Dec. 18, 1962

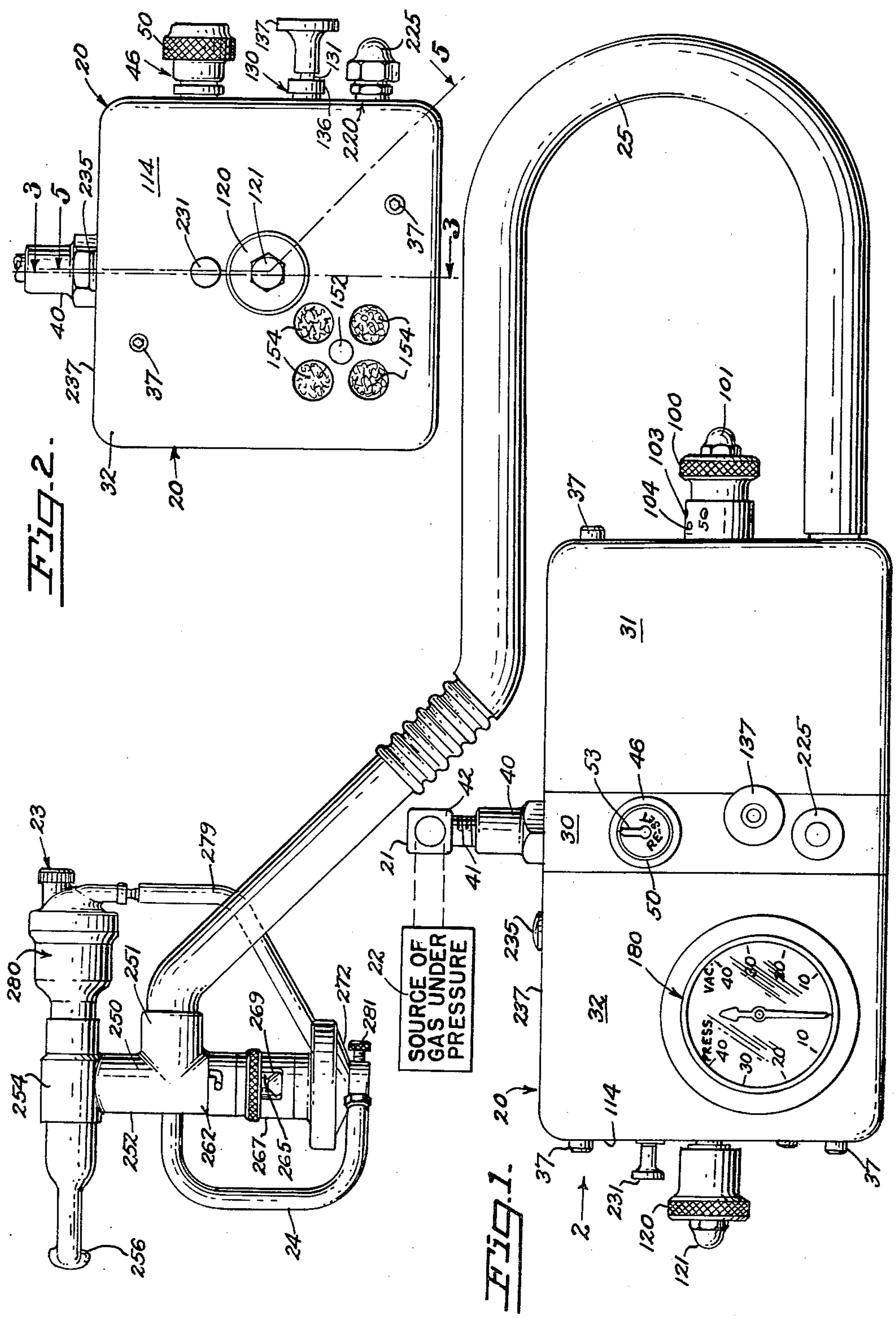
F. M. BIRD ETAL

3,068,856

FLUID CONTROL DEVICE

Filed Feb. 14, 1958

7 Sheets-Sheet 1



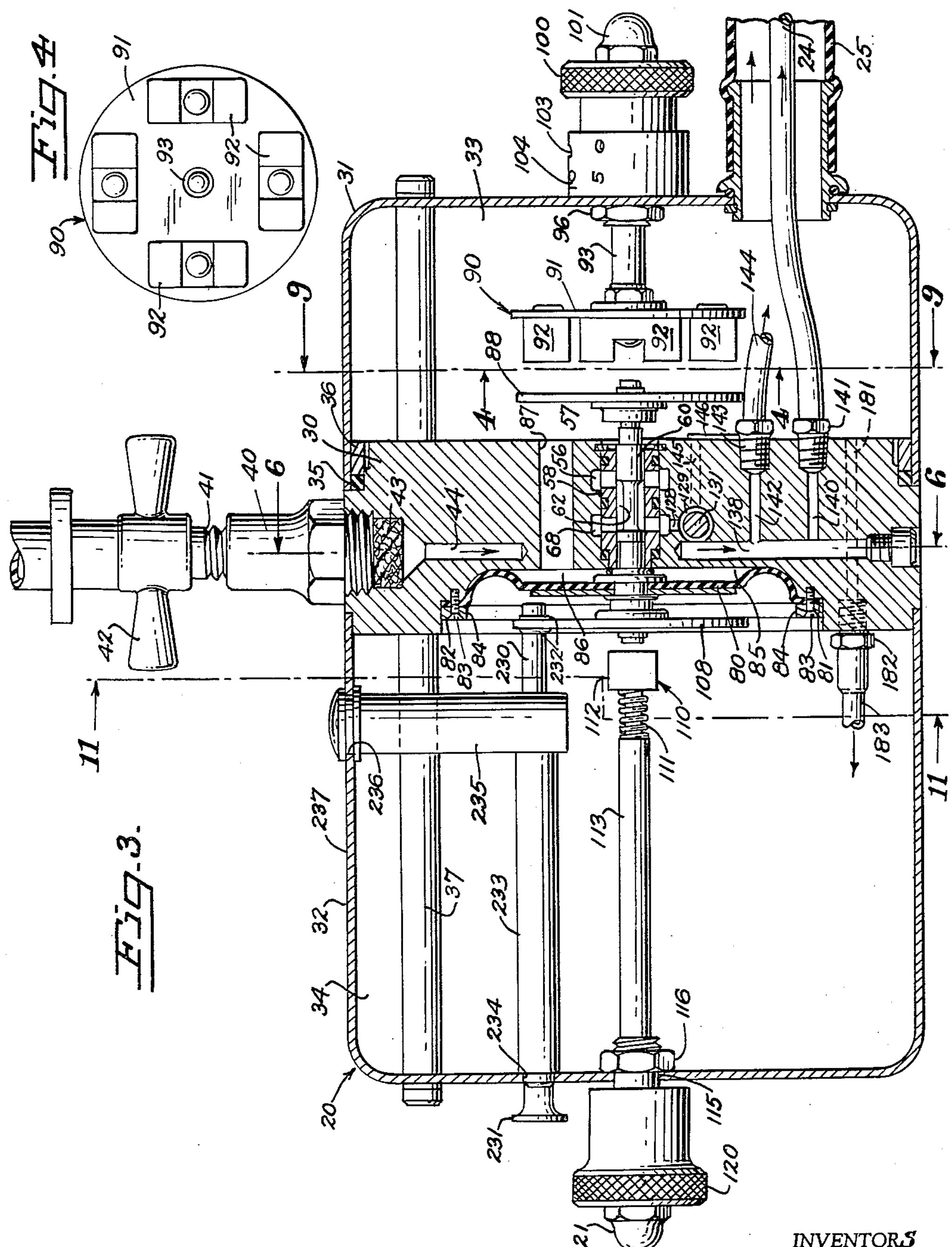


Fig. 4

Fig. 3.

INVENTORS
FORREST M. BIRD
HENRY L. POHNDORF
BY A. Graham Olsen
ATTORNEY.

Dec. 18, 1962 F. M. BIRD ETAL 3,068,856

FLUID CONTROL DEVICE

Filed Feb. 14, 1958 7 Sheets-Sheet 3

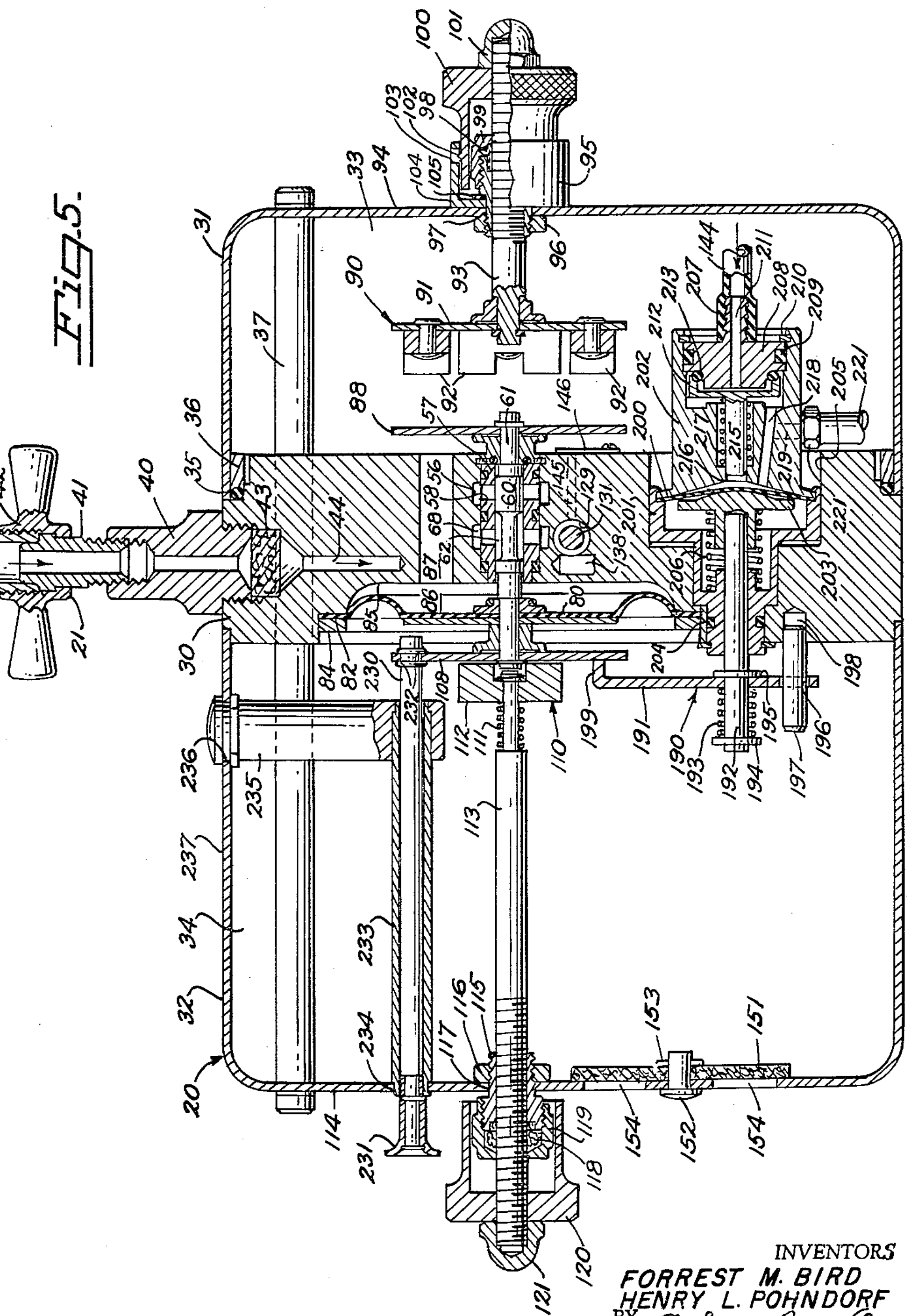


Fig. 5.

INVENTORS
FORREST M. BIRD
HENRY L. POHNDORF
BY A. Donham Owen
ATTORNEY.

