SELF-CONTAINED DIVING

BY

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Introduction

A requirement exists for a large number of engineer officers to have a knowledge of naval diving, together with a limited practical experience of the more common types of apparatus. Most of the problems that occur, after these officers have completed their short course, require the use of self-contained apparatus and, for that reason, no reference in this article will be made to the technique of Deep Diving or to the Standard (Helmet) Diving Apparatus.

Until the 1939–45 war years, self-contained diving was generally referred to, loosely, as shallow water diving, but since the introduction of oxy-nitrogen mixtures, self-contained diving is now regularly carried out to 180 feet.

Historical

It must have been very early that man realised that stream beds could not be crossed by using a hollow reed attached to a piece of cork—that is, if the lungs were more than 2 feet or so from the surface. Similarly, to-day it is a physical impossibility to dive on to the propellers of a ship wearing a patt. 230 face mask, unless the hose is supplied with air at a pressure corresponding to the depth of the lungs.

Leonardo da Vinci (1452–1519) had many ideas on diving, and one way in which he solved this major problem of supplying air automatically at the correct pressure to the self-contained diver, was to design an apparatus with an air filled flexible animal skin bag.

It is on record that Alexander the Great (356–323 BC), who himself made a descent in a machine called a 'Colimpha', used divers to destroy the submarine defences erected during the siege of Tyre. For those who desire an early precedent, this may be compared with the beach clearing and 'frogman' activities of the Second World War.

It was the last war that gave self-contained diving its biggest push forward. Prior to 1939, most jobs had to be tackled with the standard diving suit—a dress eminently unsuitable on many occasions because of its weight, bulk, air pipes and so on. *Salvus* and D.S.E.A. were in use to a small degree, but again they were not designed for many of the tasks they were called upon to perform. Utilizing the experience of the war years, there is now a Superintendent of Diving (a Commander R.N.) and a small, but highly trained, team at H.M.S. *Vernon* designing, developing and testing the diving suits and breathing apparatus that the Navy requires.

No work can be done conveniently on diving apparatus without an elementary knowledge of the theory of mixture breathing. For the sake of simplicity, the author has treated the three gases that are of particular concern to the self-contained diver separately, each gas being dealt with in its own 'watertight compartment'. In fact, the presence of large traces of one gas may well accelerate the physiological effects produced by another. The physiological effect of a gas is proportional to its partial pressure.

Nitrogen

Air is composed of 21 per cent oxygen by volume, the remainder being nitrogen. Nitrogen is valuable as a diluent for the oxygen, but it brings its own problems when breathed under pressure. There is no limit, in diving, to the speed of descent, provided that the air breathed is increased in pressure in step with the rate of descent. With practice, the ears can be 'cleared' as rapidly as desired.

'*Bends*'

The quantity of gas that dissolves in a fluid is, according to Henry's Law, proportional to the pressure. Noting that approximately 1 litre of nitrogen is dissolved in the blood at atmospheric pressure, and that more than 75 per cent of the body is fluid, nitrogen, under the two variables, pressure and time, will be absorbed in the blood and transferred to the tissues, which take it up exponentially at a rate depending on their relative blood supply. Hence during a dive, different tissues are saturated to a different extent. If decompression is carried out immediately, the tissues become supersaturated with nitrogen which may appear in the form of bubbles, causing great pain at the joints. If decompression is sufficiently rapid, the bubbles may appear in the bloodstream (viz. like a soda water bottle) causing an embolism and fatal obstruction of the circulation in various vital organs. This danger can be overcome by making 'stops' at set points during the ascent, so that a permissible supersaturation of 2 : 1 is never exceeded, and hence allow the dissolved nitrogen to be liberated at a safe rate.

As an example, the following (Table I) is an extract from the Admiralty Tables when diving on Air :—

TABLE I

Depth		*Pressure*	*Time under water* from surface to beginning of ascent	*Stoppages* time at different depths		*Total time for ascent*
Feet	Fathoms	lb per sq in	(minutes)	20 ft.	10 ft.	(minutes)
			up to 10	—	3	5
			10–20	—	5	7
78/84	13–14	$34\frac{1}{2}$–37	20–30	3	8	13
			30–40	4	13	19
			40–45	5	15	22
			45–55	8	16	26
			55–65	9	18	29

Nitrogen narcosis

Nitrogen under pressure has a narcotic effect on the body, which is normally experienced below about 140 feet, though it does not become a serious problem until a depth of 240 feet is reached. It causes the diver to behave as though intoxicated with alcohol, and to have an optimistically high sense of well-being, but, as with alcohol, it can be controlled to a degree by will-power. Described by Cousteau as '*L'ivresse des grandes profondeurs*', it disappears very rapidly on ascending.

Oxygen

Both the above dangers from nitrogen can theoretically be eliminated if the nitrogen is removed from the breathing mixture, but pure oxygen diving brings its own problems.

Oxygen poisoning

If pure oxygen is breathed under a high pressure it can have a toxic effect. Unfortunately, no table with variable depth-time limits can be worked out for oxygen in a similar manner to the nitrogen 'stops'. In over 2,000 experiments on oxygen poisoning, it was found that no curve could be drawn due to the large scatter, not only between different divers, but between the same diver on different occasions. The Admiralty has, therefore, very wisely decided to treat pure oxygen as being toxic below 33 feet (i.e. 2 atmospheres absolute or 10 times the partial pressure as compared with breathing normal air on the surface).

Hence 33 feet becomes the limit for pure oxygen diving, and if the diver wishes to go deeper, he must dilute the oxygen with nitrogen, or, in the case of deep dives below 240 feet, with helium, which eliminates the narcotic problems of nitrogen under pressure.

The symptoms of oxygen poisoning can normally be recognised in a re-compression chamber, but are more difficult to diagnose when encumbered by diving apparatus. They are mainly physical in nature, and consist, in the early stages, of lip twitching, nausea and dizziness, followed finally by convulsions.

Anoxia

Lack of oxygen or anoxia is particularly dangerous, because the diver usually receives no warning, but lapses into sudden unconsciousness. It can occur in pure oxygen apparatus, but its danger is more real in the mixture breathing sets, where a flow of gas through the diver's counterlung maintains the correct oxygen content. The counterlung could still feel properly inflated to the diver when containing only nitrogen, although anoxia would occur at some point below the 20 per cent minimum oxygen content that is designed to be maintained in mixture breathing apparatus.

Anoxia can occur with pure oxygen apparatus due to the presence of nitrogen, which dilutes a designed 100 per cent oxygen filled counterlung. This may occur through inefficient rinsing of the lungs and apparatus before diving, supply of impure oxygen, and nitrogen liberated from the blood gradually accumulating in the counterlung.

Carbon Dioxide

Exhaled air consists of from 2·5 to 4 per cent carbon dioxide, 16 per cent oxygen, the remainder being nitrogen. This carbon dioxide must not be allowed to accumulate, and in most self-contained apparatus is absorbed in 'protosorb' canisters filled with soda-lime.

