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DIVING HELMET AND AIR SUPPLY SYSTEM

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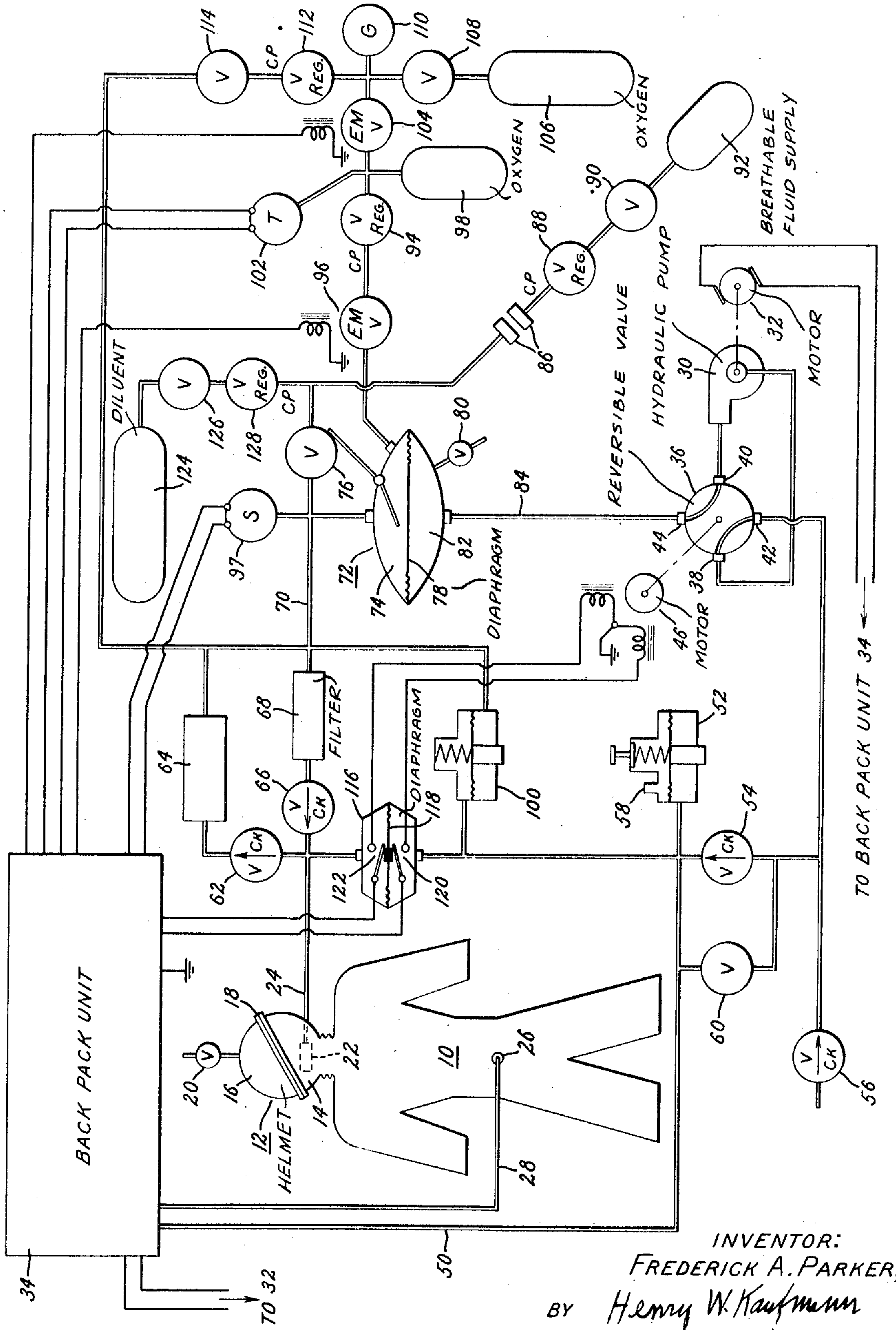

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DIVING HELMET AND AIR SUPPLY SYSTEM

