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DIVING

by

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For the Degree of
BACHELOR OF SCIENCE
From the

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1935

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528 Beacon St.,
Boston, Mass.,
January 22, 1934

Prof. James Robertson Jack,
Dept. of Naval Architecture and Marine Engineering,
Massachusetts Institute of Technology

Dear Prof. Jack:

I hereby submit my thesis as partial fulfillment of the requirements for the degree of Bachelor of Science.

Sincerely yours,

Maximilian Eugene Nohl

INTRODUCTION

SCOPE OF THESIS

I have always been interested in the sea and have always been intrigued by its depths and by apparatus that would enable a man to descend into them. However, until the start of the work for this thesis, I had never seen a diving suit or become familiar with its principles. As the result of an inspiration as to the possibilities of salvage work given to me in the latter part of my Junior year, the Spring of 1933, I deliberately decided to choose diving as a subject for my thesis.

In the year and a half that has elapsed since the day of that decision to the time of this writing, I have done little else but follow up this inspiration. As an introduction to this thesis, I will describe briefly some of the work that I have done. Unfortunately, a large part of this material can not be included in these pages.

I have divided the work of this thesis into two parts, the first which pertains to diving apparatus which protects the diver from water pressure, and the second part of which pertains to apparatus which submits the diver to water pressure. In each case, all of the work that has been done to date with that respective type of apparatus is considered and the apparatus that I have designed or built is described, and the necessary companions made.

DIVING SHELL: I completed the design of this shell in the Spring of 1933. As constructional problems arose I sought the technical men, and engineers at the companies where materials were purchased, wherever I felt that I needed it. The design was carefully gone over by my father, for his approval, by my uncle for his advice as to the practical aspects of the shell, and by a prominent engineer as to the technical aspects of the design. Pending the approval of these three men, the construction of the shell was started in June 1933. The entire summer was spent working on her, her equipment, and launching raft.

Unfortunately, it was necessary to build her on the beach at my summer home on Lake Michigan, which is not protected from the furies of the lake storms. Great difficulties were encountered toward the end of the summer in diving the shell from a raft as small as she was in the high seas that are characteristic of the late summer. The shell only had opportunities for two very shallow dives, before an unfortunate accident destroyed the possibility of further diving that summer. During a violent storm, with the shell on the raft and the latter moored in the open lake, the lashings holding her fast to the raft parted. This allowed her to swing like a pendulum on the chain fall from the beams of the superstructure, and as the raft pitched violently to the enormous waves, the swinging of the shell tore away these timbers and set her free in the water. Empty so that she could float, she was washed up on the beach, without suffering any damages to herself but breaking the window to powder on the rocks and losing one externally housed diving motor that had been on at the time. She was stored for the winter after this, because the summer was too far gone to continue any amount of work.

However she was unexpectedly brought out from her storage in the middle of winter to join the Seth Parker Expedition. The damages of the late summer's storm had not been repaired and because of the shortness of time, it was decided to take her on the expedition as she was and use her without the motors as a suspended shell with negative buoyancy, which had been one of her proposed methods of use. She was loaded on a trailer and carried 3,600 miles, joining the "Seth Parker" at Jacksonville, Florida.

Work was continued on her, repairing her damages and adding new equipment over the months that followed, and she was used for diving extremely successfully in the waters of the West Indies. She proved herself excellent for observational work and functioned perfectly. Because of the unsatisfactory nature of the expedition, I left after I was completely satisfied as to the performance of the shell. She was left on board because it would have been almost impossible for me to take her back to the States when I left with the other diving equipment that I had, and is there at this time. The "Seth Parker" is expected back very soon, and as soon as possible the shell will be obtained and transferred to my own boat for completion of her equipment, further diving, and experimentation.

DR. BEEBE'S "BATHYSPHERE": Because of a great many similarities between the "Bathysphere" and my shell, I am including a discussion of it in these pages. The information obtained was obtained from my inspection of the "Bathysphere", an interview with Dr. Beebe, and data given to me by him. A comparison of the 2 shells is made.

ARMORED DIVING DRESS: The information presented is largely based on data obtained from the patent office, data from their sole manufacturer in Germany, and reports on their operations. This type of dress can hardly be called satisfactory and its usage in American waters has been almost negligble.

OBSERVATIONAL SHELLS: I have obtained first hand experience in this type of apparatus, using my shell as a suspended device. I have also inspected the "Bathysphere" and Tesche's shell. Information on other shells has been very meager.

ACCESS TUBE: The information on this has been obtained from inspection and from an interview with Simon Lake. This applies also to Lake's submarine, the "Explorer".

SUBMARINE BOAT: Although this is ordinarily a fighting machine, there are many things of interest to diving and accordingly a very brief discussion is made of the submarine boat. This information has been obtained by inspections of submarines at the Submarine Base at New London and the Portsmouth Navy Yards where they are under construction.

STANDARD DIVING APPARATUS: I felt that the only way to successfully build a diving suit that would be superior to the present type of equipment was to be thoroughly familiar with the present type of Navy and commercial diving gear under all conditions. To carry out this I bought a complete deep water diving outfit and collected and built quite a bit of extra and auxiliary equipment. To date I have had experience in coastal waters from Boston to Miami, the West Indies, Great Lakes, and a great many inland lakes and quarries. I have had experience doing almost every type of underwater work that a diver can do, such as searching for lost articles, working on a ship's bottom, salvaging sunken ships, ect. I am including in this thesis a brief discussion and description of modern diving apparatus.

OPEN HELMET: A brief discussion of the open helmet might be pertinent and also a discussion of the one that I built since it embodies quite a few new features that have rendered it an extremely satisfactory and inexpensive piece of diving apparatus.

SOURCES OF INFORMATION: It has been found that information pertaining to diving or salvage work is very limited and difficult to obtain. Accordingly, most of the information obtained had to be gathered by means of a painstaking process of interviewing the few men familiar with various phases of the subject and from personal experience. It might be interesting to present some of the sources of information that I have sought:

A bibliography is included with my comments on the various listings, since much of even this very limited amount of literature is misleading and written to gain the appeal to people's imaginations that diving seems to have. I submit this bibliography as something that I believe is very nearly complete.

The following men were interviewed, and the time that they gave me in answering my questions and discussing this subject was greatly appreciated: Dr. William Beebe, who is responsible for the " Bathysphere" and the only diving over 520 feet that has ever been done;

Simon Lake, who had been an outstanding figure in diving, salvage, and submarine work for many years: the following professional divers: David Curney, John MCIsaacs, William Skumatz, George Duke, Jack Lowry, and Edward Obelkwich; the men at the Diving School and Experimental Diving Unit of the Navy Department at Washington; the Bureau of Mines; members of the Navy Department at Portsmouth and at the Submarine Base in New London; Harry Rieseberg of the Bureau of Navigation; Vose Greenough who put all of his gear at my disposal and gave me my first dive; and countless others who have helped me gather the information that I wanted or helped me build and use my equipment.

I have had the privelege of inspecting the Navy Experimental Unit in Washington; the Submarine School in New London, the salvage ship "Falcon", the diving gear and arrangements of many of the Navy yards, Dr. Beebe's "Bathysphere", Tesch's diving shell, Simon Lake's baby salvaging submarine, the "Explorer", the same inventor's "Access Tube", and the submarine "Cachelot" under construction, the "S-49" on display in Chicago, and several "R" and "S" type of submarines at the base at New London, and the shops of the only two American Companies that build diving gears, Morse in Boston, and Schrader in New York.

A NEW TYPE OF SELF CONTAINED DIVING SUIT: The usual factors motivating industrial research are apparently not present in the diving field. There are only two companies in the United States that manufacture diving equipment, and both of these do this only as a very small branch of their regular business. The demand for diving equipment is so small that it offers no chance for anything but a very small profit on a sideline. Under these conditions, the incentive for development is completely absent, with the result that there has been practically none. A patent taken out in 1820 describes a suit almost exactly like the modern equipment. The only changes have been in improvements, such as the addition of telephones, incorporation of finer fabrics, and very minor changes in design.

It is strange that such a situation should exist in a field offering such fantastic profits and imaginative appeal as does marine salvage. The incentive for development of equipment, then, will come not in the direction of the manufacturers, who are interested in selling suits, but from the salvage man who wishes to build a superior type of equipment ~~would be unsuitable~~. In other words, it is to develop something to use and not to sell. It is from this point of view that I have developed the self contained suit which I will describe later.

This suit as I will describe it, has never been completed, but I intend to build it as soon as possible, making changes in the design as I see fit.

Construction of this suit was started in the Fall of 1933. It occurred to me, after I had actually started building it, that I could take my standard diving suit and fit it with the breathing apparatus of the new self-contained suit, so that I could experience self-contained diving and possibly find ways of improving the design at that stage.

This was done as described later. The apparatus was thoroughly tested in Walden Pond, near Boston, during the winter of 1933, and continued after the pond froze up, under the ice. The Seth Parker Expedition interrupted this work, but it was continued during the summer of 1934 in a deep water filled quarry in Wisconsin. There had been one accident which occured in about 70 feet of water when a piece of extremely light tubing which had been used temporarily as an oxygen inlet exploded without my knowledge, but this only proved further the merits of the new dress, for I proceeded leisurely to the surface and was not aware of the slightest discomfort in respiration. Other than this, the apparatus seemed to be remarkably successful, and offered a freedom of movement and a sense of normal comfortable breathing that I could not have experienced in the donventional type of equipment. The conclusion was to proceed with the new suit as soon as possible.

Problems pertaining to the physiology of high and low oxygen percentages and partial pressures, and effects of nitrogen and helium have been discussed with men at the experimental units of the Navy Department in Washington and New London and with medical men specializing respiratory system.

A discussion is given of the problems of present day diving after which the new self contained suit is described and a discussion made of how it might overcome some of these problems.

PATENTS: To complete the sources of information, a copy of every patent that has been issued in the United States was obtained and studied. This was done primarily to insure myself that my new self-contained suit was not infringing on somebody's patent, and also to consider what ideas of value had been patented. It was found that a lot of these patents were actually ridiculous, that most of them would be unsuitable under actual practice, and that a very few of them were very ingenious. Only two of them issued during the last 100 years pertained to apparatus that is used by commercial divers today, and these were minor improvements. However, some of these patents, although basically unsound, bring out interesting ideas in their specifications, and for that reason a classification of all these patents is included in this thesis, together with very brief comments on the more interestings ones.

SETH PARKER EXPEDITION: As a result of the work that I had done along this line, I was given the privelege of joining the "Seth Parker Expedition", which it had been announced was going to seek the treasures lying in the hulks of old Spanish galleons. I was on this expedition from January 14 to June 1st and left at that time because of its unsatisfactory character. However, toward my goal, I obtained many months experience at sea and life on board ship, seamanship, diving, marine engineering, and made some very valuable contacts and collected some very valuable data pertaining to salvagable wrecks.

DATA ON SUNKEN SHIPS: Considering the vast fortunes that have sunk with ships, it is remarkable that so little information is available as to these wrecks, and that what there is, is so difficult to find. Collecting this information takes a great amount of research work, letter writing, travelling, and endless asking of questions. In the past year and a half, partly through a series of fortunate coincidences, I have succeeded in collecting a lot of very valuable information. This will not be included in the thesis, however, except for this comment.

SUBMARINES: Part of my interest has been directed toward the submarine, since the powered diving shell is in reality a submarine--the smallest ever built! As many as possible of these submarines have been visited and studied. A co-development of the diving gear has been the design and development of a new type of submarine, the principles of which arose in some considerations pertaining to the shell. A discussion of this other than this comment need not be included in this thesis. Preparations for a patent are being made at the present time.

SALVAGING: A new system of ship salvage was conceived during the course of these studies, that appears to have great merit. I am not including this in this thesis because of a patent I am preparing at the present time.

LOCATION OF WRECKS: I have been working on the design of wreck detector and am planning to build and use this in the Spring of 1935.

The principles underlying this are well known to geophysical prospecting, and I believe are adaptable to submarine work and need not be discussed here. A novel and efficient type of drag was developed, but I do not wish to disclose it here until I have some experience with it in actual location work.

CONTINUATION OF WORK: I have just bought a boat and am fitting her out at the present time for experimental diving, wreck location, and light salvage work. It seemed pertinent to give a brief discussion in these pages of why this boat was selected and how she is being fitted out for salvage work.

Salvage of sunken ships economically, has a bad reputation. There have been quite a few expeditions that have started out after some fabulous fortune, equipped themselves with vast amounts of the extremely expensive equipment required for work of this sort, and started out disregarding lack of the proper information and experience, crazed the lust that seems to surround a thing of this sort. Great success or no success seems to be the result, and in the usual case of the latter, an awful lot of money is usually lost because of the large investments and great expenses.

My fundamental idea is just exactly the opposite of this. I want to reduce the expenses of the preliminary location work and investigation work to an absolute minimum, which in my case with the equipment that I have, will be practically nothing. I believe in using as small a boat as is possible and a maximum of equipment.

After a wreck is located and everything is ready for the actual salvage operations, it is time to get the larger vessel.

This same idea is carried out in the new self-contained dress. It is something that is small, foolproof, requires no pumpers or tenders, and I can build it myself at considerably less expense than a standard diving outfit, and yet will extend the range of operations of the present type of gear.

Salvaging work of this type is essentially a gamble, with possible great profits. However, if the investment in equipment can be kept very small and direct operating expenses so small as to be almost neglible, for location and investigation work, little loss can be suffered in case of failure.

PART A

APPARATUS PROTECTING THE DIVER FROM WATER PRESSURE

1.

A DEEP WATER DIVING SHELL

GENERAL DESCRIPTION: This diving shell is the only piece of apparatus of its kind that has ever been built.

She was built in Milwaukee, Wisconsin, during the summer of 1933, and launched in Lake Michigan at Fox point, about 8 miles north of Milwaukee and unprotected from the open lake. Her launching raft was built there and she was fitted out ready for diving soon after the middle of the summer. A mooring was sunk in the lake so that she could ride to it on her raft, saving the labor involved in beaching. During the rest of the summer, she was being experimented with and her power equipment being added.

Early in September a terrific storm broke her loose from her lashings on the raft with considerable damage to her equipment.

In January 1934, she was loaded on a trailer and carried 3000 miles, to Jacksonville Florida, where she was put on the schooner "Seth Parker".

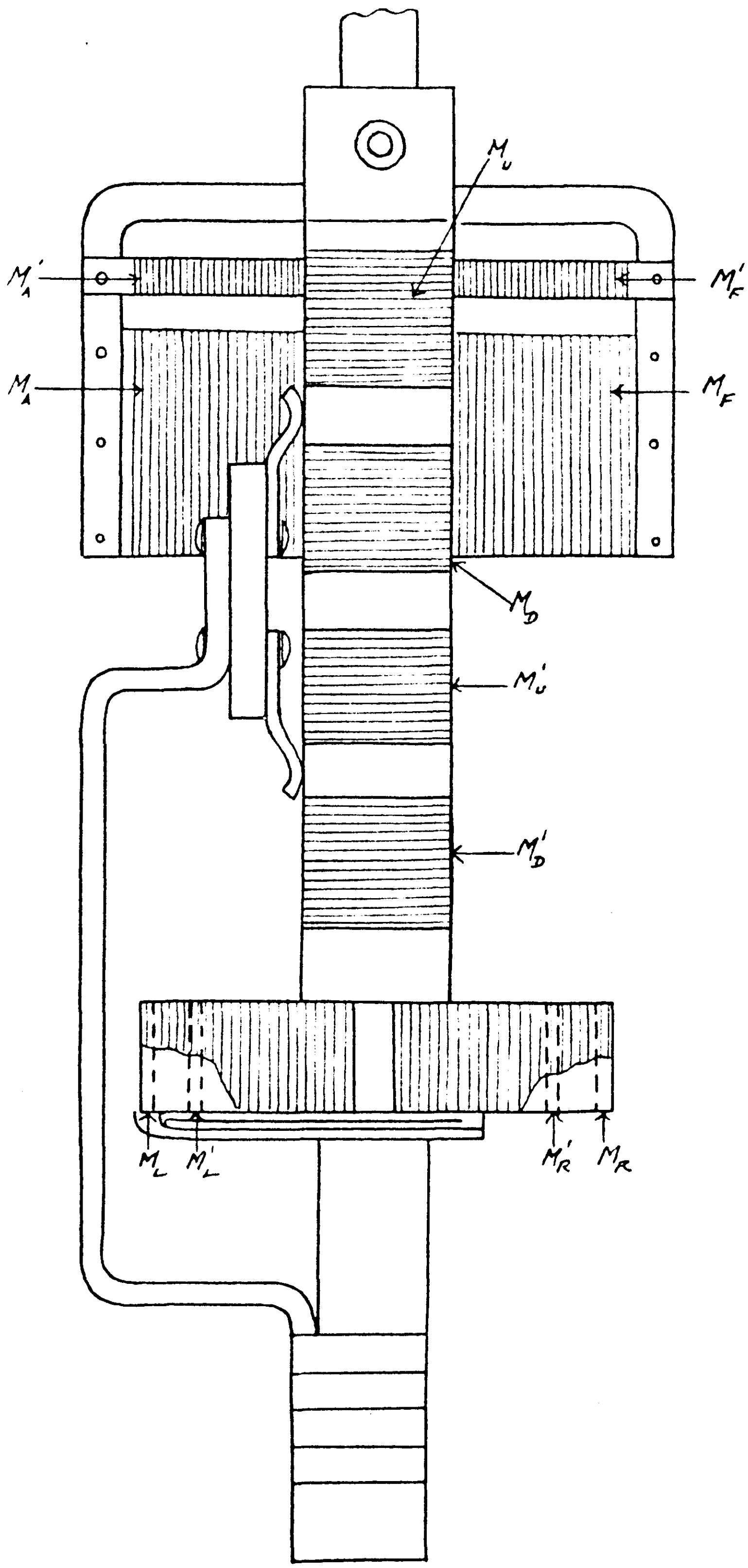
She was again made ready for diving and was successfully used that Spring in the West Indies.

The shell is designed to have zero buoyancy in the water and thereby be inert and free from suspension when submerged. She is powered so as to move in any or all of three dimensions simultaneously by means of 3 perpendicular reversible screws, all delicately controlled by the diver by a single and feather touch, 3-dimensional control stick.

The power is supplied from a small engine-driven generator on the mother vessel connecting with the shell by a flexible rubber cable, which at no time has tension in it.

The shell is made in two hemispheres, which are separated on a horizontal plane to permit the diver to get in or out. This was done for the following reasons. If a manhole had been used it should have been at least 18 inches in diameter. Considering this in relation to a sphere with an internal diameter of 38¾ inches, too great a sacrifice would have to be made in the strength of the shell; the weight of a door would necessarily be much greater than the same surface of the shell (and in this shell of zero buoyancy, every pound had to be considered); the expense of building a door would be additional; simplification in casting was possible by making two almost identical hemispheres; more comfortable entry and exit is possible; one hemispher can be laid flat and the other over it, which means that on a trailer or on board ship it can be stowed so that it would not shift or take up much space.

The diver sits on a cushion on the bottom; the upper half is

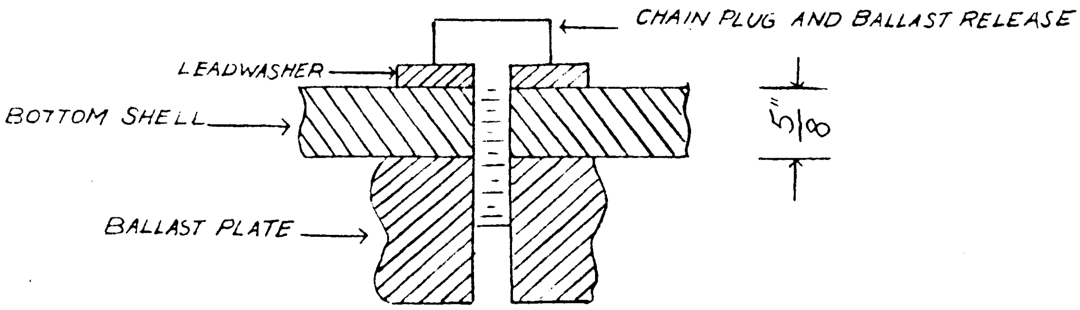


Control Stick

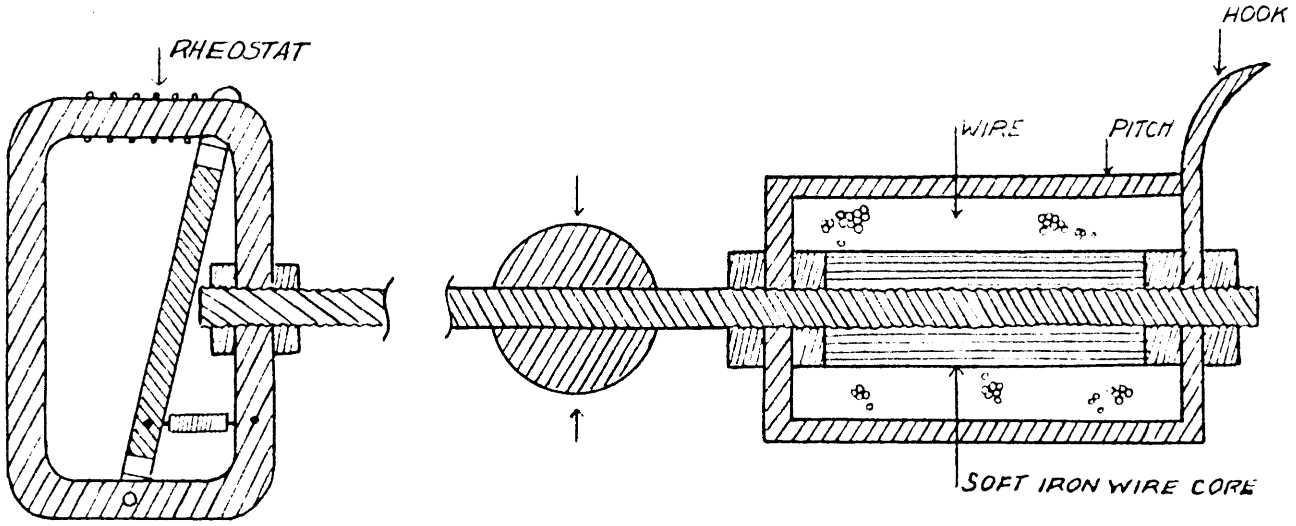
M.E. NOHL   JAN. 3, 1935

lowered into position; and the two hemispheres are bolted together into a sphere. The man inside finds the window directly in his line of vision. As the shell is bolted together, he opens two cannisters and adjusts the oxygen valve. The shell is swung overboard and lowered into the water. When barely submerged the chain fall hook is removed from the shell's lifting hook. She is now free and under the control of the diver.