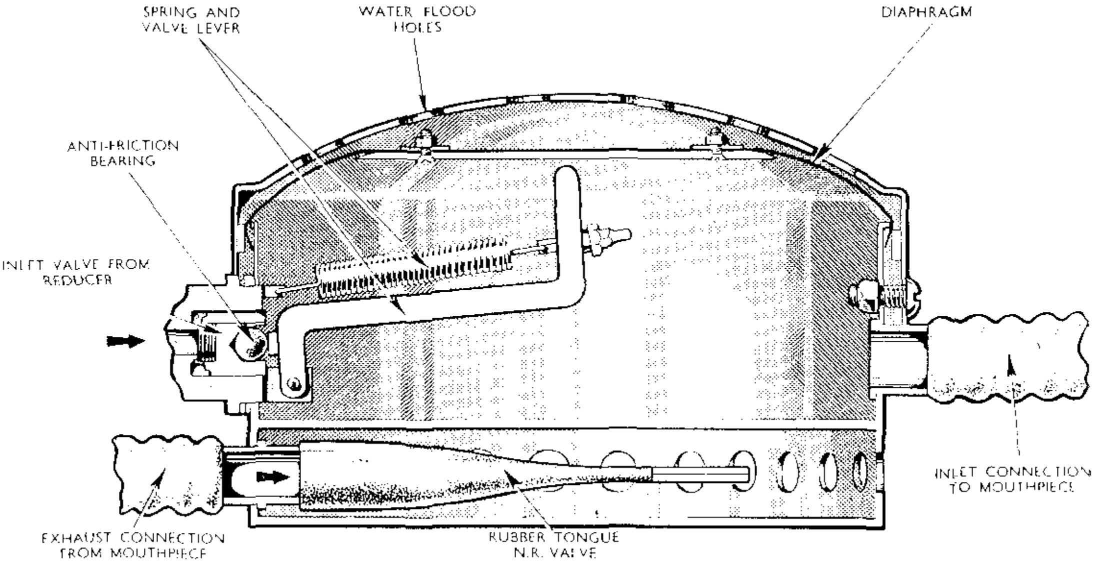

FIG. 1 LUNG OPERATED DEMAND VALVE

Excesses of carbon dioxide

Excesses of carbon dioxide have physical, as opposed to mental, effects and are thus very easily recognised. Coming normally from inefficient protosorb, the action to take is obvious, but they can occur by over-exertion. The symptoms are panting and a feeling of distress. If allowed to continue, unconsciousness will develop, but in most cases, when caused by over-exertion, the symptoms will disappear if the diver deliberately forces himself to have a ' stand-easy '.

Lack of carbon dioxide

This may appear an unusual diving disease, but since carbon dioxide is the gas that stimulates breathing it is possible, if excessively prolonged inhalations of pure oxygen are taken, to arrive at a state where breathing stops. This is usually self regulating as the build up, by diffusion, of carbon dioxide in the oxygen-rich lungs once more stimulates breathing.

SELF-CONTAINED BREATHING APPARATUS

Noting some of the physiological points raised in the previous paragraphs, the problems associated with the design of various types of self-contained diving apparatus can readily be recognised.

Compressed Air ' Aqualung ' Breathing Apparatus

Air, stored in high pressure cylinders of steel or alloy, is fed to a sea-water loaded reducing valve. This valve, due to the external loading, always supplies air at 100 lbs per sq inch approximately above ambient pressure to a lung operated demand valve. (See FIG. 1).

On inhalation, a depression from ½ in–2 in water gauge pressure produces a flow of from 30 to 200 litres per minute by depressing a rubber diaphragm, on the top of which is sea water pressure. The lowering of the diaphragm causes a valve to lift, which allows air to pass from the reducing valve into the body of the demand valve and thence to the lungs. On exhalation the diaphragm is pushed back to the static position, which shuts the valve, the exhaled air passing

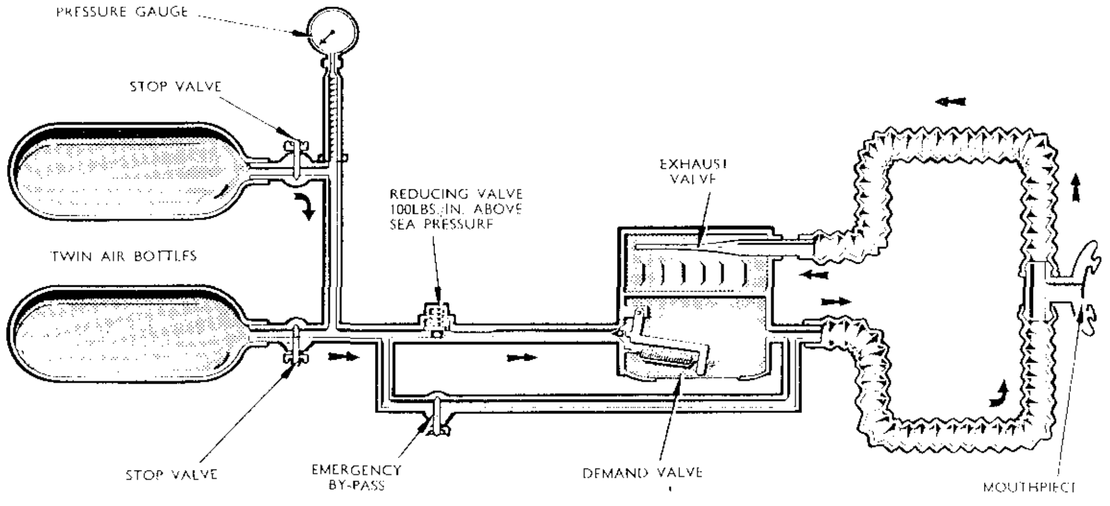

FIG. 2—COMPRESSED AIR (AQUALUNG) BREATHING APPARATUS

through a rubber N.R. valve which is located close to the demand valve. This location is important, to prevent pressure differentials occurring which could lead to the demand valve being difficult to operate, or to it blowing off continuously. Its situation, behind the shoulder blades, is a compromise position for both the lungs and for vision, which must not be obscured by exhaled air bubbles. (See FIG. 2).

Endurance

The body requires a given mass of oxygen to sustain it, while the lungs, for ventilation purposes, require a given volume. As depth increases, the aqualung becomes more and more inefficient as the following example will show :—

The compressed air breathing set shown in FIG. 3 consists of two air bottles each charged to 1,800 lb/sq in and containing 750 litres of free air.

(Volume of each cylinder is therefore 6·2 litres).

At the surface 1,500 litres are available

Assume an average ventilation rate of 30 litres/min

Endurance is 50 minutes.

At 33 feet the pressure is 2 atmospheres absolute, hence total available gas is 750 litres only.

Endurance is halved, as the ventilation rate remains the same.

Similarly at 99 feet it can be seen that

Endurance is 12½ minutes.

Physiological factors

As the diver is breathing air which is on open circuit, carbon dioxide excess or lack, and oxygen lack do not present any problem. It can be shown that oxygen excess will not concern the diver until he passes the 280 feet mark—an extreme depth for this type of apparatus, although it has been used very occasionally for short dives with success to 300 feet. Nitrogen, being present, requires attention to be given to both its narcotic and absorption properties.

