas absorbed by a liquid is proportional to the pressure. This is called either Dalton's Law or Henry's Law.

When a mixture of different gases is dissolved in a liquid, each gas will be absorbed into the liquid in the same manner as though each gas were alone. This is the Law of Dalton and Henry. For example, taking air as a mixture of 79% nitrogen and 21% oxygen, water will absorb both gases until their pressures are equalized inside and outside the solution. However, the pressure of the nitrogen is only 79% and the oxygen pressure is only 21% of the pressure of the air. Because of these differences in their pressures, the gases will enter the solution, keeping the percentages of oxygen and nitrogen the same inside and outside the solution.

If the water is saturated with air, and then oxygen alone at the same pressure is placed in contact with the water, the external pressure is then 100% oxygen and the internal pressure is still only 21% oxygen. At the same time, the external nitrogen pressure has been changed to zero while the pressure of nitrogen in the water is still 79%. Consequently, oxygen will enter and nitrogen will leave the water until the two gases are again in equilibrium and the solution is again saturated for the changed pressure conditions.

The above paragraph explains why a diver can eliminate nitrogen much faster from his body when breathing pure oxygen during his decompression.

DIVER'S AIR SUPPLY

A diver will require a minimum of 1.5 cu. ft. per minute of air at the pressure of the dive to provide sufficient ventilation to carry away the carbon dioxide. When working hard, he may require three or four times as much. When calculating the minimum quantity of air which the diver will require, 1.5 cu. ft. per minute of air may be used when hand pumps are to furnish the air. When air is supplied by any other means, use 3 times this figure or 4.5 cu. ft. per minute at the pressure of the dive.

Pressure in salt water is 0.445 lbs. per sq. in. per foot of depth. One atmosphere is 14.7 lbs. per sq. in. Pressure in salt water is therefore $\frac{0.445}{14.7}$, or .0303 atmosphere per foot. The pressure at a depth of F feet will be 0.0303 x F. atmosphere's gauge, or $(0.0303 \times F) + 1$ atmosphere absolute.

Let S be the required minimum air supply for a diver measured in cu. ft. per minute at atmospheric pressure. To find S for a diver at a depth of F ft., it is apparent that:

$P_1 = 1$ atmos.

$P_2 = 1 + (0.0303 \times F)$ atmos.

$V_1 = S$ cu. ft. per min.

$V_2 = 1.5$ cu. ft. per min.

$\frac{P_1}{P_2} = \frac{V_2}{V_1}$, or rearranged to solve

$$V_1 = \frac{V_2P_2}{P_1} \text{ or}$$

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

PROBLEMS

1. The capacity of a compressor is 15 cu. ft. per hour at 2500 lbs. per sq. in. Would you use it to furnish air for a dive to 250 ft., and why?

2. The cylinders of a two-cylinder, single-acting compressor have a 6-inch bore and a 12-inch stroke. How many r.p.m. must it make to give one diver 4.5 cu. ft. of air per minute at 200 ft.?

3. A one-cylinder, double-acting compressor has a 4-inch bore, 6-inch stroke, 1-inch diameter piston rod, 300 r.p.m. How many cu. ft. per minute can it deliver at 30 ft. depth?

4. Diver's air is being supplied from a low-pressure compressor delivering 150 lbs. per sq. in. into a receiver which is 6 ft. long and 4 ft. in diameter. If the compressor stops, how long can the diver stay at 26 ft.?

5. A four-stage compressor has the following name-plate data: 12 - 6 - 4 - 2 x 8 inches. 25 r.p.m. How deep can a diver work, allowing for a relief diver?

FLASKS

When a diver's air supply is to be taken from high-pressure air flasks, the following conditions must be met:

1. Allow 4.5 cu. ft. per minute at pressure of dive for each diver.

2. At least 3 torpedo air flasks must be used, the air in one flask to be used only in an emergency.

3. When diving from a boat in depths over 120 ft., a stand-by boat must be equipped with at least 3 charged flasks connected up ready for use so that it can be brought up and used in an emergency.

4. The pressure in any flask in use must not be permitted to fall below 220 lbs. gauge (15 atmospheres) over the pressure at the depth of the dive.

5. Allow one atmosphere from one flask to charge volume tank, hose, etc.

To find the length of time one air flask will last:

Let C = Capacity of one flask in cu. ft.
" A = Gauge pressure of flask in atmospheres.
" D = Number of divers.
" E = Pressure of dive in atmos. gauge.
" P_1 = Absolute pressure in flask.
" P_2 = Absolute pressure of dive.
" V_1 = Volume of air in flask.
" V_2 = Volume of air required by diver during the dive.

The divers cannot get all of the air from the flask. Fifteen atmospheres gauge and gauge pressure of dive must be left in the flask for safety. Also, one atmosphere gauge is used to charge test tank, hose, etc. Add another atmosphere to the sum of these pressures to get absolute pressure.

Therefore: P_1 = gauge pressure of flask plus one atmos. less all of the above losses = $(A + 1) - (15 + 1 + 1) = A - (15 + E + 1)$.
P_2 = gauge pressure of dive plus 1 atmosphere $= E + 1$.
V_1 = volume of air in flask = C.

If one diver takes 4.5 cu. ft. of air in one minute, and if he can stay down Y minutes, he will take $Y \times 4.5$ cu. ft.

So: $V_2 = Y \times 4.5 \times$ number of divers $= Y \times 4.5 \times D$.

$$\frac{P_1}{P_2} = \frac{V_2}{V_1}, \text{ or } \frac{A - (14 + E + 1)}{E + 1} = Y\,\frac{4.5D}{C}.$$

We want to find out how long the divers can stay down with one flask so we solve for Y. Multiply both sides of the equation by C and divide both sides by $4.5\ D$. We find that: One flask will give duration of dive in minutes-

$$\frac{C\ (A - (15 + E + 1))}{4.5\ D\ (E + 1)}$$

PROBLEMS

1. How long can a diver remain at 140 ft. on the air fron one flask of 16 cu. ft. charged to 1500 lbs.?

2. Two divers remain at 100 ft. for one hour. The diving boat has 3 air flasks of 11 cu. ft. each originally charged to 800 lbs. Will there be enough air for their decompression?

3. A diving job is estimated to require two divers at a time for a total of 3 hours on the bottom in 200 ft.; 18 cu. ft. air flasks are available, but they can be charged to 1,000 lbs. only. Boats available are one 50 ft., and two 40 ft. motor launches. The larger will hold 4 flasks; the smaller will take 3. What air supply will you provide for divers?

4. Calculate the pressures a diver will have left in three 12 cu. ft. flasks each charged to 900 lbs. after he makes a 20 minute dive to 150 ft. and completes his decompression.

DIVER'S AIR PUMPS

In a single-acting cylinder of an air compressor, the inlet valve is opened by the pressure of the atmosphere as the piston moves away from the cylinder head. Air enters the cylinder at atmospheric pressure. When the piston has reached the bottom head of the cylinder, it pushes against the air which has entered the cylinder. This pressure closes the inlet valve against the pressure of the atmosphere and forces the exhaust valve open, permitting the piston to push the air out of the cylinder until it reaches the end of its stroke. For each revolution of a single-acting compressor, the piston will make one suction and one discharge stroke. If there is more than one cylinder, this cycle will be carried out in each.

A double-acting cylinder is equipped with valves and heads at each end so that regardless of which way the piston is moving, it is compressing the air on one side and sucking in air on the other side. For each revolution of a double-acting compressor, there will be two suction and two discharge strokes of the piston.