Convenient to his right hand is a control stick, as shown in the accompanying drawing. This hangs down vertically from above. The stick is hinged so that it will swing fore and aft and has a telescopic handle which may be turned or moved up or down. These movements operate resistances which start, stop, reverse, and control the speed and power of the externally housed motors. The stick is built to be operated so that the diver, holding the handle in his right hand, may cause the shell to move upward by raising his hand holding the telescopic handle or to move downward by lowering it, or not move by keeping it a neutral position. Similarly he may cause the shell to move forward or aft by moving the stick in the same direction. Similarly by turning the handle to the right or left, the shell will turn to the right or left. These movements, which may occur simultaneously operate rheostats and vary the amount of power of the motors, so that a very sensitive control may be had over the speed or acceleration of the shell in



SCALE: HALF SIZE



ARM HANDLE

ARM

SCALE: HALF SIZE

M.E. NOHL JAN. 3, 1935

any desired direction. It is thus possible for the diver to place the shell in any exact position that he wished, or if a current is running to move into the current but remain stationery in respect to the bottom.

It is believed that a fourth motor, for lateral movement, with a control actuated by a lateral swinging of the stick, would be a desirable addition, especially if the current is running.

The diver wears earphones. A transmitter is located almost anywhere in the shell, since it is not necessary to speak directly into it in such a small enclosure.

A mechanically operated arm is fitted into the shell immediately below the window. This has a electro-magnetic coil on its other end with a grip rheostat control so that the diver may pick or release any tight metal object or draw himself to a metal hull. The arm also has a hook on its outer end so that something may be picked up or dropped mechanically. The arm has 3 dimensional movement through a ball point, and allows axial and turning movement with relation to the shaft. The arm may be operated by the left arm which in addition to the three dimensional control of the shell ~~gives~~ with the right hand on the control stick gives with some experience a remarkably exacting control/.

A light is provided lighting up the entire angle of vision allowed by the window.

A base is provided so that the shell may rest flat on the deck of the moter vessel or on a flat bottom.

THE SHELL WITH HER DIVING MOTOR IN LAKE MICHIGAN.

In case of leakage of any of the propeller shafts, no water can enter the shell. The motors are all housed externally and the breaking and falling out of a shaft could only mean a wet motor without any access of water to the inside of the shell.

In case of failure of the deck generator, storage batteries are provided.

In case of failure of the current carrying cable or any point of the electrical system, the shell can be hauled up by means of a light line, bent at intervals to the electric cable. Since it weighs nothing submerged, there will be very little strain on this line.

In case of failure of the motors and also the emergency line, the diver may rise to the surface by a mechanically operated ballast release shown in an accompanying drawing giving the shell positive buoyancy.

It is understood that in case of failure of the communication system, either due to a lapse of consciousness of the diver or actual breakdown, the shell is to be hauled up immediately.

USE OF SHELL: The shell is designed to further the limits of which man can explore and profit from the expanses of ocean which cover three-quarters of the earths surface.

A rubber suit allows a man to do almost any type of work that can be done on land, but as the working depth increases, amiting physiological factors increase enormously. The armored suit solves these physiological problems, but it has been impossible to build a suit of this type that will allow the diver to use his arms and legs in deep water. The only uses of this type suit have been for observational work, which is much better done from a suspended observational shell. These lack any maneuverability or dexterity, except in a crude way by maneuvering the mother vessel.

The diving shell as built by the author would seem to solve the problem of a maneuverability enjoyed by the rubber suit, with the addition of a third dimension. By the sensitive control offered by the control stick, an experienced man should be able to move and place the shell in any desired position in 3 dimensions almost within an inch.

The complete solution to the problem of dexterity seems to be almost insurmountable. It is conceivable that apparatus could be constructed, operated hydrualically or electrically with "naturally" operated controls so that a diver could work through mechanical arms mounted externally. However, the arms with which I have provided my shell gives a means of touching or picking up many things which at the present stage of development seem to be all that is necessary.

Some of the uses of the shell might be as follows:
Exploration of a bottom, looking for lost articles, study of marine life at intermediate depths, searching for wrecks, examination of wrecks, placing of charges of dynamite, placing of grappling hooks,

directing of placing of hooks or charges as maneuvered at the surface, photography under water, ect.

As a shell with negative buoyancy, many of the above things could be done, depending on surface maneuvering or position. The shell can also be towed on or near the bottom if used in this way.

By means of the arm the diver not only can pick up small articles, but can place anything lowered from the surface. The diver may also draw himself up to anything either by catching it with his hook and pulling in on the arm or by using the coil as a chuck. In this way the shell could be maneuvered about somewhat against a vertical surface such as the hull of a sunken ship.

A MOMENT BEFORE DIVING FROM THE "SETH PARKER"

ON BOARD SCHOONER
"SETH PARKER"
DIVING OFF THE COAST
OF HAITI

THE SHELL BEFORE
A TEST —

THE LOWER
HEMISPERE
BEFORE A DIVE

DETAILED DATA AND DESIGN

WEIGHT: The minium internal diameter of a sphere in which a man 6 feet 3 inches tall could sit comfortably with his knees a-kimbo, and also assume a position on his hands and knees such that he could put his face directly against the window was found to be $38\frac{3}{4}$ inches.

This was found by taking measurements of myself, drawing them to scale, and fitting the smaller circle to the extreme points of the head, heels, and buttocks as shown in this accompanying drawing. This was checked by building a skeleton sphere of 3 circular hoops of heavy steel wire which were wired together in planes perpendicular to each other.

The thickness of the shell is 5/8 inches, making the external diameter 40 inches.

Using .283 pounds per cubic inch as the weight of steel, the weight of the shell was calculated to be:

$$W = \frac{4}{3}\pi(r^3 - r^3)d$$

$$W = 4.189\left[\left(\frac{40}{2}\right)^3 - \left(\frac{38.75}{2}\right)^3\right].283$$

$$W = 867 \text{ lbs.}$$

The actual weight of the shell was slightly in axcess of this.

DISPLACEMENT: At 45 degrees Farenheit the density of distilled water is 62.42 pounds per cubic foot. The density of salt water is approximately 64.0 pounds per cubic foot.

The displacement will be:

$$W = \frac{4}{3} \pi r^3 d$$

$$W = \frac{4.189 x 64}{1782} \left(\frac{40}{2} \right) = 1210 \text{ lbs. of displacement}$$

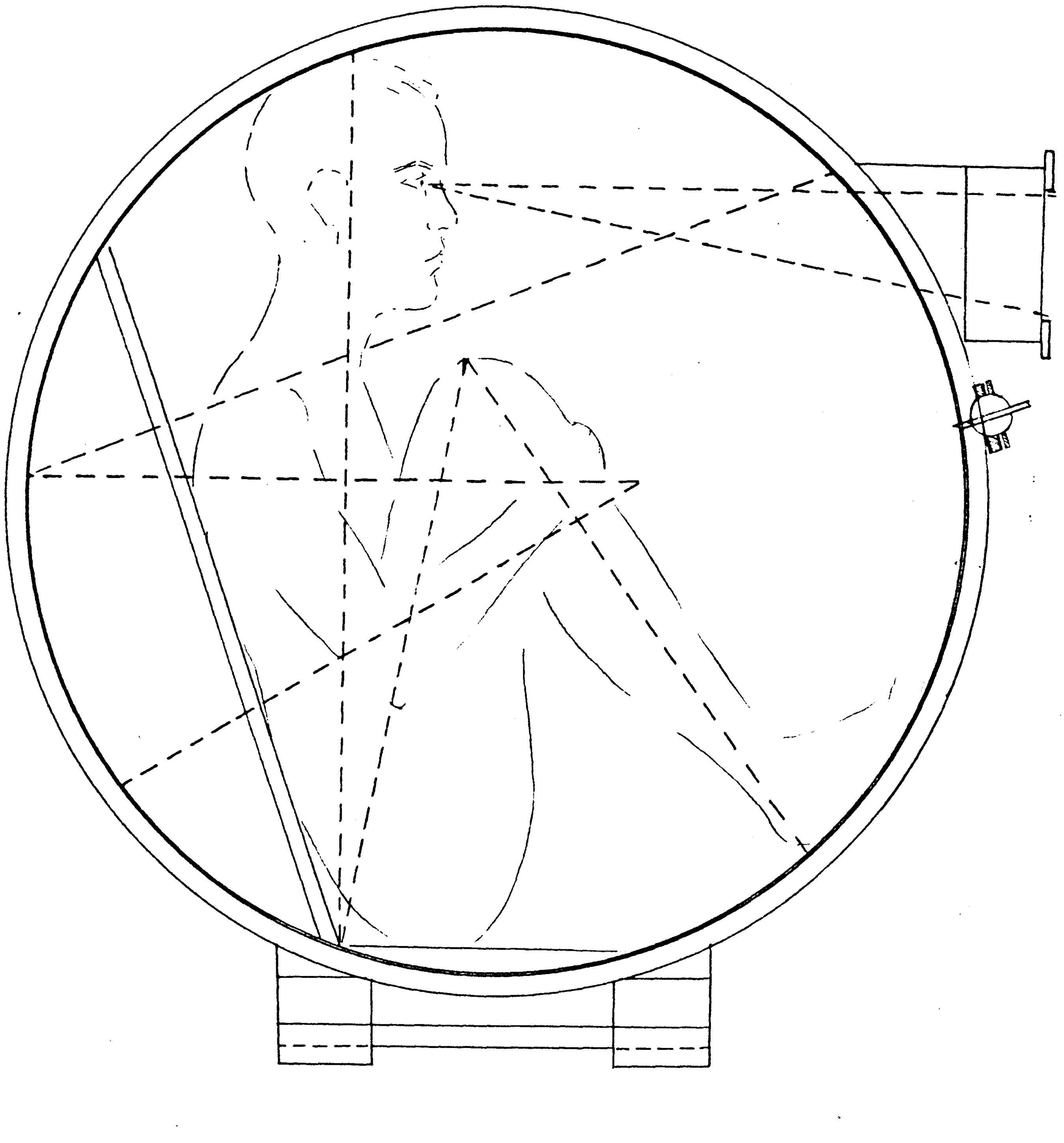
$$(64.0 - 62.4) \left(\frac{1210}{64} \right) = 30.3 \text{ lbs. decrease in displacement}$$

in fresh water.

The distribution of weights is approximately as follows:

Shell	867 lbs.
Man	170
Negative buoyancy motors	30
Equipment	25
Ballast	118
Weight of whell	1210
Displacement	1210
Buoyancy	0

The method of adjusting this is as follows: The shell is lowered into the water, containing the diver, all of the equipment, and excess ballast. After the shell is submerged the



DIVING SHELL
SCALE: 1" = 6"
M.E.NOIIL JAN 5, 1935

lowering line is belayed and then the shell lifted slightly and her weight read with a spring balance. This is the excess that must be removed to give her zero buoyancy.

If another diver goes down, the difference between the weight of the two men may be added or subtracted from the ballast.

DEPTH: Considering the shell a perfect sphere of radius r and thickness t the following will give the allowable pressure, p, which it would theoretically stand:

$$p = \frac{2\ t\ f_c}{r}$$

She was made of a high manganese steel having an elastic limit, f_c, of 55,000 pounds per square inch.

$$p = 2 \times \frac{5}{8} \times \frac{55{,}000}{20}$$

$$p = 3{,}430 \text{ pounds per square inch.}$$

This corresponds to a depth in salt water of 7,750 feet, the theoretical maximum depth which the shell could attain without exceeding the elastic limit of the steel.

In consideration of the actual depth which the shell could safely attain are the following factors:

The calculations are made assuming that the shell is a perfect sphere. Whereas internal pressure has a tendecy to make an imperfect sphere perfect, external pressure will tend to exaggerate an imperfection resulting in collapse before the elastic limit is reached as calculated by the above formula.

The shell is a casting and may be weakened by gas holes as in characteristics of castings.

A decrease in strength is found in the window opening reducing that great circle circumfirence a maximum of 4.7 %.

On the other hand, it is hard to conceive of the shell as being far from a perfect sphere, for the pattern from which it was made was a perfect hemisphere within the limits of the machine upon which it was turned.

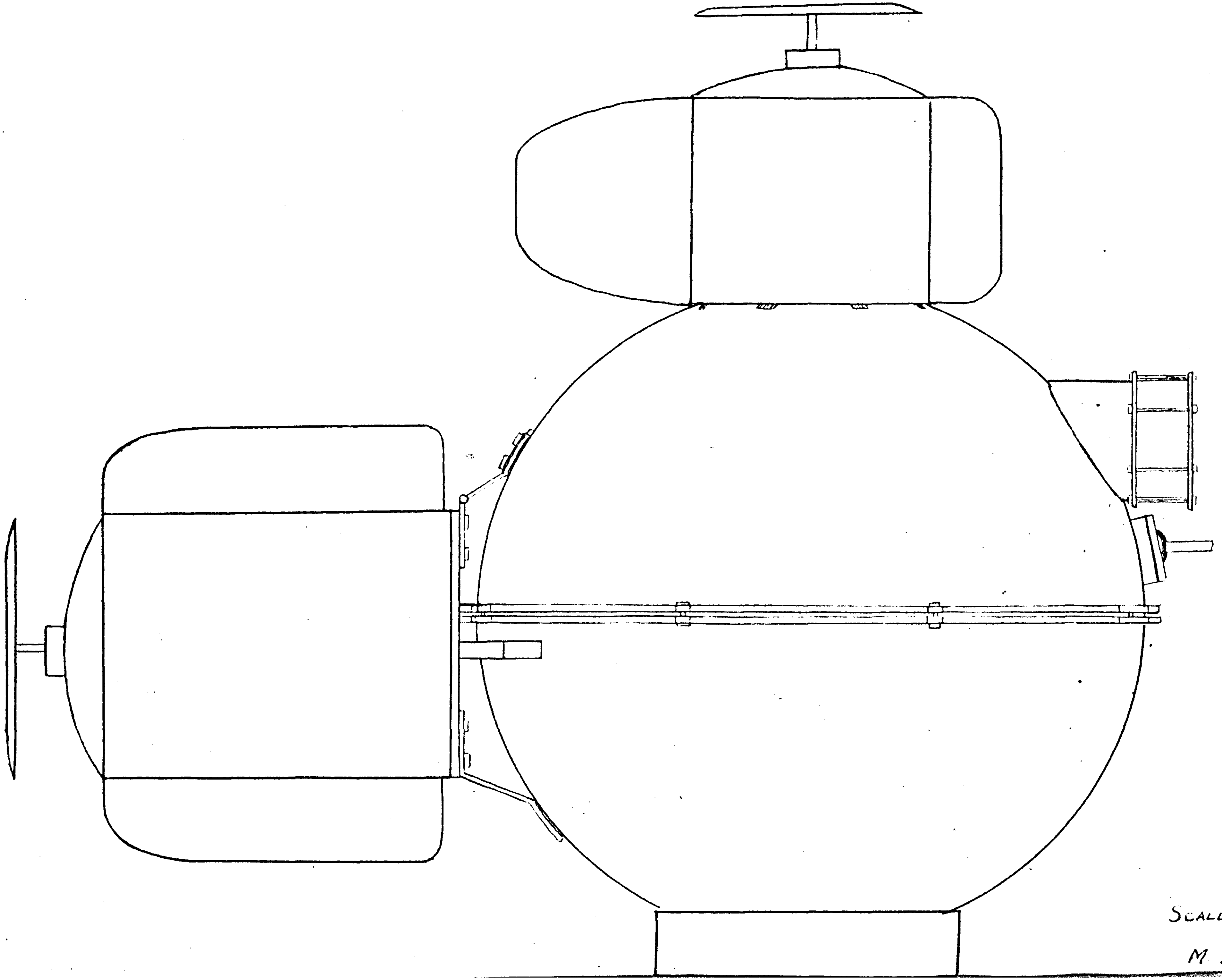
The shell was carefully annealed to remove any strains which might have set in during cooling.

The pressure to which the shell will be subjected will be water pressure and would necessarily be applied very slowly and released very slowly.

It is to be understood that the shell is to be tested before sending a diver down to any new depth by lowering her alone to a greater depth loaded with enough ballast to give it negative buoyancy.

<u>STABILITY</u>: The following calculations were made in order to roughly estimate what her stability might be.

The center of buoyancy of the sphere itself is taken at its center, about which moments are taken of the other weights.



SCALE : 1/8 SIZE

M E NOHL

Man 170 x 4.5" = 765
Equip. 25 x 17" = 425
Ballast 115 x 22" = 2530
2940 inch-pounds

$$\frac{2940}{1210} = 2.37''$$ center of gravity below center of buoyancy.

It is interesting to consider this in terms of her ability to right herself, for example, if she should have a list of 90°, her theoretical righting acceleration would be:

$$\alpha = M/I$$

I is 1610 foot-pounds.

$$\frac{2940}{12} \times \frac{1}{1610}$$ = .152 radians per second per second.

= 3.0 inches per second squared peripheral righting acceleration from a 90 degree list.

There are horizontal fins on the after part of the shell which greatly minimize any fore and aft pitching.

There are vertical fins running fore and aft on top of the shell which minimize any rolling athwartships.

There are vertical fins on the after part of the shell which minimize any tendency to yaw.

These fins are shown in the accompanying side view of the shell.

When diving in a current without the motors of when being towed by the mother ship, suspended from above and carrying ballast for negative buoyancy., the vertical fins aft tend to keep her window in the direction of the current or in the direction being towed, and the horizontal after fins tend to keep her from pitching.

WINDOW: Calculations were made using formulas for pressure acting upon circular plates. However, these were found to be useless because of the wide variations in tensile and compressive strength of any given piece of glass at different times due to changes in its molecular structure.

Fused quartz would be the ideal substance to use for the window because of its uniform strength and high degree of transparency. However, it was unavailable because of its high cost, a pane such as was used in the "Bathysphere", 3 by 8, costing approximately $500.

The material chosen was the highest grade of plate glass obtainable. The glass was cut 7 inches in diameter for a 6 inch window. The window was made up of three laminations, each 1 inch, making it 3 inches thick. The laminations were cemented together with a transparent cement. The result was a window, half as thick as its unsupported diameter, and so clear that it was impossible to tell from within the shell when she was on deck wheter the glass was in or not in without touching it.

PAINTING OF SHELL: The shell was given several coats of a heavy filler paint inside and out to protect it from the salt water. The outside was painted a bright orange so that it could be easily seen on deck when ascending and so that it could easily be found if accidentally lost overboard in shallow water on her first tests. The inside was painted black to avoid any reflection of light entering the shell through the window.

The following calculation was made to consider the crushing effect that might occur on the window where it was forced against the gasket.

$$\frac{\pi d^2 p}{4} < \frac{\pi}{4}(d'^2 - d_2^2) f_c$$

Assuming f_c for glass is 30,000 pounds per square inch and that maximum pressure corresponding to a depth of 7,750 feet is applied.

$$\overline{6.75}^2 \text{ x } 3445 < (\overline{6.75}^2 - \overline{6.00}^2)\ 30{,}000$$

$$1.00 < 1.83$$

The casting was milled plane on the window tube, and a thin leather gasket used between the window and the steel. The window is drawn into the gasket by means of an annular flat plate drawn toward the shell by bolts and lugs on the window tube. It is designed so that the pressure tends to seal the glass against the gasket.

SPEED AND POWER: The motors were placed in two housings. Her diving motor, giving ascent or descent, was placed on top of the shell with its shaft vertical and in line with the center of gravity of the shell. It was housed in a cylindrical container with a convex head through the center of which the shaft passed. The bottom of the housing was open, but its edge seated in a gasket and was held tightly against the shell by means of lugs on the shell and house. The shell was not penetrated.

The after housing held two motors. The shaft of the after - most motor was horizontal and lying fore and aft in line with the center of gravity of the loaded shell, with the housing made fast to the lower hemisphere. This motor gave fore and aft motion to the shell. The other motor in the same housing was mounted with its shaft perpendicular to the fore and aft motor and lying in a horizontal plane. The purpose of this motor is to turn the shell in either direction. This after housing is a removable steel cylinder with its after end convex, through the center of the shaft, and the turning motor mounted forward of it with its shaft going through the side of the housing radially. The housing is closed at its forward end by a removable plate and is amounted on the bottom half of the shell by lugs on each so that it may be removed readily.

A half horsepower motor was selected for the fore and aft motor and a quarter horse power for each of the others.

Attempts were made to estimate the speed of the shell in the water, none of which proved very satisfactory. If the assumption is made that there is no separation of flow and calculations are made for a sphere, from Stoke's Law it will be found that a very small part of her power will give all of the speed that could be desired. The point at which separation takes place and turbulent flow starts cannot be predicted, however. The diving motor housing would tend to disturb the flow whereas the after housing would probably tend to allow laminar flow at higher speeds.

A more satisfactory approach would be the following:
Using the formula:

$P = \frac{KWav^2}{8}$, where $\underline{P}$ is in pounds, $\underline{W}$ is density = 64 pounds per cubic foot, $\underline{a}$ is area of cross section and $\underline{v}$ is velocity in feet per second, and $\underline{K}$ is a constant determined by the shape of the body. K = .66 for a long prism; K = 0.40 for the same prism with a rounded hose; K = 0.10 for the same with a tapering stern (i.e. a streamline shape). With her long housing, the shell resembles somewhat the streamline shape and if K is selected as .20, by substituting in the above formula; and letting $\underline{V}$ be in miles per hours.

$$P = \frac{.20 \times 64 \times \pi \ \overline{2.03}^2 \times \overline{88 \times V}^2}{32.2 \times 60}$$

$$P = 7.51 \ \underline{V}^2$$

or from: $\text{H.P.} = .0199\overline{V}^{3}$

Thus for a ½ H.P. motor:

$$\tfrac{1}{2} = .0199\overline{V}^{3}$$

$$V = 2.93 \text{ miles per hour}$$

$$P = 7.51 \times \overline{2.93}^{2}$$

$$P = 64.5^{\#} \text{ maximum thrust}$$

It is believed that the above figure for maximum speed is low, by comparison with small boats that might have about the same displacement and separation of flow.

