July 20, 1943. M. E. NOHL 2,324,716

RESPIRATORY APPARATUS

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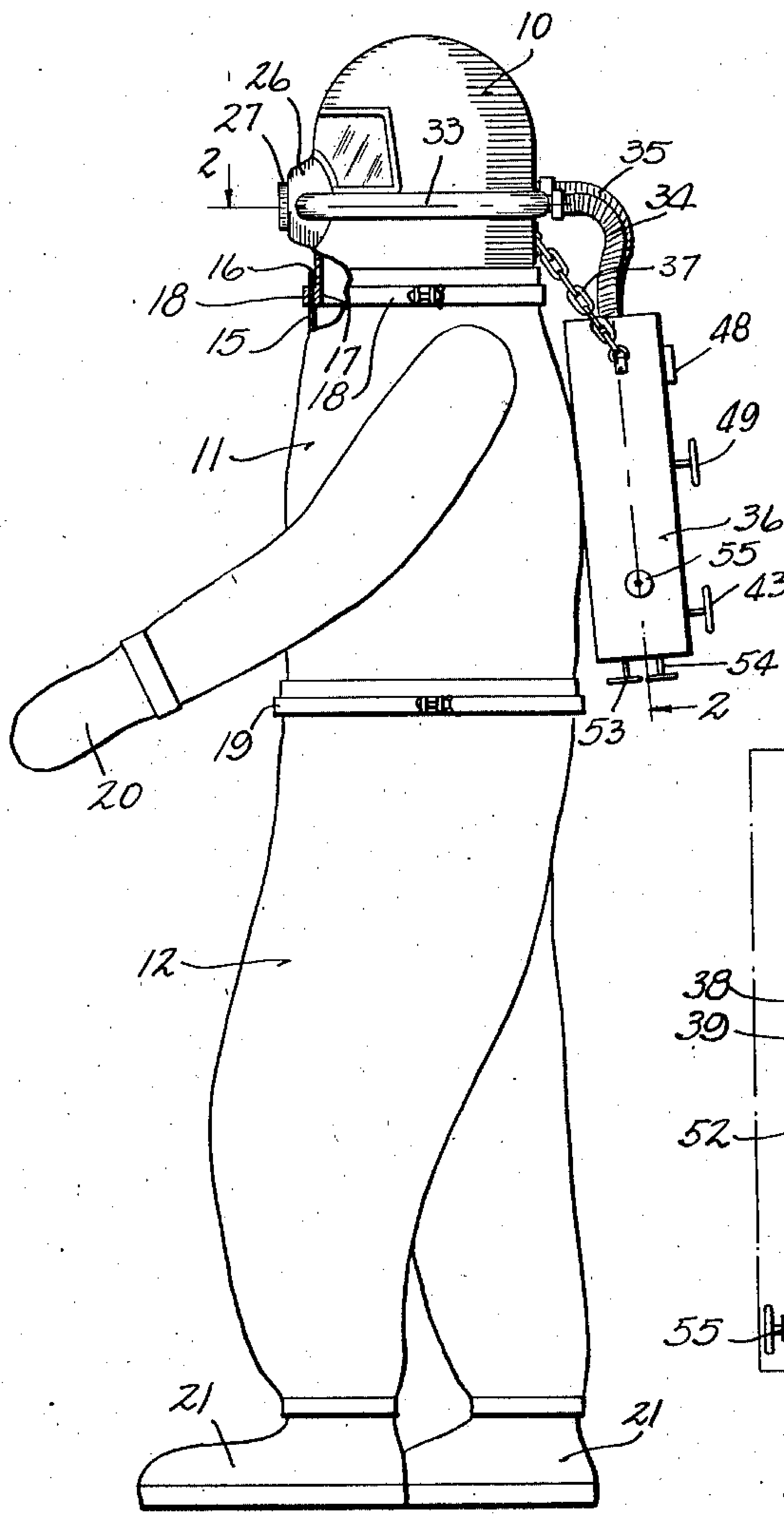

Fig. 1.