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ABSTRACT OF THE DISCLOSURE

Closed diving dress provided with supplies of diluent or normal air and of oxygen in separate tanks has electrical power supply and control system and pumps which maintain in the suit both water and breathing air pressure exceeding by predetermined constant amount the changing external water pressure, to simulate the "stiffness" of a space suit for training purposes. Carbon dioxide is absorbed and oxygen added to maintain suitable concentration; inhalation and exhalation are assisted by pump. Water circulated in suit is heated to minimize diver's heat loss. There is an underwater diving helmet and a powered system to supply breathing fluid thereto. Breathable air is forcibly pumped to the helmet and extracted therefrom. This is done by a pressure sensing control diaphragm switch which senses the difference in pressure between ambient water pressure and the air pressure supplied to the helmet. When the air pressure is greater an electrical motor is operated to move a reversible valve in one direction and when the water pressure is greater the reversible valve is moved in the opposite direction. This reversible valve is connected to a continuously running water pump which pumps water to one side of a second pressure sensitive diaphragm. The latter diaphragm is connected to the breathing fluid supplied to the helmet and, depending on the pressures subjected to, will forcibly supply or exhaust the breathing fluid to the helmet.

This invention pertains to the art of diving and the specialized apparatus therefor known generally as diving dress, including means for respiration under water.

The older apparatus for sustained diving is a flexible suit with a rigid helmet supplied with air for respiration by a hose fed from a source at the surface, the diver being weighted so he can walk on the bottom. More recent is self-contained underwater breathing apparatus which provides the diver with air from a pressurized tank through some form of regulator which approximately equilibrates the pressure of the air supplied to that of the ambient water, regardless of depth changes. Ordinarily, such apparatus comprises a mouth piece for breathing, with a faceplate to permit normal vision by shielding the diver's eyes from contact with the surrounding water, the diver being left otherwise unencumbered for swimming. So-called wet suits, usually of foam elastomer such as rubber, may be provided for thermal insulation, but are ordinarily independent of the breathing apparatus. Since the diver's active working time tends to be limited by the effort required to inhale and exhale the abnormally dense air (e.g. 13 times normal surface density at 400 feet), it has been taught to provide powered means to assist inhalation, and, in some cases, give some assistance in exhalation. However, the pressure differentials the diver has been required to overcome have remained rather considerable. Since the diver actually consumes only oxygen, exhaling carbon dioxide, it is uneconomical to supply his oxygen needs by providing gas of which only a maximum of one fifth is oxygen and the remainder is diluent nitrogen (or helium, where preferred to avoid nitrogen absorption); and for military purposes the necessity of venting the excess unconsumable diluent in a stream of revealing bub-

bles is objectionable. Thus the prior art includes various teachings for providing pure oxygen to replace that consumed, and absorbing the carbon dioxide. However, in the absence of automatic means to provide additional diluent when the diver descends to greater depths, such devices are convenient only for relatively shallow depths.

A particular recent known use of underwater diving apparatus has been to train human beings to work in space in a gravity-free environment such as would be experienced in space. To this end, the diver is so ballasted as to be in neutral equilibrium and thus experiences the gross effects of weightlessness, although immersion does not duplicate the more subtle effects of true weightlessness in which, for example, the internal organs do not press on the body structure with their normal weight. However, a space suit is surrounded by vacuum and has inside it a pressure of several pounds per square inch of atmosphere. This produces a peculiar "stiffness" or resistance to deflection in the space suit which neither exposure to the surrounding water without a suit nor inclosure in a conventional flexible suit adequately duplicates. Also, in either case, the diver is subjected to a severe heat loss to the surrounding water which, because of the high heat transfer rates which exist between solids and liquids, is much greater than that which he would experience in a space suit, and has been found, at greater depths, to be of the order of 500 watts (430 kilogram calories per hour) or more. Since this in one hour equals about one eighth of the daily food requirement of a vigorous man engaged in heavy labor, it is evident that it constitutes, quite apart from any problems of simulation, an energy drain additional to the diver's requirements for muscular activity which will not only decrease his efficiency and make him highly uncomfortable, but will necessarily limit his possible tour of active duty.