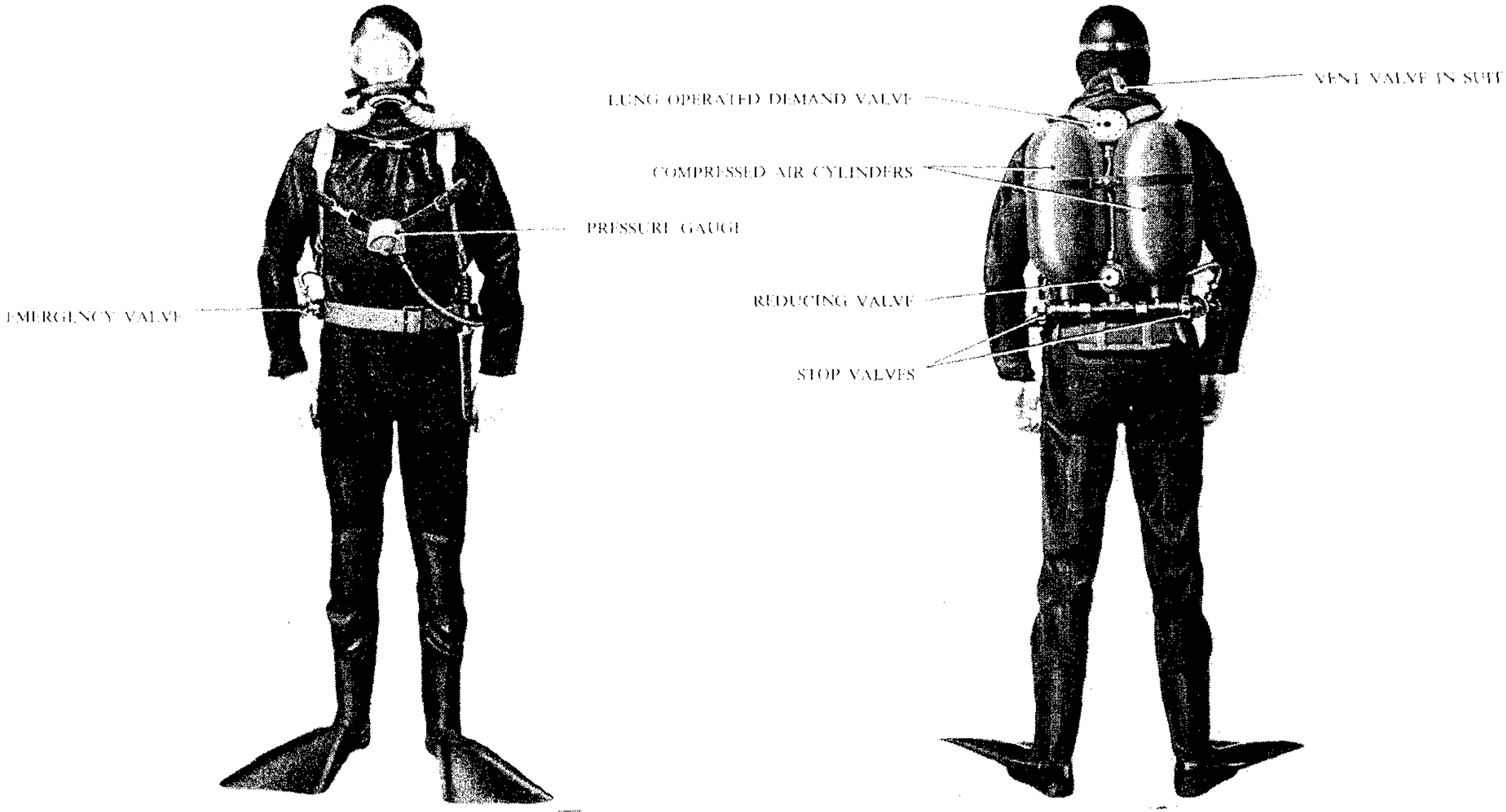

FIG. 3—DIVER WEARING SWIM SUIT AND AQUALUNG

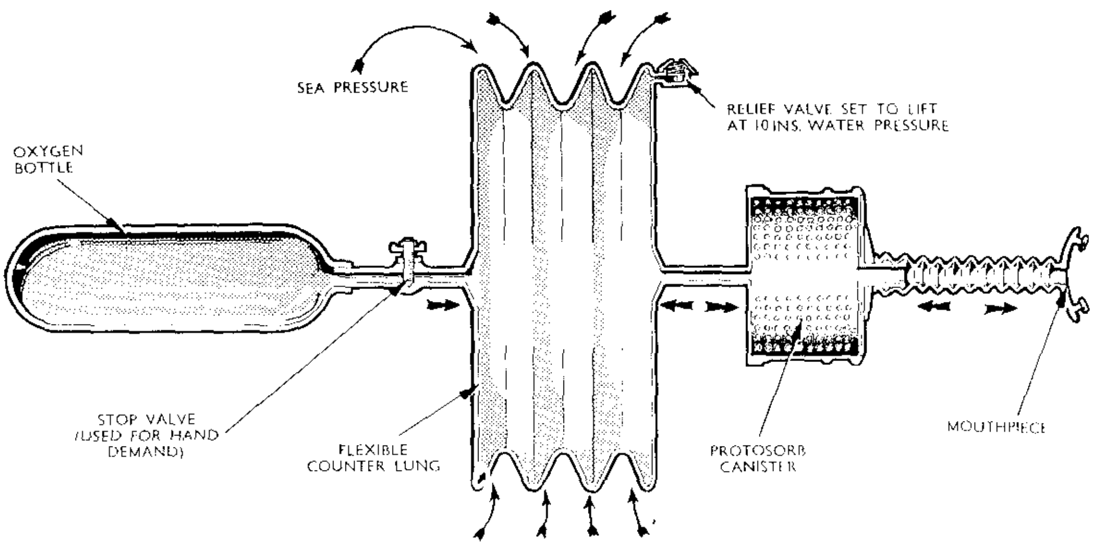

FIG. 4—PURE OXYGEN REGENERATIVE EQUIPMENT

REGENERATIVE BREATHING APPARATUS

Pure Oxygen Apparatus (U.B.A. Type)

Oxygen of more than 99·5 per cent purity is fed, either by hand or by a reducing valve as desired, to a rubber bag or counterlung of about 8 litre-capacity. A protosorb canister is fitted between the mouthpiece and the counter lung, the exhaled air passing pendulum fashion through the canister into the counterlung, and the inhaled air back through the canister to the mouthpiece. The carbon dioxide is thus absorbed, and the 4 per cent to 5 per cent deficiency in exhaled oxygen is made up by oxygen in the counterlung, which is at the same pressure as the surrounding water and, if the counterlung is slung at the correct height, at the same pressure as the lungs.

A neutral, or very slightly negative trim, as with the compressed air breathing apparatus, is established using a few small lead weights. Novices usually require more weights than the fully trained diver because they are inclined to give themselves, either by hand demand, or by a bypass in the case of the sets fitted with a reducing valve, more oxygen than required. This increases the counterlung volume and hence more weights are required to counterbalance the extra positive buoyancy.

Endurance

Endurance depends on the rate of consumption of oxygen and the quantity of oxygen and protosorb carried, and is independent of depth.

e.g. apparatus contains 2 lb of protosorb and twin oxygen cylinders each of nominal ·34 litres capacity charged to 3,000 lb/sq in.

Thus cylinders contain 136 litres of oxygen at N.T.P.

Assuming that the average consumption is 1·3 litres/minute.

Then endurance is 104 minutes.

Physiological factors

Diving is limited to a depth of 33 feet to prevent oxygen poisoning. The lungs are rinsed before diving to remove any traces of nitrogen which could be

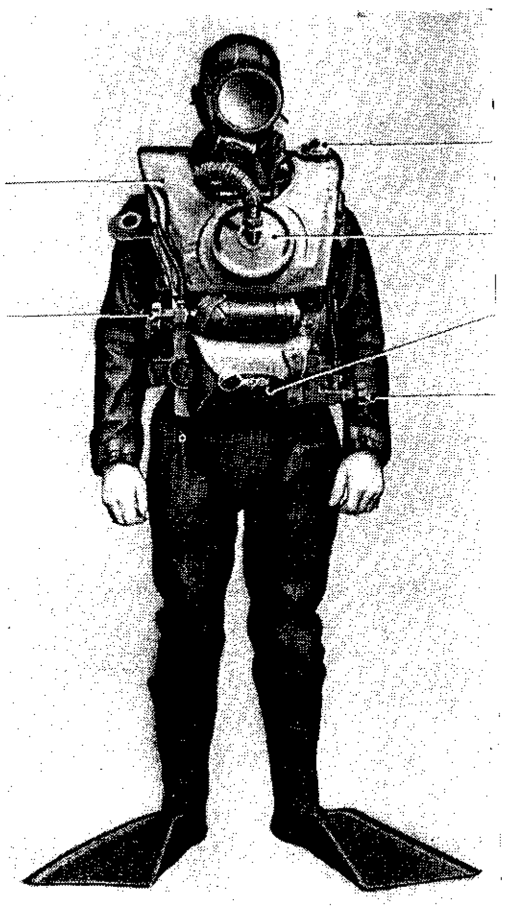

FIG. 5—DIVER WEARING PURE OXYGEN EQUIPMENT

responsible for anoxia. During a long dive, if the purity of the oxygen is questionable, the lungs and counterlung should ideally be re-rinsed, to remove any accumulations of nitrogen that may have formed.

To prevent excesses of carbon dioxide, care should be taken to ensure that the protosorb is fresh, and that during the dive it remains as dry as possible.

Mixture Breathing Apparatus. (U.B.A. Type)

Because of the hazards of oxygen poisoning, oxygen must be diluted with nitrogen, when diving below 33 feet. As the oxygen is the ' working part ' of the mixture, greater economy can be achieved by keeping the oxygen content as high as possible, but never at a greater partial pressure than two atmospheres absolute. Hence as the diver wishes to make deeper dives, the oxygen percentage in the mixture must become progressively less, until he finds that at 280 feet the ' correct ' mixture is 21 per cent oxygen and 79 per cent nitrogen, i.e. air.