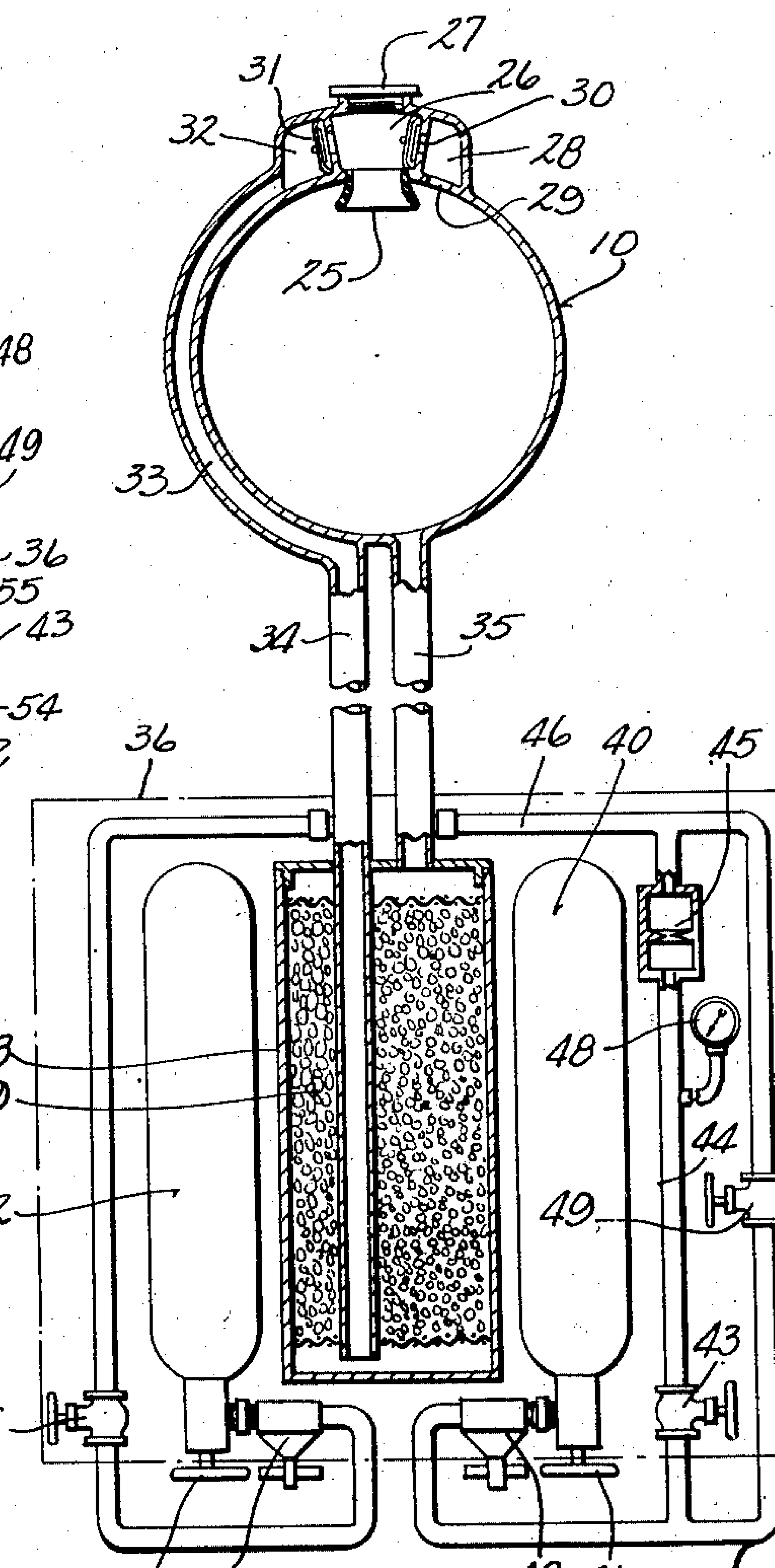

Fig. 2.

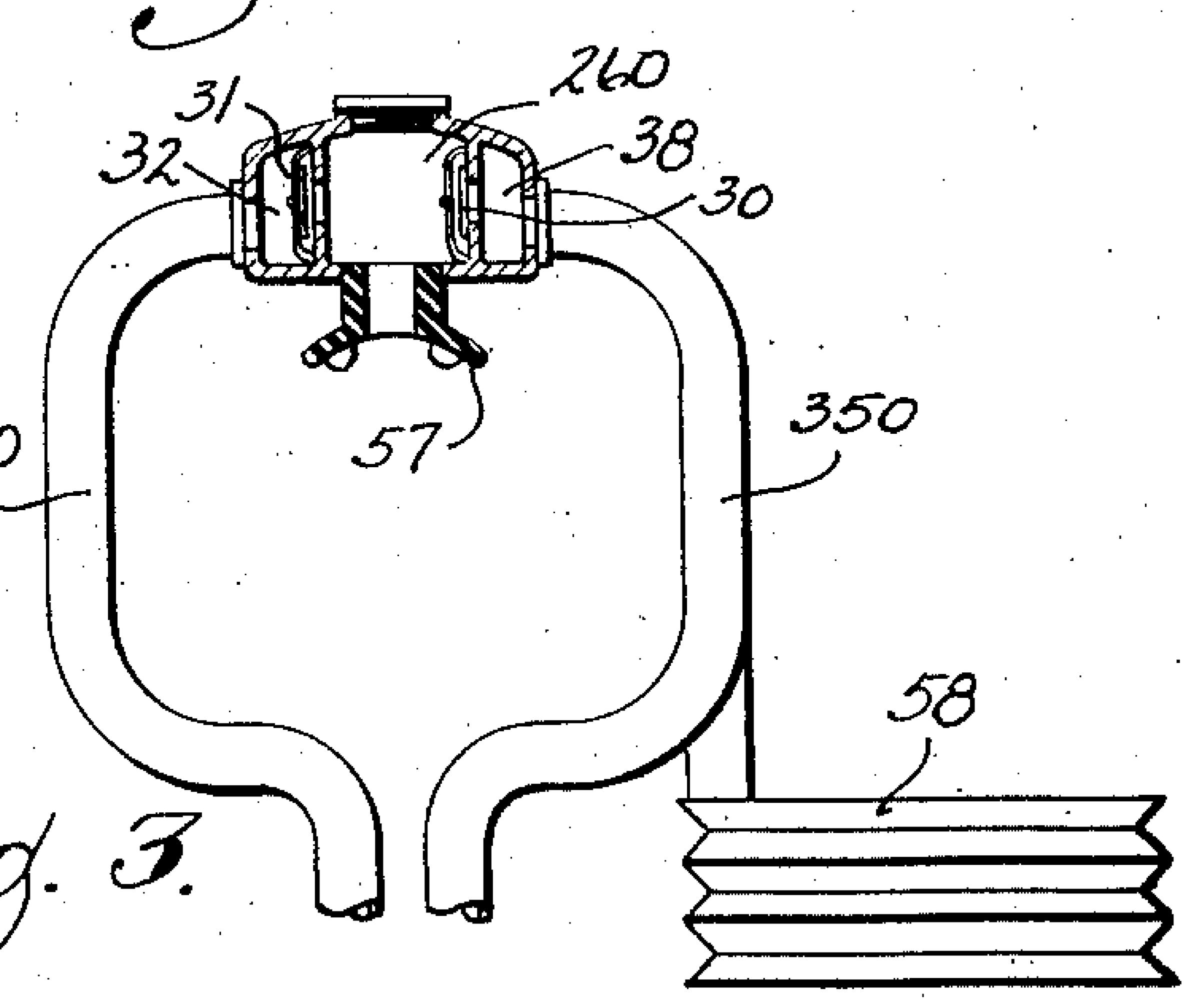

Fig. 3.