The general object of my invention is to avoid the disadvantages of the prior art devices in a device which may be used to permit free diving (that is, without a tethering connection to the surface) at varying depths under conditions of greater physical comfort and less effort than the prior art equipments permit.

Specifically, I provide a flexible water-impervious suit connected to a rigid helmet; pumping and control means to maintain, in the suit proper, water under a predetermined excess of pressure over the surrounding water; and pumping and control means to maintain, in the helmet, oxygen at approximately the partial pressure found on earth and diluent gas at the partial pressure required to provide the desired total pressure level. Very slight pressure changes produced by the diver's efforts to inhale or exhale cause pumping means to assist the inward or outward flow of gas into or out of the helmet in exact accord with his own breathing effort; and as part of the means for doing this I provide means for measuring and recording indications of the diver's breathing rate and the rate at which he consumes oxygen. Furthermore, I provide means for heating the water fed into the suit.

For better understanding of my invention I have provided a figure of drawing representing schematically the relationship of the various previously known mechanical elements comprising an embodiment of my invention.

Referring to the figure, there is represented a water-impervious suit **10** equipped with a helmet **12** having a lower part **14** permanently connected to the suit **10** and an upper part **16** which is fastened by some clamping means **18** which is indicated as a diametral double line across the helmet and may conveniently be a toggle-operated clamping ring, which renders the helmet hermetically closable. Helmet **12** is represented as equipped with a manually operated purge valve **20** which may be operated on first immersion to bleed air from the suit **10** to permit it to fill with water, or fill to some convenient level such as a face or neck seal. A breathing mouth piece **22** is represented simply as a rectangle inside the helmet **12**, since its form may vary to encompass any of the standard designs of the art, and its connecting hose, or, more generally, breathing fluid conduit **24** will ordinarily be flexible within the suit. A hydraulic connection **26** to the interior of the suit is connected to a hydraulic hose line **28**. These are the elements of the suit itself; the other elements to be described will in practice conveniently be incorporated in a back pack which will ordinarily be mechanically connected to the suit as a matter of design.

The major unit of the hydraulic system is a pump **30**, which may conveniently be a centrifugal pump, driven by a motor or other suitable electrical power means **32**, which is powered by a power source not shown, but incorporated in rectangle **34**, back pack unit which also includes electronic control devices and a recorder. The suction and discharge connections of pump **30** are connected respectively to opposite ports **38** and **40** of electrically operable four-port reversible valve **36**. As may be seen from the schematic representation, which is based upon a conventional rotating-plug embodiment of such a valve, in the position shown port **38** is connected to port **42** and port **40** is connected to port **44**. A quarter turn rotation of the valve's central plug will connect port **38** to port **44** and port **40** to port **42**. Valve **36** is represented as driven by motor **46**, which may be connected by switch **120** or switch **122** to back pack unit **34**. In view of the limited rotation required, motor **46** need not be a conventional motor, but may be a limited-angle rotator having a permanent-magnet armature arranged to rotate between two electromagnet poles in a direction determined by selective operation of one electromagnet or by the polarity of the current fed to the windings of the electromagnets; or two separate rotators, one for each direction, may be used. Alternatively, four-port valve **36** may be a slide valve of the kind conventional in hydraulic systems, driven by a linear thrust device.