To determine the acceleration:

$$F = MA$$

Assuming maximum thrust as figured previously

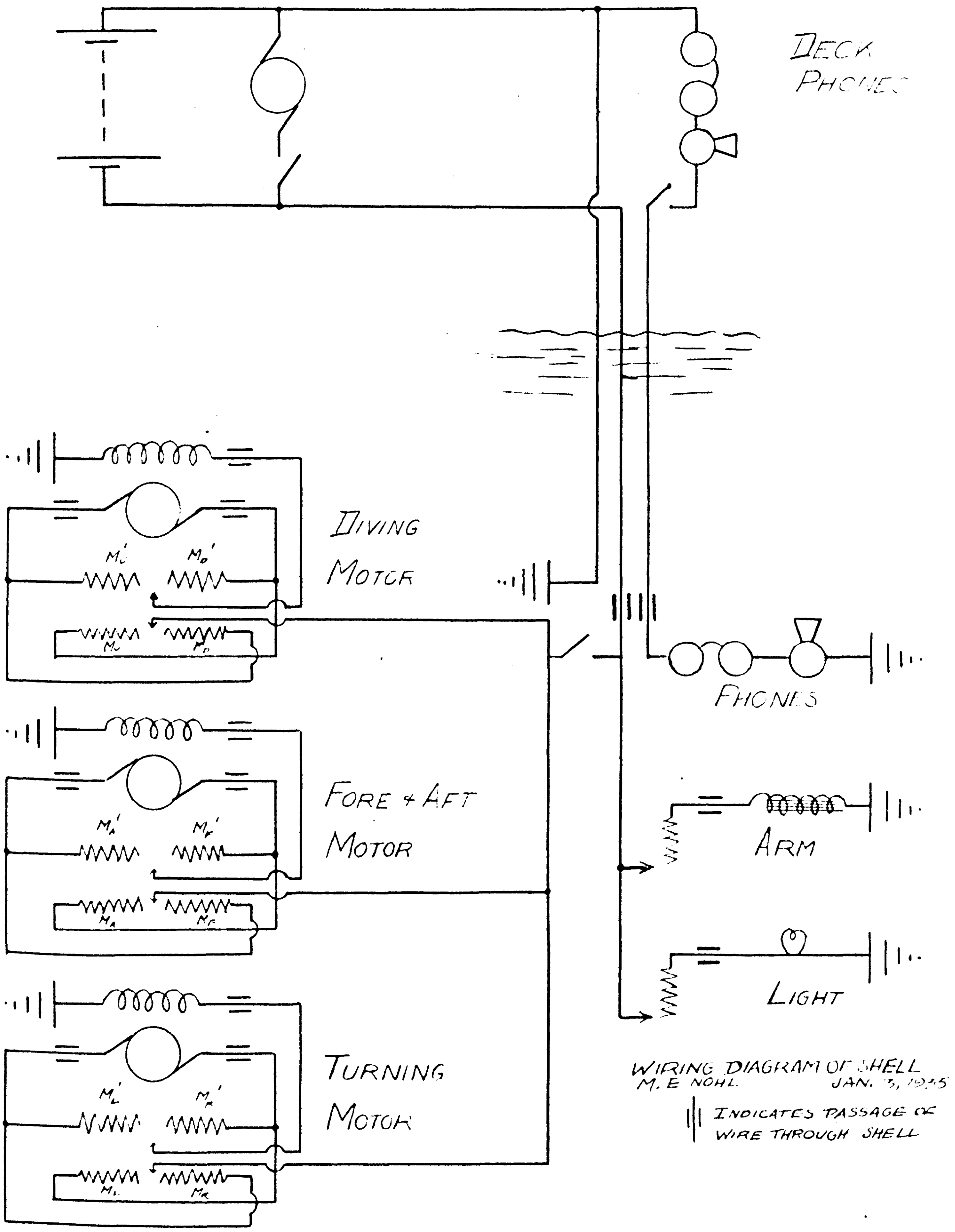
$$64.5 = \frac{1210}{32.2} A$$

$$A = 1.72 \text{ feet per second per second.}$$

From the following the performance of the shell may be estimated:

$$S = \tfrac{1}{2} A\overline{T}^{2}$$

At very low speeds, the flow will be laminar with a very small resistance, and the inertia of the shell will be the chief factor in determining the sensitivity of control obtainable. The following gives time elapsed and theoretical movement of the shell in feet:



WIRING DIAGRAM OF SHELL
M. E NOHL. JAN. 3, 1935

||| INDICATES PASSAGE OF WIRE THROUGH SHELL

Seconds:	.25	.50	.75	1.00	1.50	2.00
Feet:	.054	.22	.49	.86	1.94	3.44

Figuring a speed of 4 miles per hour as a maximum, which is equivalent to 6.5 feet per second and with a motor speed of 1600 revolutions per minute or 26.6 revolutions per second and an arbitrary efficiency of 80 percent, the pitch was figured to be:

$$p = \frac{6.5 x 12}{26.6 x .8} = 3.7 \text{ inches, pitch for fore and aft propellor.}$$

The pitch was actually made 4 inches for the fore and aft propeller and 3 inches for the other two propellors.

<u>ELECTRICAL SYSTEM</u>: The accompanying drawing shows the schematic wiring of the entire equipment.

The cable used was a light rubber covered cable, having very little weight underwater. The generator used on the raft on Lake Michigan was a Delco plant, an engine driven generator delivering 850 watts at 32 volts. 850/32 gives a maximum current of 26.5 amperes. The cable could easily carry an overload for a short time because of the cooling of the water. A number 10 (American Wire Gage) rubber covered wire with a capacity of 25 amperes was used.

The Delco plant proved a reliable source of power. Batteries are a necessary part of the plant and are used for starting the engine and automatically carry the load in case of failure of the engine. The plant was housed in a box protected from the wash, from the raft.

The cable is made fast to a hook on the shell so that a jerk on it could not endanger the plug where the current enters the shell.

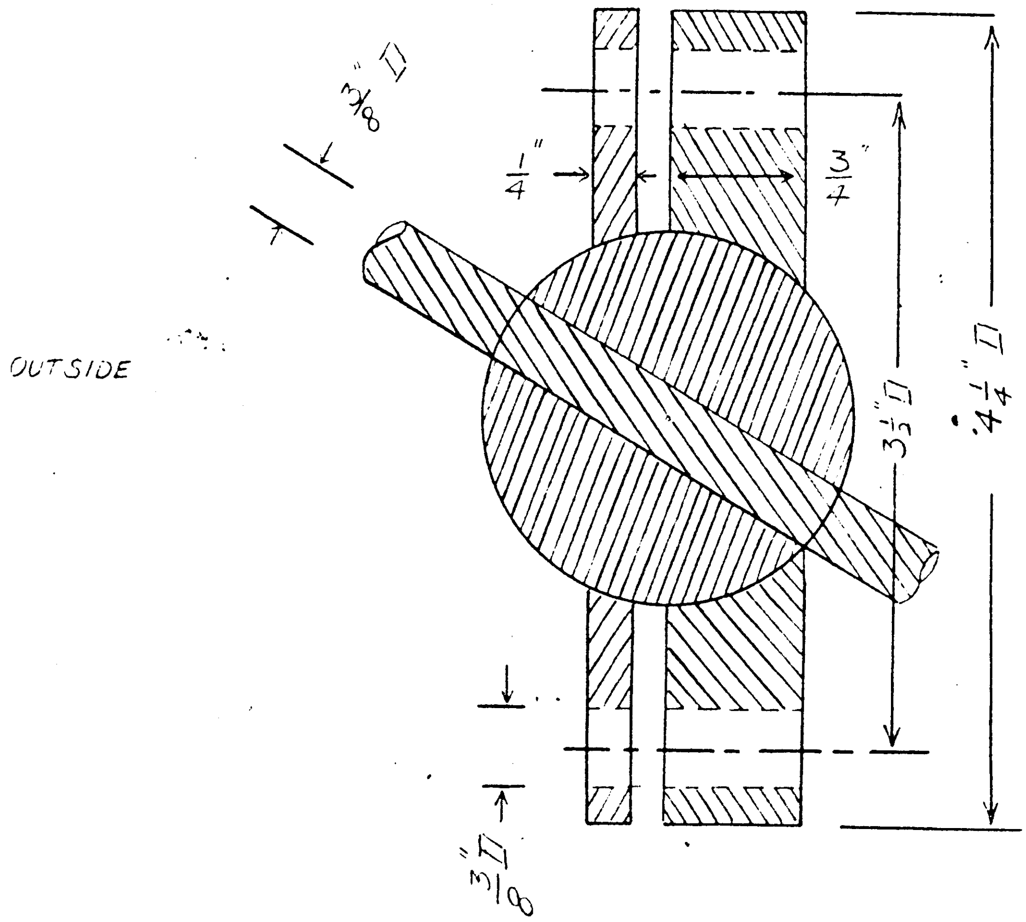
It was necessary to lead 16 wires into the shell. It was desirable to do this in as small a hole as possible and at a minimum of expense. It was originally planned to cast a tapered insulating plug containing the 16 wires, but the following home-made plug proved so satisfactory and inexpensive that it wasn't found necessary to make the more elaborate plug.

As shown in the drawing on page 21, 16 copper strips were used. These were all given several coats of dope so as to insure insulation. A treated linen covering, highly adhesive, was used to cover each one of the strips, with increasing thicknesses toward the outer end of the plug to give the desired taper. The strips were again doped and allowed to dry together under as much pressure as could be obtained in a vise, with a wooden die slipped in on each side between the jaws and the plug. The plug, when removed, was almost the desired shape and was as hard and solid as if it had been made of solid metal. A covering of tape, piano, wire, dope, and another layer of tape, allowing to dry again under pressure, completed the plug. The hole into which it was to fit was only one inch in diameter. It fitted in perfectly and was fastened with a hose clamp on the inside to make it impossible to fall out. The pressure of the water could only force it in tighter.

Connections were soldered to the copper strips inside and out and the ends of the plug thoroughly insulated.

It had been planned to use series motors throughout because of their desirable speed torque-curves and also because of simpler arrangements necessary to control their speed and reverse them. However, it was found difficult to obtain this type of winding in the 32 volt motor so it was necessary to use compound wound motors which had speed torque-curves that were quite satisfactory but brought about complications in controls. The direction of current in the armature was reversed to reverse the motor, with the series coil automatically kept in series with armature but not having its current reversed, as shown in the diagram. There didn't seen to be any conceivable way to connect up the shunt coil of a motor so that it would not be reversed as the armature was reversed (i.e. without too elaborate a control mechanism) so it was decided to connect the shunt coils permanently so that they would be drawing in all motor current whenever the power switch was closed, but no way of avoiding this with a compound wound motor seemed to present itself, and the amount of current drawn by these coils was small.

A switch was provided so that the power could be shut off completely and the control stick folded up out of the way.



BALL AND SOCKET
ARM JOINT

FULL SIZE

M. E. NOHL JAN 3, 1935

At rest, in still water or when settled on the bottom this might be desirable.

The shaft packings were homemade, punched leather cups were steamed and while hot bent into the desired shape. This type of "U" packing was used because of its low resistance at low pressures and its ability to pack itself at high pressures.

ARM: The arm is shown in the accompanying drawing. It is made of steel, so called "Accuracy Stock" and bought needing no further machining for size. The ball was a large ball bearing which had to be annealed to be drilled. The ball seated itself in its retainer under pressure, as shown in the drawing.

All of these parts had to carefully be greased before and after immersion.

In selecting the size of shaft for the arm, axial pressure and also the maximum moment had to be considered.

Because of the decreased weight of any object under water and the turning effect on the shell from picking up a heavier object, a maximum weight, W, of 20 pounds under water was decided upon and a 30 inch shaft. Under the conditions for maximum moment on the shaft--i.e. with the weight at the outer end and the ball support at the middle, the following may be used to determine its diameter.

$$M = \frac{WL}{2} = \frac{20 \times 30}{2} = 300''\#$$

For a circular cross section $I = \frac{\pi r^4}{4}$

$$f = \frac{Mc}{I} = \frac{4M}{r^3}$$

For hardened steel $f = 60{,}000$

$$60{,}000 = \frac{4 \times 300}{r3}$$

$$r = .186,\ d = .372$$

A 5/8" shaft was used.

The following gives the axial pressure on the shaft; where h is in feet:

$$F = \frac{d}{4}^{2} \times \frac{h}{2.31} = .0477\ h$$

Thus at a depth of 100 feet the axial pressure would only be 4.7 pounds.

EMERGENCY RELEASE: Mechanical independent means of releasing ballast are shown in the accompanying drawing. If the shell has zero or negative buoyancy, in either case, the amount of ballast carried outside is enough so that its release will give the shell positive buoyancy. Conditions under which the line to the mother ship would be parted are hard to imagine, but in case of such a contingency, the diver may always float to the surface, by operating this release.

AIR CONDITIONING APPARATUS: A study was made of apparatus for artificial breathing and nothing could be found that would be satisfactory. The following system I believe is unique and has proved itself remarkable successful.

In studying other systems, it was found that submarines disregard the matter. Nothing more is done than to keep the air circulating by means of blowers and to limit the diving time accordingly. Diving bells and diving suits use air pumped from the surface slightly in excess of the water pressure. The above are obviously not to be considered.

Simon Lake in his new baby submarine the "Explorer" which is not designed to exceed depths reached by rubber suit divers uses a double hose, the second one being to exhaust the foul air at the surface. This hose is extremely expensive and could not be built for great depths satisfactorily to withstand the high external pressure with the desirable flexibility.

In the stratosphers gondolas and in some armored suits, bottles of a mixture of air and oxygen have been used, the dilution with air being used to avoid the danger of high oxygen concentrations. However excess pressure must be valved or allowed to accumulate from time to time. Absorption cannisters for carbon dioxide are usually used with this system.

Dr. Beebe's system for his "Bathysphere" has apparently been the most satisfactory. He uses pure oxygen, metered out at the rate of 1 liter a minute per man and absorbs the carbon dioxide in open chemical trays.

The method used in the diving shell operates on the following principle: In the body,

$$4N_2 + C + O_2 \longrightarrow 4N_2 + CO_2$$

The nitrogen is inert; the carbon is not in gaseous form and the carbon dioxide is absorbed as follows:

$$2NaOH + CO_2 \longrightarrow Na_2CO_3 + H_2O$$

Thus for every mole of oxygen consumed, one mole of carbon dioxide is formed. If this is not absorbed the total number of gaseous moles in the sphere is constant. However if it is absorbed, the number of moles of oxygen absorbed by the diver will be the total decrease in number of moles. Thus if oxygen is admitted at exactly the same rate as it is absorbed by the body, the total number of gaseous moles will be constant. Accordingly, if a barometer is placed in the shell, a drop in pressure will indicate that there are less moles of oxygen present or a rise will indicate there are more moles of oxygen present than previously since the pressure is proportional to the total number of gaseous moles.

In diving, if the fixed hand of a barometer is set with the moving hand, a very accurate determination of the air content may be made and the valves admitting oxygen into the shell opened or closed slightly to increase or decrease the rate of flow.

On the barometer used, 1/20 of an inch of mercury could easily be read. Assuming the air 21% oxygen and the barometer at 30 inches a change of this magnitude would correspond to

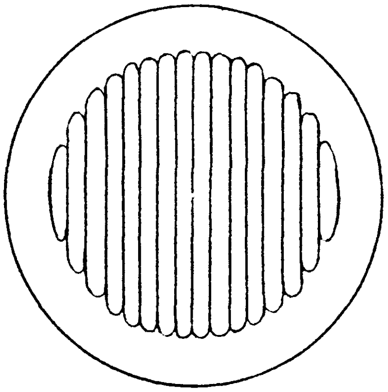
$$\frac{1}{20 \times 30 \times .21} = .0079$$

, or about .8 of one percent in the oxygen content of the shell.

The physiological limits of oxygen concentrations are discussed under the "Physiology of Diving".

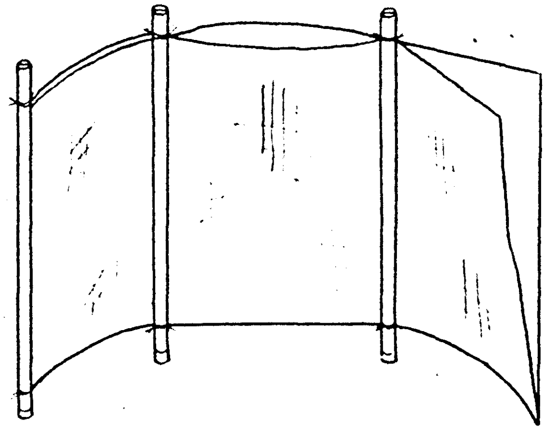
The bottles used were 18" bottles made by the Ohio Chemical Company each bottle holding 11 cubic feet. One bottle was found to contain enough oxygen for approximately four hours for one man. Two bottles were always taken along in case of previous unknown leakage and were filled from the large 220 cubic foot commercial bottles, making the cost of oxygen very small.

To assure filling the bottles almost full the following system was used. After one of the large bottles dropped below about 1700 #, the filling of a small bottle was completed from a fresh large bottle, not using much from the latter. Thus after a while 3 large bottles were in use, the first filling up, e.g., the first third of the pressure, the second the second third of the



SCALE: DOUBLE SIZE

CROSS SECTION: LEABIN PLUG



SECTION OF SCREEN USED FOR
EXPOSURE OF CHEMICALS

M. E. NOHL
JAN. 3, 1935

pressure and so on. Thus almost all of the oxygen was used and as a large bottle was emptied another is down for the first low pressure filling, ect.

Calcium chloride was used to absorbe the moisture from the air. It was found that if it wasn't used, it soon becomes uncomfortable inside of the shell and the window fogged up so that it has to constantly be wiped to see clearly out of it.

A commercial preparation known as soda lime was found most satisfactory for the absorption of carbon dioxide. It is a half-and-half mixture of sodium hydroxide and calcium oxide made up in various meshes. Since this is a patented process, it is quite expensive. Accordingly pure sodium hydroxide in a form as "technical flakes" was tried and found satisfactory except that it deliquesed and difficulty was experienced in preventing the liquid from running which was found to be very uncomfortable to the diver. A mixture of technical flakes and calcium oxide proved to be satisfactory but probably not as much so as the more expensive soda lime.

During the first experiments, chemicals were merely strewn on the bottom of the shell, with very satisfactory results for absorption but not quite as satisfactory for the comfort of the diver.

A copper screen was folded over upon itself and bent to fit the contour of the shell later. This was found very satisfactory, giving a large exposed area, without using any space. This method was used with soda lime, and with sodium hydroxide using rags to catch the drip.

The method described later in connection with the self-contained suit would probably be the most desirable absorption arrangement. This device in the shell world makes a compact, efficient, and neat means of removing the carbon dioxide.

To estimate the amount of chemicals needed the following calculations were made.

Assuming 1 liter per minute necessary, 60 liters per hours will be necessary.

$$\frac{60}{22.4} = 2.68 \text{ moles per hour.}$$

If quicklime is used:

$CaO + CO_2 \rightarrow CaCO_3$

Therefore 2.68 moles of CaO with a molicular weight of 56 will require 150 grams, or .33 pounds of quicklime per hour.

If sodium hydroxide is used.

$2\,NaOH + CO_2 \rightarrow Na_2\,CO_3 + H2O$

2×2.68 moles of NaOH with a molecular weight

THE RAFT WITH HER DIVING MOTOR, AND GENERATOR
ON THE SHORE OF LAKE MICHIGAN

weight of 40 will require 215 grams, or .47 pounds per hour.

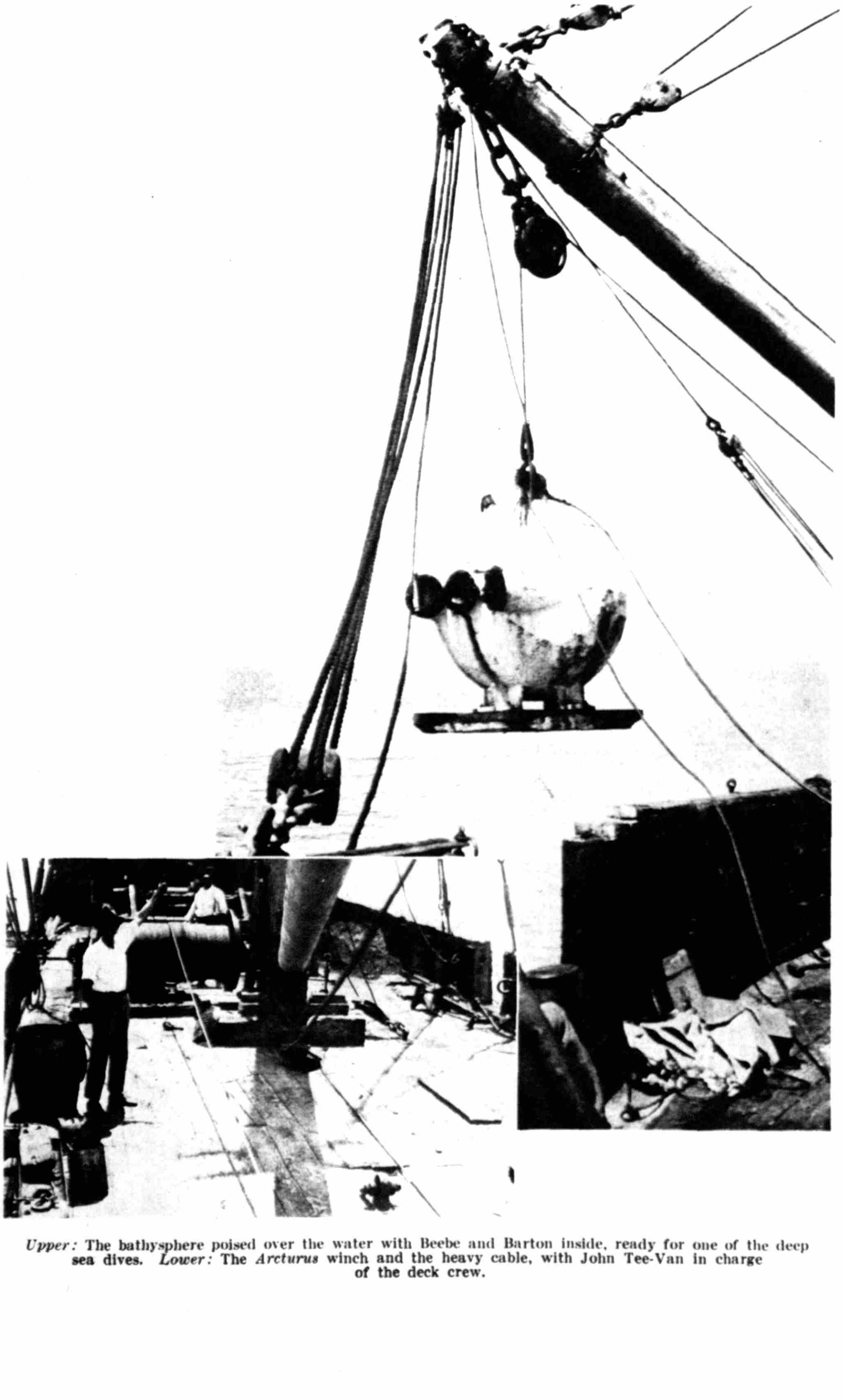
Soda lime, which a mixture of the above two, would require theoretically about 0.4 pounds per hour.

In practice the breathing was found to be perfect. At no time did I notice the slightest increase in breathing due to high carbon dioxide content or any time find that the oxygen control wasn't 100% satisfactory. Even with two men in the shell, the results have been as satisfactory.

LAUNCHING RAFT: The raft framework was built of 4 by 4s, bolted together. The floats were 60 gallon oil and alchol barrels. These were lashed to the framework with ¼ inch iron wire straps, using three to each barrel, and fastened with the appropriate size wire clamps. To further tighten the straps, wooden wedges were inserted, drawing up the barrels firmly. 2 by 4 blocks were placed across the end of each barrel to prevent, longitudinally sliding. This raft has ridden to a mooring in the open lake for a large part of two summers and has proved herself very seaworthy.

The shell was suspended from an overhead beam. A chain fall was used to lower her into the water and bring her out. A removable platform was inserted so that she could rest on it when the diver was getting in or out. The shell was lashed to the platform and the platform to the raft when the latter was riding to her mooring.

The raft and shell could be beached high by only two men. By allowing the shell to rest on the sand and slacking away on the chain fall the raft could be moved from 6 to 10 feet. The shell was then brought up the same amount with the chain fall and swung a little bit ahead, lowered again, and the process repeated.



Upper: The bathysphere poised over the water with Beebe and Barton inside, ready for one of the deep sea dives. *Lower:* The *Arcturus* winch and the heavy cable, with John Tee-Van in charge of the deck crew.

DR. BEEBE'S BATHYSPHERE

A brief discussion of this diving shell might be pertinent.