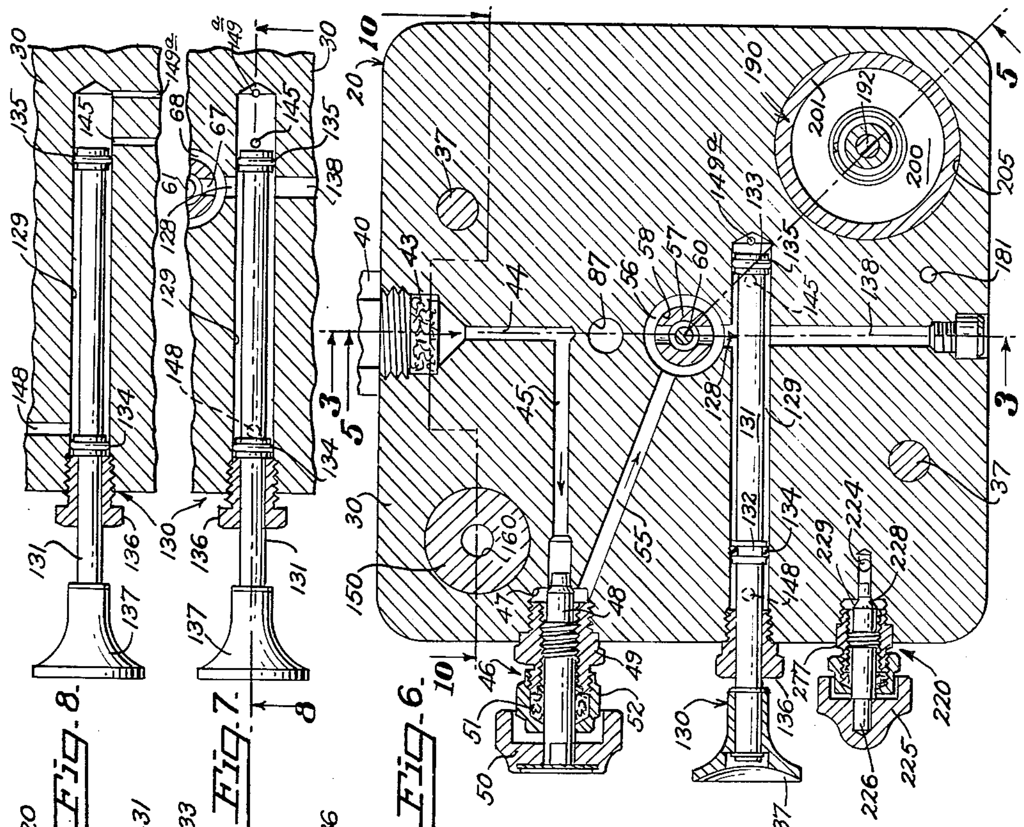


Fig. 6. Fig. 7. Fig. 8.

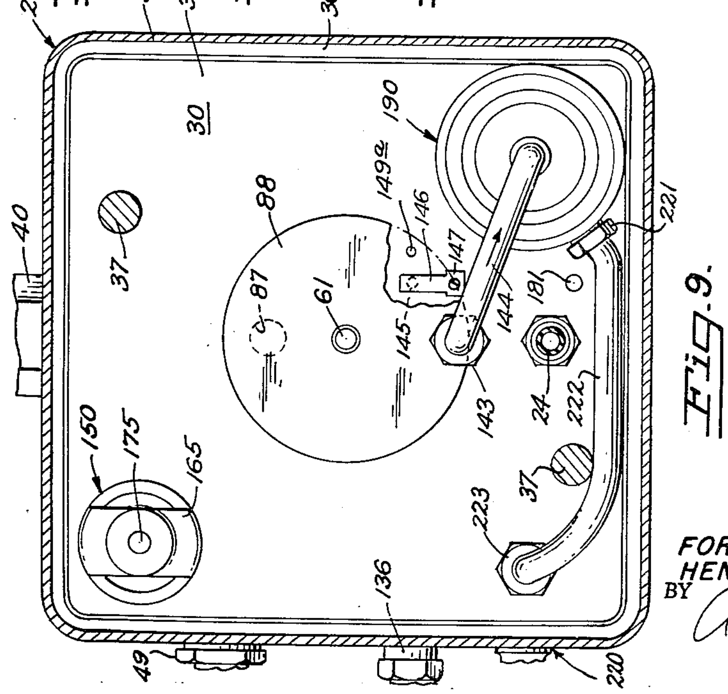


Fig. 9.

INVENTORS
FORREST M. BIRD
HENRY L. POHNDORF
BY [signature]
ATTORNEY.

FLUID CONTROL DEVICE

Filed Feb. 14, 1958 7 Sheets-Sheet 5

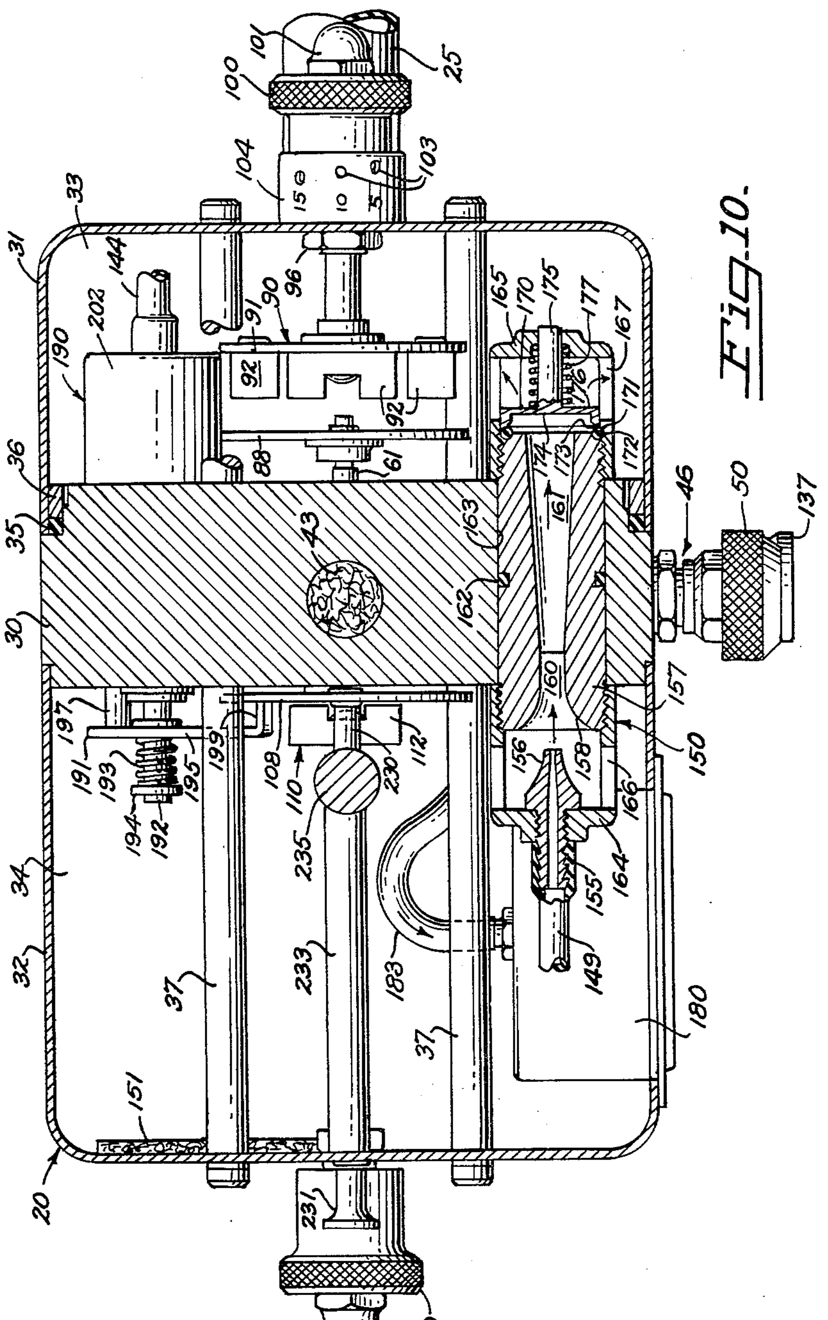


Fig. 10.

INVENTORS
FORREST M. BIRD
HENRY L. POHND
BY
A Durham Owen
ATTORNEY.

Dec. 18, 1962 F. M. BIRD ETAL 3,068,856

FLUID CONTROL DEVICE

Filed Feb. 14, 1958 7 Sheets-Sheet 6

Fig. 11.

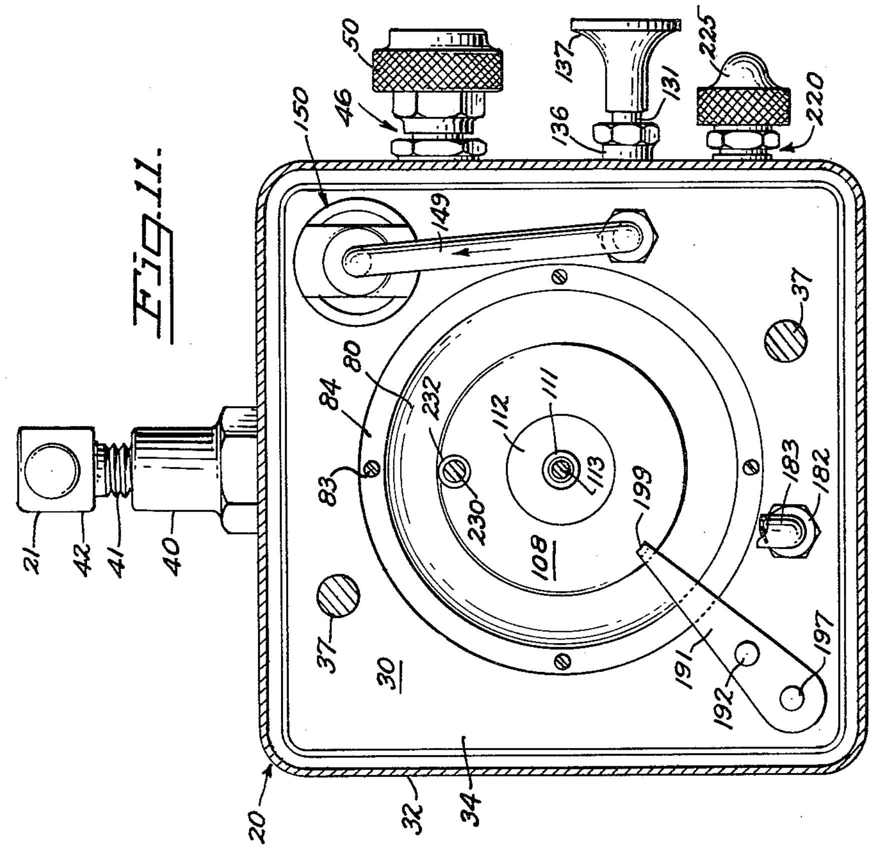
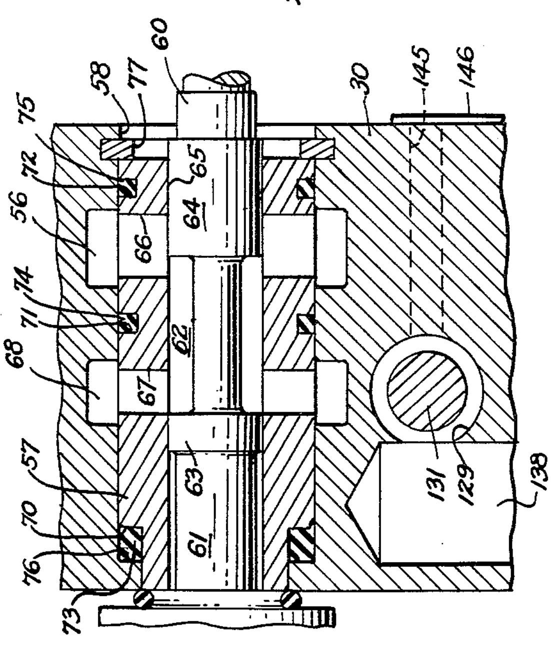


Fig. 12.



INVENTORS
FORREST M. BIRD
HENRY L. POHNDORF
BY

ATTORNEY.