The volume of air at atmospheric pressure which passes through the cylinder of a single-acting compressor at each revolution must be the length of the stroke of the piston multiplied by the area of the cross section of the piston. The volume of air at atmospheric pressure passing through a double-acting cylinder at each revolution must be the length of the cylinder multiplied by the area of the piston on one side of the piston. Because it is necessary to have piston rods to move the pistons, the piston area will not be the same on both sides. The area of the cross section of the piston rod must be deducted from the piston area on one side.

If the amount of free air which will be passed through the compressor in one revolution is known, the amount which will be passed through during any number of revolutions can be found. If the speed (revolutions per minute is known), the volume of air at atmospheric pressure which will pass through in a given length of time can be calculated.

Unfortunately, no air compressor or pump can be built to deliver this theoretical volume of air. The air coming into the cylinder is at slightly less than atmospheric pressure because the valve passages restrict its flow; there is always some leakage past pistons and the valves, etc. To find the amount of air which a compressor will actually pump, it is necessary to know the extent of those losses which reduce the efficiency of the compressor.

Efficiency is the ratio of the actual amount of air delivered by the compressor to the theoretical amount it should deliver. Since it must be less than perfect, the efficiency is always less than one. To obtain the percentage of efficiency, merely multiply the efficiency by 100.

The less efficient a compressor is, the more revolutions it must make to pump the same volume of air. A theoretically perfect compressor has an efficiency of 100% and would require the fewest revolutions to deliver the same quantity of air. The efficiency will therefore be inversely proportional to the number of revolutions that the compressor requires to deliver a given quantity of air.

Pump air into a known volume with the compressor and note the number of revolutions required to build up a certain pressure. This will be the actual number of revolutions required to pump a given quantity of air with this compressor.

From the dimensions of the pump, and the volume and pressure of the discharged air, we can use Boyle's Law to calculate the theoretical number of revolutions which this compressor would require to pump this quantity of air if it were perfect and had an efficiency of 100%.

Applying Boyle's Law:

Let P_1 = test pressure.
P_2 = atmospheric pressure.
V_1 = volume of test tank.
V_2 = volume of air at atmospheric pressure which must be compressed to give test pressure in test tank.

Let T = theoretical capacity of pump cylinders in cu. in. for each revolution.
P = test pressure in lbs. per sq. in. gauge.
C = capacity of the test tank plus air hose, fittings, and space in the discharge side of the pump in cu. in.
R = theoretical number of revolutions required to charge test tank to pressure P.
X = number of revolutions actually required to charge test tank to P.

$P_1 = P$
$P_2 = 14.7$ lbs. per sq. in.
$V_1 = C$
$V_2 = RT$

$$\frac{P_1}{P_2} = \frac{V_2}{V_1} \text{ or } \frac{P}{14.7} = \frac{RT}{X}$$

Solving for the theoretical revolutions,

$$R = \frac{CP}{14.7\ T}$$

The efficiency of this compressor will be $100 \frac{R}{X}$.

PROBLEMS

1. A Mark III Navy Standard Diving pump is to be tested. The test tank has a capacity of 1870 cu. in. Use one length of hose. It requires 50 revolutions to charge test tank to 100 lbs. per square inch. What is the per cent efficiency?

2. There is on hand a Mark II pump requiring 48 turns to charge a 1790 cu. in. test tank to 100 lbs. per sq. in., using a 50 foot length of diving hose. The waste space is 43 cu. in. for a Mark II pump. What is the per cent efficiency?

3. How many revolutions are required to charge a test tank of 1.5 cu. ft. capacity to 100 lbs. per sq. in., using a Mark III diving pump, 70% efficient. Use 100 ft. of hose.

4. If a Mark III pump is 5 per cent efficient, how many revolutions are required to charge a cubic foot tank to 50 lbs. per sq. in., using 1 length of air hose?

5. Repairs are made to the cylinders of a Mark III pump while on a job. No test tank was brought along. The diving officer decides to find the new efficiency of the pump by charging the diver's air hose, consisting of four 50 ft. lengths, to a pressure of 100 lbs. per sq. in. If 20 turns of the pump are required, what is its efficiency?

6. The nameplate of a high-pressure air compressor gives its capacity as 50 cu. ft. per hour at 3,000 lbs. per sq. in. and 400 r.p.m. If this compressor takes three hours to charge a 210 cu. ft. accumulator from 2,000 to 3,000 lbs. per sq. in., what is its present efficiency, taking the rated capacity as 100%

Because the diver requires at least 1.5 cu. ft. of air per minute at the pressure of his depth, it is necessary that his air pump be turned over fast enough to supply at least this quantity of air to his helmet. With hard work, the diver may require 3 or 4 times this amount of air.

We can calculate the minimum speed to turn a pump that is 100% efficient as follows:

Let R = Number of revolutions per minute required with the pump to furnish 1.5 cu. ft. per minute of air at atmospheric pressure.
N = Number of cu. in. of air the pump will furnish each revolution if it is 100% efficient.
1.5 cu. ft. of air per minute = 1.5 x 1728 = 2592 cu. in. per minute.

Then $R = \frac{2592 \text{ r.p.m.}}{N}$

Now let D = depth of water in feet.
X = number of revolutions per minute required of the pump to furnish 1.5 cu. ft. (2592 cu. in.) per minute at depth D.

Applying Boyle's Law:

P_1 = 1 atmosphere.

P_2 = absolute pressure of dive = (1 + .0303 D atmosphere).

V_1 = volume of free air to be supplied to diver in 1 minute = XN.

V_2 = volume of air to be supplied to diver at pressure of his depth in 1 minute = 1.5 cu. ft. per minute = 2592 cu. in. per minute.

$$V_1 = \frac{P_2 \; V_2}{P_1}$$

Substituting, $XN = \frac{(1 + .0303D) \times 2592}{1}$

Since $R = \frac{2592}{N}$, $2592 = RN$

$XN = (1 + .0303D)\,RN$

N cancels out so that $X = R(1 + .0303D)$

We know that a pump which is less efficient must make more revolutions to deliver the same quantity of air because it has greater leakage. Then X must be inversely proportional to the efficiency if the efficiency is other than 100%.