It was designed by Otis Barton and used by him and Dr. Beebe for deep water studies of marine life off Non Such Island, Bermuda, and backed by the National Geographic Society.

The world's deep water diving record previously had been 525 feet made by a German in a Swiss fresh water lake.

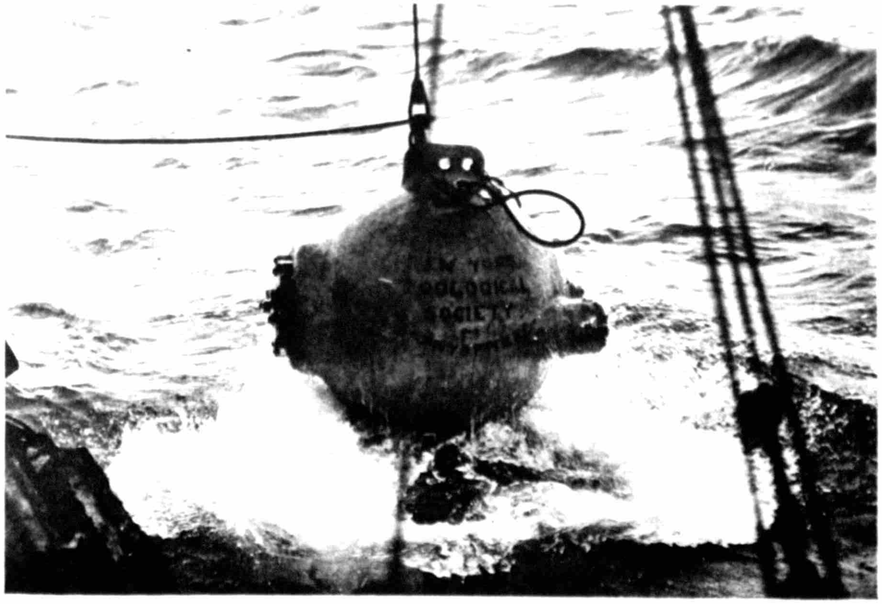
On June 11, 1930, the Bathysphere descended to a depth of 1426 feet, establishing a new world's deep water diving record.

On September 22, 1932, it broke its previous record, descending to 2200 feet.

On August 15, 1934, it descended to 3028 feet, which is the present deep water diving record.

The shell has negative buoyancy and is suspended by a cable at all times, lowered and raised by a steam winch on deck of the "Ready", the mother vessel. The ship's motion on the surface is transmitted to the shell, resulting in a violent jerking making diving almost impossible except under ideal surface conditions.

It is a hollow steel sphere 57 inches in diameter, and 1½ inches


EW YOR
OOLOGICA
OCIETY

thick, made as a single casting. It weighs 5,000 pounds out of water and 1,750 pounds when submerged.

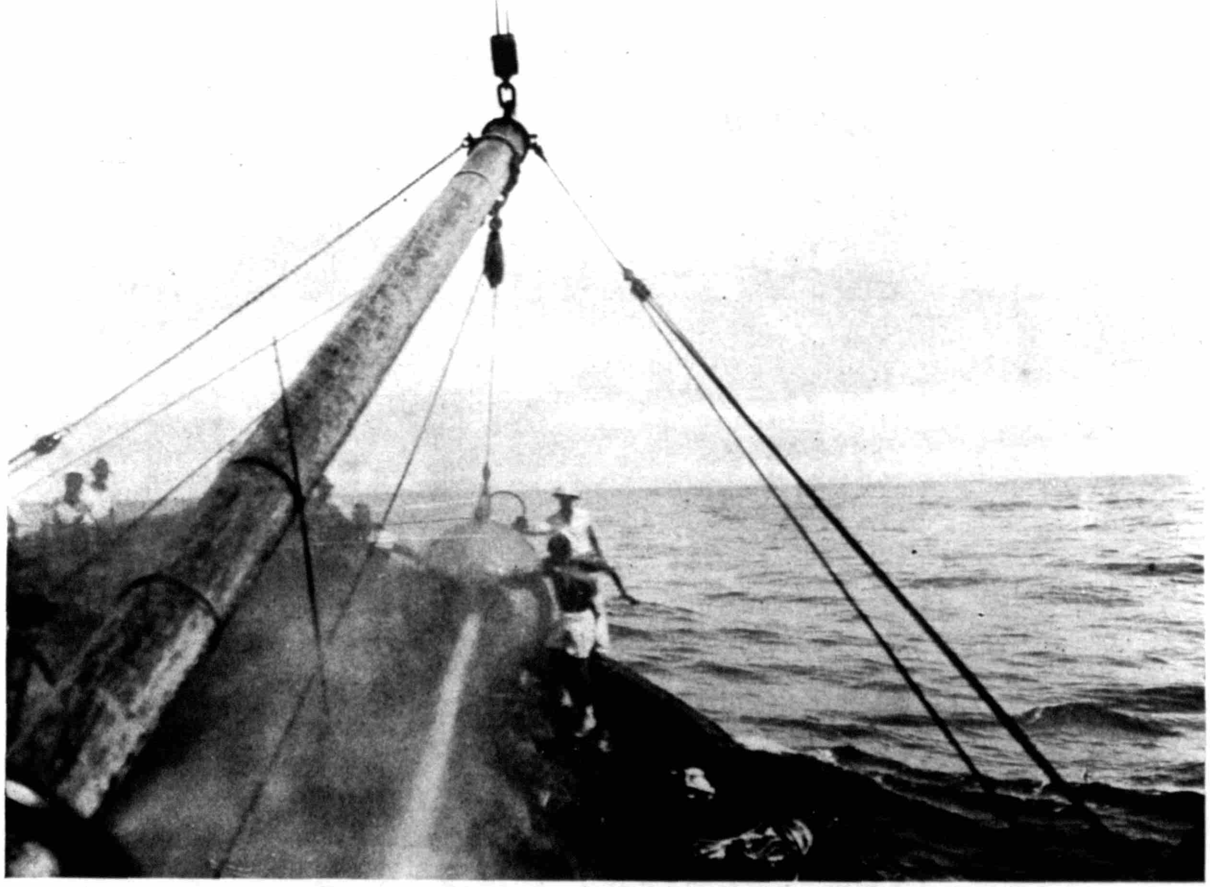
It has a 400 pound removable door in its after end which is bolted to the shell externally with 10 heavy steel bolts. In the door is a 4 inch removable plug which is not inserted until the last minute before diving.

On her forward end are three windows, made of fused quartz, 7 inches in diameter and 3 inches thick. These are seated on paper gaskets treated with white lead.

She is lowered from a 7 ton winch. 3500 feet of 7/8 inch steel center non-spinning cable is used, with a breaking strength of 29 tons and which weighs 2 tons under water. 1-1/8 inch rubber cable is used for telephone and lights. This enters the shell through a stuffing box, with an internal and external gland. It is made fast with twine to the lowering cable at 200 foot intervals. The depth is noted by a meter wheel over which the lowering cable runs and also checked by ribbon markings. The shell is lowered from a boom and held close to the sheave to prevent swinging. On one 2000 foot dive it was found that over 3 feet of the cable had been forced into the shell.

A 250 watt light was carried inside of the shell and pointed out through the window.

The breathing apparatus consisted of trays of 4 to 8 mesh soda



Standing far back, with fingers just touching the wing bolt, the Director gives it a last push and, like a shell from a cannon, it flies across the deck and crashes against the steel winch thirty feet away, making dents half an inch deep in the brass. The compressed air and water turn to steam, clouding the entire forward deck.

lime for absorption of the carbon dioxide and 8 mesh calcium chloride for absorption of moisture. Fans were used to keep the air in circulation. Recently a blower has been added. The oxygen is metered out at a predetermined rate of approximately two liters a minute for two men by a very sensitive valve and flow gage.

The mother vessel, "Ready", is an ex-British Navy ship, 123 feet overall and with a 23 foot beam. She is kept working when diving into the seas. A minimum crew of 30 men was necessary to operate the entire equipment.

A COMPARISON BETWEEN THE "BATHYSPHERE" AND MY SHELL

	MY SHELL	"BATHYSPHERE"
Weight in pounds:	867	5,000
Ratio of weights:	1	5.75
Diameters in inches:	40	57
Ratio of diameters cubed:	1	2.88
Ratio diameters:	1	1.42
Thicknesses of whell in inches:	5/8	1 1/2
Ratio of thicknesses:	1	2.40
Elastic limit of steels:	55,000	36,000 (?)
Ratio elastic limits:	1	.65
Ratios; radius/elastic limit:	1	2.17
Window:	glass	Fused Quartz
Window diameter in inches:	6	7
Window thickness in inches:	3	3
Weight submerged in pounds:	0 ±	1,750

The allowable pressure is given by the formula

$$p = \frac{2\,t\,f}{r}\text{, or: } t = (k)\,\frac{r}{f}$$

and k is a constant assuming a spherical shape.

To get a theoretical comparison between the two it will be noted that the ratio of thicknesses is 1/2.40 and the ratio of r/f is 1/2.17, or the "Bathysphere" might be said to be 11% stronger. However, the "Bathysphere" can at no time decrease its weight to less than approximately seven-eights a ton under water.

ARMORED DIVING DRESS

HISTORY: The first armored suit was built in 1875 by Lafayette, a Frenchman.

Three years later another Frenchman, Carmagnolli, built and improved the original suit.

In 1880, Tasker, an American, built a somewhat different type of suit than the first two, in that it was considerably lighter and had a "bellow" type of joint.

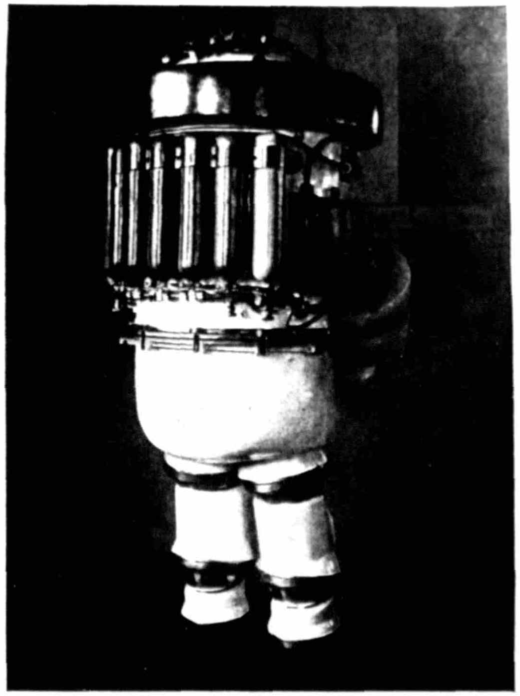
In 1897, Buchanan-Gordon built another suit which was quite similar to the Tasker suit.

Thereafter, the heavy armored type of dress seemed to be the trend, introduced by Petrie in 1903, and followed by Mac Duffie in 1914, Long in 1917, De Graff in 1918, Campos in 1919, and Jackson in 1920.

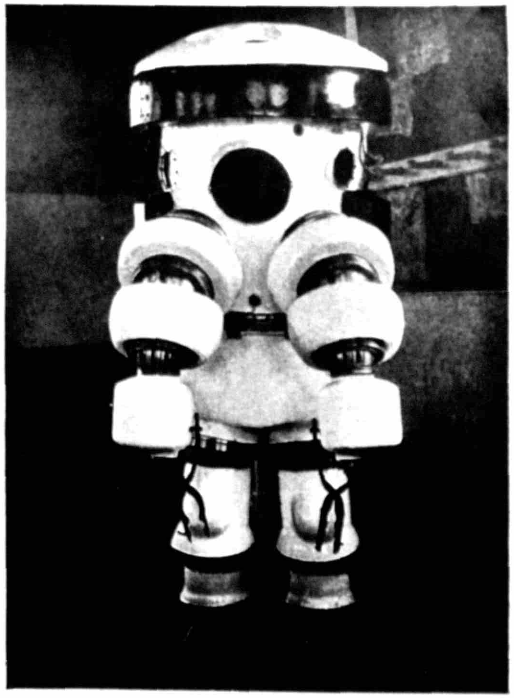
In 1915 Leavit produced another suit of the light armor type, quite similar to the Tasker suit.

Neufeldt and Kuhnke, a German concern at Kiel, produced three successive armored suits which were responsible for some successful salvage work.

The first of these was a much lighter and more compact shell than recent inventors had produced. All of the joints were on ball



THE FIRST NEUFELDT AND KUHNKE
DIVING SHELL (BACK)



THE FIRST NEUFELDT AND KUHNKE
DIVING SHELL (FRONT)

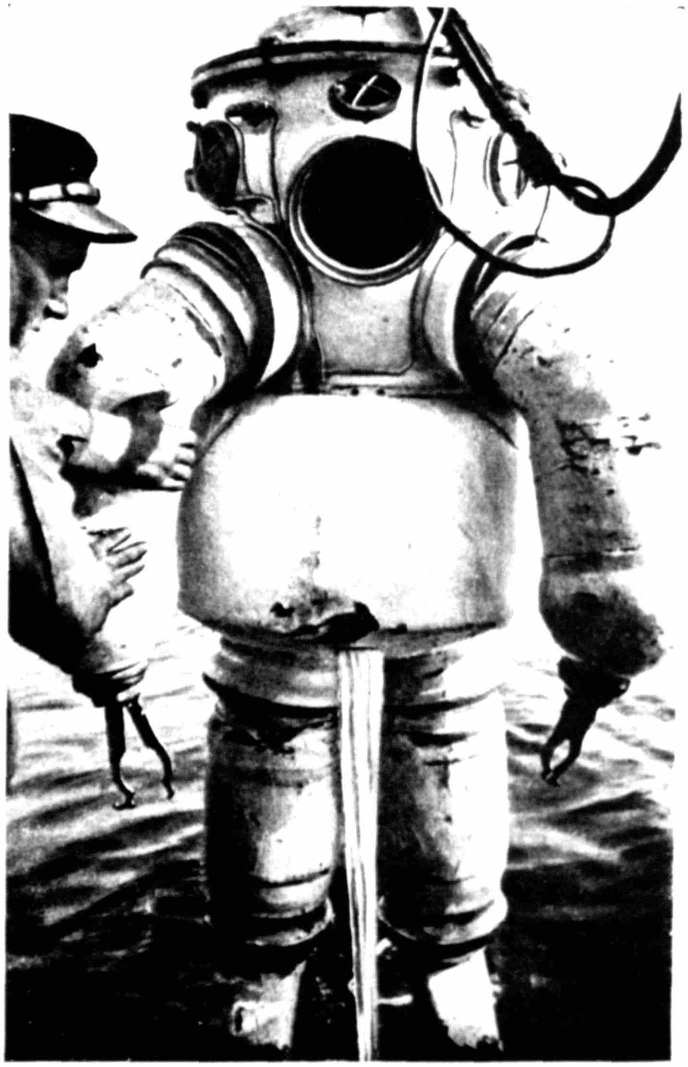
bearings with a minimum of friction. Each one of these joints was covered by a thin rubber ring, working over the ball very much as an eyelid works over an eyeball. There were three flexible joints in each arm (at shoulder, elbow, and wrist) and the same number in each leg (thigh, knee, and ankle). It carried a floatation ring which was similar to a ballast tank and could be "blown" by the diver to rise to the surface. It carried a rack of air and oxygen flasks externally on its back.

The second model was similar to the first except that the flasks were protected from snagging and simplifications were introduced. This model was used successfully by the Societa Ricuperi Marittimi, of Genoa (known as "Sorima") in the salvage of the "S.S. Washington", off Genoa at a depth of 300 feet between 1927 and 1930, when 2000 tons of steel bars, 400 tons of copper, 300 railway trucks, and 7 locomotives were brought up.

In 1929 the same company operating the salvage ship "Raffio" raised 450 tons of copper and 200 tons of spelter from the S.S. Primo, lying in 250 feet of water off the Spanish coast.

In 1930 the same company operating the salvage ship "Rostio" raised a cargo of wool and tallow from the S.S. "Ravenna", lying in 300 feet of water off Genoa.

A wrecked sea plane was salvaged, also, with this model of



A CLOSE-UP VIEW OF THE ARTICULATED DIVING-SHELL USED ON THE WRECK OF THE 'ELIZABETHVILLE'. WATER IS POURING FROM THE BALLAST TANK armored dress.

The third model reduced the number of joints from 12 to 6, it being found that as much mobility was possible with the six joint suit as with the twelve. There was one at each shoulder, thigh, and ankle.

In all three of these suits, there were pincers in the position of the hands, besides the joints mentioned, one prong being stationery and the other working in a ball joint and operating directly by the divers hand.

The third model was used by a team of German divers who tried to make contact with the crew of the British submarine, "Ml", sunk off Portland in 1925. At that time records were made by Kraft for depth and duration of time under water.

This same model was used successfully by Sorima in the salvage of the "Elizabethville" sunk in 240 feet of water off the French coast, when a cargo of ivory was recovered.

The salvage ship "Artiglio" when salvaging the P.&A. Liner "Egypt" carried this third type of shell, but found very little use for it.

The suit was made of cast steel and designed for a depth of 600 feet. It weighed 800 pounds in air and 40 pounds in water with her ballast tanks flooded. The diver is under atmospheric pressure at all times, as in all of the other armored suits. He wears a mask over his mouth and nose which is connected to a cannister of chemicals for the absorption of the carbon dioxide, the cannister being fitted with a flap per valve. He wears earphones and the transmitter is mounted on the shell, the latter which acts as a sounding box.

<u>LIMITATIONS OF ARMOURED SUIT</u>: The armoured suit put little physical strain on the diver except for the discomfort of breathing poorly proportioned artificial air, the cold usually encountered, and the accumulation of water from leakage.

The armored suit is of little value. This is evident from the fact that Gianni, the famous Italian diver of the "Artiglio" who was responsible for most of the past success of this type of suit in the salvage of the "Egypt" admitted that this type of dress was of little use to him except for observation purposes. Accordingly, an observation shell was constructed which had no movable joints and which displaced the armor.

The great disadvantage of this type of dress can be understood when it is considered that the shell must be suspended from above at all times. To place a man dangling 400 feet down in strong currents by maneuvering a large ship above is readily seen to be very difficult and almost impossible. The diver himself by means of his movable can at best by extreme effort only shuffle a few inches sideways. He can grasp things only directly in front of him. To go into the interior of a ship, he must be lowered in directly from above, which means blasting away decks to get access to anything. In all of the successful operations of this dress, the observational value only was responsible for the results.

Apparently no type of joint has ever been developed which will enable the diver to move his arms and legs except by extreme effort when submerged to only moderate depths. The finest of these suits have always leaked. This type of suit is extremely expensive (I understand that a business concern is offering these for sale at $15,000).

If an inexpensive suit could be built that would allow free movement under pressure without leakage, there would be an extensive field of salvage open to it.

A classification with brief comments on all of the patents in in the United States Patent Office on armored diving suits is as follows:

PATENTS ON ARMORED SUITS:

Patent No.	Year Issued	Inventor	State or Country	Notes of interest if other than armor design
578	1838	Taylor	N.Y.	
15898	56	Phillips	Ill.	Suit with propeller.
67760	56	McKeen	N.J.	
236858	81	Tasker	Pa.	
237141	81	Tasker	Pa.	Bellow joints.
269187	82	Darling	N.Y.	Speaking tube.
418053	89	Pelkey	Minn.	Rubber covered suit.
437779	90	Homenger	Mich.	
462202	91	Carey	England	
463477	91	Boucher Bravit Filteau	Wis.	
496686	93	Hemenger	Mich.	
594954	97	Gordon	Tasmania	
601729	98	Fasey	England	
609418	98	Day	England	
711342	1902	Petrie	N.Y.	
735809	03	Petrie	N.Y.	
766465	04	Petrie Martin	N.Y.	Means for towing out water from suit.

PATENTS ON ARMORED SUITS:

Patent No.	Year Issued	Inventor	State or Country	Notes of interest if other than armor design
767659	1904	Petrie Martin	N.Y.	
827029	06	McGregor	Australia	
984104	11	Petrie	N.Y.	
989530	11	MacDuffee	N.Y.	
1010558	11	Williamson	Va.	Flexible arm and mitten.
1022997	12	Anderson Duffer	Philippone Islands	
1096607	14	Deray	Cal.	
1099814	14	Niehoff	Va.	Double suit with air space between
1146781	15	Bowdoin	N.J.	
1183914	16	Vsener	Germany	(assigned to Newfeldt and Ruehnke
1198617	16	Boyd	N.Y.	
1226148	17	Walters	N.Y.	Double suit with air at water pressure between. Canvas suit over metal rings.
1245058	17	Stolle	Germany	Adjustable buoyancy.
1259507	18	Gall	Germany	Armored glove.
1305656	19	Long	Texas	

PATENTS ON ARMORED SUITS:

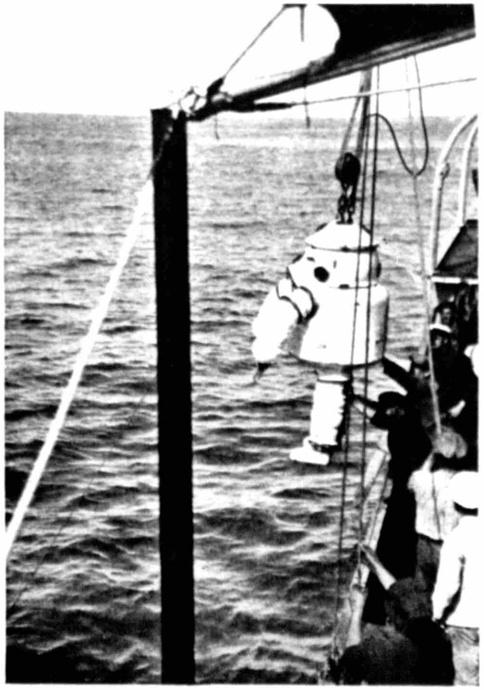
Patent No.	Year Issued	Inventor	State or Country	Notes of interest if other than armor design
1327679	1919	Leavitt	Ohio	Ball Bearing joint.
1349060	20	Gall Stoll	Germany	Ball joint.
1359132	20	Walters	B.C. Canada	
1368786	21	Graff	N.Y.	
1370690	21		Ill.	Suit with motor and propellor.
1383322	21	Marr	N.Y.	Flexible joint.
1402645	22		England	Joint
1414174	22	Campos	N.Y.	Use of Annular circular and cylindrical bearings.
1430194	22	Schweinert	N.Y.	Suit made up with inflated tubes to withstand pressure.
1466675	23	Stoll	Germany	Buoyancy control.
1519301	24	Gall	Germany	Glove armor.
1722375	29	Hipssich	Germany	Joint.
1760512	30	MacBride Ward	Australia	Compressed air venturl type injector for exhaust air.

SUSPENDED OBSERVATIONAL SHELLS

This type of diving apparatus would include Dr. Beebe's "Bathysphere", and my diving shell used without her motors. The only 3 others that have come to my attention have been: a large shell built by Bowdoin for use on the wreck of the Merida off the coast of Virginia; a shell built by Romano in Seattle which he claims has descended 400 feet; the shell used on the "Egypt" by Sorima which will presently be described, and an extremely heavy shell built by Tesch in Milwaukee. All of these (except that used by Sorima) were equipped with lights, telephone, and mechanically operated arms, but it is hard to conceive of how any use could be made of these arms, with the shell suspended from a mother vessel that is constantly pitching, rolling, and moving.