FLUID CONTROL DEVICE

Filed Feb. 14, 1958 7 Sheets-Sheet 7

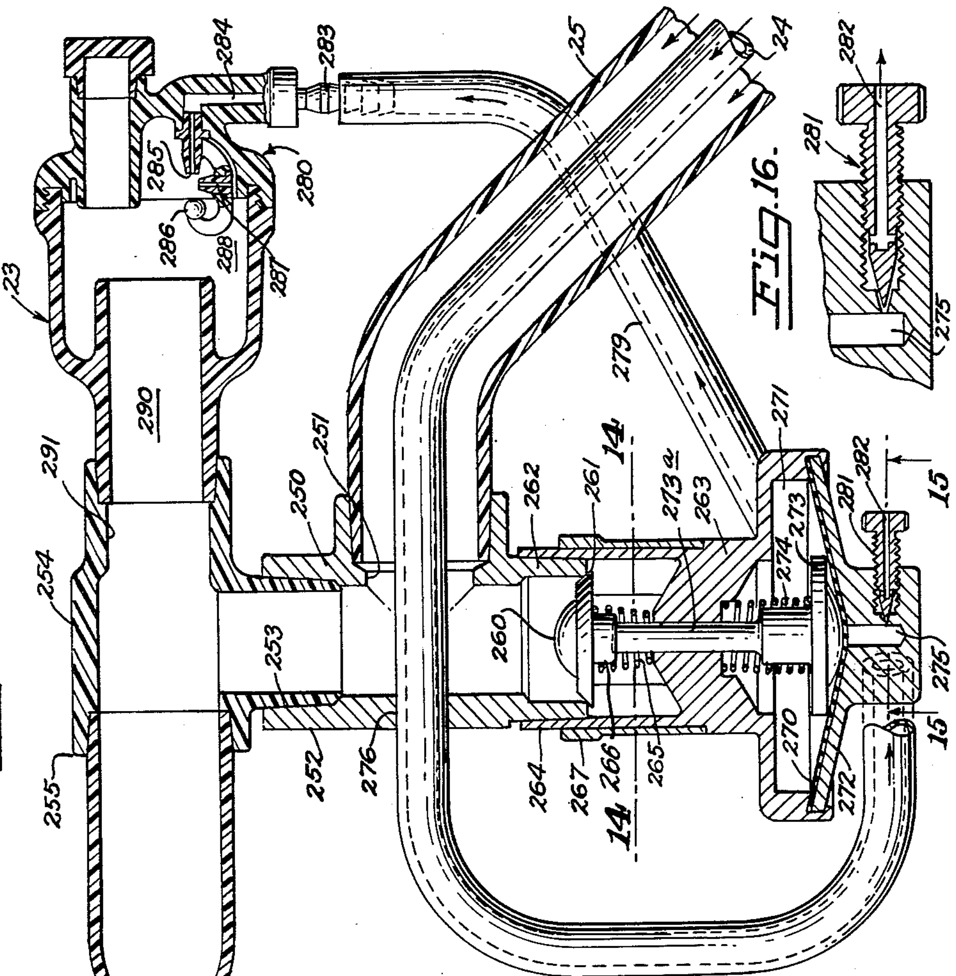


Fig. 13.

Fig. 16.

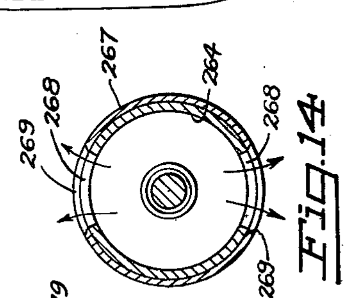


Fig. 14.

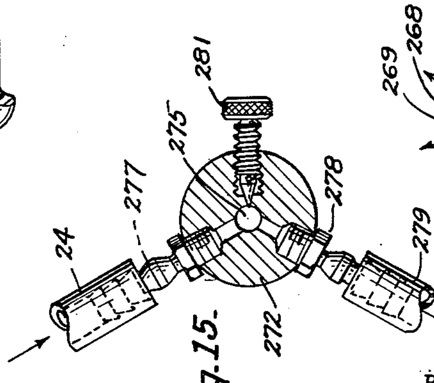


Fig. 15.

INVENTORS
FORREST M. BIRD
HENRY L. POHNDORF
BY
ATTORNEY

3,068,856

FLUID CONTROL DEVICE

Forrest M. Bird, Airport Box 970, Palm Springs, Calif., and Henry L. Pohndorf, 1227 Brewster Drive, El Cerrito 7, Calif.

Filed Feb. 14, 1958, Ser. No. 715,321
41 Claims. (Cl. 128—29)

This invention relates to an improved fluid control device. More particularly, it relates to an improved respirator system and to improvements in a respirator valve or pneumatic switch, a breathing assembly, and related parts.

Numerous problems have heretofore beset the respirator art. Respirators have tended either to require the patient to put forth more effort than he is capable of or else to provide automatic respiration at a time rate over which the patient has no control. In most respirators, the patient has to supply the force that switches the respirator "on" through a sucking effort, and every effort has a metabolic cost.

An outstanding feature of the present invention is that the patient can switch the respirator on with a very minimum of effort—0.001 centimeter of water or less. Or the respirator can be timed without any patient effort as an automatic respirator but still subject to patient control. For example, this finely sensitive instrument switches off when a patient swallows. The automatic feature can be put in reserve so that the patient will switch the respirator on so long as he is able to breathe faster than a predetermined rate that may be set individually for any patient and reset as conditions change. If his breathing rate drops below that level, the unit will take over and time his breathing. The required cost in metabolism of maintaining lung ventilation is therefore very low.

The human lung is filled more adequately when filled at a relatively slow constant rate at low pressures than when a sudden gust is directed into it. Prior-art respirators have produced sudden gusts and jagged flow rates that tended to make it difficult to get the lung filled well and properly. Flow rates of seat-and-spring-biased-diaphragm type valves have been especially erratic, and the lung pressure and flow-rate requirements have seldom been satisfied by these prior-art valves. They have tended to fill the lung too fast or too slowly, and have been directed at "average" size lungs instead of each individual lung concerned. Peak pressures and peak flow rates have been forced on patients, triggering their lungs prematurely, and reflex caused the user to exhale before the lungs were really filled. High flow rates tended to cause turbulence and "fall out" of nebulized particles, keeping medication away from the bottom of the lungs, where it was supposed to go. High flow rates also developed back-pressure resistance in the airways and against obstructions. Such resistance is proportional to the square of the velocity of the gas; so most of the oxygen did not get by to the lungs, even though it registered on a pressure gauge associated with the prior-art respirator.

The present invention solves all these problems by a new type of pneumatic valve or switch that employs two opposed magnetic fields and, between them, a diaphragm and a sliding valve responsive to the magnetic fields, the whole acting as a unit. This novel respirator acts as an on-off switch with no significant delay in time, pressure, or flow. Whenever there is flow, flow is at a preset rate which remains constant so long as the switch is on, and flow drops to zero as soon as the switch is off. Thus, the present invention eliminates the erratic flows that were characteristic of diaphragm-and-seat types of valves heretofore in use in respirators. The valve or switch of this invention stays on until the lung is filled,

and then it goes off and remains off during the exhalation and rest period. During filling, it pressurizes the lung gradually and evenly, and it accommodates the initial inspiratory phase demand from a reserve built up in a reservoir. This reserve instantaneously satisfies the breathless patient and also serves to soften the flow as it starts.

Prior-art respirators have been difficult to time accurately, and the timing has been over a relatively narrow range of values. In contrast, the timing of the respirator of this invention is simple to adjust and can be made very accurate. An important feature is that the timing rate can vary over a very wide range, from 500 cycles per minute or more down to 1 cycle per hour or less. However, at each cycle the on-off and off-on movements of the switch are very rapid, are effortless, and are substantially identical for slow timing and for rapid cycling. These features make it possible to hold the metabolic cost of ventilating a patient's lung below anything that has heretofore been possible.

The respirator unit of this invention can be attached to any source of gas under pressure. It can be made to operate over a wide range of pressures. In hospital gas supply systems a pressure of 50 p.s.i. is typical and is usually considered standard; however, the switch of this invention will work on pressures down to 15 p.s.i. or lower, even when set to work at 50 p.s.i., because of its novel construction. It will not suffer from a 70% differential in entering pressure. It will give flow rates which can be adjusted by hand to between approximately 1 liter per minute and 1000 liters per minute. Larger or smaller flow rates can be achieved as they are desired.

Another feature of the present invention is that while in most respirator valves heretofore in use the flow rate is either fixed or is affected by changes in pressure, timing, and so forth, in the present switch the flow rate can be controlled, independent of the pressure or timing, for each application. Valves heretofore in use have tried to hold the flow rate to an "average" value, which has been suitable for only a few patients and unsuitable for the vast majority. Moreover, the variation between a baby and a very large adult has been overlooked or disregarded in other respirators, with control for them being in many cases very difficult. The present invention has a wide range of adaptability. It will not only work for babies and large adults, but can be used to ventilate a cat or a horse and therefore has considerable use in veterinary medicine as well as in human medicine. It can be used for many uses outside of human medicine also, for example, it may be used in carburetors, superchargers, fluid systems, hydraulics, or wherever a positive pressure and flow switch of this nature is desired.

The magnetic principle of this flow switch applies whether there are two opposed magnetic fields or a single unopposed magnetic field. When a magnet is attracting a ferromagnetic member, the force of attraction is inversely proportional to the third power of the distance separating them. This factor means that a small change in distance can make a tremendous change in magnetic attraction force. In the valve or switch of this invention the magnet preferably never contacts the attraction plate which moves the valve and to which the valve is attached, preferably being an integral part of the reciprocating stem. The attraction plate is always at a spaced distance from the magnet, but a short difference in distance made by the diaphragm membrane can change the position enough to start a train of forces that quickly operate the flow switch.

When two opposed magnetic fields are used, one may be stronger than the other, and one may be the principal controlling magnet while the other controls the sensitivity or magnetic timing. Applied to a respirator, this means that one of the magnets, preferably the less powerful one, is used to turn "off" the air flow to the patient, while the more powerful one is used to turn the air flow on. The diaphragm operates in both instances and enables pressure control and flow control simultaneously.

A feature of the present invention that should not be overlooked is that with a sliding valve or switch operated by a diaphragm and a magnet, or by two opposed magnets, many of the problems of wear are eliminated, acute sensitivity becomes possible, and there is no need in this switch mechanism for springs or seats, which become untrustworthy after use. Magnets are of tremendously long life and do not appear to deteriorate at all with time. There is no fatigue of parts, and the sliding action of the stem in its sleeve may, by choice of proper parts and tolerances, be made to produce a very small amount of wear so that the valve is sure and certain over a very long period of time.

The invention includes not only the respirator but a novel magnetic timer, made up by the two opposed magnets, and a novel pneumatic timer comprising a separate diaphragm and needle valve arrangement which cooperate to limit the patient's exhalation time and pause to a predetermined value and then actuates the switch. While it is normal for a patient to take about one and a half times as long to exhale as to inhale, in many cases the ratio will be different. The pneumatic timer can be adjusted to compensate for any desired difference and when set, will act to actuate the switch mechanism to force air into a patient's lung if he does not breath within the prescribed time. At the same time, it gives him an adequate time to complete his exhalation and to inhale on his own.

The unit of this invention can be used with 100 percent pure oxygen or can dilute the oxygen with ambient air in any desired amount of dilution. A simple change-over switch, preferably, a pull rod, enables conversion from pure oxygen to the mixture.

Exhalation valves have also been a problem. If resistance to exhalation is insufficient, medication sought to be applied by a nebulizer will be insufficiently mixed and diffused in the lungs. Springs have been used to provide back pressure against exhalation, but these have proved objectionable in many instances because they have tended to close the valve before the patient fully exhaled. The present invention provides a novel retarder which builds up the necessary back pressure to slow down exhalation by varying the size of the exhalation opening. This means that the patient can fully exhale under a gentle back pressure before the exhalation valve is closed.

In some rare cases extremely rapid "dumping" of lung gases is desirable and no expiratory delay is mandatory. The present invention provides an adjustable bleed valve wherein the gases which balance the exhalation valve may be quickly led to the atmosphere and balance the exhalation valve on a featheredge of sensitivity.

Other objects and advantages of the invention will appear in the following description of a preferred embodiment.

In the drawings:

FIG. 1 is a view in side elevation of a respirator embodying the principles of this invention, having a control assembly connected to a breathing head assembly.

FIG. 2 is a view in end elevation of the control assembly, looking at FIG. 1 from the left-hand side in the direction of the arrow **2**, the inlet fitting being broken off in order to conserve space.

FIG. 3 is an enlarged view in longitudinal section of the control assembly taken along the line **3—3** in FIGS. 2 and 6, and showing the flow switch stem in its "on" position, where oxygen is passing throuugh the valve.