If E is the efficiency in per cent of a pump less than 100% efficient, then

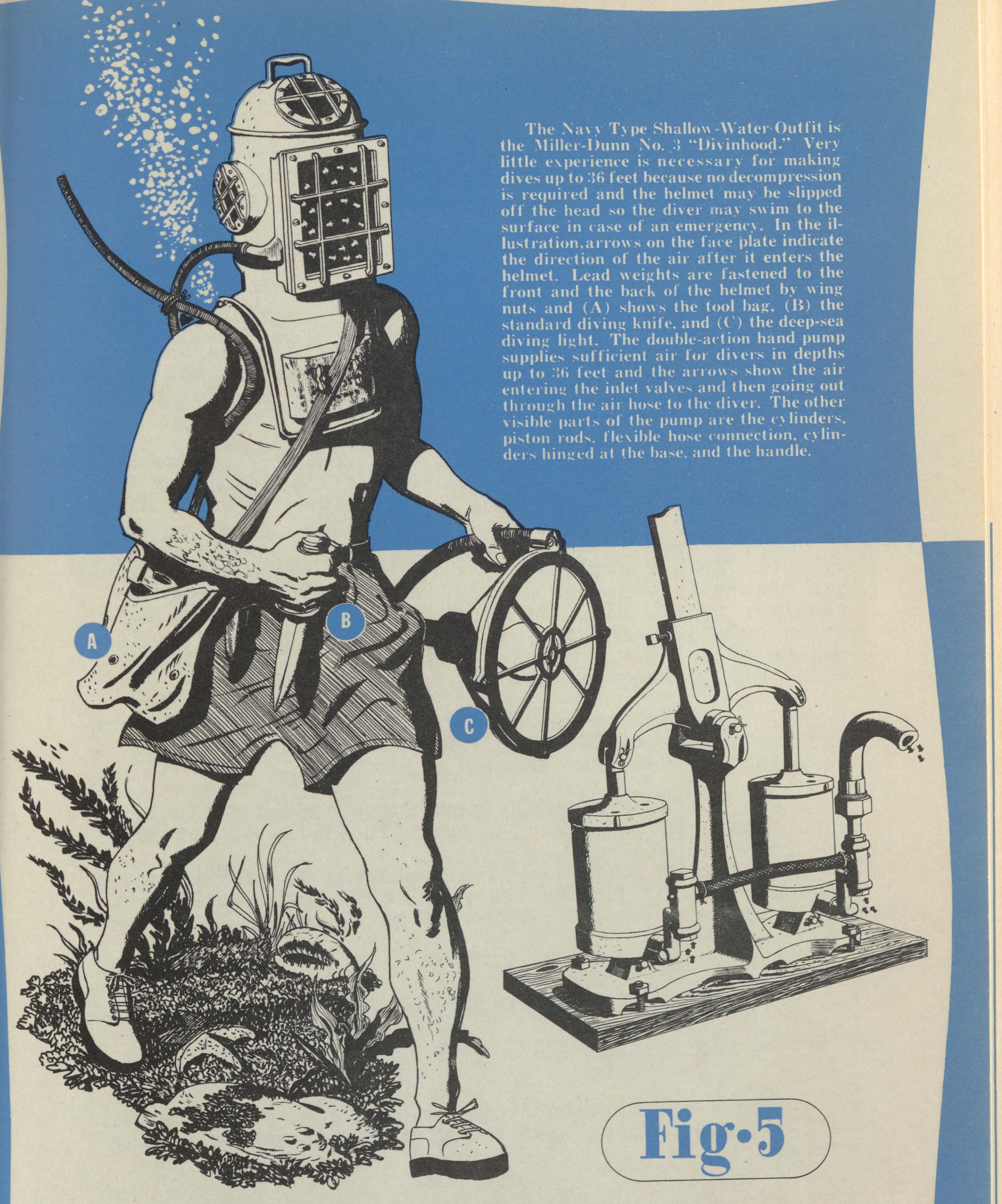
$$\frac{\text{X for a pump of E efficiency}}{\text{X for a pump of 100\% efficiency}} = \frac{100}{E}$$

or X for a pump E% efficient $= \frac{100}{E} \times R(1 + 0.0303D)$

and for any pump, $X = \frac{100R\,(1 + D\,(0.0303))}{E}$

PROBLEMS

1. A Mark III pump is 75% efficient. How many r.p.m.



The Navy Type Shallow-Water Outfit is the Miller-Dunn No. 3 "Divinhood." Very little experience is necessary for making dives up to 36 feet because no decompression is required and the helmet may be slipped off the head so the diver may swim to the surface in case of an emergency. In the illustration, arrows on the face plate indicate the direction of the air after it enters the helmet. Lead weights are fastened to the front and the back of the helmet by wing nuts and (A) shows the tool bag, (B) the standard diving knife, and (C) the deep-sea diving light. The double-action hand pump supplies sufficient air for divers in depths up to 36 feet and the arrows show the air entering the inlet valves and then going out through the air hose to the diver. The other visible parts of the pump are the cylinders, piston rods, flexible hose connection, cylinders hinged at the base, and the handle.

Fig·5

THE SHALLOW-WATER DIVING HELMET

are required to furnish minimum air supply to a diver at 50 feet?

2. With a Mark III hand pump, how deep can a diver go if the maximum possible speed of the pump is 30 r.p.m. and he receives the minimum allowable air supply?

3. Calculate the r.p.m. required for a Mark I, a Mark II, and a Mark III pump to furnish air to one diver at 20 ft., using each of the three pumps alone. All are 80% efficient.

4. Two Mark III pumps are available, each to supply air to one diver. If one is 83% efficient and the other is 72% efficient, how many r.p.m. will each have to make if the divers are at 38 feet?

5. A diver is to be sent down to 108 ft. Two hand pumps, Mark III, are available with efficiencies of 81% and 76%. How fast must each be run? Can a relief diver be sent down?

6. An air compressor is rated at 150 cu. ft. of air per minute at 400 lbs. and 300 r.p.m. By charging the receiver to 400 lbs., it appears that the compressor is doing only 52% of this. A tachometer shows that it is making only 210 r.p.m. If speeded up to designed speed, will this compressor make its rated output?

7. At what speed should a compressor be run to supply two divers at 100 ft. if it is rated at 10 cu. ft. per minute at 90 lbs. and 125 r.p.m.?

8. How many Mark III hand pumps, 75% efficient, should be used to dive on a wreck in 95 ft. of water?

In solving the foregoing problems, it will be noted that R = 6.4 for a Mark III pump, 8.75 for a Mark II, and 9.33 for a Mark I. For a Mark III pump:

$$X = \frac{100 \times 6.4\ (1 + .0303D)}{E}$$

$$= \frac{100\ (6.4 + (6.4 \times .0303D)}{E}$$

$$\text{So } X = \frac{100\ (6.4 + .104D)}{E} \text{ for a Mark III pump.}$$

This means that to compute the r.p.m. of a pump which will furnish a diver with the minimum air supply at any depth:

Multiply depth in feet by 0.194
Add 6.4 to the product
Divide this sum by the efficiency of the pump in per cent and multiply the quotient by 100.

PROBLEMS

1. Compute similar formulae for Mark II and Mark I pumps.

2. Two Mark III pumps, efficiency 68% and 74%, are to be used. Find the minimum r.p.m. for 50 ft. of water.

3. How deep can a diver descend with a Mark III pump that is 68% efficient?

4. A Mark III pump has been found to be 79% efficient. Compute the formula for finding the minimum r.p.m. for any depth.

WHENEVER A PUMP IS TESTED AND THE EFFICIENCY DETERMINED, THIS FORMULA CAN BE COMPUTED AND POSTED IN THE COVER OF THE PUMP.

CHAPTER V

THE SHALLOW WATER DIVING APPARATUS

(Miller-Dunn Navy Type)

The equipment consists of the following principal parts: helmet with weights, pump, and air hose.

The general characteristics of the apparatus are as follows: length of stroke, 3.75 inches; inside diameter of cylinders, 3.375 inches; inside depth of cylinders, 5 inches; delivery per stroke, (when 100% efficient), 33.55 cu. inches; waste space of manifold, 1.5 cu. inches; length of piston rods, 6.375 inches; diameter of piston rods, 0.625 inches; thickness of assembled piston, 1 inch; weight of helmet, (without weights), 26½ lbs; each lead weight, 8.25 lbs; total weight of helmet, with weights, 60 lbs; weight of pump with handle, 28 lbs; weight of 50 feet length of hose, 16.75 lbs. The total weight of the complete outfit is about 105 lbs. and the maximum allowable depth is 36 feet.