Port **42** of valve **36** is connected through check valve **54** to hose **50**, which extends to heating means in back pack unit **34**. (Valve **60** is closed for the present mode of operation.) In general, since an electrical power source must be provided for convenient operation of various other devices, it may be expected that a simple electrical resistance type heater of conventional design will be conveniently employed. It is, however, to be recognized that chemically reactive mixtures are known which react exothermally; and such mixtures could be provided in replaceable sealed cartridges which, by conventional connecting means, could be replaced more rapidly than a battery could be recharged, so that they might be preferable for particular applications. Regardless of the source of heat, the circuit from hose **50** through the heating means continues via hose **28** and returns thence to connection **26**, which permits the entry of heated water into the interior of suit **10**. (Suitable internal water distribution means which may comprise closed extensible heat exchanger means may be provided to distribute heat throughout the suit.) The hose line **50** is also connected to adjustable relief valve **52**. Check valve **56** is also connected to port **42** of valve **36**. When pump **30** is started, with the valve **36** in the position shown, water will flow through check valve **56** to port **42** of valve **36**, through valve **36** to port **38** and thence to the suction end of pump **30**, which will discharge it via ports **40** and **44** of valve **36** to fill a part of the system to be described hereinafter. When valve **36** is rotated a quarter of a turn (responsively to control signals generated in a manner to be described hereinafter) the suction end of pump **30** will be connected via ports **38** and **44** to the part of the apparatus to which it has previously fed water, and will discharge the water from its discharge end via ports **40** and **42** of valve **36** through check valve **54** into hose line **50** through the heat exchanger means in back pack unit **34**, into hose line **28**, and thence via **26** into the suit **10**, displacing air through bleed valve **20**. (The diver may open valve **20** sufficiently long to fill the suit to some desired level and then close it.) Since (as the subsequent description will make clear) valve **36** is rotated from one position to the other each time the driver inhales or exhales, there will be a cyclical intake of water via check valve **56** and a subsequent pumping of water into suit **10** until the pressure in suit **10** has built up to a value at which adjustable relief valve **52** will open and discharge the excess of water out into the surroundings. Pump **30** runs continuously and is preferably designed to provide a maximum discharge pressure somewhat higher than the desired pressure inside suit **10**. Adjustable relief valve **52** is adjusted to discharge at the desired pressure difference (e.g. 3.5 pounds per square inch) a sufficient volume of water to maintain the suit pressure at the desired value with respect to the outside water. Valve **52** is represented schematically as a conventional form of diaphragm valve with adjustable spring loading, the spring side of the diaphragm being exposed to the pressure of the external water through opening **58** so that its setting determines the difference between the absolute external water pressure and the internal suit pressure at which it opens.

The general arrangement of the breathing mixture system is as follows: Mouthpiece **22** is connected by hose **24** to two parallel flow paths, the first, for exhalation, being simply through check valve **62** and water extractor **64**, the second, for inhalation, being through check valve **66** and carbon-dioxide absorbing filter **68** in series. Water extractor **64** is useful simply to remove any stray slugs of water which enter the system from mouthpiece **22**, and may consist of a capped cylinder with suitable inlet and exit connections, containing a suitable capillary absorber such as a sponge, or may simply be a chamber with centrally located inlet and exit, and sufficient volume so that it can contain a useful volume of extracted water without having the water level rise to the level of the inlet and exit. Filter **68** is simply a conventional closed container for holding an absorber for animal metabolic products to be removed which, so far as present knowledge extends, consist only of carbon dioxide in the present application.