With pure oxygen apparatus, it was optional whether a reducing feed valve was fitted between the bottles and the counterlung or not, but with mixture breathing apparatus it is essential to have a means of supplying an accurate flow of gas to the counterlung. The flow, to achieve economy, must be as low as possible, but it must ensure, in conjunction with the composition of the mixture, that when the diver is resting and consuming little oxygen he does not suffer from oxygen poisoning, or that when he is working hard, the percentage of

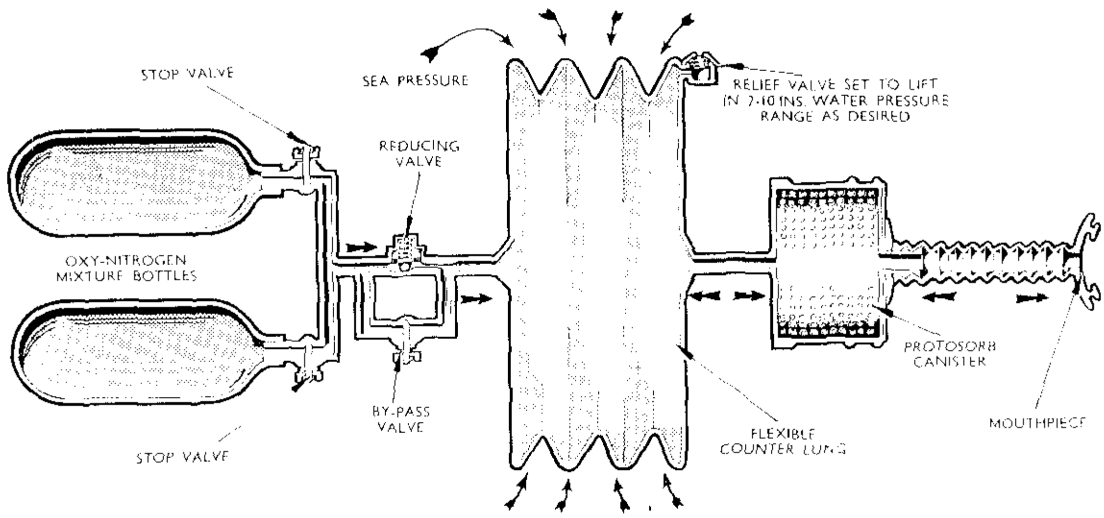

FIG. 6—REGENERATIVE MIXTURE APPARATUS

oxygen in the counterlung does not fall below a designed 20 per cent or anoxia may result. The flow of gas, because of the inert nitrogen content, must have an escape from the counterlung. This is arranged by unscrewing the relief valve on the top of the counterlung so that it lifts at an amount desired by the diver in the 2–10 inch water pressure range.

The requirements of a mixture-breathing set and its physiological implications can best be seen from the following example :—

A diver wishes to descend to an approximate depth of 80 feet.

Mixture

He requires a mixture with the maximum possible oxygen content, because of economy, and for the added advantage that it will reduce time on 'stops', but not more than the calculated maximum, because of oxygen toxic effect.

$$\text{Maximum oxygen permissible} = \frac{2 \text{ atmospheres absolute of oxygen}}{\text{Absolute pressure in atmospheres}}$$

$$= \frac{2}{1 + \frac{\text{depth}}{33}}$$

$$= 58{\cdot}4 \text{ per cent}$$

Mixture is made up in round figures, so a 60 per cent oxygen 40 per cent nitrogen mixture would be used.

Flow

The diver must be supplied with sufficient gas of the above mixture to prevent anoxia.

$$\text{Percentage of oxygen breathed (not less than 20 per cent)} = 100 \times \frac{\text{oxygen supplied} - \text{oxygen used}}{\text{total flow} - \text{oxygen used}}$$

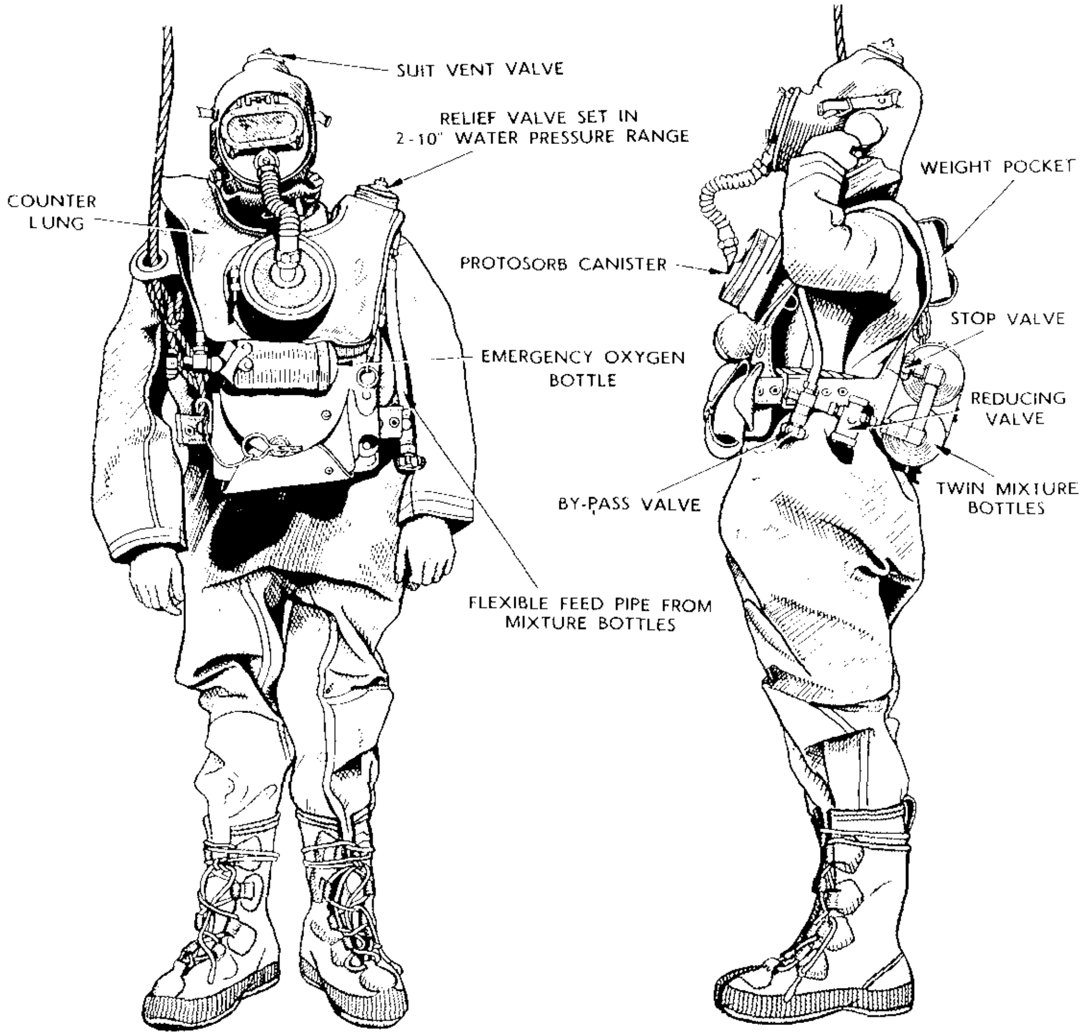

FIG. 7 THE ADMIRALTY SHALLOW WATER DIVING DRESS AND U.B.A. REGENERATIVE APPARATUS RIGGED FOR OXY-NITROGEN MIXTURE

For oxygen used, assume 2 litres per minute; being an assumed maximum consumption for short periods.

$$\frac{20}{100} = \frac{\frac{60}{100}F - 2}{F - 2} \qquad \therefore \text{ Flow} = 4 \text{ litres per minute.}$$

Oxygen content of the counterlung

From FIG. 8 the actual oxygen content of the counterlung can be determined, noting that for a given flow and mixture the actual percentage of oxygen breathed increases as the diver's consumption decreases. To calculate the maximum safe limit on this mixture therefore, use a minimum oxygen consumption rate of ·25 litres per minute.

$$\frac{\text{Percentage of oxygen breathed}}{100} = \frac{\frac{60}{100} \times 4 - 0{\cdot}25}{4 - 0{\cdot}25} = 57{\cdot}4 \text{ per cent}$$