FIG. 4 is a view in end elevation of the main magnetic control as seen when looking along line **4—4** in FIG. 3.

FIG. 5 is a view in section on the scale of FIG. 3, taken along the line **5—5** in FIGS. 2 and 6 and showing the flow switch or valve in its "off" position where no oxygen is passing through the valve.

FIG. 6 is a view in vertical cross section taken along the line **6—6** in FIG. 3. The air-mix knob is shown in its "in" position for delivery of pure oxygen.

FIG. 7 is a fragmentary view in section of a portion of FIG. 6 showing the "out" position of the air-mix rod for delivery of a mixture of oxygen and air.

FIG. 8 is a view in section taken along the line **8—8** in FIG. 7.

FIG. 9 is a view in section taken along the line **9—9** in FIG. 3, through the high pressure chamber.

FIG. 10 is a view in longitudinal section taken along the line **10—10** in FIG. 6.

FIG. 11 is a view in section taken along the line **11—11** in FIG. 3, through the low pressure chamber.

FIG. 12 is an enlarged view in longitudinal section of the flow switch or main valve for the respirator, shown in open position as in FIG. 3.

FIG. 13 is an enlarged view in side elevation and in longitudinal section of the breather head assembly of FIG. 1.

FIG. 14 is a view in cross section taken along the line **14—14** in FIG. 13.

FIG. 15 is a view in section taken along the line **15—15** in FIG. 13.

FIG. 16 is an enlarged view of a portion of FIG. 13 showing a needle valve in its open position as distinct from the closed position shown in FIG. 13.

The complete respirator or breather unit of this invention (FIG. 1) comprises a control assembly or main valve **20** having an inlet assembly **21** connected to a source **22** of gas (normally air or oxygen) under pressure and connected to a breathing head assembly **23** by a small conduit **24** (FIGS. 3 and 12) and a larger, preferably concentric, conduit **25**.

The Control Assembly 20 and Its Inlet (FIGS. 1–12)

The control assembly **20** comprises a main body **30** to which are secured case members **31** and **32**, respectively defining a pressure compartment or reservoir **33** (right side of FIGS. 1, 3, 5, and 10) and an atmospheric-pressure compartment **34** (left side of FIGS. 1, 3, 5, and 10). The case **31** is secured to the body **30** in a leak-tight fit by means of a resilient gasket **35** and a retainer ring **36**. Such a fit is not necessary with the case **32**. The body **30** and case members **31** and **32** are bored, recessed, and shaped as needed to provide passages for gas and supports for the other parts, and together may be considered as comprising a housing, as for the valve **60** (see below). A pair of longitudinally extending rods **37** help hold the body **30** and case members **31** and **32** together.

The inlet assembly **21** (see FIGS. 3 and 5) preferably includes an adapter **40** that is threaded into the body **30** and receives a nipple **41**, which holds a nut **42** that may be secured to the outlet of a regulator or to an on-off valve of a hospital manifold system. Whatever the pressure of the original source **22** of high-pressure gas, it is preferably regulated to the order of 50 p.s.i., though the control assembly **20** can accommodate widely varying pressures. Preferably, a gas filter **43** is positioned in the body **30** adjacent the end of the adapter **40** to remove foreign material from the gas.

An inlet passage **44** leads radially in from the filter **43** for a short distance and connects (FIG. 6) to an outwardly extending passage **45** that conducts the incoming gas to a needle valve **46**. The needle valve **46** controls the flow rate of gas in the respirator, so that any desired flow may be obtained over a range greater than from 1 liter per minute to 1000 l.p.m. As shown in FIG. 6, it preferably comprises a seat **47**, formed as a shoulder in the body **30**, and a movable valve stem **48** adapted to close against the seat **47** to shut off flow completely and to be moved away therefrom for various flow rates up to the maximum supplied by the source **22**. The stem **48** may be held in a threaded housing **49** and may be turned by a handle or wheel **50**. Leakage around the stem **48** is prevented by a packing ring **51**, held on the housing **49** by a packing nut **52**. An index slot **53** in the handle **50** (FIG. 1) may be used to indicate the actual or relative flow rate produced by each position of the needle valve **46**.

From the valve **46** a radial passage **55** (FIG. 6) leads into an annular chamber **56** that surrounds a stationary valve sleeve **57**, which is positioned in a bore **58** through the body **30**. At that point the gas flow is stopped or passed, according to the position of a stem or main valve **60**, which together with the sleeve **57** comprises the central flow switch mechanism.

The Main Valve 60 (See FIG. 12 Especially, as Well as FIGS. 3, 5, and 6)

The main valve **60** is a sliding valve mounted in the housing comprising elements **30**, **31**, and **32**, and comprises a shaft member **61** with a spool-like recess **62** between rims **63** and **64**. The rims **63** and **64** have a very close tolerance fit in a smooth bore **65** through the valve sleeve **57**. The sleeve **57** has a series of radial passages **66** connecting with the annular chamber **56** and a second series of radial passages **67** axially spaced away from the passages **66** and communicating with an annular chamber **68** in the body **30**. The distance between the spool rims **63** and **64** is sufficient so that the spool recess **62** bridges the passages **66** and **67** when the valve **60** is in open position (FIGS. 3 and 12), and short enough so that the rim **64** is interposed between them when the valve **60** is in its closed position (FIG. 5).

Both the shaft **61** and sleeve **57** may be made from metal, but preferably they are made from alumina ceramic with carefully dimensioned proportions to hold wear to a minimum, since the shaft **61** slides many times a minute in the sleeve **57**. The sleeve **57** may be made with a shoulder **70** at one end and with grooves **71** and **72**. O-rings **73**, **74**, and **75** seat on the shoulder **70** and in grooves **71** and **72** to seal against passage of gas between the bore **58** and the sleeve **57**. A shoulder **76** in the bore **58** positions the sleeve **57**, and engages the O-ring **73**. A split ring **77** may be inserted in a bore groove **78** to lock the sleeve **57** in place.

The shaft **61** extends beyond the sleeve **57** at both ends for reasons which will become apparent in the next section.

The Main Control of the Main Valve 60

A diaphragm **80** is mounted with a leak-tight fit against a shoulder **81** on the shaft **61**. The body **30** is recessed from one side to provide a shelf **82** on which the rim of the diaphragm **80** is secured by screws **83** and a clamp ring **84**. A concentric recess **85** with a rounded outer periphery is also provided in the body **30**, and the central part of the diaphragm **80** is spaced away therefrom to provide a small chamber **86**. The chamber **86** is connected to and operationally forms part of the high pressure compartment **33**, because a large passage **87** extends through the body **30**. So the gas in the compartment **33** urges the diaphragm **80** to the left in FIGS. 3 and 5, while the atmospheric pressure in the chamber **34** urges the diaphragm **80** to the right.

On the right end of the shaft **61** is mounted an attraction plate or armature **88** made of soft iron or other ferromagnetic metal and sensitive to magnetic attraction. Such attraction is provided for the plate **88** by a main magnet assembly **90**. The assembly **90** preferably comprises a nonmagnetic (e.g., aluminum) disc **91** on which are mounted a series of permanent magnets **92**. Four magnets **92** are shown in FIGS. 3, 4, and 5, but more or fewer may be used, and there may be only one powerful one. Powerful magnets **92** with a holding power of about ¾ lb. of dead weight each are preferred.

The disc **91** is mounted rigidly to a shaft **93**, which extends out through the end wall **94** of the case **31** and is exteriorly threaded to engage an interiorly threaded support member **95**. A nut **96** holds the support member in a case opening **97**, and a packing gland **98** and packing nut **99** prevent leakage along the shaft **93**. A handle **100** is secured to the outer end of the shaft **93** and is held in place by a lock nut **101**. An index ring projection **102** on the handle **100** shows through a series of openings **103** in a calibrated pressure ring **104** to indicate the position of the magnet assembly **90**. The pressure ring **104** clamps a gasket **105** against the support member **95** to prevent leakage through the case opening **97**.

Since the pressure in the pressure compartment **33** is always (during operation) greater than that in the atmospheric chamber **34**, the gas pressure tends to force the diaphragm **80** to the left (FIGS. 3 and 5) and therefore to close the valve **60**. However, the attraction of the magnet assembly **90** for the attraction plate **88** tends to pull the shaft **61** to the right and open the valve **60**. By turning the handle **100**, the magnet assembly **90** may be moved nearer to or farther from the plate **88** so as to achieve any desired relation between these opposed forces.

The shaft **61** does not move far between the open and closed positions of the valve **60**—usually only about ⅛–¼"—but the peculiar nature of magnetic force provides a most unusual action that is a very important feature of the present invention. To illustrate the point, suppose that the pressure against the diaphragm **80** on both sides in the reservoir **33** is at a certain value, say atmospheric pressure, holding it in equilibrium. Then suppose that the magnet assembly **90** is moved (by turning the handle **100**) to a position where, when the valve **60** is closed, the magnetic force is almost but not quite sufficient to overcome the pressure holding the valve **60** closed (e.g., the magnetic force of the magnet **110** on plate **108**, as explained later). Now if a patient provides the slightest drain of gas from the reservoir by beginning to inhale, the pressure in the reservoir **33** drops. Even so slight a drop as 0.001 cm. of water can be made to actuate this switch-type valve. For once the pressure drops, the diaphragm **80** is not in equilibrium, and the force of the magnet **90** will attract the plate **88** and open the valve **60**. But the action is not simple like that of two opposed diaphragms, for the force of attraction of the magnet **90** for the plate **88** varies inversely with the third power of the distance between them. So the movement will be a snap action like a switch. Actually the plate **88** is never permitted to move into contact with the magnets **92**, some space always being maintained, but it will be a snap action all the same.

As will be explained soon, the effect of opening the valve **60** is to send gas under pressure into the reservoir **33**. So long as the patient breathes at the flow rate set in the needle valve for that patient, gas continues to flow to his lungs and the pressure in the reservoir gradually increases. By the time the lungs are filled, gas pressure has built up in the reservoir **33** and when it is enough to barely overcome the magnetic force, it moves the shaft **61** to the left. Any movement decreases the magnetic force by the third power of the distance moved; so the action back is also a snap action. Thus the flow-switch type of valve **60** is either on or off and is substantially instantaneous. Because of that, the effort to be supplied by the patient can be infinitesimal and the timing rate can be very rapid—as much as or more than 500 cycles per minute. And by the handle **120** (as later explained), the patient effort required to switch the respirator on can be increased when the patient is able to exercise his own diaphragm to give him exactly the amount of help he needs and no more and no less.

It is important to hold in mind the fact that the diaphragm **80** is opposed by the magnetic force inversely proportional to the third power of the distance between the attraction plate **88** and the magnets **92**, as distinct from a spring opposing a diaphragm with a force linearly and directly proportional to the spring compression.

It is also important to note that the valve **60** is both flow-sensitive and pressure sensitive, for either an increase in pressure in the compartment **33** or a stoppage or reduction of flow (which results in increased pressure on the diaphragm **80**) will turn the valve off. Moving the handle **100** increases or decreases the top breathing pressure at which the valve **60** moves to its off position. The unit considered so far (i.e., without the assembly **110**) would automatically switch on and off at a speed determined by the distance between the armature **88** and the magnets **92**.

The Sensitivity Magnet Assembly 110

To prevent this automatic switching when it is not desired or to regulate the timing cycle if it is desired, the shaft **61** is provided at its left end with an armature or attraction plate **108** of the same general type as the plate **88**, and a sensitivity magnet assembly **110** is provided in the compartment **34**, acting on the attraction plate or armature **108**. The magnet assembly **110** preferably supports one magnet **112** on a shaft **113**, the magnet **112** being cushioned by a spring **111**. The magnet **112** may be identical in size, shape, and attraction to any one of the magnets **92**; so the force ratio between the assemblies **90** and **110** is four to one. The shaft **113** extends out through an end wall **114** of the case **32**. A support member **115** is secured by a nut **116** in an opening **117** of the wall **114**. A packing gland **118** and packing cap **119** prevent leakage around the stem **113**, which threadedly engages the member **115**. A handle **120** and locknut **121** on the stem **113** give the needed control for moving the magnet **112** closer to or further away from the armature **108**. So operation is substantially like that of the magnet assembly **90**, except that the assembly **110** exerts only one-quarter the force (or some other ratio, if desired).