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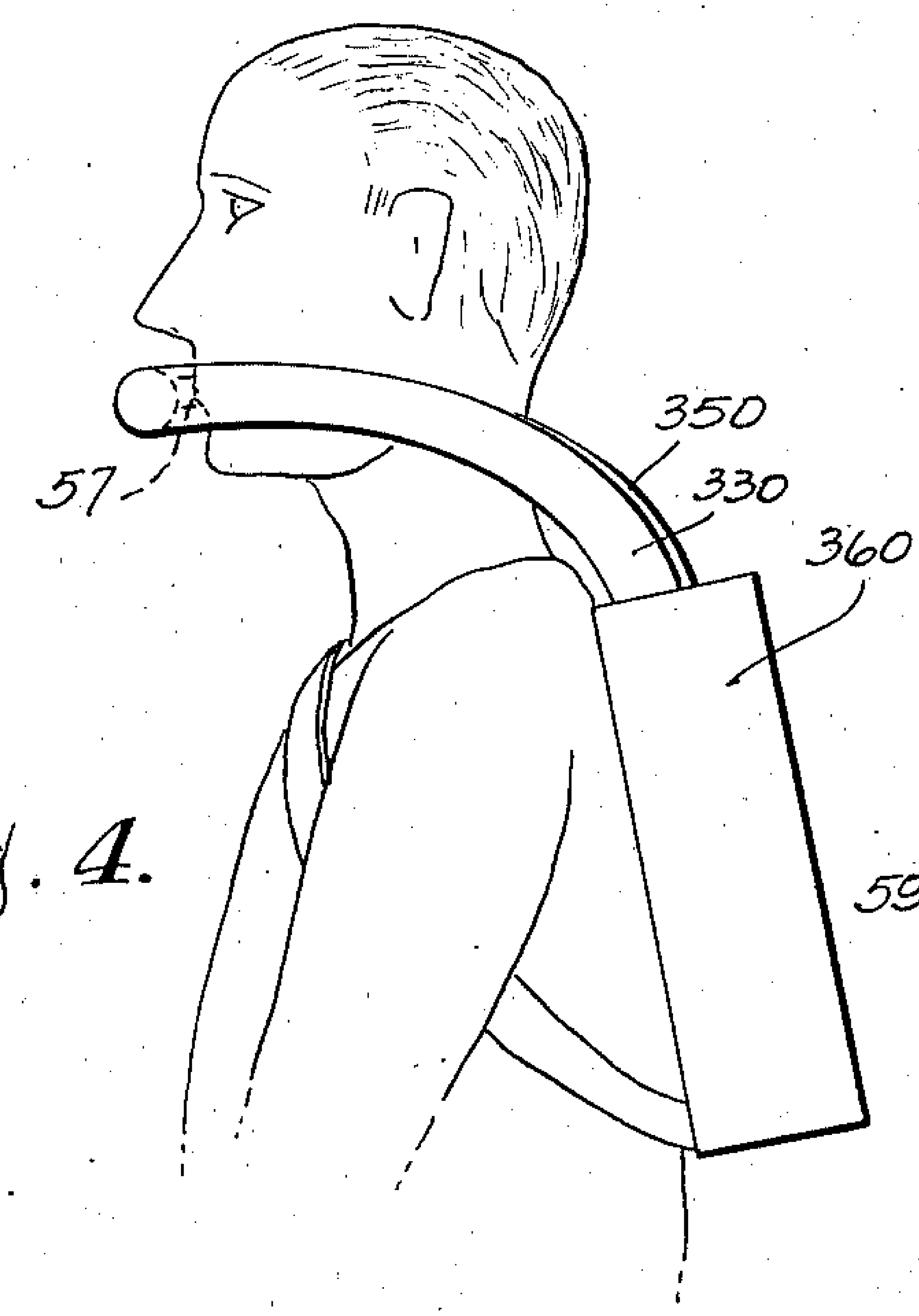

Fig. 4.