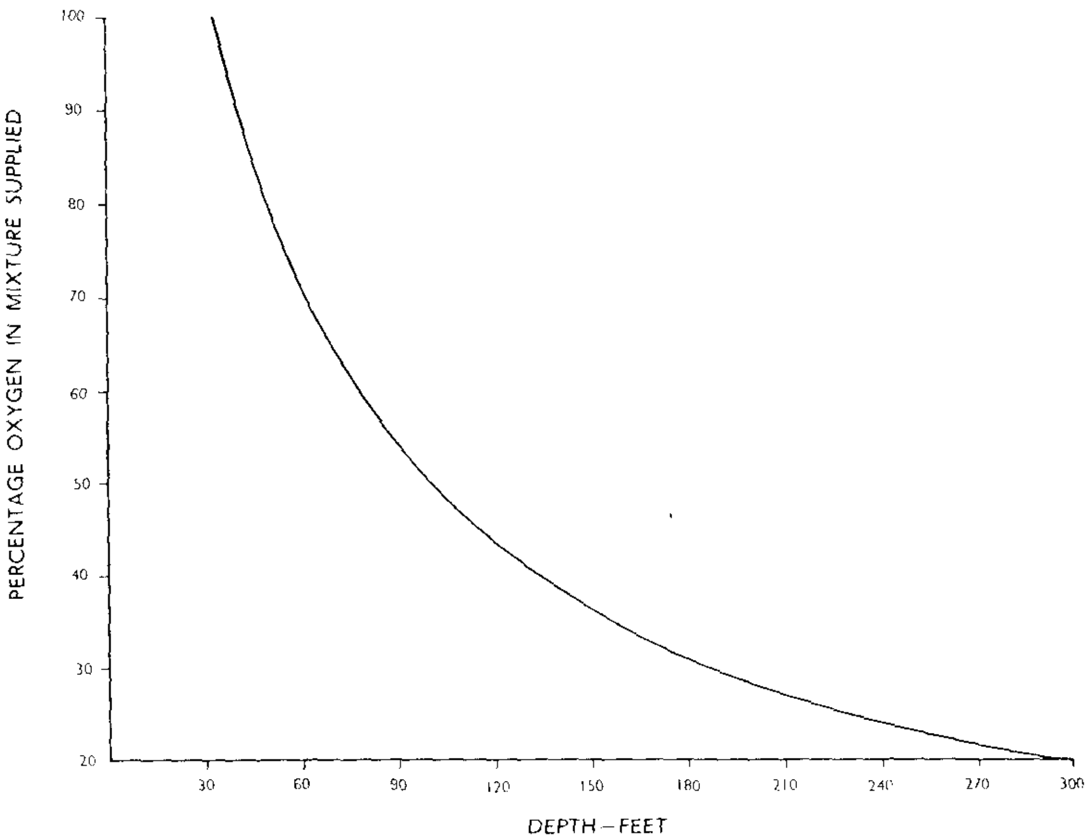

FIG. 8 – OXYGEN REQUIREMENT

Maximum safe depth

The slight lowering of the 60 per cent mixture supplied, to 57·4 per cent actually breathed, increases the maximum safe depth slightly.

Pure oxygen is safe at 66 feet (absolute)

$$\therefore \text{ A 57·4 per cent mixture is safe at } \frac{66 \times 100}{57{\cdot}4} - 33 \text{ feet.}$$

$$= 82 \text{ feet.}$$

Stops

Normal 'stoppage during ascent' tables are compiled for use when breathing air, hence a dive on a mixture containing only 40 per cent nitrogen will be equivalent, from the nitrogen absorption point of view, to a much shallower dive on air.

$$\frac{\text{Percentage of oxygen breathed}}{100} = \frac{\frac{60}{100} \times 4 - 1{\cdot}3}{4 - 1{\cdot}3} = 40{\cdot}7 \text{ per cent}$$

It is assumed for this calculation that the average oxygen requirement over the whole period of the dive is 1·3 litres per minute, i.e. a practical mean between the 2 and 0·25 litres per minute used in the previous calculations for ascertaining the flow and oxygen content of the counterlung respectively.

$$\text{Percentage of nitrogen breathed} = 100 - 40{\cdot}7 \text{ per cent}$$

$$= 59{\cdot}3 \text{ per cent}$$

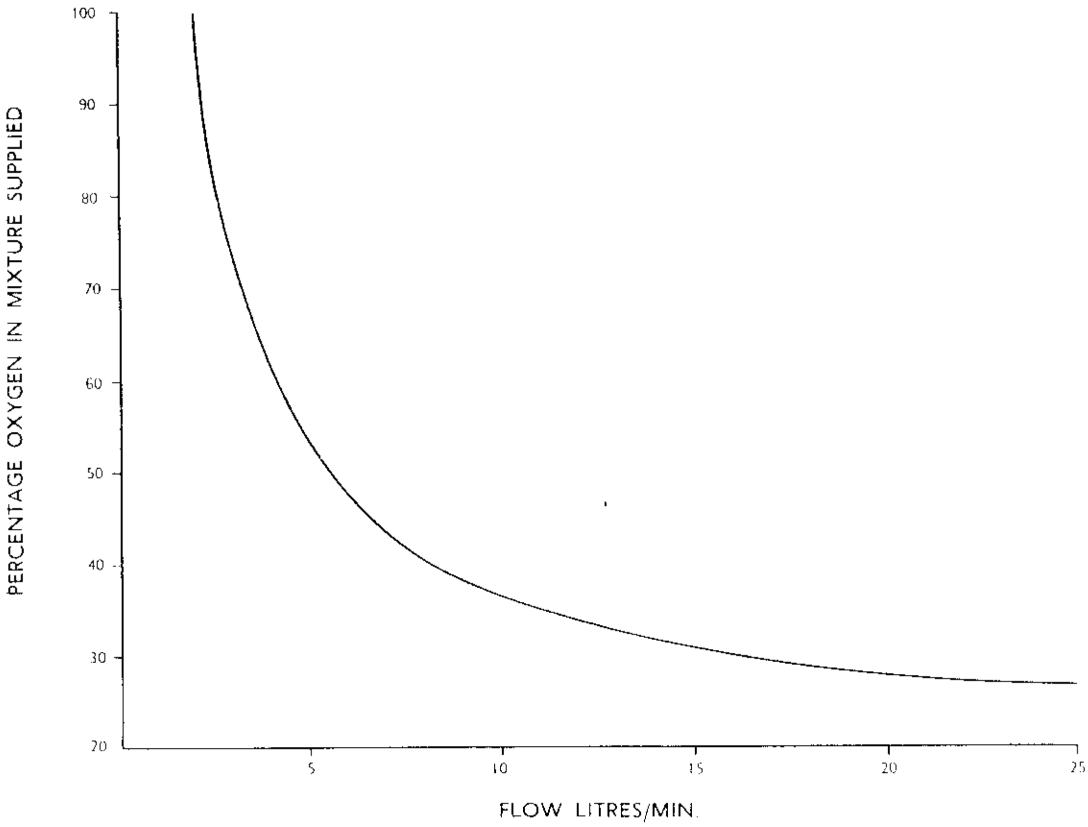

FIG. 9 – OXYGEN PERCENTAGE/MINIMUM FLOW TO PREVENT ANOXIA

A depth of 82 feet gauge = 115 ft absolute

∴ Equivalent air depth = $115 \times \frac{59\cdot3}{79}$ ft absolute

= 86·3 − 33 = 53·3 ft gauge.

Stops for an air dive to 54 feet should be given and these should be compared with the stops for an air dive to 82 feet shown earlier in Table I.