When the magnet **112** is close to the armature **108**, it takes much more effort on the part of the person breathing to move the valve **60** to its "on" position than when the magnet **112** is distant from the armature **108**. So the sensitivity assembly determines the patient effort. For example, in one embodiment, it was found that when the magnet **112** was in its innermost position (actual contact is never made) the patient effort was about 3 cm. of water below ambient atmospheric pressure. When the stem **113** is withdrawn to a certain location, easily found, a zero point is reached where it requires no patient sucking effort to turn the valve **60** on. From this point in, is the sensitivity control, where any desired amount of patient effort from zero up to the maximum (such as 3 cm. or more) can be obtained.

From the zero point out, the magnet assembly **110** functions as a magnetic timer. A magnetic pull is still exerted on the armature **108**, and the pull is sufficient to delay the automatic opening of the valve **60** by magnetic assembly **90** for a finite time. The time decreases as the magnet **112** is moved farther and farther away from the armature **108**.

Under sensitivity control the patient times the valve **60** on his own at all times and at the effort appropriate to him. Even when the switch valve **60** is timed automatically, the patient may still have some control. For example, if it is set for ten times per minute, the patient will still be able to switch the valve **60** on so long as his own breathing rate is faster than 10 times per minute, while if he falls below that level, the valve **60** times the patient. This flexibility is noteworthy. The timing speed may vary over a very wide range, between less than one cycle per hour and more than 500 cycles per minute.

The patient effort may really be minimal. At some settings of the magnetic assembly **110** a movement of the tongue or a flexure of the cheeks is enough to switch the respirator on.

The Fluid Flow From the Switch-Type Valve 60

So far the flow into the valve **60** and the operation and control of the valve **60** have been explained. When the valve **60** is in its closed position, the flow is cut off at the annular chamber **56** and radial passages **66** by the spool rim **64**. When the valve **60** is open, the compressed gas flows from the radial passages **66** around the recessed spool **62** to the radial passages **67** and the annular chamber **68**. A passage **128** leads from the chamber **68** into a bore **129** wherein is positioned a gas switch **130**. The switch **130** (see especially FIGS. 6–8) comprises a shaft **131** flanged and grooved to provide a pair of grooves **132** and **133** wherein are mounted O-rings **134** and **135** that seal against gas passage between them and the bore **129**. A shaft guide **136** is threaded into the body **30**, and the shaft **131** is provided with a handle **137**.

In both positions of the gas switch **130**, the gas (normally pure oxygen) flows from the bore **129** into a passage **138** (FIG. 3). Thence it flows through a passage **140** and fitting **141** into the inner conduit **24** which leads to the breather head assembly **23**, and its function will be explained later. For now it is sufficient to note that pure oxygen (unmixed with ambient air) is always supplied to the small conduit **24**, when the device is used as a respirator.

Pure oxygen also passes from the passage **138** through a passage **142** and fitting **143** into a tube **144** that leads to the air timing unit **190** to be explained later.

However, most of the oxygen is controlled by the switch **130** to go in one of two alternate paths. When the shaft **131** is pushed in, as in FIG. 6, the gas flows from the bore **129** into a passage **145** and from there directly to the high pressure compartment **33**. On its entry to the chamber **33** from the passage **145**, the gas has to flex a leaf spring or harmonica reed **146**, secured to the body **30** by a screw **147**. Flexure of the reed **146** helps maintain sufficient back pressure to ensure the supply of oxygen to the small conduit **24** and air timer **190**. It also diffuses the entering gas and keeps it from acting on the attraction plate **88** either pressure-wise or corrosively. It also balances the flow of pure oxygen relatively to the flow through the venturi **150**.

So when the gas switch **130** is pushed in and when the valve **60** is open, pure oxygen passes into and fills the reservoir **33** via the passage **145**. From the reservoir **33** it passes freely into the large conduit **25** and to the breather head assembly **23**. The reservoir **33** not only functions as a pressure chamber for the diaphragm **80** but also retains a supply of gas that can supply the instant peak demand of a patient as soon as he breathes and makes it possible to have a relatively low constant flow rate through the needle valve **46**.

When the handle **137** is pulled out (as in FIGS. 7 and 8) the O-ring **135** blocks off the passage **145** and routes the oxygen through a passage **148** and tube **149** to a venturi **150** where the oxygen is mixed with atmospheric air and then sent into the pressure compartment **33**. A passage **149***a* vents the passage **129** to the chamber **33**, so that the plunger **131** can move freely and not be restrained by the building up of a vacuum to the right of the O-ring **135**.

The Venturi 150 (FIG. 10)

The purpose of the venturi **150** is to dilute the oxygen with air for patients requiring oxygen enrichment but not pure oxygen. Since air is approximately 20% oxygen, it can be enriched to supply a patient with 33⅓% oxygen by mixing one part of pure oxygen with five parts of atmospheric air.

To make sure that the air is clean, it is preferably taken into the atmospheric compartment **34** through a filter **151** (FIGS. 5 and 10) which may be porous metal or glass wool or other suitable material secured rotatably by a stud **152** and cotter pin **153** against the end wall **114**, where it covers a plurality of air intake openings **154**, four of which are shown by way of example. By rotating the filter 151 a longer useful life is obtained, but it is readily replaceable. No filter is necessary for some applications.

The high pressure oxygen in the tube 149 enters the venturi 150 through a fitting 155, which it leaves through a jet 156. Preferably, the jet 156 is a small one, such as results from a #75 drill. The venturi tube 157 preferably has an accurately made elliptical cross-section inlet portion 158 leading into a neck 160 and an elongated flared outlet 161. The tube 157 has an O-ring 162 in a groove to seal it in an opening 163 through the body 30. The tube 157 also has exteriorly threaded ends and is locked in place by two cylindrical caps 164 and 165. The caps 164 and 165 have large openings 166 and 167 through their side walls; the openings 166 constitute the venturi's air inlet in the atmospheric chamber 34, while the openings 167 constitute the outlet opening in the pressure chamber 33. The cap 164 also supports an inlet fitting 155 and jet 156.

The cap 165 supports a gate or check valve plug 170 for sliding movement toward and away from a seat comprising an O-ring 171 mounted in a recess 172 around the outer rim of the tube 157. The plug 170 has an annular beveled rim 173 and a central flat surface 174, as well as a stem 175 and a rear annular flat surface 176. A spring 177 compressed between the surface 176 and the cap 165 normally holds the plug rim 173 seated against the O-ring 171. The flat surface 174 gives a rapid response to pressure in the venturi 150 to open the plug 170, and the flat surface 176 helps in a similar manner to cause its closing when the venturi flow ceases. The beveled rim portion 173 cups around the O-ring 171 because of its slope.

Note that the gate 170 is on the downstream side of the venturi 150 where much pressure is available and nothing is critical. This is in contrast to the sensitivity required on most venturis where the gate is on the inlet side. The cutoff valve 60 makes this structure feasible. Also, as in the pure oxygen against the reed 146, there is radial airflow, diffusion, and minimum turbulence.

Thus, the oxygen, diluted with air, once it comes through the venturi 150, enters the high pressure chamber 33 where it acts the same as the pure oxygen did from then on. In other words, it builds up pressure in the reservoir 33 against the diaphragm 80, and it passes through the large conduit 25 to the breathing head assembly 23.

The Gauge

In order that the operator may know the pressure in the breathing pressure chamber 33, a gauge 180 is provided (FIG. 1). A passage 181 (FIGS. 3, 10, and 11) leads through the body 30 from the reservoir 33 and is connected by a fitting 182 to a conduit 183 which leads to the gauge 180. Preferably the gauge 180 is mounted in the case 32 because there is more room on it than on the case 31, although the gauge 180 could be mounted completely separately if desired. Thus the pressure in the breathing pressure chamber 33 can be read at all times.

The Pneumatic Timer 190 (FIGS. 5, 6, 9, 10, and 11)

A pneumatic timer 190 (which may also be termed an automatic timer, breathing rate control, or secondary timer) is provided primarily for anaesthesia applications but may also be used wherever a very slow breathing rate is desired. Very precise timing is achieved by timer 190.

Referring first to FIGS. 5, 10, and 11, there is an arm 191 in the chamber 34 mounted on a shaft 192 so that the arm 191 is parallel to the attraction plate 108, and the shaft 192 is parallel to the valve shaft 61. The arm 191 is mounted yieldably by means of a spring 193 and collars 194 and 195, and its parallel alignment is retained by an oversize opening 196 and a guide stud 197 that is press fit into an opening 198 in the body 30.

An axially turned end 199 of the arm 191 is so arranged that it can strike the plate 108. If it does so, the little tap it gives is sufficient to start the shaft 61 moving to the right, and once that happens, magnetic attracion, varying as it does inversely with the third power of the distance, will snap the valve 60 open. The pneumatic timer 190 acts by moving the arm 191 to the right at the desired time.

A diaphragm 200 (FIG. 5) is mounted with its periphery clamped between a timer body 201 and a cap 202, coaxially with the shaft 192. A diaphragm plate 203 is secured to the inner end of the shaft 192, which is mounted reciprocatingly in the body 201. The body 201 is sealed, as by O-ring 204, inside a stepped through-passage 205 through the main body 30. A spring 206 biases the diaphragm 200 toward the right and urges the shaft 192 in that same direction by virtue of being compressed between the diaphragm plate 203 and the body 201. Thus the spring 206 always tends to pull the arm 191 toward the armature 108 and open the valve 60.

Oxygen passes from the passage 142 (FIG. 3) through the tube 144 to an inlet fitting 207 of a stationary plug 208 that is mounted in the cap 202, sealed there by an O-ring 209 and retained there by a retainer ring 210. The oxygen coming through the passage 211 in the plug 208 forces a plunger 212 away from an O-ring seat 213. This plunger 212 is made like the member 170 of the venturi with a beveled rim 214, and its stem 215 is made to slide in a bore 216 through the cap 202. It is normally held closed against the O-ring 213 by a spring 217. Thus the plunger 212 is a one-way or check valve. When it is forced away from the seat 213 by the pressure of the oxygen in the passage 211, oxygen passes through a passage 218 and pressurizes the diaphragm 200. This moves the diaphragm 200 to the left in FIG. 5 and holds it there.

A passage 219, however, leads to a needle valve 220 (FIG. 6) via fitting 221, tube 222, fitting 223, and passage 224. (See FIGS. 5, 9, and 6 in that order.) At the needle valve 220 a handle 225 is mounted on a stem 226 which has fine, closely spaced exterior threads that engage in a valve housing member 227 to move a needle 228 toward and away from a seat 229, whence the gas is bled away to the atmosphere. By controlling the bleed rate at the needle valve 220, the recovery of the diaphragm 200 by the spring is controlled, and the time it takes to bleed off the gas, forcing the diaphragm to the left, is the maximum time that the valve 60 will remain off. It can of course be actuated more quickly by the patient's exerting whatever effort is then required to time the valve 60 himself. But if he does not breathe before the automatic timer 190 acts, it will time his breathing for him. This is a very accurate timer.

This timer 190 does not, thus, ordinarily take the timing away from the patient, but it will do so if he does not breathe at the correct time. Note also that the timing begins at the end of inspiration; so long as the patient is breathing in, the timing will not begin. It provides a floor, an insurance, to end the exhalation time and pause. In resuscitation work, this acts automatically without overriding any patient who is breathing. No manual valve need be tripped to do this.

The timer 190 serves to send air into the patient's lungs if he does not take it up within a certain time determined by the bleed-off, but if he does take in air independently, then it will not affect him, and he will be on his own. He is given reserve support but is not given a push. There has been some trouble in prior-art devices with the patient's being forced to take air at times when he shouldn't have, and this invention overcomes that problem.

Manual Operation of the Valve 60

For manual operation or hand timing of the valve 60, a hand-operated plunger 230 is provided. The plunger 230 has a handle 231 outside the end wall 114 of the atmospheric-pressure compartment 34, and its inner end is secured to the armature 108 by a pair of washers 232. Proper alignment is maintained by a guide sleeve 233, one end of which is supported in an opening 234 through the wall 114, while the other end is held in a suport rod 235. The support rod 235 is rigidly secured in an opening 236 through the top wall 137 of the case 32. The valve 60 may be manually opened by pushing on the plunger handle 231 to move the armature 108 to the right, and the valve 60 may be manually closed by pulling on the plunger handle 231, to move the armature 108 to the left.