THE MILLER-DUNN DIVINHOOD

The Divinhood may be considered as a diving bell fitted for the diver's head. Air admitted under a pressure in excess of the water pressure maintains the water level inside the helmet well below the diver's respiratory passages, when the diver is in an erect position. The diver is thereby able to breathe freely while the rest of his body is encompassed by water. The helmet is of copper, cylindrical in shape, with a domed top, and shaped with a rolled edge at the bottom to conform with and rest comfortably on a diver's shoulders, upper chest, and back. The front of the helmet is fitted with a heavy bronze frame in which are located two helmet windows of plate glass. The windows are made watertight by being set in soft wicking soaked with white lead. Securing the windows in place is effected by right and left hand securing frames held by means of hexagonal head stud bolts to the helmet frame. Either glass may be removed for replacement without disturbing the other. The size of the windows forming the faceplate gives a wide range of vision with no blind spots. A guard with a long top and a short bottom prevents breakage of the glass. A handle is riveted to the top of the helmet to facilitate handling. An air inlet connection, termed the gooseneck, is riveted and sweated

on the right side of the helmet, curved downward and toward the rear at an angle of approximately 35 degrees to give a fair lead to the air hose. The end of the gooseneck is threaded and to it is secured the female coupling of the air hose. The bight of hose is led under the diver's right armpit, brought up in front of the right shoulder and secured by means of a marline stop hitched in an eye formed on the curve of the gooseneck. The bight of hose under the diver's arm must form a loop sufficiently large to enable the diver to throw the helmet from his shoulders in case of necessity. A copper baffle plate sweated over the air inlet inside the helmet deflects the air upon entrance and the flow is caused to pass over the faceplate, thereby preventing the glass from fogging. Small holes in the bottom part of the helmet permit the escape of excess air in addition to that which escapes around the shoulders. Broad copper straps are riveted to the front and back plates of the helmet and are for the purpose of receiving and holding the brass clips molded in the lead weights. The lead weights prevent the helmet from lifting off the diver's shoulders. The four lead weights are hung on the weight straps of the helmet, two in front and two at the back, through holes in the weights and helmet to prevent loss.

THE AIR PUMP

The air supply is furnished by a two-cylinder, single-acting manually operated pump.

The bottom plate of the air pump is an irregularly shaped iron casting having a vertical standard in the center to which is pinned a rocker arm or beam of the same material. Located at each end and integral with it are vertical pads to which the lower cylinder head lugs are pinned. Four slots are formed in the edge of the bottom plate for securing the pump by means of large wood screws to a plank or platform.

The cylinders, mounted vertically, are of seamless drawn brass, 3.375" in diameter with an inside depth of 5 inches. Each cylinder is closed at the bottom by a composition metal head screwed and sweated permanently in place. Cast with the bottom cylinder head is a hinge lug by means of which the cylinders are pinned to the bottom plate. This method of securing the cylinders permits them to move slightly in a vertical plane in order to center their axis with the ends of the rocker arm or beam which makes a vertical arc on the down and up strokes of the piston. There is a drilled, threaded extension on the side of the bottom cylinder heads into which is screwed the air lead connection integral with the valve body. Inside the cylinder, the bottom head has an air channel scored out which leads to the air connection. The top cylinder head is threaded and screws on the cylinder. Lugs, cast in one with the head, may be engaged by a hook spanner wrench for tightening or removal. The piston rod passes through a center hole in the cylinder head which forms a guide for it. Four other holes are drilled through the top cylinder head. These holes are primarily to prevent cushioning on the up stroke of the pistons but also for oiling the piston leathers, for heat dissipation, and for lightness. The rocker arm or beam pinned to the vertical standard of the bottom plate has drilled fork ends to which are pinned the upper ends of the piston rods. A socket formed in the rocker arm casting provides a means for holding the pump handle, which is held in place by a set screw. The pump handle is 37.5 inches in length and is fitted with a hardwood handgrip. Each piston consists of two cast disks with a cup leather interposed between them. The piston rod, threaded on the lower end, passes through a central hole in the upper disk and cup leather screws in a threaded hole in the lower disk. When assembled properly on the piston rod, the piston is one inch thick.

The valve bodies, carried in a vertical position, are interconnected by a seven-inch length of flexible rubber hose and these parts constitute the pump manifold. In the lower end of each valve body is screwed a nut with a 3/8 inch hole drilled through the center. This hole forms the suction intake for each cylinder. The upper, inside part of the nut forms a seat for the inlet valve. The inlet valve, which is of the floating type, has a short fluted stem and a flat seat faced with a leather washer. This valve is held seated, due to its own weight and the pressure of delivery air when its respective cylinder is under compression. On the suction stroke, the valve lifts, permitting air to enter the bottom of the cylinder. An outlet valve is located in the upper part of each valve body. They are similar in shape and size to the inlet valves. The valve seats down on a seat formed in the valve body. The compression stroke causes the valve to lift and discharge air from the cylinder past the valve to the air hose; the upper ends of the valve bodies are closed by nuts. When facing the pump manifold, the right-hand valve body nut has an air connection for the male fitting of the diving hose. Near the manifold

air connection to each bottom cylinder head is a screw which may be removed to drain excess oil collected in cylinders.

THE AIR HOSE

This is a flexible, vulcanized rubber tube surrounded by a two-ply, braided duck covering laid in rubber which is in turn covered by a smooth outer layer of rubber. The hose is 50 feet in length, 0.5 inch diameter of bore and with an outside diameter of one inch. One end of the hose is fitted with a brass male coupling having a commercial thread which connects to the pump manifold. The other coupling is of a female type and connects to the gooseneck of the helmet.

This equipment is highly efficient to depths not exceeding 36 feet. Its use is not restricted to trained divers; the only qualification required is that the user be an expert swimmer. Being light, it can be transported easily and is quickly put in operation in case of emergency. Tests have shown that the pump is 90% efficient when charging a capacity of 1888 cubic inches to a pressure of 20 pounds per square in. Only three men are required for a diving crew, as follows: Diver, tender, and pump man.

Under no circumstances should the helmet be secured to the diver. Additional weights should never be attached to the diver's body. A small life line should always be secured around the diver's body and the surface end held by the tender.

The general care of the apparatus is practically the same as that required for the Navy standard equipment.

NAVY DEPARTMENT

GENERAL ORDER NO. 49.

WASHINGTON, D. C.
May 13, 1935

DANGERS OF HELMET DIVING

1. Attention is called to the dangers involved in the practice of diving with the helmet and without the diving suit, particularly when diving to a depth for which decompression is required. Helmet diving has no advantage over diving with the full suit other than the comfort of the diver in tropical waters. In case of

difficulty, the diver can handle himself to better advantage when wearing the full suit, and he is much safer.

2. Before authorizing helmet diving, the officer in charge of the work will satisfy himself that the special circumstances make this procedure particularly desirable and that no undue hazard will be incurred by the diver. Helmet diving to depths in excess of 36 feet will be considered only for experienced divers who have been recently engaged in diving. The officer in charge, prior to the lowering of the diver, shall see that the diving air hose is looped under the diver's arm and that there is no danger from this source of accidentally pulling the helmet from his head. Descents and ascents shall be made on the descending line or stage. Ascents shall be made with the helmet on and the air supply from the surface to the helmet shall be continued until the diver is on deck and the helmet removed. In all dives in excess of 36 feet, ascents shall be made in accordance with the decompression stages prescribed in the Diving Manual. Ascents from depths of 36 feet and less may be made up the ascending line or by stage hoisted from the surface at a rate not greater than 50 feet per minute. Divers should be cautioned not to hold their breath but to freely vent air from the lungs during such ascents.