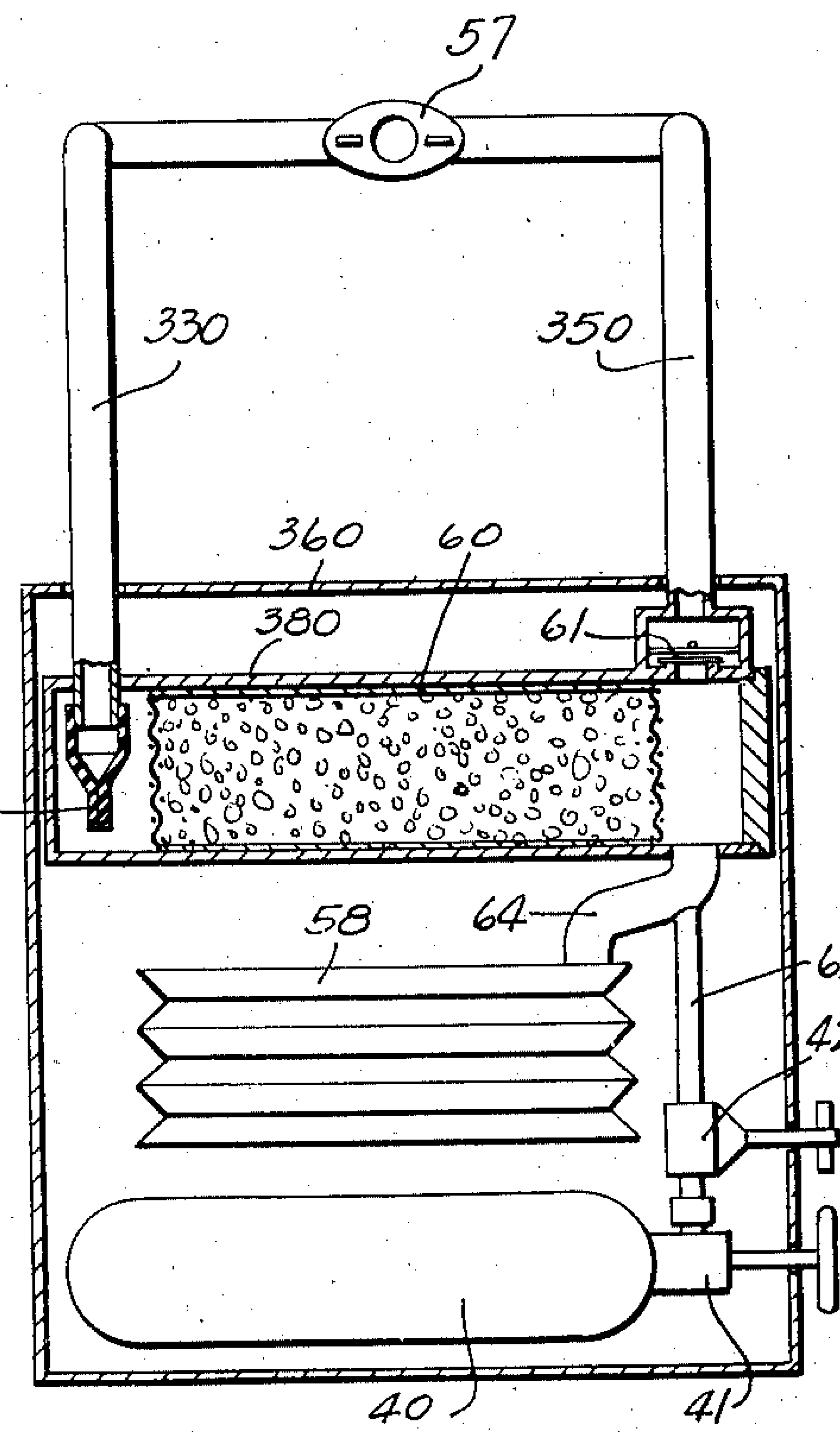

Fig. 5.

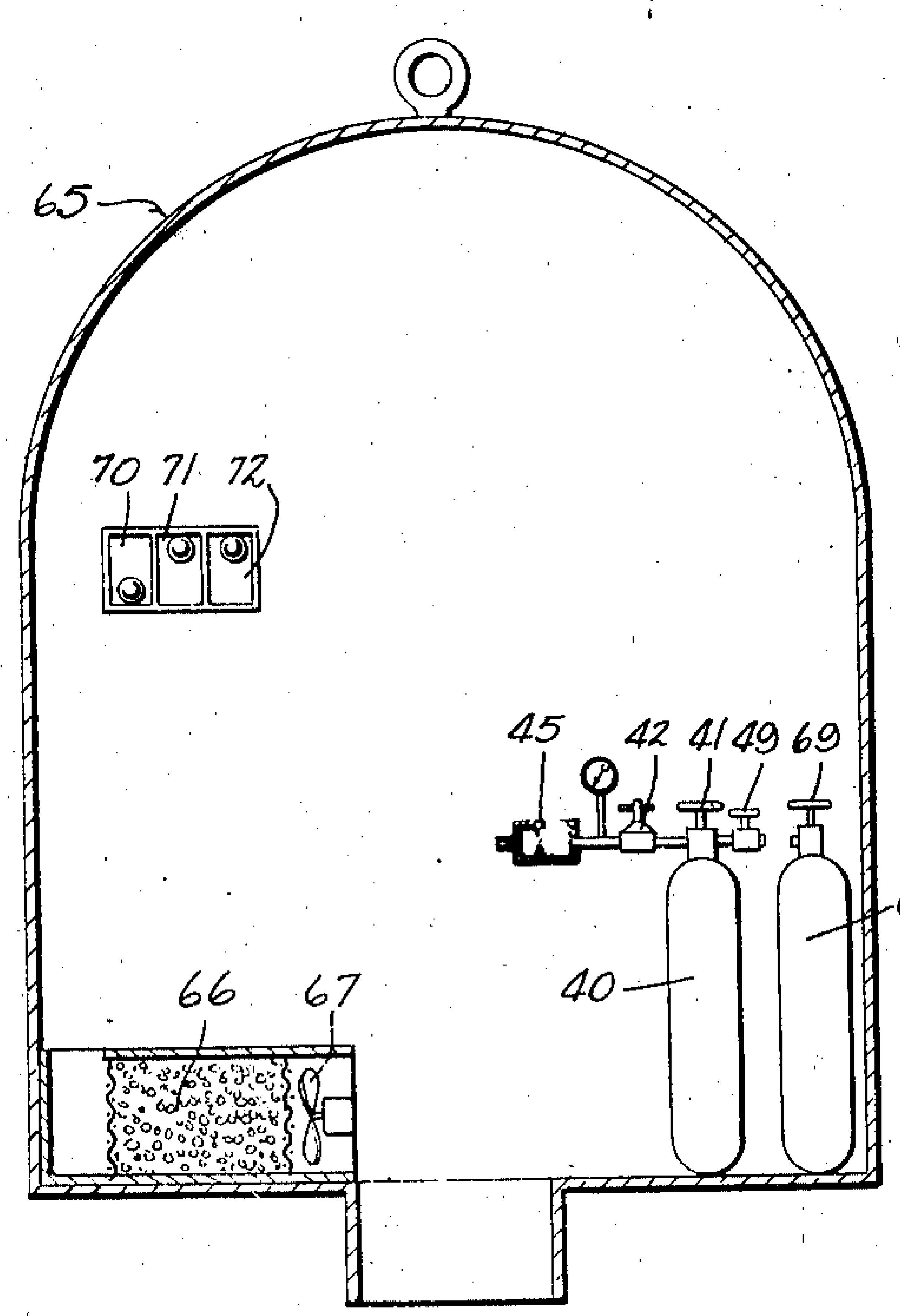

Fig. 6.

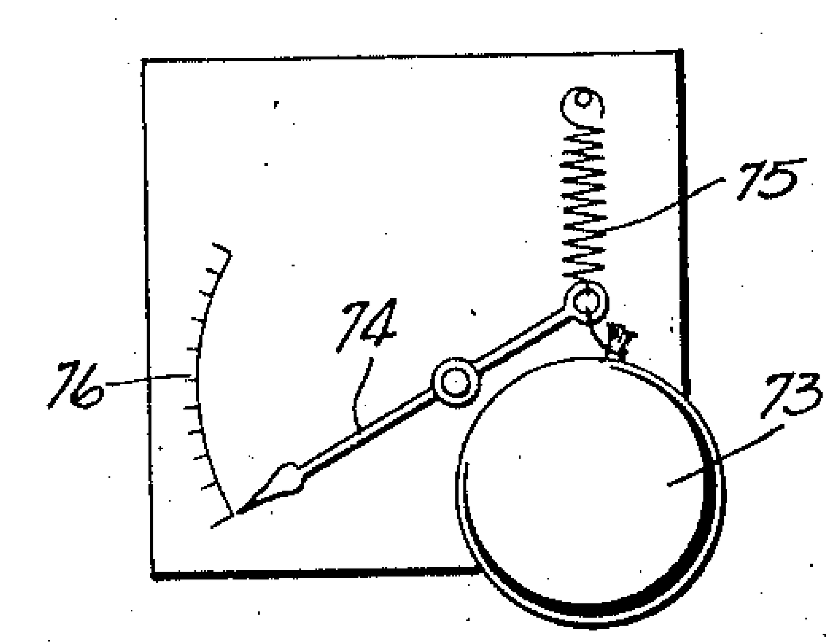

Fig. 7.