The shell used on the wreck of the Egypt is the only one that has had any known success in salvage operations, remembering however, that Beebe's "Bathysphere" has been very successful in deep water observations of marine life. Sorima's shell was built by Neufeldt and Kuhnke, of Kiel, Germany, who also built the articulated diving armor. As was previously mentioned, these dresses were found to have no use except as a means of observation, and had many disadvantages, such as considerable leakage, and the extreme care that the highly finished joints required after ex-

GIANNI WITH THE OBSERVATION SHELL. HE IS WEARING THE DIVER'S CLOTHING AND TELEPHONE HEADPIECE, AND HOLDS THE BREATHING-MASK IN HIS HAND



THE 'ROSTRO'S' DIVER GOING DOWN

posure to salt water, so the observatonal shell displaced them, at the top windows allowing 360 degrees of vision. It carried a heavy steel plate on its bottom which gave it negative buoyancy and the release of which would allow the shell to float to the surface. The windows were made of one inch plate glass, she carried telephone and lights. Her breathing system was self-contained; the diver had to wear a mask by means of which his exhaled air was passed through a cannister of carbon dioxide absorbant and a mixture of air and oxygen was admitted into the shell. The mother vessel was warped from eight buoys, each riding to a heavy mooring. These were on her head, stern, each beam, and each bow and quarter. By means of steam winches the ship was maneuvered with these warps, and the position of the dangling shell controlled as directed by the diver over his telephone. It seems truly remarkable that by this means two decks of the "Egypt's" wreck were blown off and the bullion recovered from the mail room in the third deck down.

A shell known as the "Eye" had been designed by Sandberg and Swinburne of London, but was never built. It was to travel on its descending line under the control of the diver by means of electric motors, and on the bottom was to direct various types of remotely operated salvaging machinery by electrical control from the shell.

ACCESS TUBE

Another type of apparatus was developed by Simon Lake of Milford, Conn., which he calls an "Access tube". It consists of a large steel tube, the upper end of which is hinged to the mother vessel and open to the atmosphere and the lower end of which rests on the bottom or the submerged wreck. A chamber is fitted to the tube at its lower and which has windows and an air lock so that a diver may enter the water. The entire rest of the tube is under atmospheric pressure and is fitted with a simple elevator.

Although the idea is appealing of going down to a wreck in an elevator under atmospheric pressure, I can see little practical value of such a device over diving from the surface. The amount of weight necessary to sink the tube would be enormous and result in an extremely heavy, awkward, and expensive piece of apparatus. No work can be done from the tube, other than that done by the diver who might much more safely and satisfactorily take his compression and decompression in the water. If there were currents or a tide were running, the forces on the tube would be enormous, and a very dangerous situation might develop for a diver connected by hoses to the bottom of the tube. The disadvantages of using this device for salving through the air lock is proposed and are obviously much more complicated and expensive operations than hauling up directly through the water.

LAKE'S SUBMARINE THE "EXPLORER"

This submarine is unique in that it is designed wholly for salvage work.

It was designed and built by Simon Lake and at present is lying near Stamford, Conn. She is designed to carry 4 men, has an allowable depth of 300 feet, receives her power through a cable from a mother vessel, receives and exhausts her air through a double hose, with compressors on the surface ship, is fitted with a hydraulic shovel on lazy tongs controlled from the inside which is at a atmospheric pressure, is fitted with an air lock through which a diver can enter the water, is powered and controlled in a manner similar to the convential submarine, and is equipped with wheels so that she may run on the bottom, with negative buoyancy.

I do not believe this submarine practical for salvaging operations because it is too expensive and complicated, and there is little that it can do that is not done by the diver, who can just as well and actually much more safely dive from the surface. The value of the shovel is yet to be demonstrated but it seems doubtful if any amount of work could be done with it that could not better be done from a clammshell bucket from the surface.

THE MODERN FIGHTING SUBMARINE BOAT

The following is a very brief general description of a modern submarine, a "V"-boat".

She is about 270 feet long overall and displaces 1100 tons. She has a speed below of over 11 knots. She carries 4 torpedo tubes forward and 2 aft, carrying torpedoes in her tubes in wartime and several more salvos on her racks. She carries a gun on her forward deck which is submerged when the submarine is below.

The hull of the boat consists of a tapering cylindrical tube about 15½ feet in diameter, amidships, built up of mild sheet steel on a girder frame. Her bow and stern are streamlined by means of a sheet steel falsework and her forward and after decks and bridge are built up from the hull by means of falsework drained and filled by scuppers as she comes up or goes below. Her test depth is about 250 feet.

The submarine runs at three depths. On the surface she is controlled from her bridge and has the characteristics of an ordinary ship, rumming under her Diesel engines. At "periscope depth" she is completely submerged and displaces her weight; only her periscope is above water giving her sufficient visibility for maneuvering almost unseen from surface craft. She is powered by electric motors driven by storage batteries when submerged. Below periscope depth she is running completely blind, ~~depending~~ on ~~instruments for depth she is running completely~~ blind, depending on instruments for depth, list, trim, speed, ect.

Her surface power consists of Diesel Engines developing a total of 3100 Horse Power. Below she is powered by electric motors developing a total of 3000 Horse Power. She carries two banks of batteries, delivering 230 volts, which are charged by the engines. She carries motor driven air compressors delivering air at 2000 pounds per square inch for expelling the torpedoes, also motor driven air blowers for her ballast tanks.

She is constructed with a double hull, between which are her ballast tanks and trimming tanks. In the former she carries about 250 tons of water when flooded. Her forward and after trimming tanks are connected by a motor driven pump. The ballast tanks may be used as storage fuel tanks.

The hull is divided into water and pressure tight compartments, which consist of a forward Torpedo Room, Battery Room, Central Operating Compartment, Engine Room and After Torpedo Room.

The air is circulated throughout the ship by blowers and ventilation tubes. Oxygen and carbon dioxide absorbant are available in each compartment but are supplied only for emergency use.

An external pump connection is available to each compartment to which a diver can fasten an air line in case of emergency. Also a buoy is releasable from the interior to mark her position in case of sinking, which contains a telephone line. Two escape locks are provided in addition to the conning tower. The equipment on board included "Momson Lungs" which enable men to escape from the ship in case of accident.

PART B

WATER PRESSURE DIVING

1.

OPEN HELMET DIVING

An ordinary man cannot hold his breathe much over thirty seconds. Native divers train themselves to extend this to over two minutes and are capable of swimming down to depths of over 50 feet, diving for sponges, pearls, or coins. The simplest improvement on this is a pair of glasses for better vision and protection of the eyes.

Open helmet diving is different only in that air is supplied at water pressure giving the man an unlimited time below. For example, a complete, inexpensive, homemade equipment may consist of a pail for a window in it, a garden hose, an automobile tire and tube for an air reservoir equiped with two valve stems, and a tire pump.

An open helmet is made by Morse and another popular helmet is made by Dunn and Miller in Miami, known as the "Diving Hood" (and listed at $275.00), both of which are fine open helmets.

I built an open helmet which embodies several novel features, particularly low cost of construction, and which has proved itself a fine piece of diving apparatus. A view of this helmet is shown in the accompanying illustration.

The helmet was built of a 5 gallon paint can. A large window giving 180 degrees of vision was put in, made of celluloid. The can, window, and two rubber gaskets were firmly held together between an inner and outer band steel frame drawn together by 24-¼ inch brass bolts. A band steel chest frame, well padded to to protect bare shoulders was constructed and 75 pounds of lead added at the lowest part. This frame snugly fitted to the chest and put the center of gravity so low that it was found impossible to tip the helmet off the diver's head, but yet allowed him to slip out from under it if so desired. A high handle was built on to the helmet as shown, and extended by channel irons to the weights in such a manner that in carrying the helmet no stresses were put upon it and the weight supported directly by the handle. Similarly in wearing the helmet, the weight is supported by the shoulder bands connected directly to the lead bars. This is no strain in the can or warping of the window therefore could not occur.

A non return valve was fitted in the air hose connection. A

DIVING IN LAKE MICHIGAN

THE SHELL BEFORE A DIVE ON THE "SETH PARKER"

MY OPEN HELMET AND SHALLOW WATER PUMP ON THE POOP DECK OF THE "SETH PARKER" —

vane was provided to direct the incoming air over the window and keep it clear. The inside was painted black to minimize reflections.

1/4 inch escape holes were provided in the back half of the helmet's bottom to allow as steady escape of small bubbles which would not pass the window.

A man can work at a depth up to 36 feet for any length of time and ascend immediately to the surface without decompression. For that reason, this is the usual limit of the ordinary open helmet because any tipping of it will allow air to escape and put the helmet in a state of unstable equilibnum, and causing it to fall off and leaving the diver to swim to the surface without any warning. Accordingly, the man below must be extremely careful not to tip his helmet at all which makes the work which can be done with it quite limited. Because of the exposure of the entire body to the water, it has very little practical value except in warm water. The open helmet finds considerable usage in sponge diving and pearl diving.

HALF DRESS

The half suit or "rescue dress" consists essentially of a light or regulation helmet and breast plate, and a dress fitted with a tight rubber waist band with the "trouser part" of an ordinary dress removed. It is designed only for shallow water but it could be used in as deep water as a full dress providing the water were warm enough for the prolonged exposures of decompression. Its improvement over the open helmet is that theoretically water cannot enter the diver's body when it is tilted and also that half of his body is protected from the cold water. It is more satisfactory than a full dress for certain types of work where rapidity in dressing is important, since the dress need not be disconnected from the breastplate, the diver slipping in and out at the waist band. For this reason it is known as a "rescue dress" since it is of value for rescuing drowning persons, where a moment's dressing would be essential.

In practice, this type of dress seems to offer no great advantage over the open helmet, and because of the weight of the equipment in most cases is less desirable. It is found in practice that if the wrists are higher than the waist band, as would be necessary in most work and descending on a line, that the air escapes through the rubber cuffs at the pressure level of the highest wrist. This means that no higher pressure than this can be maintained in the dress, and the waist, at a lower pressure level, must suffer an ingress of water. In doing ordinary work under water in this type of dress, it will be found that the water level is practically up to the divers chin, exactly as in an open helmet.

RUBBER SUIT DIVING

DESCRIPTION OF APPARATUS: The helmet is made of spun copper. It has a window in front, one on each side and sometimes one above, all protected by external gratings. The helmet base is threaded to fit the breast plate and the helmet may be easily removed or placed on by an eighth turn and locked by a swinging pin. The dress is punched to fit over the breast plate studs and a set of 4 flanges is bolted down to hold the two firmly together. The dress consists of 2 layers of duck canvas between which is a layer of pure rubber, all three of which are cemented together. These dresses are made in 4 sizes to include men of all heights. In the Navy type of dress, the legs are laced and in some cases the arms to prevent their distention and undesirable buoyant effect, but the commercial dress usually does not embody this feature. The dress is fitted to the wrists with tight rubber cuffs to avoid ingress of water. Cuff expanders or else soap are almost necessary to get the hand through the cuff. If the cuff is large or the man's wrist small, snap tubing is put over it to hold it tight. If the diver holds his hand higher than his shoulder, air usually escapes through the cuff and water

THE AUTHOR DIVING TO A WRECK ON LAKE MICHIGAN sometimes enters. In cold water, the diver may wear mittens. These are made with long gauntlets which are held against the sleeves of the dress between an inner ring and an outer strap. Sometimes the cuffs are removed and the mittens permanently fastened on.

A leather belt with shoulder straps passing over the breastplate is fitted with lead weights, actually totaling 100 pounds. It concentrates the weight of the diver at his mid-section and gives him negative buoyancy. Since the helmet has positive buoyancy it is important in designing a helmet that these weights be supported by the helmet rather than the body., since there have been several accidents which have resulted from not doing this and having the helmet tear away from the dress.

Leather shoes with lead, iron, or brass soles are fitted over the foot of the dress. A pair of these actually weighs about 35 pounds. This weight is intended to keep the divers feet down and minimize the buoyant effects in case of distention of the legs, which even with the shoes on will turn him upside down and start him for the surface feet first.

The hose is usually half inch 5 ply fitted with special "submarine thread" connections and is made in 50 feet lengths. It is made remarkably flexible and at the same time able to withstand high pressure. It is to be noted that the greatest strain on the hose due to pressure is at the surface, where the best

DIVING UNDER THE ICE AT WALDEN POND

lengths of nose should be connected.

Particularly for deep diving, air compressors are now being used for air supply, because of the great weight, expense, and number of men required to operate the larger hand pumps.

THE PHYSICS AND PHYSIOLOGY OF RUBBER SUIT DIVING: The pressure at a depth of "h" feet in salt water will be "p" pounds per square inch in the following:

$$p = .44\ h$$

The difference in pressure between head and feet of a 6 foot man standing upright would from the above be 2.6 pounds per square inch. Accordingly, with the dress inflated to the feet and the diver standing up, the pressure in the helmet would be 2.6 #/ square inch greater than the external pressure on it. Or with the dress collapsed up to the divers chest, there would be about 5 feet of water or 2.2 pounds per square inch excess pressure on the divers feet varying uniformly up to his chest.

Assuming a diver under the latter conditions (which would be quite probable since a man working under the water finds it desirable to keep his suit fairly well deflated to avoid the buoyant affect of the air) to suddenly fall 30 feet without an increase of pressure from the pump. Assuming a cross section at the shoulders of 144 square inch there would be a force of .44 x 30 x 144 = 1900 pounds or almost a ton driving him into his helmet, crushing him to death instantly. However if there is air in the dress at the time of the fall, there will be a certain distance which he may fall before the crushing effect starts, which may be determined from the following.

$$\frac{h_1 + 34}{h_2 + 34} = \frac{V_H}{V_H + V_D}$$

$$\text{OR: } h_2 = \frac{(V_H + V_D)}{V_H} \times (h_1 + 34) - 34$$

where the diver is falling from depth h_1 to a depth h_2 after which the crushing takes place and V_H is the volume of the helmet and V_D is the volume of air in the dress at the time of the fall. From this it may be seen that shallow water falls are very much more liable to be dangerous than deep water falls.

For example, if the diver has no air in his dress ($V_D = 0$) and the fall is from the surface ($h_1 = 0$), such as might happen when he is thrown from a descending ladder by the motion of the mother boat or a breaking wave, h_2 will be zero, which means that crushing will start immediately and be figured as above. This type of accident is one of the most gruesome associated with diving and to the unsuspecting can happen very easily. In lesser falls there is an increase of pressure on the divers chest, externally, without a corresponding increase in the helmet and lungs, making breathing impossible and tending to collapse the chest. A man on a flat bottom just falling down under the conditions for crushing as noted above (i.e. at or below the depth $\underline{h_2}$) may do himself serious injury. This type of accident is known as a "shallow water fall".

The following table gives the temperature of the air in degrees Farenheit after being compressed to the given number of atmospheres above atmospheric pressure: assuming no heat losses:

ATMOSPHERES (gauge)	TEMPERATURE (°F)
0	60.0
1	175.8
2	255.1
3	317.4
4	369.4
5	414.5
6	454.3
7	490.6

Since the length of hose in the water and the resultant **coiling** effect the pressure that would be developed by the pump in cold water and on a cold day the air would reach the diver not uncomfortably warm. In warm water the amount of cooling is reduced and if the atmosphere is also warm, diving may be very uncomfortable. Cooling of the pump is necessary for deep diving.

EFFECTS OF NITROGEN: Nitrogen is approximately four-fifths by volume of ordinary air. Under its proportional partial pressure of the atmosphere, which would be approximately four fifths of 14.7 pounds per square inch, the tissues of the body will ordinarily be in state of saturation, i.e. they will have absorbed all of the nitrogen that can be kept in solution at that pressure.

As the diver descends, the pressure of the air in his dress is increasing with water pressure, and the partial pressure of the nitrogen is maintaining its proportion of the total pressure. As this partial pressure increases the amount of nitrogen that can be held in solution increases proportionally, and the result is a state of partial saturation and an increase in the amount of nitrogen being absorbed over that being thrown out of the solution.

Assume that the diver has reached a state of saturation under his working pressure. If he should suddenly rise to the surface, the excess nitrogen representing the difference between the amounts sor saturation at the two pressures would be thrown out of

DECOMPRESSION TABLE No. 1

Ordinary time limits in deep water and stoppages to be made during ascent

Depth	Time under water, i. e., from surface to beginning of ascent	Stoppages at different depths (in minutes)									Total time for ascent
		90 feet	80 feet	70 feet	60 feet	50 feet	40 feet	30 feet	20 feet	10 feet	
Feet											*Minutes*
0-36	No limit										0-1
36-42	Up to 3 hours										1-1½
	Over 3 hours									5	6
42-48	Up to 1 hour										1½
	1 to 3 hours									5	6½
	Over 3 hours									10	11½
48-54	Up to ½ hour										2
	½ to 1½ hours									5	7
	1½ to 3 hours									10	12
	Over 3 hours									20	22
54-60	Up to 20 minutes										2
	20 minutes to ¾ hour									5	7
	¾ to 1½ hours									10	12
	1½ to 3 hours								5	15	22
	Over 3 hours								10	20	32
60-66	Up to 15 minutes										2
	¼ to ½ hour									5	7
	½ to 1 hour								3	10	15
	1 to 2 hours								5	15	22
	2 to 3 hours								10	20	32
66-72	Up to 15 minutes									2	4
	¼ to ½ hour								3	5	10
	½ to 1 hour								5	12	19
	1 to 2 hours								10	20	32
72-78	Up to 20 minutes									5	7
	20 to 45 minutes								5	15	22
	¾ to 1½ hours								10	20	32
78-84	Up to 20 minutes									5	7
	20 to 45 minutes								5	15	22
	¾ to 1½ hours								10	20	32
84-90	Up to 20 minutes								3	5	10
	20 to 40 minutes								5	15	22
	40 to 60 minutes							3	10	15	30
90-96	Up to 20 minutes								3	5	11
	20 to 35 minutes								5	15	22
	35 to 55 minutes							5	10	15	32
96-108	Up to 15 minutes								3	5	11
	15 to 30 minutes							3	7	10	23
	30 to 40 minutes							5	10	15	33
108-120	Up to 15 minutes							2	3	8	15
	15 to 25 minutes							5	5	10	23
	25 to 35 minutes							5	10	15	33
120-132	Up to 15 minutes							2	5	7	17
	15 to 30 minutes							5	10	15	33
132-144	Up to 12 minutes							3	5	5	16
	12 to 25 minutes						2	5	10	12	32
144-156	Up to 10 minutes							3	5	5	16
	10 to 20 minutes					2	3	5	8	10	31
156-168	Up to 10 minutes						2	3	5	5	18
	10 to 16 minutes					2	3	5	7	10	30
168-180	Up to 9 minutes						2	3	5	5	18
	9 to 14 minutes					2	3	5	7	10	30
180-192	Up to 13 minutes					2	3	5	7	10	30
192-204	Up to 12 minutes				2	2	3	5	7	10	32
204-225	Up to 10 minutes		2	2	3	5	7	10	10	15	58
225-250	Up to 10 minutes	2	2	3	5	7	10	10	15	15	73

DECOMPRESSION TABLE No. 2

Stoppages to be made during ascent after exceeding the ordinary limits of time on the bottom

Depth	Time from leaving surface to beginning of ascent	Stoppages at different depths (in minutes)										Total time for ascent
		100 feet	90 feet	80 feet	70 feet	60 feet	50 feet	40 feet	30 feet	20 feet	10 feet	
Feet												*Minutes*
66	Over 3 hours									10	30	42
72	2 to 3 hours									10	30	42
	Over 3 hours									20	30	52
78	1½ to 2½ hours									20	30	52
	Over 2½ hours									30	30	62
84	1½ to 2 hours									15	30	47
	2 to 3 hours								5	30	30	67
	Over 3 hours								10	30	35	77
90	1 to 1½ hours								5	15	25	47
	1½ to 2½ hours								5	30	30	67
	Over 2½ hours								20	35	35	92
96	55 minutes to 1½ hours								5	15	30	52
	1½ to 2½ hours								10	30	35	77
	Over 2½ hours								30	30	35	102
108	40 minutes to 1 hour								10	15	20	48
	1 to 2 hours							5	15	25	35	83
	Over 2 hours							15	30	35	40	122
120	35 minutes to 1 hour							5	10	15	25	57
	1 to 2 hours							10	20	30	35	97
	Over 2 hours							30	35	35	40	142
132	½ to ¾ hour							5	10	15	20	53
	¾ to 1½ hours						5	10	20	30	30	98
	Over 1½ hours						15	30	35	40	40	163
144	25 minutes to ¾ hour						3	5	10	15	25	61
	¾ to 1½ hours						10	10	20	30	35	108
	Over 1½ hours						30	30	35	40	40	178
156	20 to 35 minutes						3	5	10	20	20	61
	35 minutes to 1 hour						7	10	15	30	30	95
	Over 1 hour					20	25	30	35	40	40	193
168	16 to 30 minutes						3	5	10	15	20	56
	30 minutes to 1 hour					3	10	10	15	30	30	101
	Over 1 hour				5	25	25	30	35	40	40	203
180	14 to 20 minutes						3	3	7	10	15	41
	20 to 30 minutes					2	2	3	10	15	25	60
	30 minutes to 1 hour				3	3	7	10	20	30	35	111
	Over 1 hour				15	25	30	30	35	40	40	218
192	13 to 20 minutes						3	3	7	15	15	46
	20 to 30 minutes					3	3	5	10	15	25	64
	30 minutes to 1 hour				3	5	10	12	20	30	35	118
	Over 1 hour			5	20	25	30	30	35	40	40	228
204	12 to 20 minutes					3	3	5	7	10	20	51
	20 to 30 minutes				3	3	3	5	10	20	30	67
	30 minutes to 1 hour			3	3	5	10	15	20	30	35	124
	Over 1 hour			15	20	25	30	30	35	40	40	238
225	10 to 20 minutes			3	5	7	7	10	15	20	20	95
	20 to 30 minutes		2	3	5	7	10	15	20	25	30	121
	30 minutes to 1 hour		5	5	10	15	15	20	25	30	35	164
	Over 1 hour		10	15	20	25	30	30	35	40	40	249
250	10 to 20 minutes		2	3	5	7	10	10	15	20	30	106
	20 to 30 minutes	2	3	5	7	10	15	15	25	30	30	146
	30 minutes to 1 hour	5	5	10	15	15	20	30	30	35	40	209
	Over 1 hour	10	15	20	25	30	30	35	40	40	40	289

solution. This would cause the formation of nitrogen bubbles throughout the body, in much the same way as carbon dioxide bubbles are formed in a champagne bottle when the pressure is released by opening it.

These bubbles may have very serious effects, particularly in the heart and cerebro-spinal system. The effects of this are known as the "bends" or caisson disease.

It was found that by proper decompression, these effects could be avoided. By requiring the diver to stop at various stages on the way to the surface for a given length of time, and having him exercise at these stages, that except in rare cases (for moderate depths) the nitrogen would be gradually thrown out of the system without harmful effects.

It was further found that there can be a sudden decrease in the absolute pressure, when saturation is 100%, of the ratio 2.3: 1. From this theory and from experimental tests the two accompanying tables have been worked out, as recommended by Prof. Haldane and in accordance with British Admiralty practice, which are used universally at the present time.