Claude A. Swanson
Secretary of the Navy.

THE IMPROVED TYPE "LUNG"-PLUG TYPE FOR AUXILIARY USE AS A RESPIRATOR (See Figure 6).

The principle of operation for both the old type "lung" and the improved types is identical in every respect. Since both the old and the improved types are used in the same way, the training procedure involves no change.

The design of the metal mouthpiece is the most radical change that has been made. The new mouthpiece consists of a vertical metal cylinder containing mica disc valves and air conduits for controlling the directional flow of the inhalations and the exhalations. The cut-off valve is mounted on the top of the mica disc valve housing. The rubber mouthpiece is of the same design as used in the old type "lung" and is secured to the metal mouthpiece aft of the cut-off valve. The mica disc valves consist of both an inhalation and an exhalation valve. The inhalation valve is annular shaped and is mounted on

an annular ring provided with two annular knife-edged seats. The exhalation air duct consists of a metal tube suspended from the annular ring. The mouthpiece is secured to the breathing bag nozzle by a threaded connection of the winged nut type. By means of the winged nut, the metal mouthpiece can be secured airtight and watertight to the breathing bag nozzle by normal hand pressure, thus obviating the need of wrenches or pliers for this purpose as was the case with the old type "lung."

The removal of the respirator receptacle plug converts the "lung" from a self-contained or closed type apparatus to an open type device in which the necessary air for breathing purposes is drawn from the outside atmosphere. Before it is inhaled, the air is purified by passing through the soda lime canister centrally located in the breathing bag. The canister has a capacity of approximately 500 cubic centimeters of soda lime.

The breathing bag is of stockinette-covered rubber. Reinforced fabric has been molded into the rubber as a support for the metal flanges and all corners of the metal canister. The top edges of the bag have been recessed in the center in order to accommodate the canister nozzle.

When the improved type "lungs" are used as submarine respirators for protection against gas, care should be taken that the sealing plug is tightly replaced so that the airtight integrity of the breathing bag is re-established before using the "lungs" as submarine rescue devices.

The chemical in the "lung" canister will not protect the wearer against carbon monoxide. For protection against carbon monoxide it has been the past practice to furnish submarine respirators fitted with canisters containing the chemical hopcalite, a catalyst, which when brought into contact with carbon monoxide converts the latter into harmless concentrations of carbon dioxide. A small canister containing hopcalite has been designed to screw into the receptacle after the plug has been removed. Instructions for use are labeled on the can. It is estimated that these small hopcalite canisters can be removed from their containers and fit into the "lung" receptacle in less than one minute and when used with the "lung" will protect against carbon monoxide for a period of at least 50 minutes. They will also protect the wearer indefinitely against inhalation of smoke.

Goggles will give escaping men better vision while ascending the buoy line, and suitable goggles are available for this purpose.

CHARGING AND TESTING OF NAVY TYPE HALF-HOUR, SELF-CONTAINED OXYGEN BREATHING APPARATUS

With a complete apparatus including a regenerator charged with one pound of carbon dioxide and oxygen bottle charged to 150 atmospheres (equivalent to approximately 2½ cu. ft. of oxygen), the following tests are necessary in order to determine whether or not the apparatus is functioning properly:

1. CLOSING VALVE

The closing valve is immersed in water and escaping air bubbles will indicate leakage. The main closing valve is opened after the valve is capped and then again immersed in water. Escaping air bubbles will indicate leakage around the packing gland or valve stem. Then close valve and remove closing valve cap. Providing no leaks occurred in the above tests, place oxygen cylinder in frame and attach closing valve to reducing valve, observing that gasket is in place.

The by-pass tube is then connected to cooler and oxygen cylinder, observing that the gaskets are in place.

The mouthpiece, the inhalation and exhalation tubes are connected to the cooler and regenerator, observing that gaskets are in place.

2. CIRCULATORY SYSTEM

First place the thumb over the aperture in the rubber mouthpiece and open the main oxygen valve. If admission and reducing valves are functioning properly and there is no leakage in circulatory system of apparatus, the breathing bag will be inflated to its normal capacity. Leakage to outside atmosphere can be detected by the application of soap suds with a brush.

3. REDUCING VALVE

If there is leakage in the seat of the reducing valve and if at the same time the admission valve is functioning properly, excess pressure will operate the safety valve, thus making leakage evident. Such leakage can be remedied by suitable repairs to the valve seat.

SUBMARINE RESCUE BREATHING APPARATUS

The illustration shows a man escaping from a submarine via the buoy line. The line should be held between the feet while the hands grasp the rope in the position shown and if the man looks straight ahead he can breathe more or less normally. The visible parts of the "lung" are the chest and shoulder straps, rubber mouthpiece, nose clamp, hold-down clamps, breathing bag, and receptacle and sealing plug. Also shown is a view of the "lung" with the receptacle plug removed, exposing the soda lime dust in the canister. The "lung" now is ready to be used as a respirator for protection against gas. The plug-less "lung" can be used as a protection against carbon monoxide gas by merely adding the Hopcalite canister.

A AIR INLET VALVE
B AIR OUTLET VALVE (FLUTTER TYPE)
C CUTOFF VALVE
D HOLD-DOWN CLAMPS
E NOSE CLAMPS
F RUBBER MOUTHPIECE

Fig·6

4. ADMISSION VALVE

If the reducing valve is functioning properly but the admission valve is feeding above or below normal, such defects will be indicated by excessive inflation of the breathing bag or by lack of inflation. In event of such defects, suitable repair of admission valve or admission valve seat will be necessary.

5. ADMISSION VALVE AND REDUCING VALVE

If both the reducing valve and the admission valve are out of order, suitable repairs will have to be made to each. If such an unusual combination of defects seems present, substitute a new reducing valve for one thought to be out of order and test the admission valve again.

6. SAFETY VALVE

In order to test safety valve for proper functioning, close the admission valve by drawing the top of the breathing bag outward; then compress the copper bellows until the reducing valve seat opens, thus allowing the oxygen to flow into the reducing valve chamber at a higher pressure until the blow-off point of the safety valve is reached. This will be indicated by the safety valve whistling and allowing the excessive pressure to be reduced.

Resistance to free circulation of air in the apparatus can be detected by breathing into and from the fully assembled and charged apparatus; abnormal resistance will indicate obstruction in the circulatory system. Such resistance may be due to kinked or collapsed breathing tube, overcharged regenerator, or a foreign substance in circulatory system.

7. MOUTHPIECE

The mouthpiece, containing valves and attached corrugated tubes with connections, is tested for air tightness and functioning of valves in the following manner:

Place a solid plug in the exhalation coupling and your thumb over the opening of the mouthpiece; then blow into the inhalation coupling after immersing all parts in water; any leaks can be observed by escaping air bubbles. Place the mouthpiece in your mouth with solid plug still in exhalation coupling and attempt to exhale with the inhalation coupling in water; any leaks through the inhalation valve can be detected by air bubbles issuing from the inhalation coupling. Then with the mouthpiece in your mouth, test the exhalation valve for functioning by exhaling and inhaling, observing that valve opens and closes freely; then place the exhalation coupling against the mouth and exhale with the mouthpiece in water; any leaks through the exhalation valve can be detected by air bubbles issuing from the mouthpiece.