Both these parallel paths lead back via hose or tube **70** to hydraulically driven diaphragm-type gas pump **72** whose gas chamber **74** is fed gas from lever-operated breathing fluid mixture replenishment valve **76** whenever the diaphragm **78** of pump **72** rises above a certain predetermined displacement. The volume of gas chamber **74** is deliberately made a number of times the volume of a normal inspiration, so that it contains a reserve supply of breathing mixture. This has the advantage that the frequency of operation of valve **76** is appreciably less than the breathing rate; and it also permits moderate changes in operating depth to be accommodated without the necessity of venting excess gas for a decrease in depth, or of adding breathing mixture through valve **76** for increase in depth. A bleed valve **80** is provided for venting air from the lower chamber **82** of pump **72**, which is connected by hose or tube line **84** to port **44** of four-port valve **36**. The feed to valve **76** may be of breathing mixture fed through automatically closing quick-disconnect coupling **86** through pressure regulator **88** and valve **90** from a breathing air (or, more generally, breathable fluid) tank **92**. Such a supply is useful both for initially charging the air system with air or for emergencies in the event that some part of the more sophisticated oxygen replenishment system should fail. However, the intended normal mode of operation is by supply of oxygen through pressure regulator **94** and solenoid valve **96**, from low volume oxygen tank **98**. To effect the addition of oxygen as required, the outlet side of solenoid valve **96** is connected directly to the gas-system side **74** of diaphragm **78**. An oxygen partial pressure sensor **97** is connected to the gas system in the line **70** from pump **72** to the diver. Whenever the partial pressure of oxygen in the gas system falls unacceptably low, the output signal of partial pressure sensor **97** indicates this fact, and causes control circuitry in back pack unit **34** to cause solenoid valve **96** to open and emit oxygen directly into the gas chamber **74** of pump **72**. The diver's normal inhalations will cause samples of gas from the gas chamber **74** to be drawn past the partial pressure sensor **97** which, when it senses that the oxygen content of the breathing mixture has been raised to the maximum acceptable value, will provide back pack unit **34** with a signal indicative thereof, and circuitry in back pack unit **34** will permit solenoid valve **96** to close. Since the consumption of oxygen during a given breath is only a small fraction of the total volume of gas inhaled, at normal atmospheric pressure, and decreases in proportion to the growth of pressure, the admission of oxygen directly into the low-pressure breathing circuit does not impair the metering effect produced by the operation of pump **72**. Introduction of oxygen into the low-pressure system is desirable for a particular reason. If the diver rises suddenly, the gases in the low-pressure breathing system will expand, and be vented through valve **100**. Under these conditions diaphragm **78** will not rise high enough to operate the lever of lever-operated valve **76**; if reliance were placed on flow of oxygen from the high-pressure side of valve **76**, the diver would be deprived of oxygen during his ascent.

When the apparatus is employed to simulate conditions in a space suit, it is desirable to measure and record the diver's oxygen consumption. This is accomplished by making tank **98** small in comparison with the total volume of oxygen carried by the diver. A pressure transducer **102** is connected to measure the oxygen pressure in tank **98**, and its signals are conveyed to the electrical control system in back pack unit **34**, which is designed to open solenoid valve **104** whenever the pressure in tank **98** falls to such a value that it needs to be recharged with oxygen from oxygen supply tank **106**, which is connected through valve **108** to the input side of solenoid valve **104**, to pressure gauge **110**, and to pressure regulator **112**. The low-pressure, or regulated, side of regulator **112** is connected through emergency valve **114** directly to the parallel circuits consisting of check valve **62** and water extractor **64**, and of check valve **66** and filter **68**. In an emergency during shallow water diving (e.g. 30 feet) and when accessory tank **92** is not connected, it is possible by manually operating valve **114** to feed oxygen directly from tank **106** bypassing valve **104** and pressure regulator **94** and solenoid valve **96**. This mode of operation is not the normal one, but is provided for safety. Relief valve **100** is connected to the parallel paths, its diaphragm being subjected on one side to the pressure of water inside the suit **10** via hoses **28** and **50**, the other side being subject to the pressure in the gas system, rising to discharge gas from the gas system whenever the pressure in the gas system is, for any reason, more than a safe value (e.g. one-half pound per square inch) above the suit pressure. Valve **100** will vent excess pressure if the regulating system fails, or if the diver rises through the water to a level where the water pressure is sufficiently lower so that the reserve expansion volume **74** in diaphragm pump **72** is inadequate.