TABLE II

Depth Feet	Fathom	*Pressure* lb/sq in	*Time under water* i.e. from surface to beginning of ascent	*Stoppages* minutes at different depths 20 ft	10 ft	*Total time Minutes*
			up to ½ hour	—	—	2
			½ hr–1½ hrs	—	5	7
48/54	8–9	21–24	1½ hrs–3 hrs	—	10	12
			Over 3 hours	—	20	22

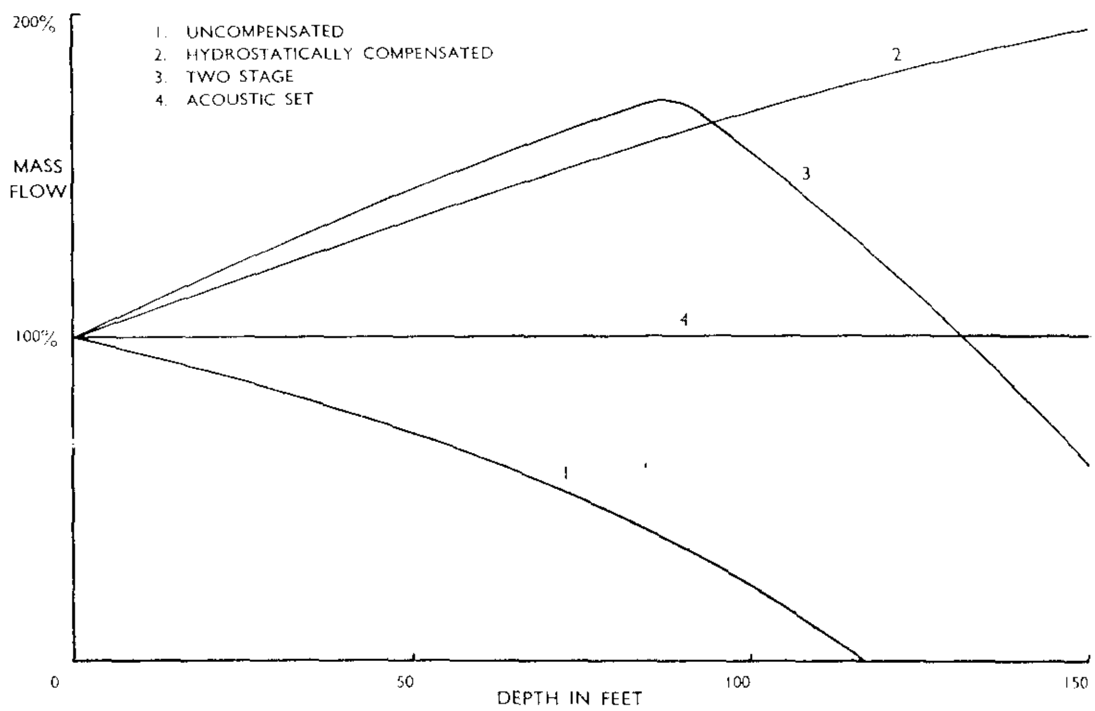

FIG. 10—FLOW CHARACTERISTICS

Endurance

Assume a set as shown in FIG. 7 consisting of a pair of bottles each of 1·97 litres, charged to 3,000 lb per sq inch.

$$\text{Endurance} = \frac{\text{Capacity (Initial pressure} - \text{Final pressure)}}{\text{Flow}}$$

The final pressure in the bottles is assumed to be 30 atmospheres, to allow for efficient working of the reducing valve, and to provide a safety margin for use with the hand operated reducer by-pass valve.

$$\text{Endurance} = \frac{3{\cdot}94\ (200-30)}{4} = 167 \text{ min}$$

But the set under consideration contains only a 2 lb charge of protosorb

∴ Endurance would be limited to 120 min

Reducing Valves in Regenerative Sets

It has been assumed in the above example that a reducing valve, set to a flow of 4 litres per minute on the surface, would continue to supply an equivalent mass of gas at any required depth. In fact, this has only recently been made possible by the work of Mr. P. F. Payne of the Admiralty Experimental Diving Unit, on an acoustic jet which allows a constant mass of gas to be delivered to the diver at any depth.

From FIG. 10 it can be seen that only an acoustic jet gives the ideal answer, the remaining valves being uneconomical. They upset a carefully calculated breathing mixture and make it difficult to calculate the endurance of a dive, bearing in mind 'stops' at various depths.

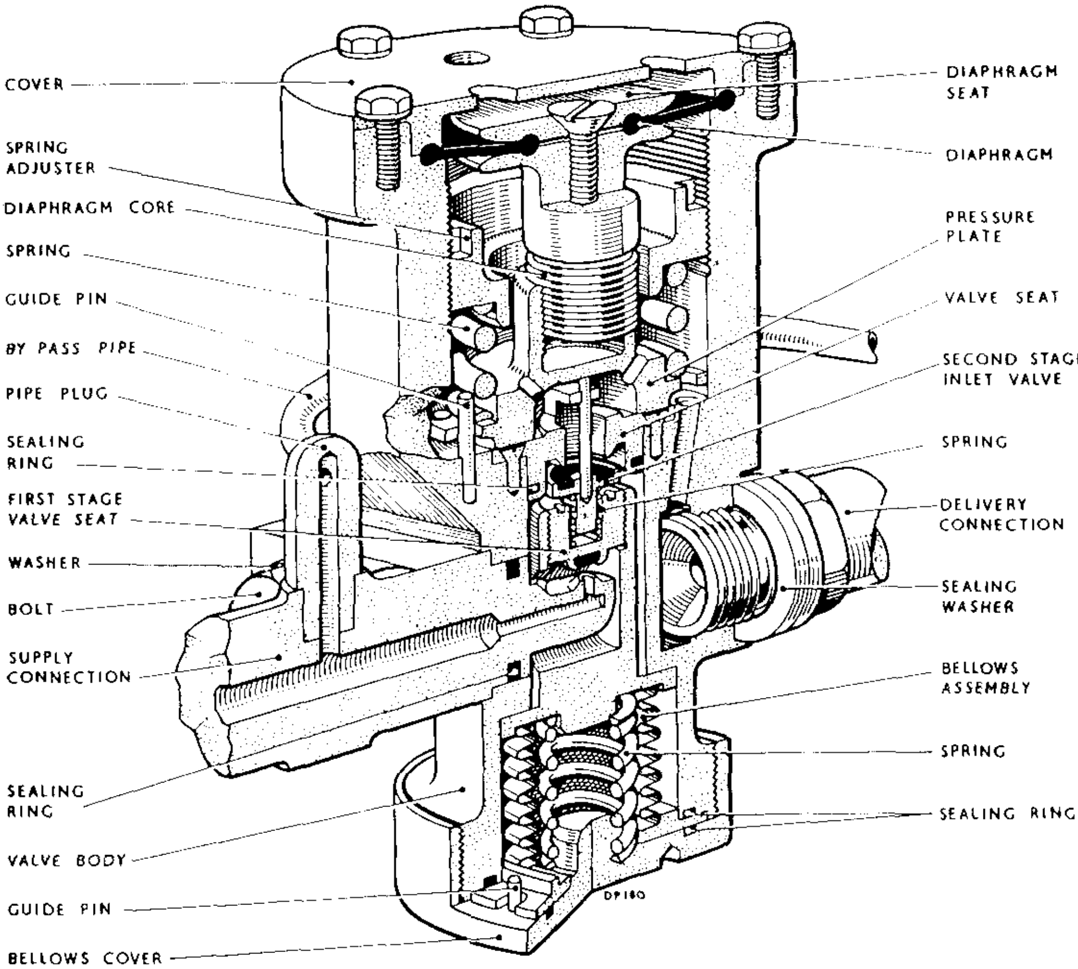

FIG. 11—TWO STAGE REDUCING VALVE
(The Dunlop Rubber Co. Ltd.)

The uncompensated reducer can be used in shallow water dives, but for normal work a hydrostatically controlled reducer is often used. The result is a rising mass flow and hence wastage, increasing with depth.

Another method used extensively in the Navy to increase the economy of the reducer was to build two stages into it (FIG. 11). When the stop valve is opened, the gas flows through the first stage valve and fills the valve chamber and the volume outside the bellows. Simultaneously, the gas flows through the open second stage valve and the holes in the pressure plate to the diaphragm chamber, and thence through the two angular holes to the delivery connection and the adjustable restrictor valve. This valve, not shown in the sketch, is adjusted on the surface to give the desired flow. Because of this restriction a pressure build up occurs, which lifts the diaphragm core and pressure plate against the spring in the diaphragm chamber. This movement is followed by the second stage valve until, at a pressure of 50 lb/sq in, the valve is just about to close. When this pressure increases in the diaphragm chamber, the second stage valve is held upon its seat by its spring.