8. RELIEF VALVE

The mica valve in the saliva trap can be tested by putting solid plug connections in the inhalation and exhalation couplings; then immerse the rubber mouthpiece in water. By removing relief valve and blowing into relief valve barrel, any leakage through mica valve can be detected by air bubbles issuing from the rubber mouthpiece.

Before attaching mouthpiece and tubes to apparatus and after removing solid plug connections, test operation of the saliva trap and the relief valve by placing the palm of the hand over the end of the exhalation tube, pressing the relief valve open and exhaling several times, observing that exhaled air passes freely to the outside through the relief valve.

9. GENERAL TEST FOR TIGHTNESS

If above tests have shown apparatus to be airtight and functioning properly, complete the assembly of the apparatus, and give the final test with soap suds and brush all connections for airtightness, putting air pressure in the apparatus by opening the by-pass momentarily.

INFORMATION ON HALF-HOUR APPARATUS

Analysis of Oxygen in Large Oxygen Cylinder.

The Bureau of Mines' specifications call for 98 per cent pure oxygen, impurity to consist of nitrogen only.

Analysis of Air in Breathing Bag.

When the wearer inhales from the apparatus and exhales to the outside atmosphere at least three times, the analysis of air in the breathing bag is approximately 75 per cent oxygen and 25 per cent nitrogen.

Relief Valve and Saliva Trap.

The relief valve should be used at least once in every twenty minutes, thus enriching the mixture of air in the breathing bag with oxygen. This is an added and desirable factor of safety in case the apparatus cylinder contains more nitrogen than the specifications call for. An advantage of a combined saliva trap and relief valve in the mouthpiece is that when saliva is released to the outside, the air in the breathing bag is automatically enriched with oxygen.

REDUCING VALVE.
The pressure in the reducing valve is approximately three pounds per square inch.

SAFETY VALVE.
The blowoff pressure in the safety valve is set at approximately seven pounds per square inch. In releasing, the safety valve gives a warning whistle to the wearer when the pressure exceeds seven pounds.

PRESSURE IN BREATHING BAG.
The pressure in the breathing bag upon exhalation is approximately 3/4" positive pressure water gauge; upon inhalation the pressure is approximately 1/8" positive water gauge; the normal pressure in a breathing bag under ordinary working conditions is approximately 1/4" water gauge.

INFORMATION OF McAA NAVY TYPE HALF-HOUR BREATHING APPARATUS.

1. STEEL CYLINDER.
Cylinder holds 2-1/2 cu. ft. of oxygen at 150 atmospheres pressure and meets the requirements of the Interstate Commerce Commission as shown by the stamp of the Commission on the cylinder. The cylinder is 3-1/4 inches in diameter, 7 inches in length, and approximately 3/16 inches in thickness.

2. OXYGEN CLOSING VALVE.
The oxygen closing valve consists of the following principal parts: brass forgings, copper tube, main valve, by-pass, valve, safety cap, connection for reducing valve and by-pass, and lock nut.
(a) BRASS FORGING.
A brass forging is used rather than a casting in order to prevent oxygen leakage likely to develop under high pressure due to possible porous conditions of casting.
(b) COPPER TUBE.
A straight copper tube 1/4" outside diameter, closed at one end with two 1/8" diameter perforations 1/2" from the closed end, is screwed into the intake end of the closing valve and projects 2" into the bottle when the closing valve is installed in the bottle. This arrangement makes it possible to secure the oxygen from near the center of the bottle, thereby preventing sediment or moisture from entering the closing valve.
(c) MAIN VALVE.
This valve controls the supply of oxygen to the reducing valve. The valve consists of the following mechanical features: the wheel is fastened solidly to a non-rusting German silver stem; this stem has a shoulder on it above the packing gland in order that the wearer cannot screw stem out more than four turns and thus waste the supply of oxygen by complete unscrewing of valve wheel. One full turn opens the valve seat. The end of the stem and casting seat makes a valve of the needle-point type. The threads on stem and casting are arranged in such a manner that the packing does not work down into the threads and make the valve hard to open or close. The packing gland collar is held in place by a lock nut so that when the shoulder of the valve stem is turned out, the friction on the packing gland collar will not cause it to work loose, thus making a leak around the packing and stem.

(d) BY-PASS VALVE.
This valve is for the purpose of furnishing oxygen to the wearer in event of failure of the reducing valve or admission valve to furnish sufficient oxygen, and it is entirely independent of the main closing valve.
(e) SAFETY CAP.
The safety cap is designed for the purpose of releasing the pressure in the bottle if exposed to fire during storage or transportation. The safety cap is made up in accordance with provision of Schedule 13, U. S. Bureau of Mines, which requires that when apparatus is equipped with high-pressure oxygen cylinders the safety cap attached to the closing valve shall in addition to the usual fragile copper disc provided, be filled with a metal (such as Rose's metal) fusing at a temperature of approximately 94° C. Such fusible metal shall not extrude from the safety cap under a pressure of 150 atmospheres.

3. REDUCING VALVE
The reducing valve consists of the following principal parts: high-pressure fittings, housing, flexible copper bellows, nozzle, and mechanism for controlling the supply of oxygen.
(a) HIGH-PRESSURE FITTING.
This is a brass forging which allows high-pressure oxygen to be conducted to reducing valve and pressure gauge. It is connected to oxygen closing valve by a union nut and gasket. The high-pressure fitting is connected to the nozzle and housing by three brass screws. The other end of the high-pressure fitting has a needle-

point closing valve which controls the oxygen supply to the pressure gauge and provides a means for the wearer to shut off the oxygen in case of leakage in pressure gauge, pressure gauge tube, or pressure gauge tube connections, without interference with the supply of oxygen to the reducing and admission valves.

(b) NOZZLE.

This oxygen nozzle forms part of the seat for admitting oxygen to the reducing valve and is made from non-rusting material, such as monel metal or German silver.

(c) MECHANISM FOR CONTROLLING THE SUPPLY OF OXYGEN.

The interior arrangement of the reducing valve consists of a lever, one arm of which is attached to metal bellows so that when oxygen pressure increases the length of the bellows, the other arm of the lever will press a seat over the end of the nozzle shutting off the flow of oxygen into the reducing valve. The lever has two loose pin connections, one extending to the end of the bellows screw, the other fastened in a rigid housing to the end of the nozzle. Both pins are cotter keyed so that they cannot work loose. The screw connecting the end of the bellows to the lever arm has a square head which fits into a square opening on the end of the bellows, securely locking the screw. A screw cap is placed over the end of the square opening on the bellows. The non-rusting spring (brass or bronze) around the nozzle places a pressure on the valve seat so that it keeps the valve always open, until the pressure against the bellows has increased sufficiently to overcome this tension and shut off the oxygen supply.

4. SAFETY BLOWOFF VALVE.

The spring safety valve is so designed that when the pressure of the reducing valve chamber reaches seven pounds per square inch, the safety valve releases to the outside atmosphere, thus preventing excessive pressure and at the same time giving a distinct whistle, warning the wearer.

5. METAL COOLER.

This is a copper box 6-1/4 inches long, 3-1/2 inches wide, and 2-1/2 inches thick, made of No. 24 B & S gauge copper. It connects with inhalation tube, by-pass, regenerator, and breathing bag. Enclosed in it is a metal tube supplying oxygen to the casting for the admission valve, which is also enclosed in cooler.