The Breather Head Assembly 23

The large conduit 25 conducts the main current of oxygen or oxygen-enriched air from the control assembly 20 to the breather head assembly 23. More specifically, it conducts gas from the reservoir 33 to a lower T 250, where it enters through a central passage 251. To the upper branch 252 of the T 250 is secured the central branch 253 of an upper T 254. From there the gas passes through the left branch 255 of the upper T 254 directly to a mouthpiece 256 or to a face mask if desired. Thus the main gas flow is direct and unimpeded between the reservoir 33 to the mouthpiece 256, and therefore any peak inhalation can be accommodated by the gas present in the reservoir 33 and conduit 25.

For exhalation, an exhalation valve 260 of the mushroom type is normally held seated against a seat 261 on the lower end of the lower branch 262 of the lower T 250. Exhalation forces the valve 260 away from the seat 261. An exhalation valve body 263 has a sleeve 264 that is fixed by a bayonet joint to the lower T branch 262. A spring 265 surrounds the stem 266 of the valve 260 and bears between the valve 260 and the body 263. The spring 265 urges the valve 260 to its normally closed position with a relatively light pressure, easily overcome by exhalation. However, the mean positive exhalation pressure is adjustable by rotating a retarder sleeve 267 to vary the size of outlet opening provided by registration or partial covering of the openings 268 (FIG. 14) in the body sleeve 264 and similar openings 269 in the retarder sleeve 267. This is important in many cases, to assure thorough mixing and diffusion of medication in the lungs. In contrast with apparatus relying on springs to increase the pressure on the exhalation valve, this retarder sleeve 267 acts by reducing the outlet area available; so as exhalation slows down toward the end, the back pressure is decreased by the outflow overbalancing the exhalation. The retarder may easily be adjusted to secure the exact exhalation rate desired. Expectoration may be induced with the aid of detergent medicaments, since the airways are kept open by the positive expiratory pressure as the bronchi shorten.

A diaphragm 270 closes a chamber 271 at the lower end of the body 263, to which the outer periphery of the diaphragm 270 is clamped by a cap 272. A diaphragm 273, secured to the lower end of a stem 273*a* forming a lost-motion connection with the stem 266, is urged downwardly thereagainst by a spring 274, but a small chamber 275 is formed in the cap 272 on its side of the diaphragm 270. The small conduit 24 passes an opening 276 in the lower T 250 and terminates at a fitting 277 that leads directly into the chamber 275. So the gas in the small conduit 24 builds up pressure in the small chamber 275 during inhalation to push the stem 273*a* into engagement with the stem 266 and thereby help keep the valve 260 closed even while the pressure in the T 250 is increased by the flow of gas under pressure. Without such a pressure operation, the increased pressure would overcome the spring 265 and open the valve, but this cannot happen because of the pressure bias.

Another fitting 278 and conduit 279 conduct the gas from the chamber 275 to a nebulizer 280, while a needle valve 281 (FIG. 16) controls the bleed rate from the chamber 275, out through a passage 282 in its stem, thereby controlling the time it takes the valve 260 to open after inhalation stops. So both time delay and a positive expiratory pressure can be obtained by use of the sleeve 267 and needle valve 281. In many cases the needle valve 281 will be fully closed, in others, it may be opened and adjusted to balance the exhalation valve on a featheredge to give extremely rapid dumping of lung gases without substantial expiratory delay.

Gas from the conduit 279 enters the nebulizer 280 through a fitting 283 and passage 284 and exits through a jet 285. A ball-shaped target 286 breaks it up, and liquid for humidification or medication in the bottom of the nebulizer is sucked in through a passage 287 from a reservoir 288. The moisture bearing jet then passes through the connecting tube 290 and branch 291 of the upper T 254 and joins the main flow of gas that is passing into the lungs. A suitable nebulizer is explained in detail in Patent No. 2,432,660.

Operation

Gas from any suitable pressure source enters the inlet fitting 21, whence it flows through the filter 43 and passages 44 and 45 to the flow-control needle valve 46. After being metered to the desired constant flow rate, it flows through the passage 55 into the annular chamber 58 and radial passages 66 and 67 to the valve 60. If the valve 60 is closed, it goes no further.

The valve 60 is switched "on" by any of: (1) reduction of pressure in the reservoir 33 which may be caused by the effort of a patient to breathe, (2) movement of the magnet assembly 90 to the left to where it overbalances the diaphragm 80, (3) movement of the magnet assembly 110 to the left to where its force is reduced, (4) movement of the arm 191 against the armature 108, by bleeding off of the pneumatic timer 190, or (5) manual movement through the plunger 230 of the plate 108 to the right. The valve is switched off by any of the following: (1) an increase in pressure in the reservoir 33, which may be caused by a patient's starting to exhale or ceasing to inhale, (2) movement of the magnet assembly 90 to the right, reducing its pull relative to the force on the diaphragm 80, (3) movement of the magnet assembly 110 to the right far enough, or (4) manual retraction of the plunger 230 and plate 108.

In normal operation, incipient inhalation of the patient switches the valve 60 on, and incipient exhalation switches the valve 60 off, the magnet assembly 90 being positioned to determine the patient effort that turns the valve 60 off, while the magnet assembly 110 is adjusted to determine the patient effort needed to turn the valve 60 on or to determine the rate of timing where automatic (no patient effort) timing is employed. The pneumatic timer 190 gives an overriding control, taking over from the patient if his breathing rate drops below a predetermined level.

When the valve 60 is slid to its "on" position, the high pressure gas flows from the radial openings 66 in the spool recess 62 to the radial openings 67 and the annular chamber 68. From there gas passes whenever the valve 60 is "on," through passages 128, 138, and 140 to the small conduit 24 and to the diaphragm chamber 275 where it biases the exhalation valve 260 toward its closed position. It also flows from the chamber 275 through the conduit 279 to nebulizer 280 and entrains humidifying water or medication and directs it to the mouthpiece 256. Gas also passes at each cycle from the passage 138 through the passage 142 and tube 144 to the pneumatic timer 190 and biases the diaphragm 200 to the inactive position.

When the valve 60 is "on" and the air switch 130 pushed in (FIG. 6), pure oxygen also passes from the passage 128 into the bore 129 and through the passage 145 against the reed 146 and, flexing the reed 146 away, passes into the reservoir 33. The flexure of the reed 146 assures passage of gas also into the passage 138 as described in the preceding paragraph and balances the flow of pure oxygen into the reservoir 33 with that of diluted oxygen coming into the reservoir 33 from the venturi 150 as described in the following paragraph. It also assures radial flow into the reservoir 33. From the reservoir 33, the gas flows directly to the patient through the large conduit 25 and mouthpiece 256, mixing with the nebulized gas in the T 254.

When the valve 60 is "on" and the air switch 130 pulled out (FIGS. 7 and 8), pure oxygen flows from the bore 129, passage 148, and tube 149 to the venturi 150. There it entrains atmospheric air through the ports 166, the air having entered the chamber 34 through the openings 154 and filter 151. The diluted gas stream forces the check valve 170 open and flows radially into the reservoir 33 and thence through the large conduit 25 and mouthpiece 256 to the patient, mixing with the nebulized gas as before.

In all instances, the gas in the reservoir 33 is in contact with the diaphragm 80 through the passage 87 and is conducted to the gauge 180 via the passage 181 and tube 183.

When the patient's lungs are filled, back pressure through the conduit 25 and reservoir 33 moves the diaphragm 80 to the left and moves the valve 60 to its "off" position, where it is held by the magnet assembly 110. If the switch 130 is out, the venturi 150 is shut off by closure of the check valve 170 on its outlet end. The reed 146 acts as a check valve for the passage 145. In a moment pressure builds up enough to force the exhalation valve 260 open against its spring 265. The needle valve opening 282 in cooperation with the nebulizer orifice 285 bleeds off the gas in the chamber 275 that has been biasing the diaphragm 270, controlling the reaction time by the position of the needle valve 281. The shutting off of the valve 60 also begins the bleed cycle for the pneumatic timer, the needle valve 220 bleeding off the gas from the passage 218 via the conduit 221, and causing the spring 206 to move the diaphragm 200 and shaft 192 to the right, so that if the patient fails to actuate the valve 60 "on" within the bleed time, the arm 191 will engage the plate 108 and do so.

The reservoir 33 acts to dampen flow so that the actual breathing curve of a human lung not using the respirator, if superimposed over the breathing curve of the same lung when the respirator is employed, will coincide. In order to achieve these results, it is important for the reservoir 33 to be the proper size. Tests have shown that the proper size is approximately 1.2 liters. A reservoir 33 of this size also gives minimal resistance to the institution of the respiratory phase.

It will be noted that the stabilizer 280 is actuated and is operative only when the switch valve 60 is in its "on" position. This is important in preventing waste of medication and deposit of gummy medicine on various parts of the breathing head assembly. In other words, this invention provides interrupted nebulization, and the interruption is automatically adjusted to the breathing cycle. It takes approximately 7 p.s.i. to make a nebulizer function, and this is much higher than breathing pressure. The present invention taps into the downstream pressure on the exhaust side of the main switch valve 60 and bypasses the necessary 7 p.s.i. through the conduit 24 to operate the exhalation valve and the nebulizer venturi. The flow switch-nebulizer combination of this invention would be impossible with a spring-biased diaphragm valve of the type used in the prior art, because there it is not possible to tap off 7 p.s.i. from any stage nor to turn the nebulizer flow on and off in perfect harmony and time with the respirator. Consequently, prior-art devices have employed nebulizers that are on all the time—not only during inspiration but also during the exhalation and the pause portions of the breathing cycle. This meant that 150% more medication was used in these devices, the entire excess being wasted and in fact harmful in forming deposits on the breathing head assembly. So the present invention has solved that problem by this novel interrupted nebulizer.

However, the most important thing to keep in mind about operation is the effect of the two opposed magnetic fields with interposed valve and diaphragm. The diaphragm 80 is opposed, not by linear spring force, but by third-power magnetic force of the magnet assembly 90 for the attraction plate 83, and the magnet assembly 90 is easily adjusted by the handle 100 to give the proper balance. And the magnet assembly 90 is opposed by the similarly adjustable magnet assembly 110, which acts as a sensitivity meter and magnetic timer, as explained before.

To those skilled in the art to which this invention relates, many changes in construction and widely differing embodiments and applications of the invention will suggest themselves without departing from the spirit and scope of the invention. The disclosures and the description herein are purely illustrative and are not intended to be in any sense limiting.

We claim:

1. A respirator including in combination a main valve having a housing; gas-pressure-actuated means dividing said housing into first and second compartments, said housing having an inlet passage, an outlet passage from said first compartment, and a third passage leading into said first compartment; valve means movable in said housing between an "on" position joining said inlet passage and said third passage, thereby connecting said inlet to said outlet, and an "off" position for closing off said inlet passage, separating it from said third passage, and stopping the flow of gas through said inlet passage, said valve means being operatively connected to said gas-pressure-actuated means; magnetic attraction means in said first compartment exerting attraction on said valve means opposite in direction to that of said gas-pressure-actuated means; and a breathing head assembly connected to said outlet passage and having an exhalation valve biased to a normally closed position.

2. The respirator of claim 1 having second magnetic means opposed to said first magnetic means and acting on the opposite end of said valve.

3. A respirator including in combination a main valve having a housing; a diaphragm dividing said housing into first and second compartments, said housing having an inlet, an outlet from said first compartment, and a passage leading into said first compartment; valve means movable in said housing between an "on" position joining said inlet and said passage and an "off" position for separating them, said valve means being operatively connected to said diaphragm; a permanent magnet in said first compartment exerting attraction on said valve means opposite in direction to that of said diaphragm; a breathing head assembly connected to said outlet and having an exhalation valve biased to a normally closed position; and means for increasing the bias on said exhalation valve when said valve is in its "on" position.

4. The respirator of claim 3 wherein there is a gas switch member connecting said passage to a second passage when in one position and alternately to a third passage when in another position, said second passage extending directly into said first compartment through an outlet opening; and a venturi connected to said third passage, having an outlet leading into said first compartment and having an air intake for diluting the gas coming through said third passage.

5. The respirator of claim 4 having a check-valve on the outlet side of said venturi in said first compartment; and means for closing said check-valve when the flow through said venturi into said first compartment ceases.