The Navy Department has recently been attempting to revise these tables and has succeeded in lowering somewhat the amount of time required for decompression, but these results have not been published as yet and do not represent any appreciably decrease in time.

It has been found that nitrogen is more than five times as soluble in fat as in tissues which means that a man having excessive fat on his body would be unsuited for deep diving.

A recompression chamber has been used for emergency work. Should some exignecy arise, such as a diver "blowing up", pump trouble, or air hose failure, or a case of the "bends", the man may be recompressed to the pressure at which he had been working until all symptoms disappear, and them be decompressed according to the tables in the chamber.

This practice of hauling a man out of deep water and getting him into the recompression chamber as quickly as possible has been ordered to be discontinued in Navy diving except in emergency because of the large number of cases of the "bends".

Stage decompression as indicated by the tables has proven and seems logically to be superior to uniform decompression.

In studying the tables, it will be noticed the time required at the stages increases toward the surface.

The rate of descent of the diver seems to be controlled by the ears.

Dr. Haldane, in an article on artificial air for diving says: "If the oxygen percentage is allowed to fall gradually, while the carbon dioxide is absorbed, consciousness is sometimes lost without any warning symptom. In most persons, however, there is a distinct increase in breathing, and some subjective uneasiness, before consciousness is lost. As a rule the first objective symptom is failure of the limbs. After paralysis of the limbs the senses fail one by one, the sense of hearing being apparently the last to disappear. Probably the power of thinking and acting rationally is in reality affected first of all. The subject always imagines that he is all right, just as does a man suffering from alcoholic intoxication. In reality he may be acting in a blindly irrational manner and is very apt to be possessed with the fixed idea of going on with what he is doing regardless of the threatened danger. If with the helmet containing a mixture of oxygen and nitrogen, the oxygen supply were suddenly cut off, as has often happened, it is evident that the diver would be in imminent danger. For the oxygen percentage in the air breathed would rapidly fall, until less than ten per cent of the oxygen were present at which point dangerous synptoms would develop rapidly".

EFFECTS OF OXYGEN: At atmospheric pressure the partial pressure of the oxygen in the air is approximately 21 per cent . If this falls to one tenth atmosphere, dangerous symptoms begin to appear.

The diver is breathing air in which the partial pressure of the oxygen is much greater than on the surface, i.e. for every 34 feet, he is below the surface he is subjected to an additional one-fifth atmosphere partial pressure of oxygen. At 100 feet the diver might begin to feel an "oxygen intoxication".

This is a state resembling an alcholic intoxication. There is a certain amount of exhilarlation accompanied by a deadening of the higher nerve centers with a resultant feeling of carelessness and contentedness.

The advanced stages of this intoxication are known as "oxygen poisoning", which also resembles the advanced stages of alcoholic intoxication. It is evident that the factors that control the state of posioning would be the pressure of the air in compressed air diving or the depth, the amount of time spent at the maximum depth and at intermediate states, and the sensitivity of the diver.

At 170 feet he is receiving air of one oxygen atmosphere partial pressure; although the ratio of oxygen and nitrogen has not changed the diver is subjected to the same physiological effects as if he were breathing pure oxygen at the surface.

Experiments with animals show that over one oxygen atmosphere is dangerous and that over 3 oxygen atmospheres will cause convulsions and death. It has been found that high oxygen atmospheres cause intense congestion of the lung tissues and a hemorrhagic exudation, i.e. a typical pneumonia.

It is apparent that if the oxygen percentage could be reduced in the air as the pressure is increased the undesirable effects of high oxygen partila pressures could be avoided. Very little is known as how far this could be done. There has been some speculation as to whether, at extreme depths with the correct one-fifth atmosphere partial pressure of oxygen, the greatly reduced volume of the oxygen in the air might not introduce further difficulties. This might resolve itself into the question of whether the oxygen absorbed is proportional to its partial pressure (assuming allowable physiological adjustments at moderate depths in the present type of compressed air diving) as would be expected if it were going into solution in the alveolar blood vessels, or whether it goes into some sort of chemical combination and the volume of the oxygen present is a factor, or whether it is a combination of both as would seem to be the case. These problems can only be answered by further experimentation.

It has been suggested that a chemical be used over which the compressed air going to the diver would pass, that would absorb part of the oxygen. The control of such a device appears difficult and because of the large volumes of air required at the greater depths would be quite expensive.

A comment on experiments conducted at the Bureau of Mines using a helium oxygen mixture at high pressures with reduced oxygen volumes is given later.

EFFECTS OF CARBON DIOXIDE: Under normal pressure, a person involuntarily regulates his breathing so that the carbon dioxide content of the alveolar air is 5.6 percent by volume, which is constant for any person but varies slightly in different individuals. If this percentage increases or decreases, breathing increases or decreases, respectively, until the percentage is again 5.6. If physical work is done more carbon dioxide is given off; under hard work as much as eight times the normal amount is given off. When air of a high carbon dioxide content is breathed, the same controlling effect is exercised on breathing. Thus 3% will cause hard breathing, 5.6% great distress, and 10% unconsciousness.

This partial pressure, 5.6% of one atmosphere or .82 pounds per square inch as the total pressure varies. Thus at 102 feet or 4 atmospheres absolute air pressure, the normal partial pressure of carbon dioxide in the alveoar air is 5.6% of one atmosphere of 5.6/4 = 1.4 percent of the air in the lungs, Under these conditions air of .7% carbon dioxide will cause hard breathing, 1.4% great distress and 2.5% unconsciousness, corresponding to the above. Thus, the greater the depth of which a diver is working, the greater will be the distress caused by a small percentage of carbon dioxide.

It has been found that a man at rest breathes .25 cubic feet per minute of air, approximately. It had been found also that a man in a diving dress under atmospheric pressure and engaged in light activity requires 1.5 cubic feet of air per minute blowing through his suit to keep the percentage of the carbon dioxide below that which causes discomfort and fast breathing. Accordingly the following table gives the air requirements for different depths;

From the above discussion it will be apparent that as the air pressure is increased n times, the same physiological effects will be produced by a partial pressure of carbon dioxide of 1/n times that at atmospheric pressure, and the flow of air through the suit must be n times as great.

FEET OF SALT WATER	CUBIC FEET PER MINUTE OF FREE AIR
DEPTH	AIR
0	1.5
33	3.0
66	4.5
99	6.0
132	7.5
165	9.0
198	11.5
231	12.0

The necessity for this may be considered also from a flow standpoint. At the surface a man at rest produces approximately 0.014 cubic feet of carbon dioxide and a man in a diving suit finds that a flow of 1.5 cubic feet of air per minute will maintain this at a comfortable percentage.

$$\frac{0.014}{t} \times \frac{t}{1.5xn} = \frac{0.46}{n},$$

where it is t or time in minutes and n is in atmospheres absolute pressure. From this it may be seen that as n increases, to keep the CO_2 content 0.46/n, the free air delivered must be 1.5 n.

It is the carbon dioxide partial pressure that determines the amount of air needed by the diver then, and not the consumption of oxygen, as might be supposed.

As the depth increases the pressure against which the air must be pumped increases proportionately, and also the volume of free air that must be pumped against this pressure. This means that the amount of work done by the pump increases with the square of the absolute pressure. The result of this is that for deep water diving the hand pumps are prohibitively large and expensive and require a large number of men to operate them. For this reason, in recent years, the air compressor driven by a gasoline engine had come to displace the hand pump for any extended diving operations. However, it is still necessary to have the hand pump ready for immediate use in case of engine failure.

As an example of this, my deep water diving pump which is one of the two large types of hand pumps made in this country, is listed at $725.00, weighs 1,360 pounds, and would require two crews of four men each to operate it for one diver in deep water.

DISADVANTAGES:" The disadvantages and limitations of rubber-suit diving may be summarized briefly as follows:

120 feet is generally considered the practical limit for useful work.

The decompression tables indicate the small amount of working time which a diver may have in comparison with the total time which he must spend under water. Thus for an hours work at 250 feet including descending time, 5 hours and 50 minutes would be required in the water.

The only alternative to underwater decompression is the use of recompression chambers. However, these do not lend themselves to ordinary work because of the great expense of installing them, the large amount of room required for them on board ship, the limitation **that** only one diver or else a group of divers having been sent down simultaneously may use one at a time, and the somewhat unsatisfactory results which have been obtained with their usage except under emergency conditions.

The Navy has forbidden their divers to use these chambers except for emergency, because of the large number of cases of the "bends" encountered with their use for decompression.

If a squall should come up, which might happen in five minutes without warning, the jerking of the mother vessel might quickly part the air lines or the ship might drag her anchor with disasterous results to the diver. A man in deep water under these conditions with a large decompression time required before he could get to the surface, would be in a very dangerous position if no recompression chambers were available, which would ordinarly be the case.

Paralysis is generally considered more dangerous than the bends and it is very often advisable to omit the large decompression stages in case of the former, with whatever consequences might occur. Paralysis is quite common.

If there are strong currents and a man is in deep water, they are apt to break the hos, with apparent disasterous results. Because a diver weighs very little under water, and because of the high density of water it is impossible for a man to stay on a bottom in a strong current. He often will find himself swept off his feet and up in an arc at the end of the hose, with no consideration for the latter or for the necessary decompression.

Working under limited light particularly in wrecks and debris it is very easy for a man to tear his suit.

The dexterity and maneuverability of a rubber suit is of little value in deep water because a man's respiration and pulse are so forced up that it is impossible to exert himself to any extent.

In cold weather, the moisture in the air freezes and jams the helmet valves leaving the driver without air and almost helpless.

If the air line is severed, if valves jam or a compress or fails there is only air left in the helmet to keep a man conscious for 4 or 5 minutes.

Considering that the surface of a man's body is approximately 2000 square inches, a ten foot swell will cause an increase of pressure of 8,800 pounds. This continuously fluctuating pressure every time a wave or swell passes overhead may easily kill a man, cause intense pain in his eardrums or even break them, and cause bleeding of the mouth and nose.

There is a great danger of falling or just bending over on a level bottom. Considering a sudden increase in depth of the chest of 5 feet, the resultant increase of pressure of 2.2 pounds per square inch would crush in the chest with such a force as to make it impossible to breathe.

The danger of "blowing up" is especially dangerous for the inexperienced diver. If the air valve is admitted air too rapidly or the exhaust valve is not correctly set, clogged, or frozen, the suit will become inflated causing the diver to rise suddenly. To add to the confusion, he will find himself upside down, his buoyant feet and lower trunk carrying him rapidly toward the surface. As he rises and the water pressure decreases his rubber suit expands more and more, adding to the buoyant effect. This continues until the suit explodes or he crashes into the hull of the tending ship. This is particularly dangerous if there is a chance of his lines catching on wreckage as he starts to rise.

If for any reason the helmet air pressure falls off, due to leakage, pump, or valve trouble, the water pressure will collapse a man's chest crush him into his helmet with a force of many tons.

Even with the most exact precautions, the danger of tangling lines with resultant catastrophies is ever present. With group diving, considering a life line and air line for each man, their circling lines, shot lines, light lines, torch lines, grappling lines, stage cables, ect., all mixed up with shifting wreckage in the dark with every sense of direction gone it is not hard to understand what tangles might result or how easily lines may be severed.

If a man has a cold or any blocking of the Eustachian tube he will suffer intense pain and may break his ear drums, and will come up bleeding from the mouth and nose.

In deep water diving the diver will experience "oxygen intoxication" which may be felt in less than 100 feet of water and makes sustained diving almost prohibitous at greater depths. At deep water this latter becomes go great as to cause a poisoning with serious physiological effects.

Diving Equipment is very expensive. A.J. Morse, lists a complete diving outfit for one man at $1,302.

From the above it may be concluded that rubber suit diving is very dangerous and is limited to about 120 feet under favorable conditions for commercial work.

OTHER WATER PRESSURE APPARATUS

ROUQUAYROL-DENAYROUZE APPARATUS: This type of apparatus was designed to overcome the danger of a divers falling or the danger of being "blown up".

It differs from an ordinary dress only in that a double chamber is connected between the air connection on the helmet and the air hose. The chamber connected to the hose acts as a reservoir and carries air at a pressure of approximately 5 pounds greater than the other chamber. The latter is connected to the air pipe on the helmet and is at the same pressure as the inside of the helmet. These two chambers are connected by a valve actuated by the water pressure through a diaphragm. Then the pressure in second chamber falls off below the external water pressure the latter actuates the diaphragm and opens the valve admitting air from the reservoir. If the air pressure in the second chamber becomes greater than the water pressure, the former closes the valve between the two chamber.

This apparatus has not been used to any extend because it was too complicated and offered too much of a hazard if it should fail to operate.

DIVING BELL: This is another type of apparatus that hardly needs more than a mention. Its principle is the same as an open helmet except that is large enough for several men to get in and work on the bottom.

I have a small bell, but it is of little practical value, because a weight equal to its displacement is necessary to sink it, and it is too heavy and awkward to transport.

CAISSON WORK: The physics of this is exactly the same as in the diving bell. This is usually associated with shallow harbor work.

TUNNEL WORK: Although this type of work does not require the use of diving suits, since the men are working in a medium of air, a great deal has been learned pertained to the physiology of subjection to high pressures. In this work a large group of "Sand hogs" are submitted for long periods of time to high pressures e.g. 55 pounds per square inch.

MOMSON LUNG: This apparatus is designed to enable men trapped in a sunken submarine to secape. It is self-contained but is unsuitable for anything but the purpose for which is designed. It consists of a mouthpiece connected with a double piping fitted with mica disk flapper valves so that the exhaled air must pass into a rubber bag which encloses the entire apparatus and which is filled with pure oxygen. The mixture of foul air and oxygen is passed through a cannister of soda lime and to the inlet pipe of the mouthpiece to be rebreathed.

SIEBE-GORMAN SELF CONTAINED DRESS:

A. Injector Type. To my knowledge, this is one of the only two self contained water pressure suits that have ever been built. It is made by Siebe-Gorman & Company of London. It employs flasks containing a mixture of 50 percent oxygen and 50 percent air, which is released into the suit at a rate of 5 liters per minute through an injector. This injector is arranged to suck air from the suit through an externally mounted absorption cartidge, thereby adding the consumed oxygen and absorbing the carbon dioxide given off. An automatic valve is provided to valve excess pressure.

B. Non Injector Type. This is made by the same company, and is probably a more satisfactory arrangement. The dress is similar except that the circulation of air is accomplished by requiring the diver to wear a mouthpiece by means of which his exhaled air is passed directly through the absorption cannister, and the necessity for the injector is eliminated. As the suit is used, it is necessary for the diver to breathe through his nose and exhale through his mouth.

C. Disadvantages.

The suits are too complicated and might easily get out of order with danger to life, particulary the injector type.

The apparatus is too expensive.

Expert operation is required.

The suits can only be used in shallow water.

The diver can only stay under water a very short time because of the large volume of compressed gases required for longer dives.

The means for absorption of carbon dioxide has not proved itself satisfactory for hard work, with resulting excessive partial pressure of carbon dioxide.

There is great danger of oxygen poisoning, particulary when the suit is used in deeper water.

The keeping and supplying of exygen and absorption chemicals had been awkward at sea.

In conclusion, the suit has in general proved itself unsatisfactory. It has been used successfully in flooded tunnel work, a shallow water job which would be awkward with an air hose because of the necessity of dragging it behind for along distance and danger of its fouling or tearing. Although the suit is still available from Siebe-Gorman, interest in it has subsided.

D. <u>Fleuss Dress</u>. This is the other type of self contained suit, which has not been satisfactory, and is similar to the non-injector type described above. It is not recommended for depths in excess of 17 feet.

OXYLITHE: A chemical by this name consisting of 1 part sodium hydroxide, 2 parts potassium peroxide, and 2% anhydrous copper sulfate has been used for the rejuvenation of air.

$$K_2O_4 + Na_2O_2 + 2CO_2 \longrightarrow K_2CO_3 + NaCO_3 + 2O_2$$

This would appear to be quite satisfactory for self contained breathing apparatus, since the 2 gaseous moles of CO_2 are replaced by the same number of gaseous moles of O_2 and all of the other moles remain as solids, which is the desired result. It has been used experimentally in submarine escape apparatus, but the "Momson Lung" seems to have been found more satisfactory.

THE PHYSIOLOGICAL EFFECTS OF HELIUM

Experiments have been made by the Navy Department, the United States Public Health Service, and the Department of the Interior--Bureau of Mines as to the physiological effects of helium as a possible mitigation of a caisson disease.

In conclusion to these test, it was stated "Were it not for the high cost of Helium, the possibilities of using a synthetic atmosphere of helium and oxygen during the entire period would be almost unlimited".

Helium is a inert gas. It is odorless and tasteless. Its molecular weight is 4; the molecular weight of nitrogen is 28. Its solubility co-efficient for water at 30 degrees centigrade is 0.008175, (Cady, Elsey, and Berger. "The Solubuility of Helium in Water Journal of the American Chemical Society, Vol. XLIV. July-Dec. 1922), as compared with a solubility co-efficient for of nitrogen in water at the same temperature of 0.013400; or the helium is 62 percent as soluble as the nitrogen under these conditions. Because of the low solubility of helium and also because of its high rate of diffusion (since its molecular weight is 4 as compared to 28 for nitrogen), which means that the rate of diffusion of helium is $\sqrt{28} \; / \; \sqrt{4} = 2.64$ times that of nitrogen.

it would be expected that as the pressure was released from the body of a diver, the helium dissolved in the tissues would pass more quickly into the blood stream and be released from the lungs, thereby making reduced decompression time possible. This has been verified by experiments on animals.

Experiments have been conducted on animals in which they were subjected to a pressure of 500 pounds per square inch using a helium-oxygen mixture (equivalent to a depth of 1200 feet) and decompressed with no bad effects.

The Navy Department started some experimental work in the use of helium for diving, but discontinued it several years ago and stated that so little date was obtained that it did not justify publication.

BUREAU OF MINES INVESTIGATIONS: In a group of experiments at Pittsburgh on rats and guinea pigs using helium oxygen mixtures it was found that decompression time could be reduced to as low as one-sixth of that required for compressed air.

The experiments were conducted by placing the animals in an 8 by 10 inch cylindrical chamber connected to large separate bottles of helium and oxygen, and fitted with a door and window.

6 white rats were exposed to a pressure of 680 feet of water and decompressed in 34 minutes, with 150% normal partial pressure of oxygen, all emerging in good condition. The same test (except with

270% normal partial pressure oxygen) conducted with compressed air resulted in death to 5 of the rats and severe paralysis in the 6th.

8 guinea pigs were exposed to a pressure of 340 feet of water and decompressed in varying length of time, with approximately 750 percent normal partial pressure of oxygen. The results of these tests with exposures to pressure of one, two, and three hours were approximately the same and as follows: With the helium-oxygen mixtures, a total decompression time of approximately 4 minutes was found to be the minimum, above which there were few symptoms and below which death usually resulted. This same corresponding time for compressed air was found to be 33 minutes.

The ratio of the decompression periods is greater than can be explained from the ratio of the solubility coefficients, indicating that the high ratio of diffusion of heluim as well as its low solubility coefficient tend to make it desirable for minimizing decompression time.

The rapidity of the release of helium from the tissues would undoubtedly be accompanied by a corresponding rapidity of absorption when pressure was being increased, which would indicate that in very short dives, some of the benefits of using helium would be lost because of the faster rate of absorption. However, for ordinary length of time on the bottom, this would not apply.

PATENTS ON THE USE OF A HELIUM OXYGEN MIXTURE:

In 1923, patent number 1,473,337 was issued to C. J. Cooke of Washington, D.C. and in 1928, patent no. 1,681,029 was issued to the same man, pertaining to a means of using a helium-oxygen mixture for diving.

Cooke uses an enclosed double hose system to the diver, one hose of which system carries a pressure in excess of the water pressure of the diver and the other which carries the foul gas to the surface at atmospheric pressure. The latter passes the foul gas through a gasometer and over trays of purifying chemicals and is then brought back to pressure by means of a pump. Oxygen~~s~~ and helium are admitted into the system as needed. Automatic valves are provided on both hose connections at the helmet so that the inlet and outlet of gas will be automatically controlled.

In 1927, patent number 1,644,363 was issued to Yant, Sayers, and Hildebrand, comprising a system whereby a person under pressure is supplied with compressed air having a reduced oxygen percentage and under decompression with a gas consisting of oxygen and helium.

PATENTS ISSUED BY THE UNITED STATES PATENT OFFICE

APPARATUS SUBMITTING THE DIVER TO WATER PRESSURE

Patent No.	Year Issued	Inventor	State or Country	Comments on patent
	1810	Hall		
	34	Norcross		Principles of modern diving suit.
	35	Campbell		Allglass helmet.
46902	65	Hawkins	Pa.	Mouthpiece with flapper valves.
59529	66	Rouquayrd	France	Automatic valve regulating pressure.
67874	67	Hale	Mass.	Vertical pockets for diving weights.
329391	85	Huntley	Conn.	Tank on deck with man under pressure for communication with diver through hose as speaking tube.
458750	91	Stove	London	Means connecting dress to helmet.
484885	92	Stove	London	Means connecting dress to helmet.
609085	98	Devine	Pa.	Fish-like suit for under-water swimming.
616409	98	Crawford	Mass.	Raised compartment on helmet for telephone transmitter. Assigned to A. J. Morse & Son.
617675	99	Crawford	Mass.	Removable weights for belt. Assigned to A. J. Morse & Son.

APPARATUS SUBMITTING THE DIVER TO WATER PRESSURE

Patent No.	Year Issued	Inventor	State or Country	Comments on patents
813431	1906	Woodward & Iwanami	D. C.	An electrically operated float automatically supplying the correct amount of air.
867719	07	Hanson	Denmark	Continuous band fastening dress to breastplate with 2 bolts.
989531	11	MacDuffee	N. Y.	Device allowing free movement hose and regular air supply from external chamber.
989532	11			
989533	11			
989534	11			Reel for air hose to avoid kinking.
1073370	13	Stelzner	Germany	Pretzel-like exhaust pipe to avoid ingress of water.
1139850	15	Conkle	Ohio	Rubber mask.
1153030	15	Claren	Germany	Dress separating at waist for quicker dressing.
1159125	15	Stelzner	Germany	Collapsible helmet.
1162525	15	Stelzner	Germany	Distribution of weights.
1197454		Deuter	Minn.	Air pump operated by diver and collapsible chamber.
1209223	16	Stelzner	Germany	Means for fastening dress, breastplate, and helmet.
1209224	16	Stelzner	Germany	Means for fastening dress, breastplate, and helmet.
1238952	17	Stelzner	Germany	Weighted block on the bottom through which the hose runs.