As the pressure continues to rise in the first-stage valve chamber the bellows assembly collapses against the spring, and moves the first stage valve seat on to the valve orifice. When a pressure of approximately 100 lb/sq in exists in the first stage valve chamber, the valve seat covers the valve orifice and shuts off the pressure supply. As soon as a drop in diaphragm chamber pressure occurs,

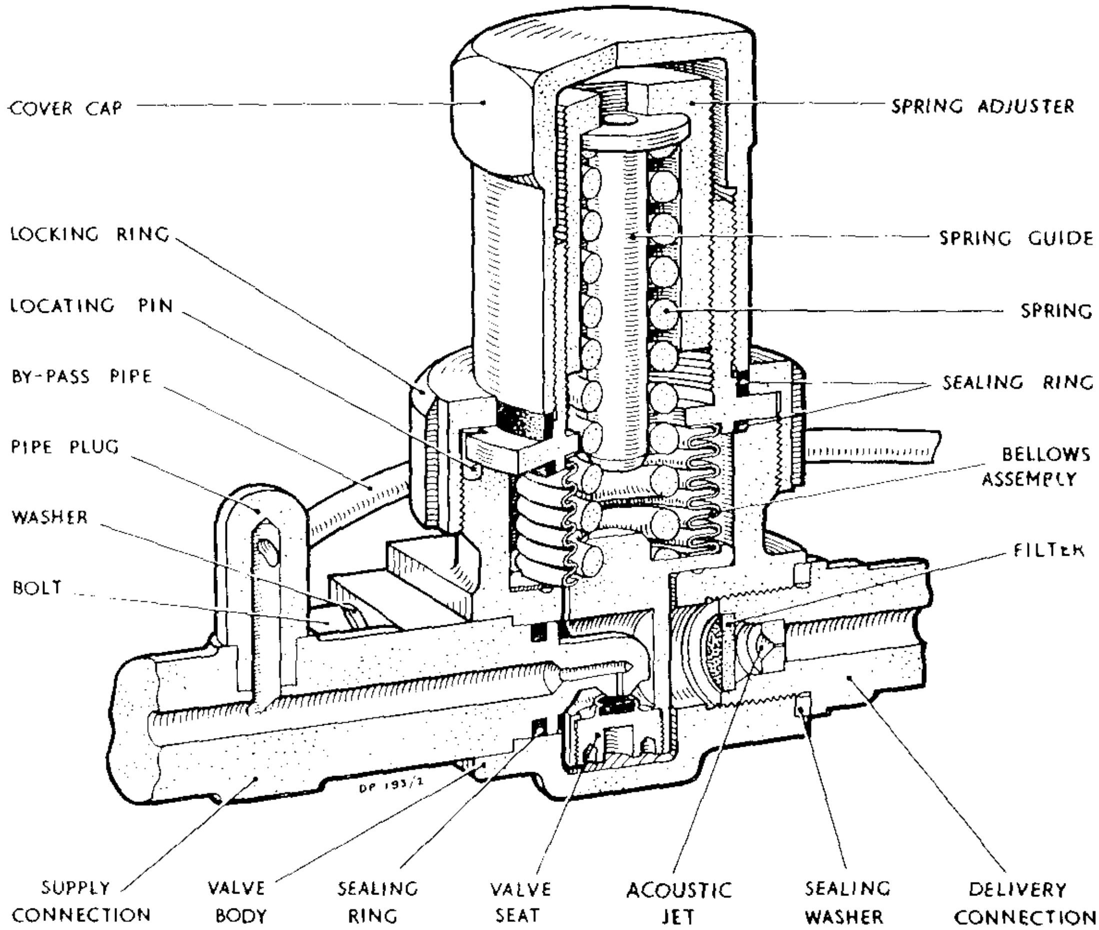

FIG. 12— UNCOMPENSATED REDUCER INCORPORATING ACOUSTIC JET
(*The Dunlop Rubber Co. Ltd.*)

the pressure plate moves under the action of the spring and opens the second stage valve. Upon the consequent reduction of pressure in the first stage valve chamber, the bellows assembly expands and opens the first stage valve, thereby restoring the pressure and maintaining the flow. As the diaphragm, and thus the second stage valve only, is loaded by the ambient water pressure, the second stage of the reducing valve supplies gas to the restrictor at 50 lb/sq in above ambient until a depth is reached (about 100 feet) when the second stage pressure has increased to that of the first stage. The second stage valve now stays wide open and the reducer operates on the first stage only. As can be seen from FIG. 10 from this depth it has the falling characteristic of an uncompensated reducer.

Acoustic Jet

If a gas is passed through an orifice at, or above, the speed of sound, then any pressure change below the jet cannot be registered on the supply side of the jet. Using an uncompensated reducer to supply the jet, a constant mass flow of gas will be maintained regardless of alterations in pressure in the diver's sea-water balanced counterlung. Only at a depth where the water pressure reaches about 60 per cent of the reducer pressure (both absolute), and the quantity of gas in the bottles becomes too small to maintain a flow at the speed of sound, will the constant mass flow fall off.

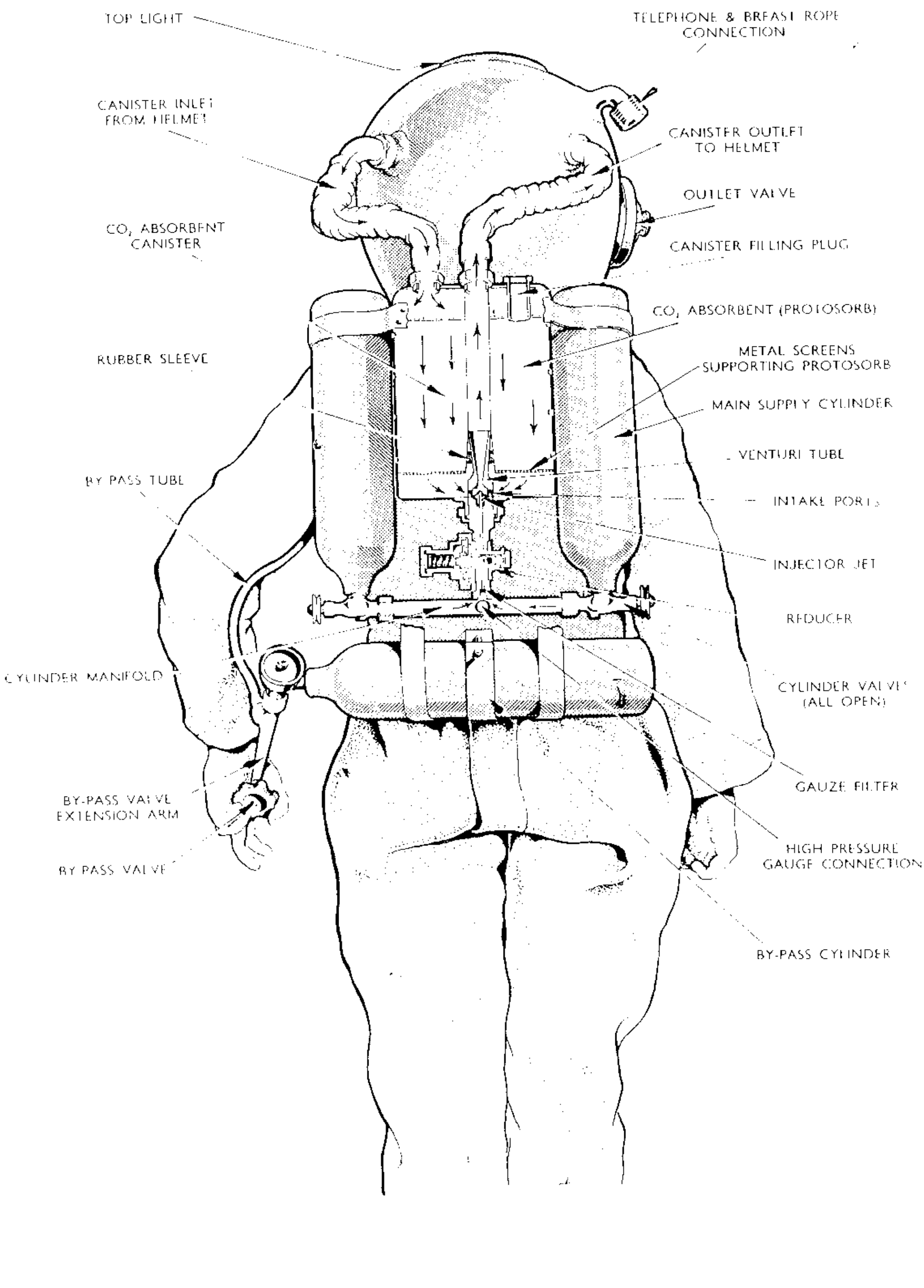

FIG. 13—REGENERATIVE APPARATUS INCORPORATING A VENTURI INJECTOR

By a suitable selection of orifice and pressure any required flow can be maintained at any depth. As an example, from the relation of volume velocity × area, a ·01 in diameter jet will pass 1 litre per minute of gas at the speed of sound.