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RESPIRATORY APPARATUS

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13 Claims. (Cl. 128—191)

This invention relates to improvements in respiratory apparatus.

The device may be used for diving in water in the form of a diving suit, helmet or mouthpiece, or diving bell. In the alternative, the device may be used to promote proper respiratory pressure conditions in tunnels or other enclosures.

It is the object of the invention to provide novel and improved means for supplying in proper proportions and at proper pressures any natural or artificial mixture of oxygen with other gases for respiration purposes, such mixture being hereinafter referred to as air, whether it consists of oxygen and nitrogen or, as is preferred for diving purposes, of a mixture of oxygen with helium, or some other relatively physiologically inert gas.

More specifically, it is one of the objects of the invention to provide, in preferred embodiments, two sources of gas available to the respiratory organs of the user, one source preferably constituting pure oxygen delivered at a substantially constant rate to replace the oxygen consumed to meet metabolic requirements, and the other source comprising air supplied under the direct control of the operator to maintain the appropriate pressure in the dress or chamber without altering the ratio of oxygen.

It is another specific object of the invention to provide a circulatory respiratory system with means for handling the variation of displacement occasioned by the breathing of the operator, and means for automatically removing carbon dioxide impurities and replacing the consumed oxygen at a substantially constant rate irrespective of pressure, the pressure being separately controllable by the operator.

Another specific object of the invention is to provide a device of this character with suitable automatically and manually controllable means for regulating the constituent proportions, direction of flow, and pressure of gases in a closed system which are used for respiration by an operator within the system.

Other objects have to do with means for giving the operator a direct reading of the proportionate constituents of the air which he is breathing at any given time. Still other objects will be apparent to those skilled in the art from the following disclosure of the invention.

In the drawings:

Fig. 1 is a view in side elevation of a diving dress embodying the invention, this dress being particularly designed for deep diving.

Fig. 2 is a diagrammatic view of a portion of the apparatus shown in Fig. 1 as it appears on the line 2—2 of Fig. 1.

Fig. 3 is a view similar to Fig. 2 showing fragmentarily a modified embodiment of the invention.

Fig. 4 is a fragmentary view in side elevation, of a further modified embodiment of the invention used particularly for shallow diving or for mine work.

Fig. 5 is a view on an enlarged scale showing diagrammatically in section the device illustrated in Fig. 4.

Fig. 6 is a view in section through a diving bell in which the invention is incorporated.

Fig. 7 is a detail view of a modified gauge for indicating the proportionate constituents of the air.

Like parts are identified by the same reference characters throughout the several views.

The suit shown in Fig. 1 is of special construction. It is made in three units to comprise a helmet **10**, a jacket **11**, and a pants unit **12**. The units **10** and **11** are connected together in the manner indicated in section in Fig. 1. The jacket unit **11** is made of flexible material such as rubber, ending in a tubular neck portion **15** which is beaded over at **16** to engage over the shouldered terminal tube **17** of the helmet and is clamped thereon by the clamp ring **18**. A similar clamp ring **19** is used at the waist of a diving suit to hold the pants unit and jacket unit together. The jacket unit is provided with tight cuffs or with integral mitten or glove extensions **20** and the pants unit has integral shoe or boot extensions at **21** so that the whole suit is hermetically sealed about the operator. The space within the flexible diving dress communicates freely with the space within the helmet.

The respiratory apparatus comprises a mask at **25** which fits closely about the mouth, or mouth and nose, of the operator so that the air which he breathes is not drawn directly from the interior of the suit but from the valve chamber **26** into which he also respires. The plug **27** removably screwed into the front of valve chamber **26** furnishes a speedy way of giving the operator access to exterior air when desired.

The valve chamber **26** communicates at one side with the intake chamber **28** which in turn communicates through opening **29** with the interior of the helmet and consequently with the entire interior of the suit. A check valve at **30** prevents any return of gases to the suit through the intake chamber **28**.

At the other side the valve chamber **26** communicates through check valve 31 with an outlet chamber 32 from which a pipe 33, preferably constructed integrally with the helmet, at the exterior thereof, leads around the helmet, to the rear, where connections are made to a flexible pipe 34. A similar flexible pipe 35 leads the purified return air back into the diving suit through the rear of the helmet.

The pipes 34 and 35 afford communication with the air proportioning, purifying and pressure regulating mechanism carried by the case 36 which is suspended, as by chains 37, on the operator's back. The mechanism which may desirably be housed within the case 36 is shown diagrammatically in Fig. 2 without any effort to show the parts in any necessary relative position, the arrangement being a matter of design.

The exhaled air delivered through pipe 34 to the case 36 passes to the bottom of a canister 38 which may be filled with any usual means (such as soda and lime) of absorbing carbon dioxide. Lime is one of the ingredients usually used for this purpose. The exhaled breath of the operator passes upwardly through the lime or other chemical purifying agent incorporated at 39 in the canister and issues from the top of the canister into pipe 35 for return to the diving suit.

It will be understood that when the air was taken into the operator's lungs its oxygen was consumed and carbon dioxide was substituted. Consequently the removal of the carbon dioxide from the air in the canister 38 leaves the air with insufficient oxygen to supply the requirements of the operator.

Consequently a flask of oxygen under high pressure is supplied at 40 within case 36. A cut-off valve 41 controls the flow of the oxygen to the reducing valve 42 in which its pressure is cut down to any desired low level which the metering apparatus can conveniently handle. Another manually controlled valve may be incorporated at 43 in the pipe 44 which leads to the metering orifice 45.