APPARATUS SUBMITTING THE DIVER TO WATER PRESSURE

Patent No.	Year Issued	Inventor	State or Country	Comments on patents
1252780	1918	Stelzner & Claren	Germany	Weighted distribution.
1253485	18	Gunnerson	N. Y.	Exhaust valve.
1285741	18	Konopski	Canada	Suit with propellors and rudders.
1324747	19	Runyan	Tex.	
1370316	21	Houdini	N. Y.	Suit opening at waist for quick dressing and undressing.
1387049	21	Zess	Md.	Sandal.
1409808	22	Wood	Va.	Compass on helmet.
1643667	26	Levy	N. Y.	Double suit for 2 divers.
1681029	28	Cooke	D. C.	An enclosed double hose system with a pump, carbon dioxide absorbant, helium and oxygen tanks, gasometer, automatic inlet and outlet helmet valves, and a mixture gauge.
1689079	28	Murakami	Australia	Mask set in collapsible suit for direct exhalation into water.
1692591	28	Stelzner	Germany	
1935132	33	Scrimjeour	D. C.	Helmet and breastplate together for quick removal. Large window. Air baffles.
1967792	34	Troisi	Pa.	Simple escape valve.

OPEN HELMET

Patent No.	Year Issued	Inventor	State or Country	Comments on patents
1195793	1916	Dunn & Miller	Fla.	Claims on open helmet principle.
1595908	26	Miller	Fla.	Design of the well known "Divinghood".

RESCUE DRESS

1199277	1916	Kelley	Pa.	All canvas dress and helmet with tight rubber bands at waist and arms near shoulders.

SELF CONTAINED DIVING SUITS

Patent No.	Year Issued	Inventor	State or Country	Comments on patents
40114	1863	McKeen	N. Y.	Compressed air tanks, Collapsible containers for controllable positive or negative buoyancy.
244062	81	Khotinsky	N. Y.	Oxygen, carbon dioxide absorption apparatus.
638392	99	Hensley	Tex.	Air purified by passage through water.
829274	1906	Knopf	Ill.	Compressed air tank and pump operated by diver to exhaust foul air.
894757	08	Spear & Cable	Mass.	Escape jacket using oxylithe.
896447	08	Stewart & Rees	England	Oxylithe regenerating and purifying apparatus.
1000721	11	Cypra	Mass.	Air tanks and fans for circulation.
1180744	16	Stelzner	Germany	Device for supplying air and oxygen separately at a predetermined mixture ratio.
1692591	28	Stelzner	Germany	Weight distribution.

DEVICES SUBMITTING THE DIVER TO WATER PRESSURE WITH BREATHING AT ATMOSPHERIC PRESSURE

Patent No.	Year Issued	Inventor	State or Country	Comments on patents
119210	1871	Wilson	Conn.	
156599	74	Schmitz	Cal.	For underwater swimming.
361925	87	Bruce	N. Y.	Heat on surface causing convection currents.
587604	97	Pollard	Va.	Incorporates metal tank.
835950	1907	Iwanami	D. C.	
908690	09	Neubert	Australia	
1423923	22	Eckert	Conn.	For swimming under water.
1824512	26	Szamier	Conn.	Pivoted rigid vertical tube so diver can assume various positions.

A NEW TYPE OF SELF COTAINED DIVING SUIT

A discussion of the field of development and research in diving was included in the Introduction.

A discussion of the disadvantages of the present type of gear has been given and of the attempts that have been made to overcome these.

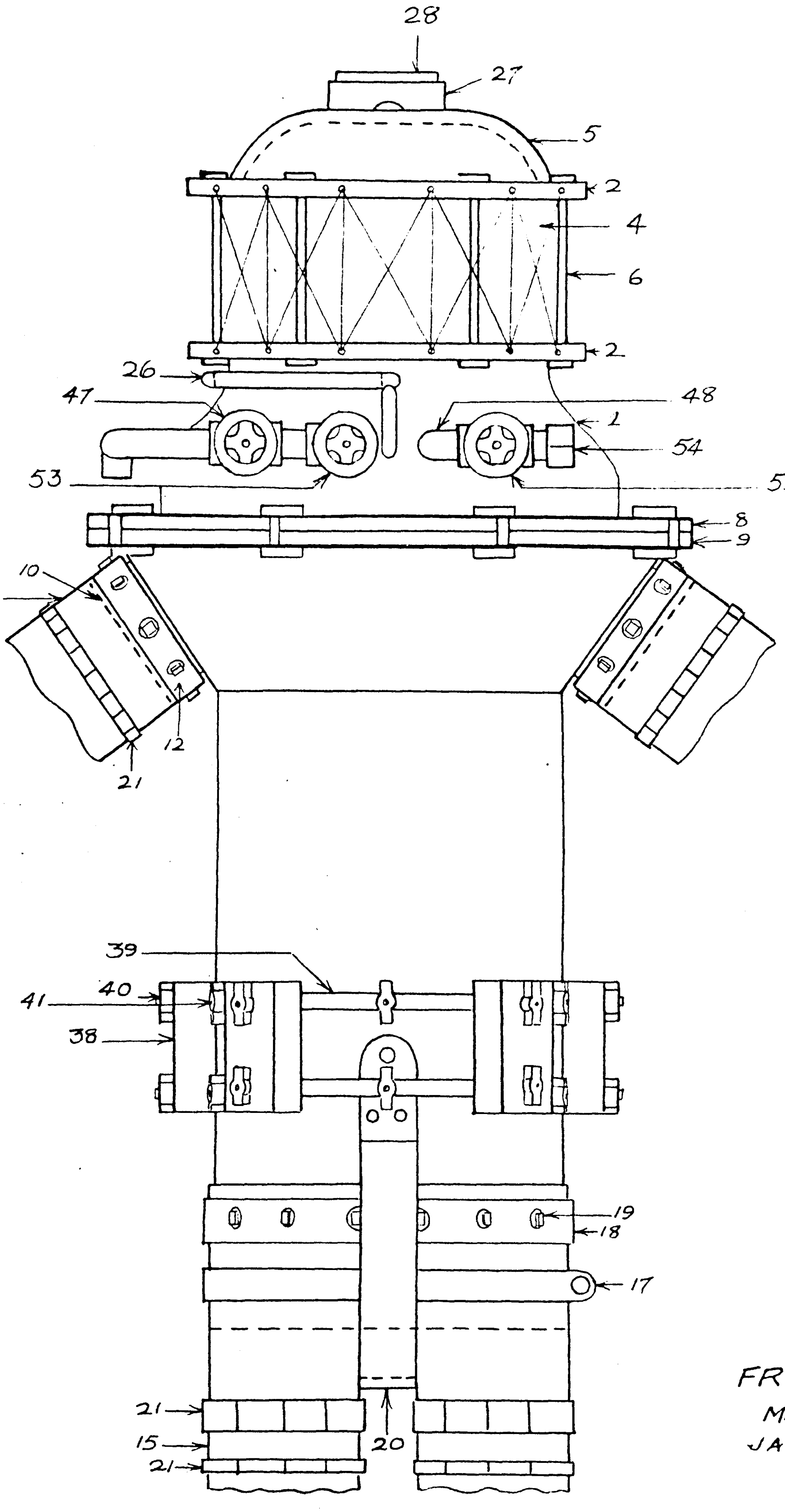
A discussion of patents and self contained suits that have been built has been given.

Experiments as to the advantages of heilum as a substitution for nitrogen in the mitigation of caisson disease have been given.

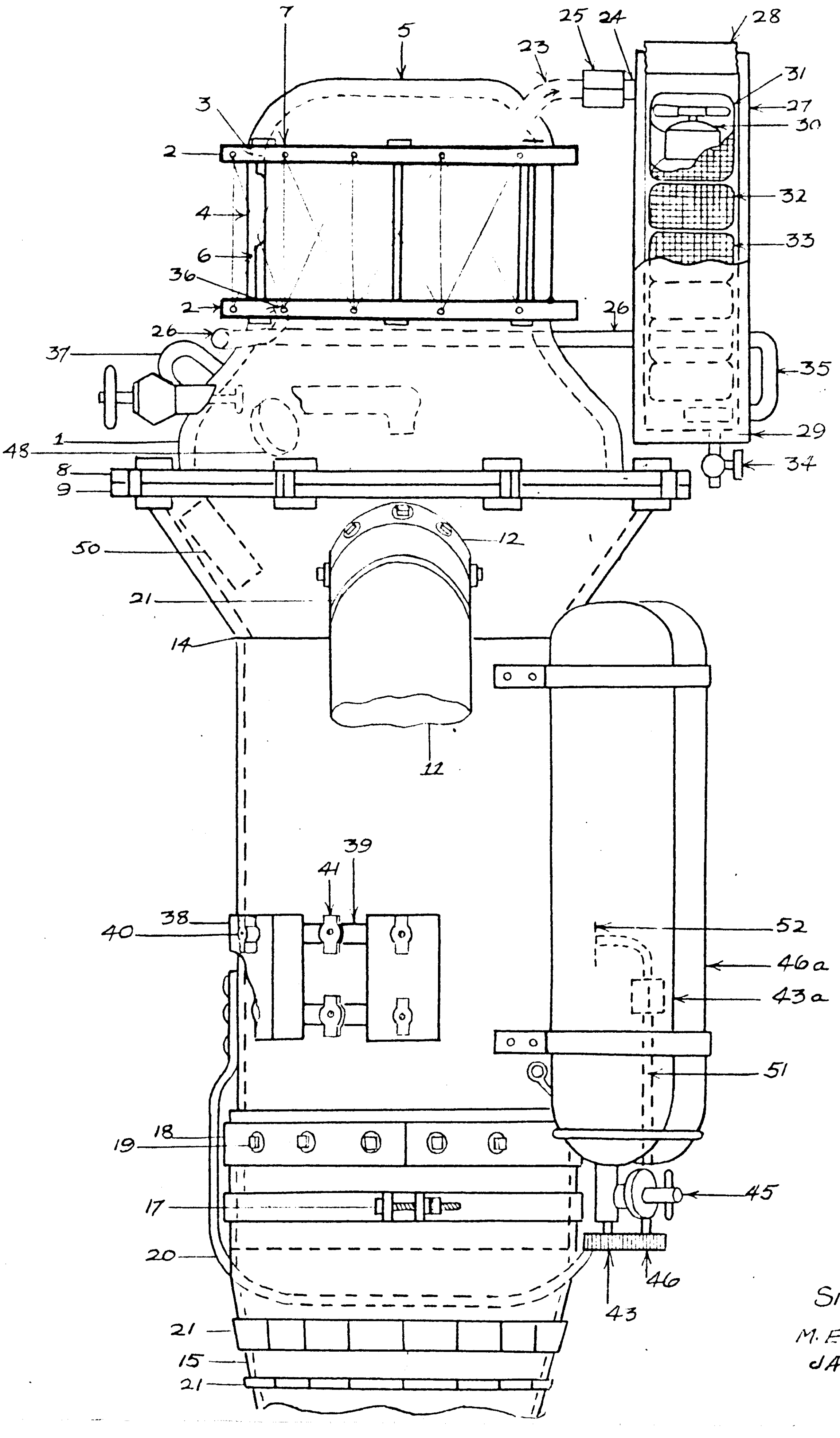
With these in mind, I submit my design for a superior type of diving suit. Tests that have been made on early forms of this suit have been mentioned.

CONSTRUCTION OF SUIT: Front and side views of the suit are shown in the accompanying drawings:

The helmet is made of two castings 1 and 5 which have circular cross sections so that their patterns may be readily made. Flanges,2, are provided, recessed at 3. Into these recessesfits the cylindrical window 4 with a rubber gasket between them. The helmet top and the helmet base 1 are drawn together by the bolts 6. These flanges of the helmet are tapped for screws 7. Between the screws and over the



FRONT VIEW
M.E. NOHL
JAN. 3, 1935



SIDE VIEW

M.E. NOHL

JAN. 5, 1935

window is wound a pattern of wire, such as piano wire, to protect the window and not obstruct the vision. The flange 8 on the lower part of the helmet is made with a male joint to fit into a female on the breastplate.9. The two flanges are drawn together by bolts passing through slots, for quick removal.

The breastplate is fitted with a short steel sleeve 10 as shown, made with a groove or series of grooves around it. The canvas and rubber sleeve 11 fits over the inner metal sleeve and an outer steel band 12 is fitted over this. Eight bolts draw the two metal parts together holding the canvas sleeve firmly between them.

The trunk section is made of a welded sheet steel tube, and may be welded to the breastplate at 14. This is made to come approximately down to the hips. The diving pants are made of the same material as the sleeves. This may be a heavy rubber with a heavy canvas on the outside, preferably cemented together and preferable with another layer of light canvas on the inside. The latter would be a similar construction to the conventional diving dress except that the outer canvas and rubber layers would be considerably heavier. This canvas should be able to withstand the desired pressures and sewed or laced accordingly. The pants 15 come up over the bottom of the metal trunk and are held firmly against it by a steel band, tightened by the clamp 17. The band, 18 which may be continious or made up in segments is bolted with lead washers to avoid leakage,by means of the bolts 19.

The strap 20 is passed between the legs and is designed to take some of the axial pressure when the suit is distended and also help support the weight of the diver if he should be dangling from a line in the air. This strap could be leather, canvas, or steel. The strap 21 is made of band steel and is sewed to the outer canvas of the dress. These same bands are fitted to the arms and legs to relieve some of the internal pressure from the canvas. Manilla or wire rope straps might be substituted for these bend steel straps.

The feet of the suit are similar to the feet of a standard diving suit, except that they are more firmly sewed. The shoes worn with the suit may be a standard diving shoe, which would be worn over the canvas and rubber dress as is customary.

Mittens or gloves are made an integral part of the suit. These are fastened on in the same way that they would be secured to a conventional dress, i.e. with an inner grooved band and an outer adjustable strap, except that these would be made heavier to account for an internal pressure in the suit.

An elbow 23 is fitted into the top of the helmet. The pipe 24 is fitted to it by the coupling 25. A removable cylinder is fitted to the back of the helmet, held in place by the connecting pipes 24 and 26. This cylinder 27 may be a section of pipe, threaded at either end to receive plugs 28 and 29, which are removable. A small electric motor 30 is fitted in a wire screen cylinder, which drives a fan 31 to keep a circulation of air passing through the cylinder 27, preferably in the direction of the arrows.

Two or more removable screen cylinders, 32 and 33 rest in the cylinder 27. As shown these are each made of screen bent in a cylinder, soldered, and covered at both ends with screen, the top base of each cylinder being removable for filling. These are meant to hold porous chemicals such as soda lime, through or by which the foul air may pass. One or more of these may be used for calcium chloride to remove the moisture from the air if so desired. Any number of these removable cylinders, used full or partially full may be used by varying the size of each. These cylinders may be prepared beforehand and kept in sealed cans until ready for insertion, or they may be kept in position indefinitely and protected from the moisture by inserting a cork in each of the pipes 23 and 26 on the inside of the helmet. A cock 34 is provided to drain any liquid collected in the bottom of the cylinder, which can be done by the diver, if necessary, when submerged since the helmet pressure is always in excess of the water pressure when standing erect. The pipe connection 35 is made as shown so that it will be impossible for any of the liquid that might have collected in the bottom of the cylinder to flow into the helmet. The flow of air would best be in the direction shown so that it would be helped by the natural convection currents. The inlet pipe 26 is brought around to front of the helmet where it enters and the incoming air is deflected across the window preventing clouding. The pipe is fitted with a mouthpiece 36 so that the diver may take this in his mouth in case of failure of the motor 30. He may suck air himself through the cannister in this way, either intermittently or continuously, and thereby not be endangered. Although just a simple mouthpiece is shown since this is only for emergency conditions, a double flapper valve arrangement might be added very simply so that air must be inhaled from the cannister and exhaled into the helmet. However with the mouthpiece shown, inhaling through the mouth and exhaling through the nose can very quickly become automatic.

A lifting hook 37 is provided so that the diver may be taken in or out of the water on a tackle, if desired, or helped in and out of the water by a line. The life line may be snapped to this hook also.

The lead or iron weights 38 are fastened to the iron bands 39 by the wing nuts 40 and the band is fastened to studs in the trunk by the wing nuts 41. The bands 39 are semicircular. There are several arrangements of giving positive buoyancy to the diver, which will be of value to him because of the possibilities that he may take decompression in the dress as explained later.

The suit may be designed to have positive buoyancy without the weights 38, with or without the legs and arms distended. In this case by removal of the wing nuts 41 the diver may slip his belt and float to the surface. A light line or wire may be fastened to the belt so that he may let himself up on this if he wishes and even take some decompression on this line, ormerely have the end fastened so that at the surface the belt may be hauled up. Another method, in case it was found desirable to build the suit with negative buoyancy with the belt slipped, would be to have a small folded and tied canvas and rubber bag connected with one of the bottles so that by opening a valve the diver could distend this bag which would give him the desired positive buoyancy. This bag would be fitted with a spring valve so that it would automatically valve excessive difference in pressure. It could be designed to be used with or without slipping the belt. It is understood that the ordinary way of ascension would be in the customary way, i.e. on the descending line.

Two, three, or four bottles may be fitted to the back of the suit held by the steel bands 42. If two are used, one of these would carry oxygen and the other the inert gas. Extra oxygen bottles could be carried as desired or extra bottles of inert gas. Three of the small sized, 18", (11 cubic feet) bottles will hold enough oxygen for approximately 12 hours. The bottles 42 and 43 are arranged on the back of the suit as shown. The valves are at the bottom convenient to the divers hand. The inert gases may be admitted directly into the manifold 51 (entering the suit at 52) by the valve 46 on the bottle 46a, since no accurate adjustment is necessary here. The corresponding valve 43 on the oxygen bottle 43a admits oxygen to the delicate control valve 45, which in turn admits it to the manifold 51. This wave is adjusted before the diver enters the water to approximately 1 liter a minute. The diver readjust this as he finds it necessary, although ordinarily this will not need adjustment.

A valve 47 is provided so that the diver may valve excess gas in the dress if he has admitted too much of the inert gas during descent or so that he may valve gas during the ascent. A spring seated adjustable tension outlet valve 53 is provided so that by opening the valve 47 the dress will automatically valve the correct amount of gas upon ascent if this is done in the customary manner without using the suit as a decompression chamber, either during with or without a hose.

A standard hose connection is proved at 48, covering with a cap 54 when not in use and fitted with a shut off valve 55 so that the suit may be used with an air compressor and hose in the ordinary manner if so desired.

It is advisable that the diver have certain instruments which he can read. These may be placed in the base of the helmet as shown at 48. The gauges used will depend upon the usage to which the suit will be put, but the following might be of great value; A flow gauge for the oxygen, which would normally read about 1 liter a minute; a gauge indicating the depth in feet which would be valuable in decompressing without a marked line, and would be of considerable interest to the diver; a gauge indicating the difference in pressure in feet of water between the inside and outside of the suit. (it would be desirable to have this guage placed so that it could be read from the outside of the dress also in case of emergency when it would be desirable to have another man on deck regulate the decompression); a watch for better estimating the time for decompression; and possibly a compass. The transmitter for a telephone if this used may also be placed in this space. It would be necessary to have a small shielded light operated by a switch which the diver could flip on and off with his chin to read these instruments under conditions of diminished external light.

A small battery 50, preferably one that may be charged, is carried inside the dress as shown or may be carried externally in a casing. This furnish electricity for the blower, instrument lights, and could also be used for an external light, or a small electrically driven window wiper to keep the window clear. This latter could be mounted at the center of the top of the helmet and sweep through an arc over the front portion of the window. A Ford Electric windshield wiper with its arm bent 90 degrees would be satisfactory and would insure clear vision.

The helmet could be used as it is as an open helmet, or a light band steel framework similar to the one I used for my open helmet as previously described with or without extra weights, could be made for instant attachment which would serve as a shoulder piece.

Short snap rubber sleeves could be substituted for the long sleeves readily and the diving pants removed which would result in a piece of apparatus which could be used with compressed air and a hose, similar to an open helmet but actually coming down to the divers hips. A snap rubber waist band could be used which would give a piece of apparatus similar to a rescue dress. Numerous other combinations could be worked out for uses of this dress.

OPERATION OF DRESS: The dress would ordinarily be laid down flat with the back up, and the diver would slide in. The helmet would be put on by means of the bolts which would be inserted in the slots and tightened up. With some assistance or preferable with the help of a davit or boom and tackle the diver is lowered into the water. Ordinarily a life line would be made fast to the hook on his helmet.

The blower would be started before putting on the helmet, and the oxygen valve opened either by the diver or his tender.

The following discussions refers to using the dress with helium and oxygen. However, if nitrogen, hydrogen, or compressed ~~in~~ air were substituted for the helium, the same general precedure would apply.

He decends now as rapidly as possible, clearing his ears if necessary. As the arms and legs of the dress collapse against his body, he opens his helium bottle admitting enough to expand the dress for another leg of the decent, after which he again pauses and admits more helium into the dress, doing this until he reaches the bottom.

After a very little experience, the diver may eliminate these pauses by merely opening the helium bottle a little and descending so the helium is entering the dress at about the same rate it is being compressed due to the increased depths. If he has opened his helium valve too much or too little by this method, he may adjust it at any time at the valve or govern his rate of descent by the rate at which his gas is entering the dress. At the bottom, he turns the helium off. If his suit is collapsed too much, he admits a little to make it comfortable or if he had admitted too much he may release a little by means of the cock. In no case can he "blow himself up", even if his dress is completely distended. He is now at his working depth, with his suit comfortably adjusted. The gases in the suit consist now of oxygen, nitrogen, and helium. The oxygen and nitrogen will occupy respective volumes approximately of 1/5 and 4/5 divided by $(h/34+1)$. where h is the depth in feet; the helium will occupy the rest of the space. Thus at 306 feet, the oxygen will occupy 2 percent, the nitrogen 8 percent, and the helium 90 percent by volume. This ratio of nitrogen and helium will thereafter remain constant.

If oxygen is taken into the system by the laws of solution, this percentage of 2% will be the correct one to maintain. If the oxygen enters the dress at approximately the same rate it is consumed which should be about one liter per minute, this percentage will remain constant. Adjustments for variations in this amount may be made as follows:

The physiological symptoms of excess and reduced oxygen partial pressures were discussed previously. Since warning symptoms appear at about 12 pounds per square inch (corresponding to 100 feet of water in compressed air diving) for excess and at 1.5 pounds per square inch for too little before any harmful physiological effects have occured, the diver could be watchful for these symptoms and when noticed rejust his oxygen flow accordingly following a temporary reajustment of the gases in the suit either by a flushing with inert gas or an admission of the needed amount.

For normal diving depths the amount of oxygen in the dress may be determined by the state of collapse or distention of the canvas arms or legs. For example, a diver on a 100 bottom‸ should have a theoretical volume of oxygen of 5 percent. It might be advisable for him to actually have this 15 percent, i.e. 200 percent excess. Under these conditions, a variation of 10 percent in either direction would not vary this out of a safe range. But this variation of 10 percent would produce vary obvious effects to the state of the diving dress.

Considering the large volume of gas in the laced arms and legs, the variation of 10 percent would be the difference between a completely distended and completely collapsed set of arms and legs. The level of collapse would be an even more sensitive gauge of variation of the number of molecules in the dress. I believe that as small a variation as 1 or 2 percent could be observed by a diver. The sensitivitey of this method obviously decreases as the suit is used in deeper water.

Because of the fact that the oxygen molecule weighs 8 times as much as the helium molecule, a hydrometer type of gauge could be constructed that would read directly the ratio of the two gases, with a correction for the depth. A gauge of this sort might be made of a float, spring, and a lever actuating a pointer.

Ordinarily, after a little experience the diver will know what his rate of oxygen consumption is since basal metabolic rates are very nearly constant for any person, and by adjusting the delicate flow valve carefully, an entire dive may be made without any consideration of oxygen consumption.