The orifice ideally should be convergent, but in practice good results are obtained with straight drilled jets having a chamfered entry. It has been seen that deeper dives require an increase in gas flow ; orifices of adjustable area as in the two stage reducer can achieve this, but normally it is simpler to use a fixed jet and vary the pressure before diving with an adjustable reducer. (FIG. 12).

Gas Circulation

In the foregoing, only examples of regenerative breathing apparatus suitable for use with the soft hooded diving dresses have been considered. For certain types of work at greater depths, it is more comfortable to dive in a flexible suit containing a rigid helmet, in appearance somewhat similar to the Standard Diving Suit. Because of the greater freedom inside the helmet and the consequent fitting of a telephone, an alternative method of gas circulation is required, that will leave the mouth free for speech. This is achieved by means of a venturi injector operated by the incoming mixture. (See FIG. 13). There is no external counterlung to the above apparatus, but the functions of one are performed by the upper part of the flexible suit, which forms a water balanced reservoir for the circulating mixture. In this system, as in the counterlung type, a spring loaded relief valve is fitted to release the surplus mixture from the breathing circuit.

COMPARISON OF THE AQUALUNG AND THE REGENERATIVE TYPES OF BREATHING APPARATUS

Aqualung Type

Advantages

(*a*) No risk of oxygen or carbon dioxide excesses or deficiencies.

(*b*) No danger if internal parts of apparatus are accidentally flooded.

(*c*) Minimum of drill required for use.

(*d*) No rubber counterlung to tear.

(*e*) No reasonable depth limitations.

Disadvantages

(*a*) Endurance is poor, rapidly decreasing with depth. At 33 feet, for instance, about 50 times the quantity of gas must be carried as in the pure oxygen type for a dive of given length.

(*b*) No ready means of assuming positive buoyancy is built into the apparatus.

(*c*) The apparatus contains heavy, bulky air cylinders, which can however be conveniently carried on the back.

(*d*) Bubbles appear on the surface.

Regenerative Type

Advantages

(*a*) Very good endurance for the bulk and weight of the apparatus carried.

(*b*) There are no exhaust bubbles with the set rigged for use with pure oxygen, and reduced bubbles from the mixture sets.

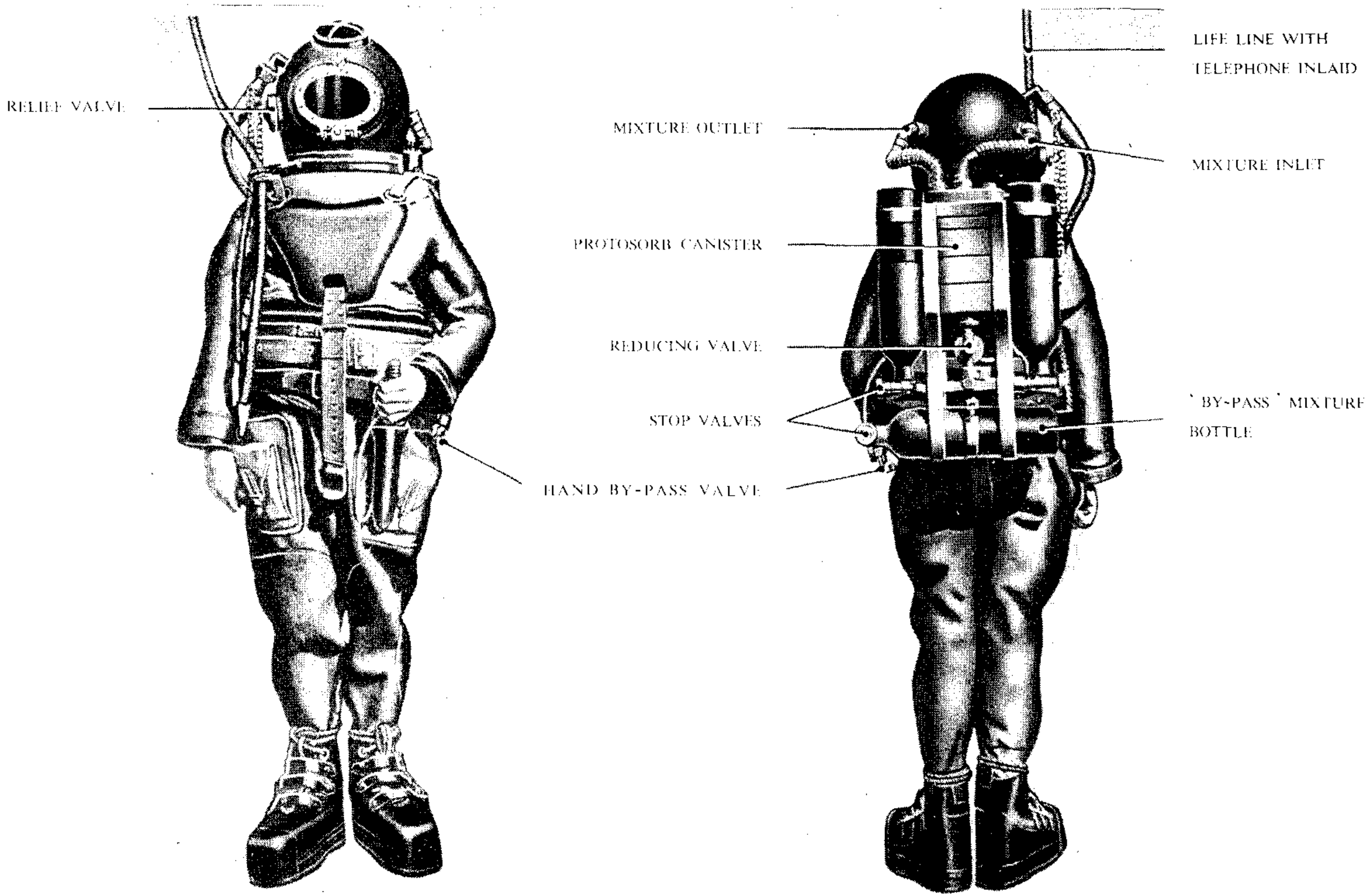

FIG. 14 RIGID HELMET SUIT WITH INJECTOR CIRCULATION

(*c*) Positive buoyancy is readily obtainable by the diver by inflating his counterlung.

Disadvantages

(*a*) Care must be taken not to exceed the maximum depth for the particular mixture carried.

(*b*) The physiological hazards of self contained diving must be thoroughly understood.

(*c*) The rubber counterlung must be carefully protected against damage, as any water inside the set renders the protosorb inefficient. Hence accidental flooding must be avoided, and care must be taken to have watertight joints in all counterlung fittings.

(*d*) Depth changing when swimming in this gear is more difficult because of the varying buoyancy of the counterlung when subject to fluctuating ambient pressures.

(*e*) The supply of pure oxygen and protosorb is more difficult than compressed air, which is ' laid on ' in most of H.M. Ships.

FUTURE DEVELOPMENT

Self contained diving in the future will, in the author's view, ideally require two main types of breathing apparatus.

An Improved Aqualung Set

It will need the endurance increased by the introduction of very high pressure alloy cylinders. It will need, also, better streamlining and the introduction of sensitively operated, but robust demand valves. An easily inflatable buoyancy stole will be necessary, as a means of surfacing when in difficulty. The set would normally be used in cold climates with the Mark I swim suit and fins. Uses of set : propeller clearing, hull inspections, light underwater repairs, recovery of light articles from the sea bed, firefighting and sport.

An Improved Regenerative Mixture Set

It must contain pure oxygen in bulk and sufficient nitrogen, or similar gas, to act automatically as a diluent for the oxygen. It would then have a greatly increased endurance over the existing regenerative sets, and would be exhaust bubble free, an important point when employed on operational offensive work, and such defensive applications as dealing with the acoustic mine. It should be anti-magnetic. It could be worn with the Mark I swim suit and fins, or with the Admiralty shallow water diving dress and rubber boots for work on the sea bed.