At any given setting of reducing valve 42 the orifice at 45 will pass oxygen at a substantially constant rate of flow to pipe 46 which leads to pipe 35, whereby the oxygen is mingled with the oxygen-depleted air which is being restored from the canister to the diving suit. The entire interior of the diving dress acts as a mixing chamber within which the oxygen is freely mixed with the depleted air before being consumed by the operator through the mask 25 as previously described. The diving dress also acts as a bellows, expanding and contracting slightly to compensate for the expansion and contraction of the operator's lungs as he breathes. There is really very little bellows movement of the diving dress required because the operator, as he breathes, moves his chest and diaphragm in such a way as to increase the space within the diving dress in proportion to the decrease of capacity of his lungs and vice versa.

A pressure gauge at 48 enables the operator's assistants to know, before he commences his dive, how much pressure he is supplying through the reducing valve 42, and consequently the rate of oxygen flow is readily ascertainable. Such a gauge might be mounted inside the helmet for observation by the diver or might be omitted or removed when the proper flow has been determined.

For emergencies a by-pass valve is provided at 49 in the by-pass pipe 50 whereby the operator can supply himself with additional oxygen as desired to compensate for any special exertion on his part without changing the metered flow of oxygen as established by the reducing valve 42 and the metering orifice 45.

It is a big advantage of the type of respiratory apparatus herein disclosed that it is not necessary to use air as a means of supplying fresh oxygen, and it is not necessary to use undiluted oxygen as a means of compensating for the increased pressures encountered in submersion.

Pressures are compensated for by a separate supply of air under pressure in the container 52 which has a cut-off valve 53, a reducing valve 54, and a manually operable exposed cut-off valve 55 which the operator may manipulate at will to supply additional air to the suit as he descends. This additional air is preferably supplied to the tube 34 through which the gases exhaled from his lungs pass to canister 38.

In the greatly simplified apparatus shown in Fig. 3 the operator wears no helmet to enclose his head. He need not even have a complete mask, but may simply hold the mouth grip 57 in his mouth, inhaling from and exhaling into the valve chamber 260 from which the exhaled air passes through check valve 31 to the outlet chamber 32 and thence through pipe 330 to a container which he carries on his back and which holds the apparatus shown in Fig. 1 and Fig. 2. The purified and re-oxygenated air is returned through pipe 350 directly to the inlet chamber 38 where it enters the valve chamber 260 subject to control by the check valve 30. In this instance a bellows 58 is connected to the return pipe 350 as a means of receiving surplus air during the exhalation of the operator and supplying the gases to the operator during his inhalation, thus making it possible for the operator to keep his nose closed and to breathe in and out through his mouth in a closed respiratory system which functions without loss of air.

Still greater simplification is achieved in the device shown in Fig. 4 and Fig. 5, in which the valves are not directly associated with the mouthpiece. In this device the mouthpiece 57 corresponds exactly with that shown in Fig. 3, as do the pipes 330 and 350 which receive gases from and return air to the mouthpiece. Within the case 360 pipe 330 terminates in a rubber check valve 59 of well known type which is disposed in one end of the canister 380. Within the canister is a removable cartridge 60 which contains the purifying chemicals and from the outlet of the chamber a check valve 61 permits the return of the air through pipe 350 to mouthpiece 57. Even though the check valves are located in remote ends of the pipes 330 and 350 respectively, they nevertheless maintain a unidirectional flow of gases through said pipes to and from the mouthpiece.

In this device there is no means for supplying air under pressure since the device is intended only for light work either out of water or in shallow water. The oxygen is housed in the cylinder 40 as above described, which is supplied with a shut-off valve 41, and reduction valve 42 beyond which a pipe 63 leads to pipe 64 which affords communication between the bellows 58 and the end of the canister 380.

In the diving bell 65 (Fig. 6) the breathing of the operator is unconfined and the air is purified by circulating the air within the bell constantly through the mass of chemicals at 66 by means of a fan 67. Similar apparatus may be used in caissons and other confined places.

The oxygen cylinder **40** with its usual cut-off valve **41** and reducing valve **42**, supplies oxygen to a metering orifice at **45** from which the oxygen issues directly into the interior space of the diving bell. When air pressure is desired to counteract the water pressures encountered as the bell descends, air is admitted from the compressed air receptacle **68** under the control of the hand valve **69**.

When the air in the bell **65** becomes deficient in oxygen, as may be the case when there is any unusual exertion required of the occupants, the occupants may open the by-pass valve **49** to permit an additional flow of oxygen from the cylinder **40** directly into the interior of the bell without changing the setting of the metering valve **45** or reducing valve **42** which normally maintains an inflow of oxygen exactly calculated to serve the requirements of the operator or operators.

It is not easy for the operators to ascertain by their own feelings when the supply of oxygen is becoming deficient or excessive. As a means of indicating the proportion of oxygen in the air which they are breathing within the bell, it is possible to provide a gauge. Two such gauges are shown in Figs. 6 and 7 respectively, which may be used either in the diving suit or in the bell.

In Fig. 6, I have illustrated three small cages at **70**, **71** and **72**, within which I have provided three small balloons inflated to like dimensions under like pressures. These balloons contain varying proportions of oxygen and inert gas. For example, the balloon in cage **70** may contain thirty percent of oxygen and seventy percent of helium. The balloon in cage **71** may contain twenty-one percent of oxygen and seventy-nine percent helium. The balloon in cage **72** may contain fifteen percent oxygen and eighty-five percent helium. As the heavy oxygen constituent of the air within the diving bell or other enclosure varies, its buoyancy will vary and accordingly the balloons will rise or fall to indicate the approximate proportions of the constituents of the air. The balloons are indicated in the positions which they will occupy for one desirable range of oxygen content. If the balloon in cage **70** should rise it will indicate the presence of an excess of oxygen. If the balloon in cage **71** should fall it would indicate an oxygen deficiency which would become extreme if the balloon in cage **72** should fall.