6. TELESCOPE ADMISSION VALVE.

This valve consists of a valve stem and two telescoped parts; one end is fastened to the casting in cooler, the other end fastened to the top part of breathing bag and two springs arranged in such a manner that when the breathing bag is inflated, the outer spring overcomes the inside spring tension, thus placing a tension upon and closing valve seat. The inside spring is used for the purpose of opening the valve seat and admitting oxygen, above atmospheric pressure, to the cooler and breathing bag. When the wearer inhales, the valve opens and he is furnished the needed supply of oxygen; the valve closes when sufficient oxygen has been admitted or when he exhales. Operation of admission valve depends on inflation and deflation of breathing bag.

The low-pressure oxygen fitting consists of a T-threaded casting fastened on a frame, and by means of a union it connects the reducing valve to the oxygen tube in the cooler.

7. REGENERATOR.

The regenerator consists of a hollow copper box with connections to cooler and exhalation tube. An opening is provided in the regenerator with a suitable screw cap for charging regenerator with carbon dioxide without undue resistance to breathing.

8. FLEXIBLE CORRUGATED RUBBER TUBES.

Flexible corrugated rubber tubes are covered with stockinette. The tubes are provided on one end with suitable metal connections to cooler and regenerator respectively; the other ends are fastened rigidly to the metal mouthpiece by shellacking, wire wrapping, and taping. These tubes are made of flexible material in order to allow free movement of the head.

9. METAL MOUTHPIECE.

The metal mouthpiece consists of a tube containing two horizontal mica disc valves arranged in such a manner that they are closed automatically except by some action of the wearer, such as inhaling or exhaling. The horizontal type of valve was adopted for this apparatus to avoid difficulties met with on other types of valves due to slip leakage.

10. RUBBER MOUTHPIECE.

The rubber mouthpiece is attached to the metal mouthpiece by means of shellacking, wire wrapping, and taping. The rubber mouthpiece has four straps which afford means for attaching same to wearer's cap and making airtight connection between it and his mouth. A rubber flange extends entirely around the opening in the rubber mouthpiece and fits snugly between the wearer's teeth and lips. Two rubber lugs extend at right angles to the mouthpiece and are placed between wearer's teeth.

11. SALIVA TRAP AND HAND-PRESSURE RELEASE VALVE.

The saliva trap and the hand-operated release valve are attached to the metal mouthpiece in such a manner that the saliva flows into the trap. By reason of its U-tube mica disc valve and hand-operated release valve, the arrangement of the saliva trap allows the wearer to exhaust saliva or excess air pressure to the outside atmosphere, but it will not permit any external air to be drawn into the apparatus.

12. STEEL WIRE WISHBONE NOSE CLIP.

A steel wire wishbone nose clip is used to seal the nostrils completely. This nose clip is attached to the apparatus by a strong cord to prevent possible loss by the wearer.

13. RUBBER BREATHING BAG.

The rubber breathing bag consists of a heavy rubber fabric made in the form of a bellows with all seams vulcanized. The bag is airtight and constructed of material impervious to gasoline fumes and other gases and vapors. The capacity of the bag when normally inflated is 5 liters of air. There is one opening in the breathing bag to the cooler, this opening affording free circulation of air to and from the cooler. The outer wall of the breathing bag is suitably attached to the admission valve.

14. FRAME.

All parts of the apparatus are fastened in a compact manner to the frame, which is non-rusting material (Duralumin).

15. HARNESS.

The straps for holding the apparatus are made of stout webbing 2½ inches wide and arranged in such a manner that an adjustment can be made at waist and shoulders. A ring is fastened on the harness at the intersection of the shoulder straps in order that the wearer may be hoisted bodily to safety in case of necessity.

NOTES ON DIVING STAGE

This type of diving stage was used for all diving operations conducted by the FALCON and gave excellent results. Two sizes were carried. The rigging of the stages was identical, the difference being in the sizes of the platforms; the larger size was designated as #1 stage and was the size most generally used due to the fact that it could accommodate three divers. The smaller size, designated as #2 stage, could accommodate only two divers. However, a smoother operating condition was had by handling two divers on the larger and one on the smaller size. Two complete stages of each size were carried in the equipment. The #1 stages were handled by the larger booms and the #2 stages by the smaller, (diving stage), booms.

OPERATION

The divers are dressed while sitting on a small stool placed close to the stage; being taut, the stage whip holds the iron rods, (bales), rigid. The diver when ready, assisted by a dresser on either side, steps on board the stage and grasps the iron bales. The tool bag is slipped over his right arm. The stage, hoisted rail high, is guyed clear of the ship's side by hand. The stage and diver are lowered until the diver is submerged. He remains on the stage until he assures himself that his suit is tight, the air valves and telephone are O.K. Then he steps off the stage and is hauled to the descending line (usually made fast at the point where the stage is put over); on the descending line he is given the water light. The stage is then brought back on board and the next diver sent over after the first reports "On the Bottom."

GETTING THE DIVER ABOARD

The stage is shackled to the descending line by a 1½-inch screw shackle, (bow of shackle to line). This is necessary to avoid the possibility of the shackle belt being either unscrewed or screwed up too tight, caused by its sliding along the descending line, under tension of the weight of the stage as it is lowered down to the diver's first stop, or first stage. The diver coming up the descending line must necessarily meet the stage and climb on board. Guarding against the diver's possible fall, extra vigilance must be exercised by the tenders while assisting the diver aboard the stage. The telephone tenders should be thoroughly familiar with this phase of diving in order that they may readily understand the few (often rapidly spoken) words from the diver and transmit them to the tender. For example, the diver ascending, feels or can see the stage and often calls over his phone, "Slow," "Hold," "Up a little," "Lower," etc.; intelligent cooperation is, of course, the crux of any successful operation. At times the diver will find that he has turns around the descending line with his air hose and telephone cable, or he may experience difficulty due to tides; under these conditions a green tender and telephone man can cause the diver considerable trouble and annoyance while getting on the stage. With the first diver on the stage, the second comes up and climbs on board. The divers facing each other, they are then ordered to unshackle the stage from the descending line.

When working on the S-51 and S-4, divers usually worked in pairs, always sent down singly, but brought up in groups of two or three. However, it was the practice to use two stages when bringing up more than two divers at one time. Five was the greatest number working below at any one time on the S-51 and S-4. However, three and four divers down at one time was common practice.

UNDERWATER ELECTRIC WELDING

The equipment and procedure for above water electric welding are readily adaptable to underwater work. The technique, however, varies to some extent and it is estimated that an experienced welder can learn the underwater technique with about twenty-five hours of practice underwater.

The first experiments in underwater welding were begun in the New York Navy Yard and carried on as far as time and facilities would permit. These experiments were continued at the Experimental Diving Unit and the Deep-Sea Diving School at the Navy Yard, Washington, D. C. A technique has been developed to the point where it is now possible to give a course in underwater welding to all student divers, first class.