6. The respirator of claim 4 wherein said second passage outlet opening is normally covered by a flexible reed.

7. The respirator of claim 3 wherein said breathing head assembly includes a breathing opening connected both to said first compartment outlet and to said exhalation valve and has a nebulizer with a venturi directed toward said breathing opening and connected by a conduit to said valve means outlet; so that said nebulizer is operative

when and only when said valve means is in its "on" position.

8. A respirator including in combination a main valve having a housing; gas-pressure-actuated means dividing said housing into first and second compartments, said housing having an inlet, an outlet from said first compartment, and a passage leading into said first compartment; valve means movable in said housing between an "on" position joining said inlet and said passage and an "off" positon for separating them, said valve means having magnetically attractable opposite ends, one in each of said first and second compartments, and being operatively connected to said gas-pressure-actuated means; magnetic attraction means in each of said first and second compartments exerting opposite attraction on the opposite ends of said valve means tending to move said valve; a breathing head assembly connected to said outlet and having an exhalation valve biased to a normally closed position; means for increasing the bias on said exhalation valve when said valve is in its "on" position; a pneumtaic timer comprising second gas-pressure-actuated means connected to said valve by a lost-motion connection and urged to an inoperative position by gas pressure when said valve is in "on" position; mechanical means tending to urge said second gas-pressure-actuated means to an operative position when the gas pressure thereagainst is relieved; and means for bleeding off said gas pressure at a controlled rate when said valve is in "off" position.

9. A respirator including in combination a main valve having a housing; a diaphragm dividing said housing into first and second compartments, said housing having an inlet, an outlet from said first compartment, and a passage leading into said first compartment; valve means slidable in said housing between an "on" position joining said inlet and said passage and an "off" position for separating them, said valve means having magnetically attractable opposite ends, one in each of said first and second compartments, and being operatively connected to said diaphragm; magnetic attraction means in each of said first and second compartments exerting opposite attraction on the opposite ends of said valve means tending to move said valve; a breathing head assembly connected to said outlet and having an exhalation valve biased ot a normally closed position; means for increasing the bias on said exhalation valve when said valve is in its "on" position; a pneumatic timer comprising a second diaphragm connected to said valve by a lost-motion connection and urged to an inoperative position by gas pressure when said valve is in "on" position; mechanical means urging said second diaphragm to an operative position when the gas pressure thereagainst is relieved; and means for bleeding off said gas pressure at a controlled rate when said valve is in "off" position.

10. A respirator including in combination a main body having opposite sides, inlet passage means, second passage means spaced from said inlet passage means, open third passage means through said body from one side to the other, and a valve opening through said body; a pair of casings closing against the opposite sides of said body to provide a pressure compartment on one side connected to said second passage means and an atmospheric compartment on the other side; a sliding valve shaft movable in said valve opening and having means for joining said inlet passage means and said second passage means when in an "on" position and for separating them when in an "off" position, said shaft having a pressure compartment end and an atmospheric compartment end, with a ferromagnetic armature mounted on each said end; a diphragm carried on said shaft adjacent its said atmospheric compartment end having its periphery closed against said body, said diaphragm separating said pressure compartment, which communicates with one side of said diaphragm through said third passage means, from said atmospheric compartment; first magnetic means adjustably supported by the casing enclosing said pressure compartment coaxial with said valve shaft and spaced from said pressure compartment armature; second magnetic means adjustably supported by the other said casing in said atmospheric compartment coaxial with said valve shaft and spaced from said atmospheric compartment armature; and a breathing head assembly connected to said pressure compartment by a first conduit and having a breathing outlet, an exhalation valve, a second diaphragm operatively connected to said exhalation valve, a diaphragm spring for said second diaphragm biasing said exhalation valve to a normally closed position, a diaphragm chamber on the opposite side of said second diaphragm from said exhalation valve and connected to said second passage by a second conduit so that when said valve shaft is in an "on" position the pressure of gas passing through said second conduit reinforces said diaphragm spring to hold said exhalation valve closed, a needle valve for bleeding off said diaphragm chamber, a nebulizer and means connecting said nebulizer to said diaphragm chamber and to said breathing outlet and for directing nebulized air toward said breathing outlet.

11. The respirator of claim 10 having an exhalation retarder comprising means to vary the size of opening of said exhalation valve when it is in its open position.

12. The respirator of claim 10 having a gas switch comprising a manually movable valve member connecting said second passage to a fourth passage in said body when in one position and alternately to a fifth passage in said body when in another position, said fourth passage extending directly into said pressure compartment through an outlet opening; and a venturi connected to said fifth passage, having an outlet into said pressure compartment and having an air intake in said atmospheric chamber for diluting the gas coming through said fifth passage, said atmospheric chamber having an inlet from the atmosphere.

13. The respirator of claim 10 having a pneumatic timer comprising a third diaphragm having a diaphragm chamber connected to said second passage when said valve shaft is in the "on" position, a timer shaft on the opposite side of said third diaphragm from its said diaphragm chamber, a spring urging said shaft against said third diaphragm and opposing the pressure in its said diaphragm chamber; a lost-motion connection between said timer shaft and the atmospheric compartment armature for moving said armature and said valve shaft to the on position when said spring overcomes the force of the diaphragm chamber in said third diaphragm; and a needle valve for bleeding said diaphragm chamber.

14. The respirator of claim 12 wherein there is a closure valve on the outlet side of said venturi in said pressure compartment; and means for closing said closure valve when the flow through said venturi into said pressure compartment ceases.

15. The respirator of claim 12 wherein the outlet opening from said fourth passage is covered by a flexible reed that builds up back pressure and diffuses the gas passing through said outlet opening.

16. The respirator of claim 10 wherein said pressure compartment constitutes a gas reservoir for breathing gas of approximately 1.2 liters capacity.

17. A respirator including in combination a main body having opposite sides, inlet passage means, second passage means spaced from said inlet passage means, open third passage means through said body from one side to the other, fourth and fifth passage means, and a valve opening through said body; a pair of casings closing against the opposite sides of said body to provide a pressure compartment on one side and an atmospheric compartment on the other side, said atmospheric compartment having air inlet means thereinto incorporating a filter; a flow-rate needle valve mounted in said inlet passage means; a sliding valve shaft movable in said valve opening and having means for joining said inlet passage

means and said second passage means when in an "on" position and for separating them when in an "off" position, said shaft having a pressure compartment end and an atmospheric compartment end, with a ferromagnetic armature mounted on each said end; a diaphragm carried on said shaft adjacent its said atmospheric compartment end having its periphery closed against said body, said diaphragm separating said pressure compartment, which communicates with one side of said diaphragm through said third passage means, from said atmospheric compartment; first magnetic means supported by the casing enclosing said pressure compartment coaxial with said valve shaft and spaced from said pressure compartment armature; means for adjusting the distance between said first magnetic means and its associated said armature; second magnetic means supported by the other said casing in said atmospheric compartment coaxial with said valve shaft and spaced from said atmospheric compartment armature; means for adjusting the distance between said second magnetic means and its associated said armature; a breathing head assembly connected to said pressure compartment by a large conduit and having a gas outlet, an exhalation valve biased by a spring to a normally closed position, a second diaphragm operatively connected to said exhalation valve, a diaphragm chamber on the opposite side of said second diaphragm from said exhalation valve and connected to said second passage by a small conduit inside said large conduit so that when said valve shaft is in an "on" position the pressure of gas passing through said small conduit reinforces said diaphragm spring to hold said exhalation valve closed, a needle valve for bleeding off said diaphragm chamber, a nebulizer, means connecting said nebulizer to said small conduit through said diaphragm chamber, and means connecting said nebulizer to said gas outlet; a pneumatic timer comprising a third diaphragm having a diaphragm chamber connected to said second passage when said valve shaft is in the "on" position, a timer shaft on the opposite side of said third diaphragm from its said diaphragm chamber, a spring urging said shaft against said third diaphragm and opposing the pressure in its said diaphragm chamber; a lost-motion connection between said timer shaft and the atmospheric compartment armature for moving said armature and said valve shaft to the on position when said spring overcomes the force of the diaphragm chamber in said third diaphragm, and a needle valve for bleeding said diaphragm chamber; a gas switch comprising a manually movable valve member connecting said second passage to said fourth passage when in one position and alternately to said fifth passage when in another position, said fourth passage extending directly into said pressure compartment through an outlet opening; a reed of spring material over said opening and flexed when gas passes therethrough into said pressure compartment; a venturi connected to said fifth passage and having an air intake communicating with said atmospheric compartment for diluting the gas coming through said fifth passage; a check-valve on the outlet side of said venturi in said pressure compartment; and means for closing said check-valve when the flow through said venturi into said pressure compartment ceases.

18. A respirator valve including in combination a main valve having a housing; gas-pressure-actuated means dividing said housing into first and second compartments, said housing having an inlet, an outlet from said first compartment, and a passage leading into said first compartment; valve means movable in said housing between an "on" position joining said inlet and said passage and an "off" position for separating them, said valve means being operatively connected to said gas-pressure-actuated means; magnetic attraction means in said first compartment exerting attraction on the end of said valve means opposite in direction to that of said gas-pressure-actuated means; a pneumatic timer comprising second gas-pressure-actuated means connected to said valve by a lost-motion connection and urged to an inoperative position by gas pressure when said valve is in "on" position; mechanical means urging said second gas-pressure-actuated means to an operative position when the gas pressure thereagainst is relieved; and means for bleeding off said gas pressure at a controlled rate when said valve is in "off" position.

19. A respirator valve including in combination a housing; a main body dividing said housing into two portions and having inlet passage means and second passage means spaced from each other, open third passage means through said body from one side to the other, and a valve opening also through said body from one side to the other; valve means movable in said valve opening and having means for joining said inlet and second passage means when in an "on" position and for separating them when in an "off" position, said valve means having an armature mounted on one end; a diaphragm carried on said valve means adjacent the other end and having its periphery closed against said body, said diaphragm dividing said housing into a pressure compartment including said third passage means and one said portion, and an atmospheric compartment in the other said portion, said pressure compartment being connected to said second passage means and having an outlet; and a permanent magnet supported adjustably by said housing in said pressure compartment away from said armature.

20. A respirator valve including in combination a housing; a main body dividing said housing into two portions and having inlet passage means and second passage means spaced from each other, open third passage means through said body from one side to the other, and a valve opening also extending through said body from one side to the other; valve means movable in said valve opening and adapted to join said inlet and second passage means when in an "on" position and to separate them when in an "off" position, said valve means having an armature mounted on each said end; a diaphragm in one said portion carried on said valve means adjacent one end having its periphery closed against said body, said diaphragm dividing said housing into a pressure compartment, joined to said second passage means and including the other said portion and said third passage means, and an atmospheric compartment in said one said portion, said pressure compartment having an outlet; first attraction means supported adjustably by said housing in said pressure compartment away from one of said armature, one of said armature and said first attraction means constituting a permanent magnet, the other constituting a ferromagnetic member attracted by said magnet; and second attraction means adjustably supported in said housing in said atmospheric compartment away from the other said armature, one of said other armature and said second attraction means constituting a permanent magnet, the other constituting a ferromagnetic attraction member for said magnet.

21. A respirator valve including in combination a housing; a main body dividing said housing into two portions and having two passages means spaced from each other, open third passage means through said body from one side to the other, and a valve opening also extending through said body from one side to the other; a sliding valve shaft movable in said valve opening and having means for joining said two passage means when in an "on" position and for separating them when in an "off" position, said shaft having a ferromagnetic armature mounted on each said end; a diaphragm in one said portion carried on said shaft adjacent one end having its periphery closed against said body, said diaphragm dividing said housing into a pressure compartment, including said third passage means, said pressure compartment comprising the other said portion on the opposite side of said body from said diaphragm and including said third passage means and an atmospheric compartment, said pressure compartment having an outlet, and being connected to one of said two passage means, the other of said two passage means providing an inlet to said housing; a first permanent magnet supported adjustably by said housing in said pressure compartment away from

one said armature; and a second permanent magnet adjustably supported in said housing in said atmospheric compartment away from the other said armature.

22. The valve of claim 21 wherein said first permanent magnet is much stronger than said second permanent magnet.

23. The valve of claim 21 having a pneumatic timer, said timer comprising a second diaphragm, means providing a diaphragm chamber on one side of said second diaphragm and connected to one said passage, a timer shaft on the opposite side of said second diaphragm from said diaphragm chamber, means urging said shaft against said second diaphragm and opposing the pressure in said diaphragm chamber, a lost motion connection between said timer shaft and the atmospheric compartment armature for moving said armature and said valve shaft to the on position when said spring overcomes the force of the diaphragm chamber in said second diaphragm, and a needle valve for bleeding said diaphragm chamber.