The gauge shown in Fig. 7 uses a single balloon at **73** inflated with a mixture of gases and including oxygen and helium or other inert gas buoyed from a carefully balanced pointer **74** which is pivoted and suspended by a very light spring at **75**. The free end of the pointer moves over a calibrated scale **76** which would indicate the proportion of oxygen in the air on which the balloon **73** is buoyed.

As above indicated, helium is preferred to nitrogen as an inert gas with which to make up the artificial air to be used within the respiratory apparatus and stored under high pressure in the flask **52** or **68**. It is important that such air contains oxygen in the desired proportion to the inert gas also contained therein so that when auxiliary air is introduced to compensate for a change in pressure it is not necessary to vary in any way the normally automatic feed of oxygen into the apparatus.

It is also important that the oxygen contained in the air pressure tank is not relied upon to supply the metabolic requirements of the user. If it were, it would be necessary either to make up a mixture excessively rich in oxygen, which would involve a mixing problem, or to expel from the diving suit the proportion of inert gases which would become excessive as the oxygen was consumed. This would necessitate too bulky and heavy storage flasks.

Respiratory apparatus embodying this invention is self-contained in the sense that it may be worn or used without requiring supply lines. The operator is unhampered and unrestricted in the sense that he would be if he were required to maintain a hose affording communication between his helmet and a source of air supply.

The indicating apparatus herein disclosed will function satisfactorily when helium is used as the inert gas for admixture of oxygen to constitute the artificial air breathed by the operator. The molecular weight of oxygen is 32 and the weight of helium is only 4. Consequently a comparatively slight change in composition of the air will result in a very substantial change in its buoyancy. The change in buoyancy would be much less easily perceptible if the oxygen were mixed with nitrogen.

In the apparatus shown in Figs. 4 and 5 the apparatus should preferably be flushed with pure oxygen before being used. The necessity of admitting additional oxygen in this apparatus would be indicated by the partial collapse of the bellows. In this device, which can be used down to a depth of sixty feet for a period of three hours without injury, the admission of oxygen is preferably under the direct control of the operator, no automatic control being provided. Optionally, this apparatus can be used for some purposes in connection with the complete diving suit. This would make it unnecessary to employ a bellows and the compression tank **52** could be eliminated or, like tank **40**, it could be filled with oxygen.

Similarly in Fig. 3, in which the air pressure is used only to distend the bellows **58**, it is possible for some purposes, to dispense with the air and to use pure oxygen as in Fig. 5.

While I have referred to the flask or compression chamber **40** as containing pure oxygen, it will be understood that a mixture of gases extremely rich in oxygen might be substituted without change in principle so far as the broad purposes of the invention are concerned, this being in contradistinction to the use of flask or compression chamber **52** for the storage of air or other gaseous mixtures of an oxygen content substantially like that required by the operator, so that the controlled admission of the air from this tank will not disturb the balanced rate of oxygen admission from the other tank.

I claim:

1. A respiratory system comprising means providing a closed respiratory circuit, an oxygen pressure chamber communicating with said circuit and provided with means for automatically supplying substantially constantly in accordance with the operator's requirements a predetermined admission of oxygen to said circuit, and an air pressure chamber communicating with said circuit and provided with a control valve independent of said oxygen supplying means and independently manually operable for the admission of air to said circuit for controlling the pressure therein, said air pressure chamber containing air having an oxygen content substantially corresponding to the operator's requirements, whereby the admission of air to the circuit will not upset the predetermined rate of supplying oxygen thereto, said system comprising a self-contained

portable unit, all of which is assembled to be carried by a person using the system and to whom said air admitting control valve is directly accessible.

2. In a device of the character described, a face-piece adapted to supply air to the user and to receive air from the user, a circulating system including an air purifier and valve controlled pipes affording communication between said face-piece and purifier in a closed system, and means comprising a flexible wall in said system, together with means for supplying oxygen to said system at a substantially constant rate proportioned to the consumption of oxygen in said system by respiration and independent means for varying the pressure exerted interiorly of said system on said wall, said independent means comprising a source of air under pressure in excess of that to which said system is subject, said air containing oxygen in substantially the proportion at which oxygen is maintained in said system by said oxygen supplying means, the whole device being unitarily assembled for self-carrying by the user, and said independent pressure varying means including a valve controlling the admission of air to said system and directly manually operable by the person carrying the system.

3. A diving helmet provided internally with a mask for controlling the user's inspiration and expiration, an air conditioner communicating with said mask, and valve means controlling such communication for inducing unidirectional air flow between said conditioner and mask.

4. In a device of the character described, the combination with a diving helmet, of an internal mask adapted to fit the diver's face to receive his breath and return to him air for breathing, air conditioning apparatus, and means built into said helmet providing communication from said mask to said apparatus and from said apparatus to said mask, said means including air passage means provided with check valve means for unidirectional flow, said passage means communicating with the interior of said helmet and said helmet having an extension provided with a flexible wall.

5. The combination with an enclosure containing air in predetermined volume comprising oxygen in predetermined proportion, of carbon dioxide absorbing means, means for admitting oxygen substantially constantly to said enclosure at substantially the rate of oxygen consumption, whereby to avoid substantial change of volume, and means for admitting air containing oxygen in substantially said proportion whereby to vary the volume of air without substantial change of oxygen proportion, said enclosure and means being mechanically connected in unitary assembly and said air admitting means comprising a valve operable independently of said oxygen admitting means and positioned to be directly subject to the control of a person providing the air of said enclosure.

6. A device of the character described, comprising a closed respiratory circuit including a respiratory chamber having chemical means for absorbing carbon dioxide from the air in said circuit, means for directing air circulation in said circuit over said chemical means, an oxygen tank containing oxygen under pressure, and means affording communication between the tank and circuit and comprising a reducing valve and a metering orifice for introducing oxygen into the air of said circuit at a substantially constant rate substantially proportioned to the rate of consumption of oxygen from said air in respiration, whereby the introduction of oxygen does not vary the volume of air in said circuit, together with a by-pass pipe and a control valve for the emergency admission of additional oxygen from said tank to said circuit without disturbing the setting of said reducing valve and orifice.