Rubber suit divers have been down to a depth of 307 feet which corresponds to an increase of 900 percent in oxygen partial pressure. In the experimental tank at Washington this depth is attained quite frequently. From this it may be seen that in the self contained suit, an excess of oxygen could hardly produce worse effects than the present type of dress. It would be advisable to maintain the oxygen percentage in excess of the 3 pounds per square inch which the body is accustomed to, because of the less harmful and more obvious results of excessive partial pressures.

CLAIMS TO ADVANTAGES OVER OTHER DIVING GEAR

1. SUBSTITUTION OF HELIUM FOR NITROGEN: By doing this it is believed decompression time may be reduced to one-half or one-sixth of that required for compression.

2. GREATER DEPTHS POSSIBLE: Because the depth to which a diver may descend is limited indirectly by the decompression time, which he must spend to return to the surface, deeper water is possible.

3. OXYGEN INTOXICATION ELIMINATED: Because of the intoxicating and extremely irritating affects of breathing of high partial pressures of oxygen as in the case in compressed air diving, depths are greatly restricted. I claim controllable partial pressures of oxygen within safe limits.

4. DANGER OF THE "BENDS" DECREASED: Because of the characteristics of helium, which forms finer bubbles and clears itself more quickly from the blood, upon release of pressure, danger of caisson disease is greatly minimized.

5. USE OF NITROGEN OR COMPRESSED AIR INSTEAD OF HELIUM IF SO DESIRED: Without any changes either of these may be used at any time in the self-contained dress.

6. PRESSURE CARRYING DRESS: The diver may take his decompression in the dress at any time or for any stages of the decompression or recompression that he wishes. Considering the fact that the first stage of decompression, is at a depth less than half the absolute pressure of

the working depth, and that the time spent of the first stages is small and increases rapidly, so that the last stage, at a depth of 10 feet requires considerable time, by eliminating the latter stages, a much larger percentage of time is saved under water.

E.g, from the Decompression Tables (for compressed air) for a dive of 250 feet, 1 hour being spent from entering the water to beginning of ascent, the following time in minutes would have to be spent at succeeding stages.

Depth:	100	90	80	70	60	50	40	30	20	10
Stoppage:	10	15	20	25	30	30	35	40	40	40

This totals 289 minutes. By ascending with 44 pounds pressure in his suit, corresponding to 100 feet of water the diver could reduce the decompression time to nothing.

By carrying 30.8 pounds pressure in the suit, the diver could reduce the time to 45 minutes, taking the first three stages.

By carrying only 13.2 pounds pressure the diver could reduce the required time by two hours, or 45%.

By carrying only 4.4 pounds pressure, the time could be reduced 40 minutes, or 15%.

7. <u>DANGERS ELIMINATED</u>: If the mother vessel should drag anchor, if a squall should come up suddenly, or if for any other reason it would be desirable to get the diver out of the water, he would be in no danger

since he could decompress in his dress. Thus the dangers of "blowing up" are eliminated, of being swept to the surface by a strong current, or of being dragged to the surface by the surface ship dragging her anchor.

8. NUMBER DIVING DAYS INCREASED; For deep water diving, there are only scattered days in which it would be advisable to dive. With this dress it would be possible to dive under almost any conditions, the danger of a squall being eliminated and the terrors of varying swell pressures being eliminated.

9. DEEP WATER DIVING WOULD BE POSSIBLE TO SMALLER CONCERNS WHO COULD NOT AFFORD A RECOMPRESSION CHAMBER:

10. THE ADDED SAFETY OF A RECOMPRESSION CHAMBER WOULD BE PRESENT FOR ORDINARY DIVING: Because of the tremendous expense and size of ship required to carry these chambers, they are not used except in very elaborately equipped outfits.

11. PUMPERS ELIMINATED: For deep water pump diving of 2 shifts of four men would be required at the pumps, whose expense would be eliminated.

12. SMALLER DIVING BOAT POSSIBLE: Since a deep water pump weighs almost half a ton and four men are required to operate it, a large boat is required for diving, adding to the invested equipment. Or in another sense, the danger of capsising always present in an overloaded boat is

eliminated, since the diver is not dependent on a surface pump.

13. ORIGINAL COST VERY MUCH LESS: It is estimated that this dress could be produced at less than 20% of the cost of a corresponding complete diving outfit as listed by both American manufacturers (in excess of $1300.00).

13. THE DANGER OF SEVERAL DIVERS TANGLING THEIR LINES IN ELIMINATED: This would lessen the hazard of operating groups of divers together.

14. THE DANGER OF FOULING LINES IS ELIMINATED: Thus it would be possible for a diver to enter tangled wreckage without the great danger ordinarily associated with this type of work.

15. HORIZONTAL APPROACH POSSIBLE: This dress would be useful for work in flooded tunnels or approach to a wreck lying near the shore, which would not be possible by having the diver drag out his air lines.

16. ENTRANCE INTO A HULL WOULD BE POSSIBLE: A diver could enter a hull, holding his distance line if he wished, but he would not have to drag his lines behind him and risk tangling or parting them on jagged edges, or he wouldn't have to return by the same way that entered if he so desired. Thus the complete exploration of a ship's interior would be possible.

17. AIR LINE PULL WOULD BE ELIMINATED: In a current of tideway, the pull of the long exposure of lines would be eliminated, thus making possible diving under unfavorable current and tide conditions.

18. THE DANGER OF FREEZING OF VALVES WOULD BE ELIMINATED: Because the condensed moisture due to the compression of air will freeze on the outlet valve of the diver's helmet, winter diving is made extremely dangerous and on humid days impossible. This danger is completely eliminated.

19. SWELL PRESSURE VARIATIONS MAY BE ELIMINATED: If decompression is taken under water, or in working on the bottom by carrying a very slight excess pressure in the dress, the tormenting swell pressure variations may be eliminated. The necessary pressure regulating outlet valve of the compressed air dress is absent, and the swells could not continually be affecting the pressure balance.

20. THERE IS VERY LITTLE CHANCE OF TEARING THE DRESS: Because of its metal body construction and heavy legs, there is very little chance of a tear.

21. THE DANGER OF ATTACK BY SHARK AND BARRACUDA WOULD BE MINIMIZED: Because of the metal protection.

22. THE DRESS MAY BE USED WITH HOSE AND PUMP OR COMPRESSOR WITHOUT ANY CHANGE: Thus if it is for any reason desirable to dive using compressed air, the dress may be used as it is.

23. THE HELMET MAY BE USED FOR OPEN HELMET DIVING FOR ANY TIME:

24. THE HELMET MAY BE USED AS A "RESCUE DRESS" DIVING OUTFIT AT ANY TIME:

25. THE HELMET OFFERS SUPER-VISION: There is 360 degrees of vision allowed. The glass is cylindrical shaped so that the diver looking out radially will experience no distortion due to the refraction. In the flat glass, the only line of vision which does not produce distortion is that from the divers eye perpendicular to the glass.

26. A WIPER IS PROVIDED TO CLEAR THE INSIDE OF THE WINDOW OF MOISTURE: This will insure clear vision.

27. INSTRUMENTS ARE PROVIDED: A gauge is provided which will enable the diver to regulate his own decompression and another to give him information at to what depth he is at. Other instruments such as a watch and compass may be provided also.

28. AN ASCENSION DEVISE IS PROVIDED: By any combination of slipping his belt (and recovering it), using a buoyant bag, or using the available distention of the suit, depending on the weight distributions of the particular design, the diver may float to the surface from any depth and decompress in his suit.

29. IMPROVED AIR CONTROL: The cumbersome method of signalling to the surface for a variation in the amount of air is eliminated. The diver can make his adjustment exactly, quickly and certainly. The danger of "blowing up" is thereby eliminated and also the danger of "crushing" which are ordinarily caused by conditions beyond the diver's control.

USING COMPRESSED AIR AND HOSE ABSORPTION

CANNISTER: In using the dress in this manner, the bottles might be removed or else carried for emergency use. A standard diving hose is connected and the exhaust valve is opened allowing the gas to exhaust against the adjustable pressure of the outlet valve. The absorption cannister and blower is used.

However, as much as this might appear to be like ordinary compressed air diving, I am introducing the following new principle that I believe will make this type of dress more suitable for deep water diving than the present type of suit; As the diver goes into deeper water, the percentage of oxygen in the air is reduced, thereby eliminating or greatly reducing the effects of oxygen intoxication and oxygen posioning. The other desirable characteristic of the usage of the dress is that the amount of work that must be done by the pump will not increase as the square of the depth but will be extremely small.

The following have been discussed before. A man needs approximately 1 liter per minute of oxygen for normal breathing, which is equivalent to 0.035 cubic feet per minute. This, then, is all of the free oxygen that is consumed by the diver regardless to what depth he is at. In a standard diving suit, however, a very much larger amount of air must be furnished the diver, the reason for which is not the increased demand for oxygen but to didute the carbon dioxide which has similar adverse physioligical effective pressure as an inverse function of the absolute pressure. Thus at a depth of 304 feet 15 cubic feet per minute must be supplied to the diver as (0.035×5 to account for the nitrogen in the air) compares with 0.175 cubic feet per minute to supply the necessary oxygen.

In theory, in this proposed usage of the dress, the pump would be operated so as to supply .175 cubic feet per minute of free air, corresponding to 1.5 cubic feet per minute required by the ordinary diver. As the depth increases, the pump speed would be kept constant, and the same amount of free air would be pumped. Thus the work of the pump would increase as a direct function of the depth, whereas it would increase as the square of the depth in the case of the standard apparatus. The work required would be slmost negligble; only 10.50 cubic feet of free air would be pumped every hour.

In practice, an excess above 10.5 would be pumped, since small excessive oxygen partial pressure are harmless and advisable.

The result of this system would be a small pump intake; a small inexpensive and light pump requirement; the necessity of having only one man at the pump at the most; a small amount of air in the hose and entering the helmet; much lower carbon dioxide percentages than in the ordinary diving helmet; almost constant or slightly increasing oxygen partial pressures at all depths with the corresponding avoidance of oxygen poisoning; a small volume of exhaust gases which consist largely of nitrogen mixed with the excess oxygen (which obviously means that excess oxygen must be present as just noted) and few bubbles in the water.

USING COMPRESSED AIR IN BOTTLES AND CANNISTER

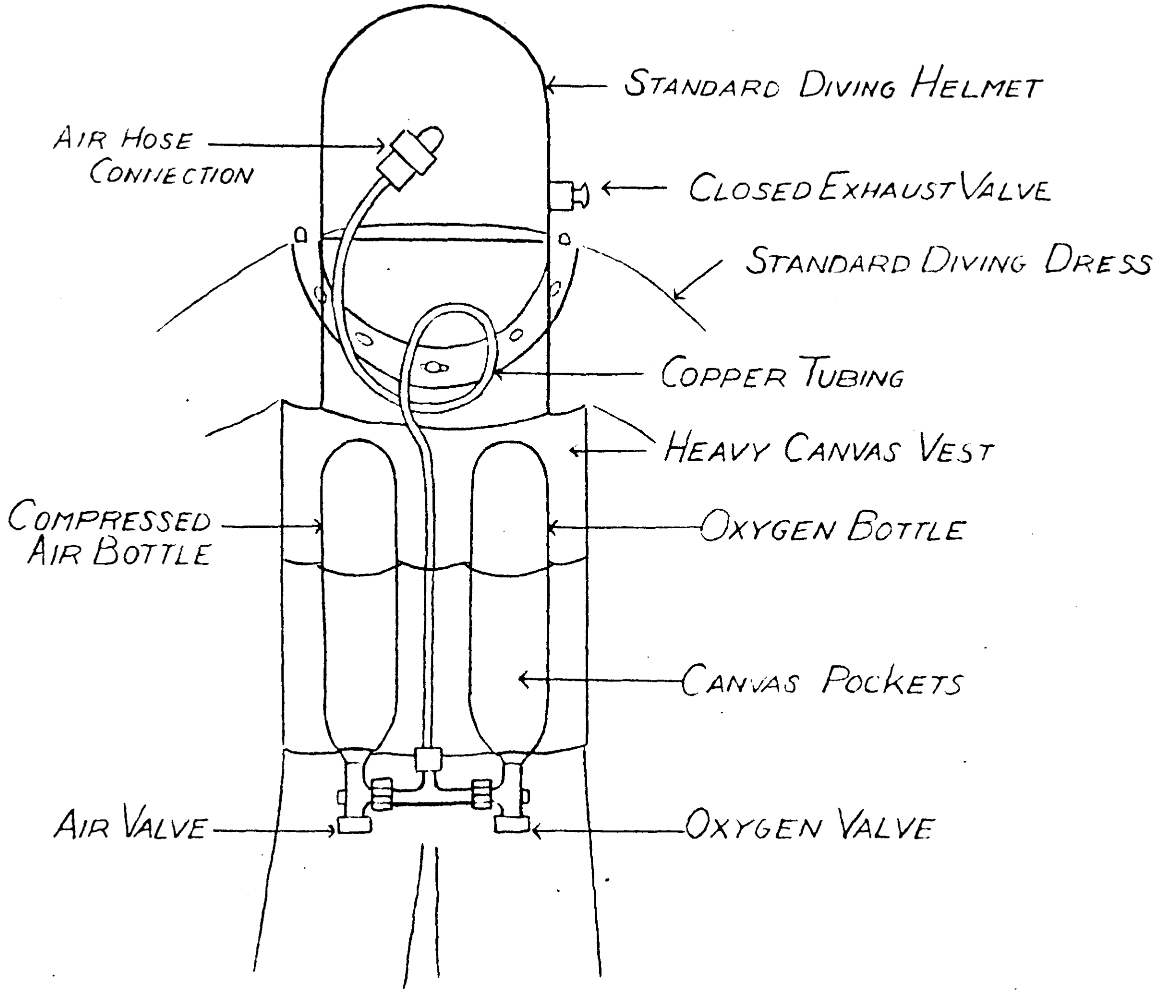
This is essentially the same principle as just discussed except that no hose or pump is necessary, i.e. a self-contained suit.

In the patents discussed are several would-be self-contained suits in which the inventors supplied the diver with air from bottles, the fallacy in which lay in the amount of air required by the diver. Thus an 18 inch bottle holding 11 cubic feet of air at 2200 pounds per square inch would last the diver at a depth of 102 feet one minute and 50 seconds.

However, using the type of suit that I am proposing, with the cannister for the absorption of carbon dioxide, this same bottle of compressed air would last the diver 11/.175 or 63 minutes. Since 2, 3 or 4 bottles can be carried on the suit, this would make compressed air diving in a self-contained suit possible and also give the advantages of controlled and reduced oxygen percentage as the pressure increases.

EXPERIMENTATION WITH SELF CONTAINED DRESS: The accompanying drawing shows the adaptation that I made of my standard diving suit to experiment with the principles involved in the self contained design just presented.

The dress was bound in such a way that it could withstand a pressure of approximately 4.4 pounds per square inch, which would correspond to



EXPERMENTAL SELF-CONTAINED SUIT
USED FOR PRELIMINARY TESTS

MITTENS WERE WORN TO AVOID VALVING AT THE CUFFS.

A SEMI-CIRCULAR DOUBLE SCREEN WAS BUILT INTO THE INSIDE OF THE HELMET WHICH HELD THE ABSORPTION CHEMICALS.

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the elimination of the last stage of decompression in the water. A canvas vest was made as shown which would bind the trunk of the dress and also have pockets for the bottles. Because of the relatively small diameter of the legs and arms in contrast to the trunk, the former were not bound, and even though they were not designed to carry any pressure did not tear or even leak. The vest was laced in front, between the legs, and over the shoulder of the breastplate. The bottles were put in the pockets up side down and the valves were found to be very conveniently operated.

It was found that it was very awkward to bend either arms or legs with the suit distended with 10 feet of water internal pressure. However, by using a lacing band at the elbows, knees, and wrists it was found that free movement was still possible.

The absorption device consisted of a double screen similar to the one used in the diving shell, placed in the back half of the helmet. The absorption was so effective that at the maximum depth of 70 feet at which the suit was used, doing active work, not the slightest increase in breathing was noticed. The air at all times was fresher than that ever experienced under the same conditions in compressed air apparatus.

Compressed air only was used as the inert gas in the tests.

It was found in shallow water that because of the lack of the automatic regulation action of the ordinary spring seated adjustable exhaust valve (which was permanently closed during the experiments), small changes in depth and small errors in the adjustment of the entering gases caused serious changes in stability, since the body of the dress would quickly distend with embarrasing buoyant effects. At one time an error of this sort resulted in an unexpected "blowing up" and I suddenly found myself shooting toward the surface feet first from a 30 feet bottom, and at the surface was so helpless that I had to be towed in like a buoy, inside down. This accident would be impossible, however, in the designed dress, because of its non-distending trunk and the slight distention allowable in arms and legs.

PART C

MISCELLANEOUS

1.

UNDERWATER VISIBILITY

A brief comment on underwater visibility might be pertinent.

The photographs taken through the window of the diving shell give interesting evidence of the amount of light absorbed by the water. The water in which these pictures were taken is the fabulously clear waters in the West Indies.

Salt water seems to change from an almost transparent substance near the surface to a green as the depth increases. This gradually changes into a darker bluish green and finally into a black. Fresh water seems to change from a transparent substance through stages of brown and finally into black as the depth increases.

It is interesting to note that visibility under water is not as good under a bright overhead sun as it is on a day with a hazy sky or in mid-morning or afternoon.

The following observations of other divers are interesting:

Visibility was reported as better than 60 feet in working on the wreck of the "Drummond Castle" lying in 180 feet of water. Down at the wreck of the "Egypt" on a 400 foot bottom, visibility was reported as 24 feet.

Moving pictures have been taken successfully at 30 feet in the West Indies by natural light.

Beebe made the following observations with a spectrascope from the "Bathysphere":

Just below the surface, the red decreased to one half its normal width on the spectrum.

At 20 feet, only a thread of red remained.

At 50 feet, orange was dominant.

At 150 feet the orange disappears.

At 300 feet the yellow was almost gone.

At 350 feet, the colors were divided as follows: 50% blue violet, 25% green, and 25% pale light.

At 450 feet, the blue disappears, leaving only violet and a very faint green.

At 800 feet, only a pale gray is left. Looking outside only a deep blackish-blue could be seen.

A pyrex water bulb, 3" in diameter with a 1/16 inch wall had been developed by Westinghouse. It has a life of 100 hours and gives 2000 candlepower, and is listed at $25.00.

I have found that an ordinary electric light bulb with the base removed and the proper waterproof connections made will stand pressures up to 100 feet (and probably greater) and give quite satisfactory service.

ARRANGEMENT OF MY BOAT FOR DIVING

A few notes on the arrangements of my diving and salvage boat may be pertinent. She is being equipped at the present time for experimentl diving, location of wrecks, investigation of wrecks, light salvage work, and an extended tropical cruise.

The boat is 36 feet overall, 31 foot at the waterline, 16 foot beam, and 4 foot 6 inches draught. She is cutter rigged, sturdily built, and has a heavy duty auxilliary engine.

This boat was selected for the following reasons: For maneuvering in coral reefs in locations where wrecked ships are to be found, a small boat is desirable. The difference between overall and waterline lengths give small overhangs for bow and stern avoiding pounding. The exaggerated beam is extremely desirable not only because of the spacious accommadations and room for supplied diving gear, and salvage gear it allows, but also for the stability it gives to the boat at sea and when hoisting salvaged goods aboard and also in getting divers in the water, whether they be in a bell, suit, or the diving shell. The shoal draught is desirable because of accessibility it gives to shoals in searching for or salvaging wrecks. The auxiliary is a necessity for maneuvering in dangerous waters of this sort and the sail eliminates operating expenses for off shore cruising. An expedition of this nature can thus be conducted with ridiculously low expenses, since a boat of this type can be bought very inexpensively, and practically no loss can be incurred whatever little success results. In case of very fruitful investigations, a larger ship can be chartered after it is assured that the added expense will be justified. Thus a venture of this sort is economically sound, having little to lose and almost anything to gain.

The auxiliary engine is connected with an engine driven generator which in turn is connected with an air compressor, the latter by a clutch and the former by a belt drive. From this the following fool-proof combinations may be obtained.

The compressor is ordinarilly driven by the small engine but may be driven with a momen'ts notice by the dynamo from the batteries or by the auxiliary engine. A hand pump is standing by and connected through a valve.

The generator may be driven by the small engine or by the auxiliary engine, the latter driving or not driving the propellor.

The engine may be started by the dynamo from the cockpit, or either or both the small engine and dynamo may drive the propellor for emergency.

A niggerhead for hoisting may be driven by the dynamo, auxiliary or small engine.

Underwater lights and ships light and power are taken from the batteries with or without the generator.

To avoid the customary tangle of lines associated with diving, the following arrangements have been provided for:

A heavy ladder is provided for getting into the water. This is arranged so that it may be lowered into a moment's notice. High hand rails are provided so that there can be no danger of the diver falling into the water before being completely dressed or with his face plate off.

The descending line is held off the ship's side, by an arm secured to the laddeer. This line is used for lowering all tools, the decompression stage, hoisting lines, ect., by fastening the desired subject to it with a snap ring.

A tank is used for storing air. The compressor and hand pump are connected to this at all times through valves.

A small detachable boom can be fitted to the mainmast and a power hoist may be obtained from the niggerhead previously mentioned.

Salvaged articles may be lowered into the forc'sle through a hatch or into the midships section through a hatch. A large amount of space is available in the deck and in the cockpit for lashing down larger articles. For any extensive work, a larger ship would be chartered, after preliminary investyation proved the project economically sound.

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It is strange that so little has been written about diving and that there is such a meager amount of information pertaining to it, because it offers a fascination to most people.

The only impression most people have of diving has been obtained from a very few moving pictures pertaining to it and a few fiction stories, which have given extremely erroneous impressions.

It might be noted at this point that there are only two manufacturers of diving equipment in the United Ststes. The diving gear of 1934 is almost exactly the same as the equipment used in 1890, with only minor changes. Materials making up the gear have been improved but other than that, little changes such as allowing the incoming air to blow across the window, changing the shape of the windows, etc, are about all that could have been done.

In the last two years there has been a remarkable trend in home made open helmets. I believe it was all started by an article published in "Popular Mechanics" on how to build an open helmet at home. Boys all over the country have suddenly taken up this craze to build these inexpensive helmets, and a great deal of interest in commercial diving is developing, but all in all this field is almost unrecognized.

The only information I have been able to find that gives any amount of satisfactory information on diving is the "Diving Manual" which is Chapter 36 of the Manual of the Bureau of Construction and Repair of the Navy Department, published by the Government Printing Office in 1924. Unfortunately this cannot be obtained by the layman, since it is not allowed to be owned by a civilian. This manual has 108 pages and is well illustrated. It gives a good description of standard Navy diving gear, and gives a brief discussion on the physics and physiology of diving, discussing only the type of apparatus in which the diver is under water pressure.

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"A Diving Manual and Handbook of Submarine Devices",
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United States Naval Medical Bulletin, Vol. 9 pp. 227-252, Government printing Office, Washington. 1915.

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William Beebe, G. P. Putnam's Sons, N.Y. 1928 is an interesting account of his shallow water diving and tropical marine biology.

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