24. A respirator valve including in combination a housing; a main body dividing said housing into two portions and having inlet passage means, second passage means spaced from said inlet passage means, open third passage means through said body from one side to the other, and a valve opening through said body; a sliding valve shaft movable in said valve opening and having means for joining said inlet passage means and said second passage means when in an "on" position and for separating them when in an "off" position, said shaft having a ferromagnetic attraction plate mounted on each said end; a diaphragm carried on said shaft adjacent one end, having its periphery closed against said body, and dividing said housing into a pressure compartment connected to said second passage means and including one of said housing portions and said third passage means, and an atmospheric compartment in the other said housing portion; a first permanent magnet supported by said housing in said pressure compartment coaxial with said valve shaft and spaced from one said attraction plate; means for adjusting the distance between said first permanent magnet and its associated said attraction plate; a second permanent magnet supported by said housing in said atmospheric compartment coaxial with said valve shaft and spaced from the other said attraction plate; and means for adjusting the distance between said second permanent magnet and its associated said attraction plate.

25. The valve of claim 24 wherein said first magnet is more powerful than said second magnet.

26. The valve of claim 24 having a pneumatic timer comprising a second diaphragm, means providing a diaphragm chamber on one side of said second diaphragm and connected to said second passage, a timer shaft on the opposite side of said second diaphragm from said diaphragm chamber, a spring urging said shaft against said second diaphragm and opposing the pressure in said diaphragm chamber, a lost motion connection between said timer shaft and the atmospheric compartment armature for moving said armature and said valve shaft to the on position when said spring overcomes the force in the diaphragm chamber on said second diaphragm, and a needle valve for bleeding said diaphragm chamber.

27. A respirator valve including in combination a main body having opposite sides, inlet passage means, second passage means spaced from said inlet passage means, open third passage means said body from one side to the other, and a valve opening through said body; a first casing closing against one side of said body to enclose a pressure compartment therebetween, having an outlet therefrom, said pressure compartment being connected to said second passage means; a second casing closing against the opposite side of said body to enclose an atmospheric compartment on the other side open to the atmosphere; a flow-rate needle valve mounted in said inlet passage means; a sliding valve shaft movable in said valve opening and having means for joining said inlet passage means and said second passage means when in an "on" position and for separating them when in an "off" position, said shaft having a pressure compartment end and an atmospheric compartment end, with an armature mounted on each said end; a diaphragm carried on said shaft adjacent its said atmospheric compartment end having its periphery closed against said body, said diaphragm separating said pressure compartment, including said third passage means, from said atmospheric compartment; first attraction means supported by the casing enclosing said pressure compartment coaxial with said valve shaft and spaced from said pressure compartment armature, one of said pressure compartment armature and said first attraction means constituting a permanent magnet, the other constituting a ferromagnetic member attracted by said magnet; means for adjusting the distance between said first attraction means and its associated said armature; second attraction means supported by the other said casing in said atmospheric compartment coaxial with said valve shaft and spaced from said atmospheric compartment armature; one of said atmospheric compartment armature and said second attraction means constituting a permanent magnet, the other constituting a ferromagnetic attraction member for said magnet; and means for adjusting the distance between said second attraction means and its associated said armature.

28. A breathing head assembly comprising a breather head with an open outlet, and an inlet adapted to be connected to a source of gas under pressure; an exhalation valve biased to a normally closed position; a diaphragm operatively connected to said exhalation valve; means forming a diaphragm chamber on the opposite side of said diaphragm from said exhalation valve and adapted to be intermittently connected to a second source of gas under pressure so that when said chamber is pressurized said pressure acts through said diaphragm to help to hold said exhalation valve closed; and a needle valve for bleeding off said diaphragm chamber, said needle valve being open to the atmosphere at all times to pass gas thereto at a controlled rate insufficient to prevent said second source from building up pressure in said diaphragm chamber when connected thereto and acting to lower the pressure in said diaphragm chamber when said second source is not connected thereto.

29. A breathing head assembly comprising a breather head with an open outlet, and an inlet adapted to be connected to a source of gas under pressure; an exhalation valve; a spring biasing said valve to a normally closed position; a diaphragm operatively connected to said exhalation valve; means forming a diaphragm chamber on the opposite side of said diaphragm from said exhalation valve and adapted to be intermittently connected to a second source of gas under pressure, during inhalation only, so that when said chamber is pressurized said pressure acts on said diaphragm to reinforce said spring to hold said exhalation valve closed and bleed means from said diaphragm chamber to the atmosphere at all times open a controlled small amount for reducing the pressure in said chamber during the exhalation phase, at which time said diaphragm chamber is cut off from said second source.

30. The assembly of claim 29 wherein retarder means is provided to vary the outlet area of said exhalation valve.

31. The assembly of claim 29 wherein there is a passage connecting said diaphragm chamber and said open outlet and a nebulizer is connected to said last-mentioned passage between said chamber and said open outlet.

32. A breathing head assembly comprising a breather head with an open outlet, and an inlet adapted to be connected to a source of gas under pressure; an exhalation valve; a spring biasing said valve to a normally closed position; a diaphragm operatively connected to

said exhalation valve; means forming a diaphragm chamber on the opposite side of said diaphragm from said exhalation valve and connected to a second source of gas under pressure so that when said chamber is pressurized said pressure acts on said diaphragm to help said spring to hold said exhalation valve closed; a needle valve for bleeding off said diaphragm chamber; a nebulizer; means connecting said nebulizer to said diaphragm chamber; and means connecting said nebulizer to said open outlet.

33. A pneumatic timer comprising two passages, a valve alternately connecting and separating said two passages, a diaphragm, means providing a diaphragm chamber on one side of said diaphragm and connected to one said passage, a timer shaft on the opposite side of said diaphragm from said diaphragm chamber, a spring urging said shaft against said diaphragm and opposing the pressure in said diaphragm chamber, a lost-motion connection between said timer shaft and said valve for moving said valve to its connecting position when said spring overcomes the force in the diaphragm chamber, and a needle valve for bleeding said diaphragm chamber.

34. A pneumatic timer comprising an inlet passage, a second passage, a sliding valve alternately connecting and separating said inlet passage to said second passage, a diaphragm, means providing a diaphragm chamber on one side of said diaphragm and connected to said second passage, so that said diaphragm chamber is pressurized when said valve connects said inlet passage to said second passage, a timer shaft on the opposite side of said diaphragm from said diaphragm chamber, a spring urging said shaft against said diaphragm and opposing the pressure in said diaphragm chamber, a lost-motion connection between said timer shaft and said sliding valve for moving said valve shaft to its connecting position when said spring overcomes the force of the diaphragm chamber on said diaphragm, and a needle valve for bleeding said diaphragm chamber.

35. A respirator including in combination a main valve having a housing; gas-pressure-actuated means dividing said housing into first and second compartments, said housing having an inlet, an outlet from said first compartment, and a passage leading into said first compartment; valve means movable in said housing between an "on" position joining said inlet and said passage and an "off" position for separating them, said valve means being operatively connected to said gas-pressure-actuated means; magnetic attraction means in said first compartment exerting attraction on said valve means opposite in direction to that of said gas-pressure-actuated means; a breathing head assembly connected to said outlet and having an exhalation valve biased to a normally closed position, and means for increasing the bias on said exhalation valve when said valve is in its "on" position and for decreasing the bias when said valve is in its "off" position.

36. The respirator of claim 35 wherein said exhalation valve includes a pneumatic bias supplied with gas when said valve means is on.

37. The respirator of claim 35 wherein said pneumatic bias is provided with an adjustable bleed valve.

38. The respirator of claim 35 wherein the gas for said pneumatic bias is supplied by a conduit leading from the outlet of said valve means and wherein said gas is connected from the bias via a conduit and a venturi type nebulizer to said breathing head, so that said nebulizer is operatively only when said valve means is in its "on" position.

39. A respirator including in combination a main valve having a housing; gas-pressure-actuated means dividing said housing into first and second compartments, said housing having an inlet, an outlet from said first compartment, and a passage leading into said first compartment; valve means movable in said housing between an "on" position joining said inlet and said passage and an "off" position for separating them, said valve means being operatively connected to said gas-pressure-actuated means; magnetic attraction means in said first compartment exerting attraction on said valve means opposite in direction to that of said gas-pressure-actuated means; a breathing head assembly connected to said outlet and having an exhalation valve biased to a normally closed position, said exhalation valve having a body provided with openings; and means for adjusting the size of the exhalation valve body openings so as to provide back pressure during exhalation.

40. A respirator including in combination a main valve having a housing; gas-pressure-actuated means dividing said housing into first and second compartments, said housing having an inlet, an outlet from said first compartment, and a passage leading into said first compartment; valve means movable in said housing between an "on" position joining said inlet and said passage and an "off" position for separating them, said valve means being operatively connected to said gas-pressure-actuated means; magnetic attraction means in said first compartment exerting attraction on said valve means opposite in direction to that of said gas-pressure-actuated means; a breathing head assembly connected to said outlet and having an exhalation valve biased to a normally closed position, a pneumatic timer comprising second gas-pressure-actuated means connected to said valve by a lost-motion connection and urged to an inoperative position by gas pressure when said valve is in "on" position; mechanical means for urging said second gas-pressure-actuated means to an operative position when the gas pressure thereagainst is relieved; and means for bleeding off said gas pressure at a controlled rate when said valve is in "off" position.

41. A respirator including in combination a main valve having a housing; gas-pressure-actuated means dividing said housing into first and second compartments, said housing having an inlet, an outlet from said first compartment, and a passage leading into said first compartment; valve means movable in said housing between an "on" position joining said inlet and said passage and an "off" position for separating them, said valve means being operatively connected to said gas-pressure-actuated means; magnetic attraction means in said first compartment exerting attraction on said valve means opposite in direction to that of said gas-pressure-actuated means; and a breathing head assembly connected to said outlet and having an exhalation valve biased to a normally closed position; a venturi-type nebulizer directed into said breathing head for entraining liquids, said nebulizer being connected to said first compartment outlet so that it is operative only when said valve means is in its "on" position.

References Cited in the file of this patent

UNITED STATES PATENTS

2,071,215	Peterson	Feb. 6, 1937
2,251,323	Burke	Aug. 5, 1941
2,462,614	DeWitt	Feb. 22, 1949
2,567,225	McKee	Sept. 11, 1951
2,593,046	McKee	Apr. 15, 1952
2,598,525	Fox	May 27, 1952
2,669,249	Wittmann	Feb. 16, 1954
2,736,331	Seeler	Feb. 28, 1956
2,774,346	Halliburton	Dec. 18, 1956
2,828,740	Kindred	Apr. 1, 1958
2,996,071	Takaoka	Aug. 15, 1961

UNITED STATES PATENT OFFICE

CERTIFICATE OF CORRECTION

Patent No. 3,068,856 December 18, 1962

Forrest M. Bird et al.

It is hereby certified that error appears in the above numbered patent requiring correction and that the said Letters Patent should read as corrected below.

Column 3, line 71, for "throuugh" read -- through --; column 10, line 62, for "The" read -- This --; column 11, line 4, for "suport" read -- support --; line 6, for "137" read -- 237 --; line 55, after "diaphragm" insert -- plate --; line 60, after "passes" insert -- through --; column 13, line 4, for "T" read -- tee --; line 48, for "stabilizer" read -- nebulizer --; column 14, line 75, for "outlet;" read -- outlet, --; column 15, line 21, for "pneumtaic" read -- pneumatic --; line 45, for "ot" read -- to --; line 70, for "diphragm" read -- diaphragm --; column 16, lines 47 and 48, and column 17, line 44, for "the on position", each occurrence, read -- the "on" position --; column 18, line 45, strike out "of", first occurrence; line 55, for "passages" read -- passage --; column 19, lines 17 and 59, for "the on position", each occurrence, read -- the "on" position --; line 66, after "means" insert -- through --; column 21, line 67, for "operatively" read -- operative --.

Signed and sealed this 10th day of September 1963.

(SEAL)
Attest:

ERNEST W. SWIDER
Attesting Officer

DAVID L. LADD
Commissioner of Patents