The normal mode of operation of the interacting hydraulic and gas systems depends upon differential pressure switch unit **116**. This may be, and is represented as, a diaphragm-operated switch unit having the lower side of its diaphragm or pressure difference sensing control **118** exposed to the pressure of water fed to suit **10** through hose **28**, and having its upper side exposed to the pressure of air fed to mouthpiece **20** through hose **24**. When the air pressure is greater than the water pressure, the diaphragm is moved downward and closes lower switch **120**; and when the air pressure is less than the water pressure, the diaphragm is displaced upward to close upper switch **122** contacts. Assuming that the air and water pressures are initially equal, when the diver inhales, reducing the pressure in hose **24**, the diaphragm of control **116** will move upward, closing its upper switch **122**. This will close a circuit from back pack unit **34** which will operate motor **46** so as to turn valve **36** to the position represented in the figure. Water at the discharge pressure of pump **30** will then be applied to diaphragm **78** of pump **72**, causing it to move upward and force breathing mixture from its upper chamber **74** through filter **68** (which absorbs any carbon dioxide) and check valve **66** through hose **24** to mouthpiece **20**. Thus the diver need produce initially only the slight vacuum required to operate switch unit **116** (which may be of the order of one-tenth of a pound per square inch) to be supplied with breathing air. Check valve **62** will be closed during this part of the cycle. When the diver subsequently exhales, raising the pressure slightly in mouthpiece **22** and hose **24**, diaphragm **118** will be depressed, closing lower switch **120**. This, by its connection to back pack unit **34**, will cause motor **46** to turn in the proper direction to place valve **36** in its alternate position, not here represented, causing the intake end of pump **30** to be connected to pump **72** and apply suction to the diaphragm **78**, causing diaphragm **78** to move downward, creating a vacuum which will withdraw the exhaled mixture through check valve **62** from mouthpiece **20** via hose **24**. Thus the diver's exhalation is assisted by the action of pump **72**. Check valve **66** will be closed during this part of the cycle. It is evident that the diver's breathing, both inhalation and exhalation, need be only against the small pressure difference required to move diaphragm **118**. When consumption of oxygen causes partial pressure sensor **97** to cause solenoid valve **96** to open and admit oxygen to the low-pressure system, it flows through pressure regulator **94** from oxygen tank **98**, causing a reduction in the pressure in tank **98** which is sensed by pressure transducer **102**, which transmits to the circuitry in back pack unit **34** a signal representative of the reduced pressure. A recorder may be incorporated in back pack unit **34** to record the pressure existing in tank **98** at any moment; and when the pressure in tank **98** falls to a predetermined lower value (still high enough to operate pressure regulator **94** and feed oxygen to valve **96** and thence to the diver) circuitry in back pack unit **34** causes solenoid valve **104** to open, permitting oxygen to flow from supply tank **106** through valve **108** and into tank **98** until pressure transducer **102** signals that the pressure in tank **98** has reached a predetermined upper limit, responsively to which the circuitry in back pack unit **34** permits solenoid valve **104** to close. Since the record of the pressure variations in tank **98** indicates the rate of consumption of oxygen from tank **98**, and also how often tank **98** is refilled from tank **106**, by recording the indications of transducer **102** in a recorder in back pack unit **34** a complete record of the rate of oxygen consumption by the diver is provided. The sensitivity of the system may be adjusted by making tank **98** sufficiently small so that the withdrawal of a given volume of air to be measured will produce a pressure change in the tank **98** sufficiently great to be readily sensed and recorded accurately. Putting filter **68** in the inhalation circuit has the advantage that the air to be breathed is filtered as close as possible to the point of consumption; it could be placed in series with check valve **62** in the exhalation circuit.

Since the partial pressure of oxygen is limited to approximately that existing in the atmosphere at the earth's surface, it is necessary to add a diluent gas to compensate for increases in pressure as the diver descends, or to replace gas which may be leaked from the system. Diluent tank **124**, connected through manual valve **126** and pressure regulator **128** to lever-operated valve **76**, provides this function. If the residual gas in the upper chamber **74** of diaphragm pump **72**, including any oxygen supplied through solenoid valve **96**, is too small to produce pressure adequate to keep diaphragm **78** in its approximately normal range of motion, diaphragm **78** will rise enough to operate the lever of lever-operated valve **76**, and admit diluent gas from tank **124** in sufficient volume to allow diaphragm **78** to return to its normal range of motion. The frequency of this action will depend upon the tightness of the helmet and its connections, and the extent to which the diver remains at an approximately constant depth. If he descends, diluent must be admitted; when he ascends again, breathing air, including both diluent and oxygen, will be vented through valve **100** (assuming he exceeds the reserve capacity or volume in the diaphragm pump, gas chamber **74**); if he then again descends, more diluent will be consumed. Thus each descent and ascent beyond the designed reserve volume constitutes a cycle of drain upon the diluent supply.