The equipment recommended for underwater welding is the following:

(a) One commercial portable welding machine, D. C., with independent volt and ampere control, of 300 ampere, 50 volt capacity.
(b) One insulated, flexible welding cable for the ground, size 00, and one insulated cable for the electrode lead.
(c) Electrode holder of "Stoody" type, or one similar in design.
(d) Suitable "C" clamps to secure a ground wire to the work.
(e) Wire brush (Stock No. 42-C-17840).
(f) One carrier for welding rods and brush (See Bu. Ship's plan No. 434634, Washington Navy Yard No. A1275).
(g) Chipping hammer, (hand), with metal handle.
(h) Welding rods. Type 1, Grade EA, Class 1, 5/32" diameter. (Una-Weld 2500 or Fleetweld No. 7)
(i) Acetone.
(j) Celluloid.
(k) Supplementary faceplate for diving helmet, C&R Plan No. 318847.
(l) Lens for faceplate No. 8.
(m) Lens for faceplate No. 6.
(n) Lens for faceplate No. 4.

PROCEDURE

In order to carry out welding underwater it has been found that the voltage and amperage must be raised. Where 18 to 22 volts and 140 to 165 amperes would be used to weld with a 5/32" electrode on the surface, it is suggested that 28 to 32 volts and 160 to 190 amperes be used for underwater work with the same electrode. It will be found that this increased voltage and amperage will produce a tendency to heavy undercutting.

Normal (Straight) polarity is preferred for underwater work. The ground wire from the welding machine to the work is positive and the lead from the machine to the electrode holder is negative. Reverse polarity with the ground wire negative and the electrode positive cannot be effectively used since electrolysis will cause the holder to be unfit for use in a few hours; however, if reverse polarity electrodes are used, equally effective welds can be made although deterioration of the holder continues rapidly.

In general the equipment from the welding machine to the electrode holder is the same for both underwater and surface welding. It is essential that the welding lead and ground wire insulation be in good condition and all submerged joints be well taped and water tight in order to reduce power loss and electrolysis to a minimum.

Commercial flux-coated electrodes must be given a waterproof insulating coating. A number of coatings have been tried. The most satisfactory found to date is an acetone celluloid compound. The procedure in applying this coating is as follows:

(1) Manufacture a container by welding a base about 5" in diameter to one end of a piece of 2" pipe, 13½" long.
(2) Manufacture a drying rack by drilling holes about 5/32" in diameter along a piece of two-by-four.
(3) Fill the container to within ¼" of the top with the acetone solution.
(4) Dip the electrodes and wipe off excess solution when removed from the dip.
(5) Place uncoated end of electrode in the drying rack, being certain to keep them separated. Do not touch until completely dry.

After electrodes have been dipped and dried they may be stored indefinitely in the usual manner. Nevertheless, care must be taken in handling to prevent scraping or

breaking the waterproof insulation.

WELDING

Welds in mild steel plate made under water should have about 80 per cent of the tensile strength and about 50 per cent of the elongation of welds made in air. Attempts to weld materials other than mild steel under water may not be successful because the rapid cooling of the metal by the water will prevent the necessary flow of metal to give sufficient fusion. Furthermore, the characteristics of the material welded may be affected. Mild steel patches, however, can be welded over holes in armor.

A No. 8 welding lens will give the diver excellent protection in clear water and will permit him to see what he is doing. Muddy water may require the use of a No. 6 or No. 4 lens. Goggles with one lens removed may be worn by the diver for a quick job. He must use one eye at a time with this rig. When much work is to be done, it is recommended that the welding lens be attached to the helmet in place of the faceplate guard as shown in the "Section on Diving." Skilled welders should be selected for the course in underwater welding. Experience has shown that a good welder will soon learn to perform satisfactory work under water once he understands the rudiments of diving. It is quicker to teach a welder to dive than to try to make a welder out of a diver.

While welding under water, be sure to hold a rather short arc and run straight beads slowly. Fuse the metal well and fill the undercut. Weld downward on vertical work with the electrode pointing at an angle of about 45 degrees to the work. Oscillate the electrode about 1/16". Advance very steadily, laying a narrow bead about 5/16" in width. Overhead welds are somewhat more difficult to make than either flat or vertical welds.

No attempt should be made to weave the bead as this traps slag. Clean each bead well with a wire brush and chipping hammer before running another bead along it. The wire brush should be weighted with a piece of lead tacked to the wooden back. The diver must have a steady platform on which to work and should attempt to brace himself in order to hold a steady arc. Since the arc gives off bubbles and smoke, the diver must place himself in a position so that he can view his work from a side angle.

If there are breaks in the bead, the welder is advancing unsteadily. It will probably take the welder some time to become accustomed to welding in a diving suit as freedom of movement is somewhat restricted.

While 5/32" diameter electrode is the most satisfactory size for general work and is the maximum size for general work to be used in sea water, it is suggested that 1/8" be used for overhead work.

UNDERWATER CUTTING

Underwater cutting under normal conditions should be performed with either the oxygen-hydrogen torch or the electric arc oxygen torch. Steel plate can be cut, however, under water by using the welding electrodes with insulated coating and other equipment required for underwater welding if 50 volts and 300 amperes are used as a power supply. In order to do this the diver merely punches a series of holes in the plate to be cut.

8 September 1942

Metallurgical Laboratory Report No. 2912

N.Y.P.S.

Subject: Underwater Arc-Welding Using Westinghouse Flux-Arc (SW) Electrodes - Test of.

Reference: (a) Specification 46-E-3 (Int) of 1 December 1941.

Enclosure: (A) Photographs No's. 1363-42, 1444-42 and 1789-42.

1. Tests have been conducted by the Metallurgical Laboratory on arc-welds produced by diver, Check No. 616023, under 20 feet of water. The welding was performed on 3/8" and 3/4" mild steel plates with Westinghouse Flux-Arc (SW) 5/32" electrodes, using 195 amperes, 30 to 35 volts, D. C. current, reversed polarity.

2. Physical Tests
Welds made on 3/8" galvanized and black mild steel plate, photograph No. 1444-42, enclosure (A), were subjected root bend tests as specified by reference (a), and also transverse tensile tests with the following results:

	Black to Black	Galvanized to Black
Tensile Strength----	62,000 psi*	66,500 psi*
Yield Point---------	50,000 "	57,200 "
Elongation----------	17.19%	17.19%
Root Bend-----------	55 degrees	40 degrees

*----Broke in plate.

Welds made on 3/4" plate using the electrodes with and without a coating of acetone and cellulose were tested for deposited metal properties as specified by reference (a), Figure 3. The physical properties of deposited weld metal samples were as follows:

	Flux Coated	No Coating
Tensile Strength------	68,500 psi	68,000 psi
Yield Point-----------	66,500 "	66,000 "
Elongation------------	2.3%	3.9%
Red. of Area----------	5.8%	8.5%

3. Transverse sections of the welds were prepared and Macro-etched and are shown on the photographs of enclosure (A).

Photograph No.	Macro-Section
1363-42	Lap Weld-1/4" Black Mild Steel.
1444-42	Butt Weld 3/8" Black and Galvanized Mild Steel.
1789-42	Butt Weld 3/4" Black Mild Steel Flux Coated.

4. Remarks:
The welds produced under 20 feet of water using Westinghouse Flux-Arc (SW) electrodes produced sound deposited metal of high tensile strength. No particular advantage was indicated by the tests in the use of a special coating over the electrode's original coating.

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(Sr. Materials Eng.)

For further information on underwater welding and electric cutting refer to:

(a) Bureau of Ships' Restricted Letter QP/W & C-(2)-(1)(8688), EN 28/A2-11, dated May 12, 1941.

(b) Bureau of Ships' Letter S92-(2)(8688), EN 28/A2-11, dated February 17, 1942.

Photographs of the above tests are on file at the Puget Sound Navy Yard, Bremerton, Washington

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