7. In a device of the character described, the combination with a diving helmet, of an internal mask adapted to fit the operator's face, to receive his breath, and to return to him air for breathing, air conditioning apparatus, and means built into said helmet providing communication from said mask to said apparatus and from said apparatus to said mask, said air conditioning apparatus including means for absorbing carbon dioxide and means for supplying oxygen to the air at a substantially constant rate substantially proportioned to the consumption of oxygen by the operator, means for augmenting the supply of air without substantial change of oxygen proportion, and means built into the helmet providing closed circuit communication from said mask to said apparatus and from said apparatus to said mask, said means including air passage means provided with check valve mechanism for unidirectional flow, said passage means communicating with the interior of the helmet and the helmet having an extension provided with a flexible wall.

8. A completely self-contained respiratory system comprising the combination with a breathing chamber applicable to the person of a user, of means providing a closed respiratory circuit including said chamber and substantially open to operate at substantially equal pressures throughout, said circuit including means for removing carbon dioxide from air circulating therein and means providing a flexible wall whereby pressures in said circuit approximately correspond to external pressures, an oxygen pressure chamber communicating with said circuit, means controlling flow from said oxygen chamber to said circuit at a rate adapted to maintain substantially continuous oxygen deliveries to said circuit at a rate approximately equal to metabolic requirements of the user, and means independent of said oxygen flow-controlling means for regulating pressures within said chamber, said pressure regulating means comprising an air pressure chamber communicating with said circuit and an independent control valve for the admission of air to said circuit, said air pressure chamber containing air having an oxygen content substantially corresponding to metabolic requirements of said user, whereby the admission of air to the circuit will not upset the predetermined rate of supplying oxygen thereto.

9. A self-contained respiratory system comprising, in unitarily portable assembly adapted to be carried by the user of the system, the combination with a respiratory air circuit having a breathing connection available to the user and open to function at approximately equal pressures throughout and having a flexible wall, whereby the pressures within said circuit will approximately correspond to external pressure; of means for maintaining the oxygen content of air in said circuit substantially constant and comprising carbon dioxide eliminating means, a reservoir of oxygen under pressure, and means for the introduction of oxygen to the circuit substantially continuously at a rate satisfying metabolic requirements of said user; and means for increasing air pressures within said circuit in accordance with increase in pressures externally of said

chamber whereby to keep said wall from undue distortion, said pressure increasing means comprising an air pressure reservoir containing air under pressure and having an oxygen content substantially corresponding to said metabolic requirements, and means including a separate and independently operable valve providing controlled communication between said air pressure reservoir and said circuit wholly independently of the admission of oxygen to said circuit from said oxygen reservoir, said valve being operable solely to increase pressures within said circuit without affecting the proportionate oxygen content of air in said circuit.

10. A respiratory system comprising in unitarily portable combination a series of elements assembled for carrying by the user of the system; said combination of elements comprising elements constituting a closed respiratory air circuit including a breath receiving and delivering means personally applicable to a user, a flexible wall, and purifying means for removing carbon dioxide from air in said circuit; an oxygen reservoir element communicating with said circuit and containing oxygen under pressure and provided with means for automatically releasing oxygen substantially constantly to said circuit at substantially the rate of metabolic requirements; and pressure determining elements entirely independent of said oxygen reservoir element and the control thereof, said pressure determining elements comprising a reservoir containing under pressure higher than the maximum to which said flexible wall is subject a supply of air containing oxygen substantially in the proportion required to satisfy metabolism of said user, and a valve positioned to be freely accessible for manipulation by a person carrying the system, said valve being independent of the oxygen supplying element and being adapted to be opened and closed as required to raise the pressure in said circuit to a pressure sufficient to compensate for external pressures on said flexible wall without varying the predetermined ratio of oxygen in said circuit.

11. A respiratory system comprising a self-contained unitary combination of elements assembled for carrying by the person using the systems, said combination of elements including elements constituting a closed respiratory air circuit containing a flexible wall; a pressure regulating element for maintaining pressures within said circuit at values compensatory for increasing external pressures to which said wall is subject and comprising an air reservoir containing under pressure exceeding such external pressures air having an oxygen content in predetermined proportion to meet metabolic requirements, and valve means accessible to a person carrying said system for the controlled admission of such air to said circuit; oxygen maintaining elements operable independently of air admission to said circuit for maintaining a substantially constant proportion of oxygen in the air of said circuit approximately corresponding to the proportion of oxygen in the air of said reservoir, said last-mentioned element including carbon dioxide eliminating means exposed to the air traversing said circut, an oxygen reservoir containing oxygen under pressure, and means for the controlled admission of oxygen substantially constantly to said circuit at a rate to satisfy metabolic requirements by replacing oxygen converted by respiration into carbon dioxide and removed as carbon dioxide from said circuit.

12. The device of claim 11, in which the oxygen maintaining elements comprise a by-pass pipe from the oxygen reservoir to the air circuit, and a control valve for said by-pass pipe directly subject to manipulation of the person using the system for the emergency admission of additional oxygen to the circuit without disturbing the rate of controlled oxygen admission as provided in the structure of claim 11.

13. A respiratory system comprising a self-containing unitary combination of elements assembled for carrying by the person using the system, said combination of elements including elements constituting a closed respiratory air circuit containing helium and oxygen in a proportion to satisfy the metabolic requirements of the person using the system, said circuit including means making the air of said circuit accessible to said person, an air reservoir containing under pressure helium and oxygen in substantially the proportion in which such helium and oxygen are incorporated in the air of said circuit, means including an air valve directly accessible to a person carrying the system for the controlled admission of air from said reservoir to said circuit, a carbon dioxide eliminating means exposed to the air of said circuit, an oxygen reservoir, and means for the controlled and substantially constant admission of oxygen from said reservoir at a rate to maintain said predetermined proportion of oxygen and helium in the air of said circuit, said oxygen admitting means and said air valve being entirely independent, whereby the helium and oxygen content of the air of said circuit will be maintained automatically substantially constant during the use of said circuit by a person carrying the system, irrespective of pressure, the oxygen consumed being replaced and the helium conserved, and whereby the pressure in said system may be increased subject to the direct control of the user without disturbing the proportion of oxygen and helium in said circuit.

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