It is evident that the various features of my invention other than those whose sole function is to assist in the pressurization of the suit are useful for general diving purposes. Obviously, the adjustment of valve **52** so that it will open at a trivial pressure differential will reduce the internal suit pressure to one negligibly different from that of the surrounding water. The recirculation of heated water which results from continuing the connection to connection **26** may well justify its continued use, although it would be possible to forego this advantage. But connection **26** (or even suit **10**) and hose **28**, valves **54**, and **56**, and relief valve **52** may simply be eliminated, port **42** of four-port valve **36** being open to the surrounding water (preferably through a strainer). The water sides of the diaphragms of valve **100** and switch unit **122** will also be left open to the pressure of the surrounding water. This latter mode of operation will have the advantages of self-contained breathing apparatus in which oxygen is supplied automatically as required without a substantial change in the partial pressure of oxygen within the system, and carbon dioxide is automatically absorbed; but it will have the particular novel advantages that both inhalation and exhalation occur with only slight pressure differentials in the diver's lungs. (This being understood to be a particularly valuable attribute at great depths where the greatly increased density of the atmosphere otherwise causes a substantial amount of energy to be required to breathe.)

However, the embodiment represented in the figure has provision for operation with negligible pressurization of suit **10**. This may be achieved by opening valve **60**. Then valve **54** will be bypassed, and suit **10** will be connected for flow in both directions via connection **26**, hose **28**, back pack unit **34**, and hose **50** to port **42** of four-port valve **36**. Then, as the diver exhales a given volume of breathing mixture through mouthpiece **22**, diaphragm **78** will descend to displace from chamber **82** approximately the same volume of water, which will flow into the suit **10**, becoming heated in its passage through back pack unit **34**. When the diver inhales, the diaphragm **78** will rise, admitting into chamber **82** an approximately equal volume of water which will flow out of suit **10**. Thus there will be little occasion for discharge of water through valve **52**, since whatever water the diver displaces in inhaling will be received into chamber **82**, and then returned (through the heating means in back pack unit **34**) when he exhales. Thus very little heated water will be thrown away; and further breathing will not involve any major flexing of the suit, since the total volume inside the suit (volume of diver plus volume of filling

water) will remain approximately constant. It is evident that this mode of operation will minimize loss of heated water. A similar mode of operation is possible with suit **10** pressurized above the pressure of the external water by opening valve **60** and adjusting the output pressure of pump **30** to approximately that at which valve **52** is on the verge of opening. Indeed, it is possible to mount electrical contacts in mechanical connection with the diaphragm of valve **52** and use them in an on-off servo arrangement to control the speed of motor **32** so that the output pressure of pump **30** is maintained, on the average, at the value described. This has not been illustrated because the usual purpose of pressurization is to simulate space operations; and such simulation may conveniently be done at moderate depths where water temperatures approximate surface temperatures so that heat conservation would not be so necessary as at the cold of greater depths.

What is claimed is:

1. An underwater diving helmet and breathing fluid supply means comprising in combination:

a hermetically closable helmet means adapted to be worn by a diver;

breathing fluid conduit means connected to said helmet for the ingress and egress of a breathing mixture thereto;

an electrical power means;

a hydraulic pump means operatively connected to said power means;

a reversible valve means connected to said pump means;

a pressure sensitive diaphragm means connected to said breathing fluid conduit means to forceably supply or exhaust breathing fluid to the helmet and also connected to said reversible valve means;

a filter means located in said breathing fluid conduit means between the helmet and diaphragm means;

a breathing fluid mixture replenishment valve means connected to said diaphragm means;

a source of breathable fluid connected to said valve means;

a pressure difference sensing control means to sense the difference in pressure between fluid in the diver's helmet and ambient water pressure;

and switch means connected to said sensing control means to control the direction of movement of said reversal valve means depending on the pressure difference sensed.

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