

[54] **AUTOMATIC THERAPEUTIC VENTILATOR**

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[22] Filed: Dec. 11, 1970

[21] Appl. No.: 97,279

[52] U.S. Cl. 128/145.8, 137/566

[51] **Int. Cl.**..... **A61m 16/00**

[58] **Field of Search** .. 128/145.6, 145.8, 188, 145.5;
137/566, 624.14, 624.15

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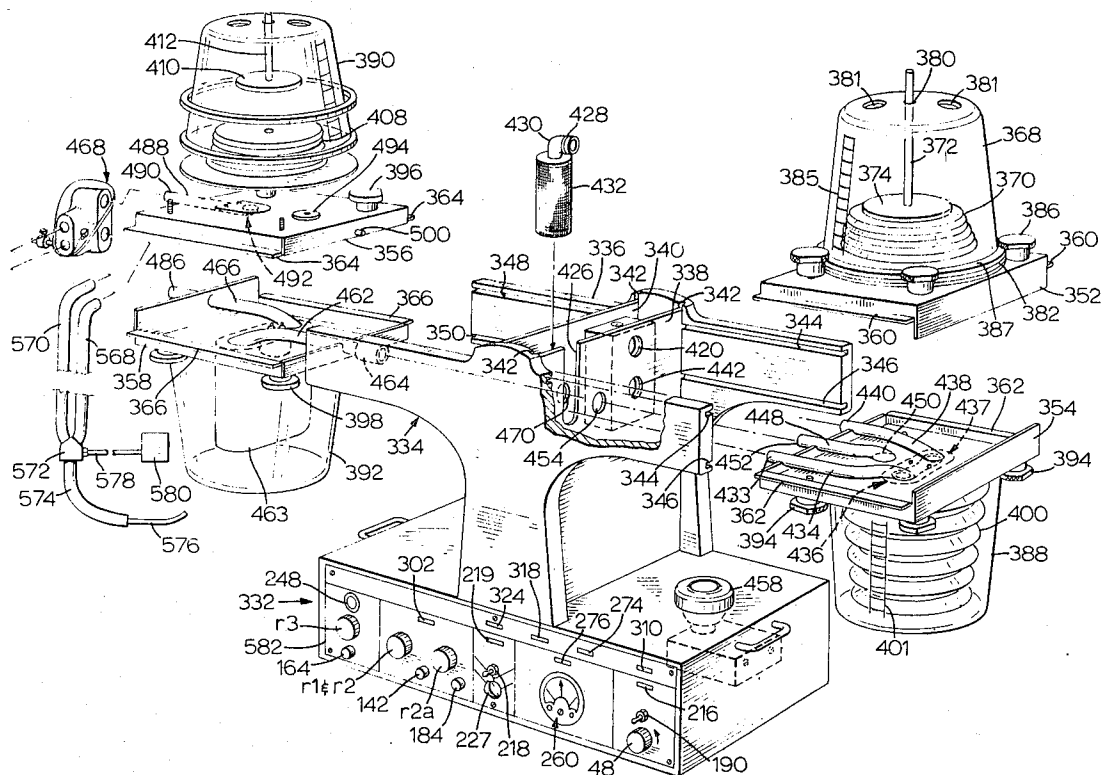
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[57]

ABSTRACT

An automatic therapeutic ventilator having an oxygen bellows for receiving and measuring a volume of oxygen and a breathing mixture bellows for mixing the oxygen with air in a predetermined ratio. Pneumatic and electrical control circuits are provided for automatic, semi-automatic, and patient-triggered modes, and a sigh circuit is incorporated in the control circuits. The bellows are mounted on trays which can be replaced simply.

37 Claims, 12 Drawing Figures



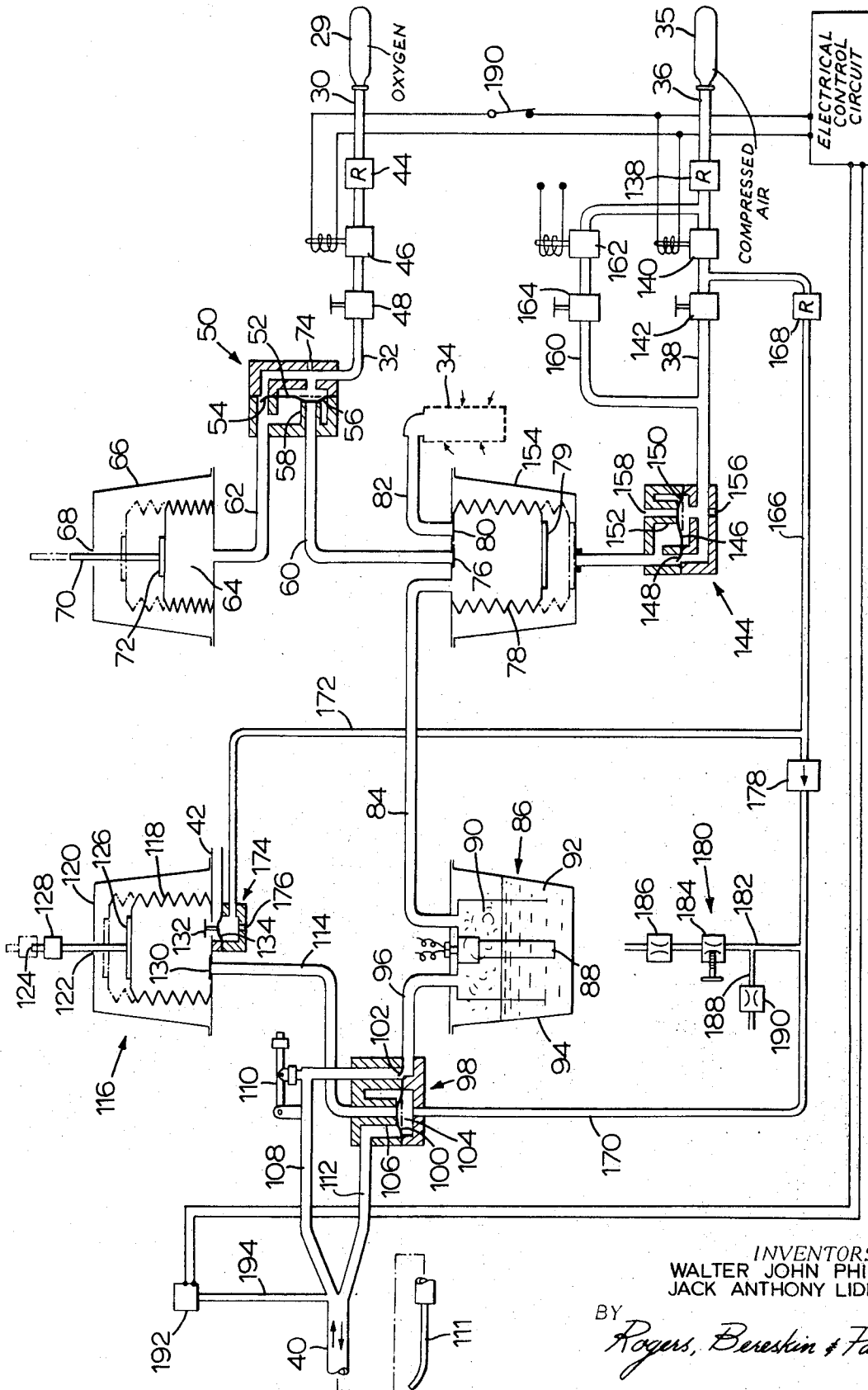
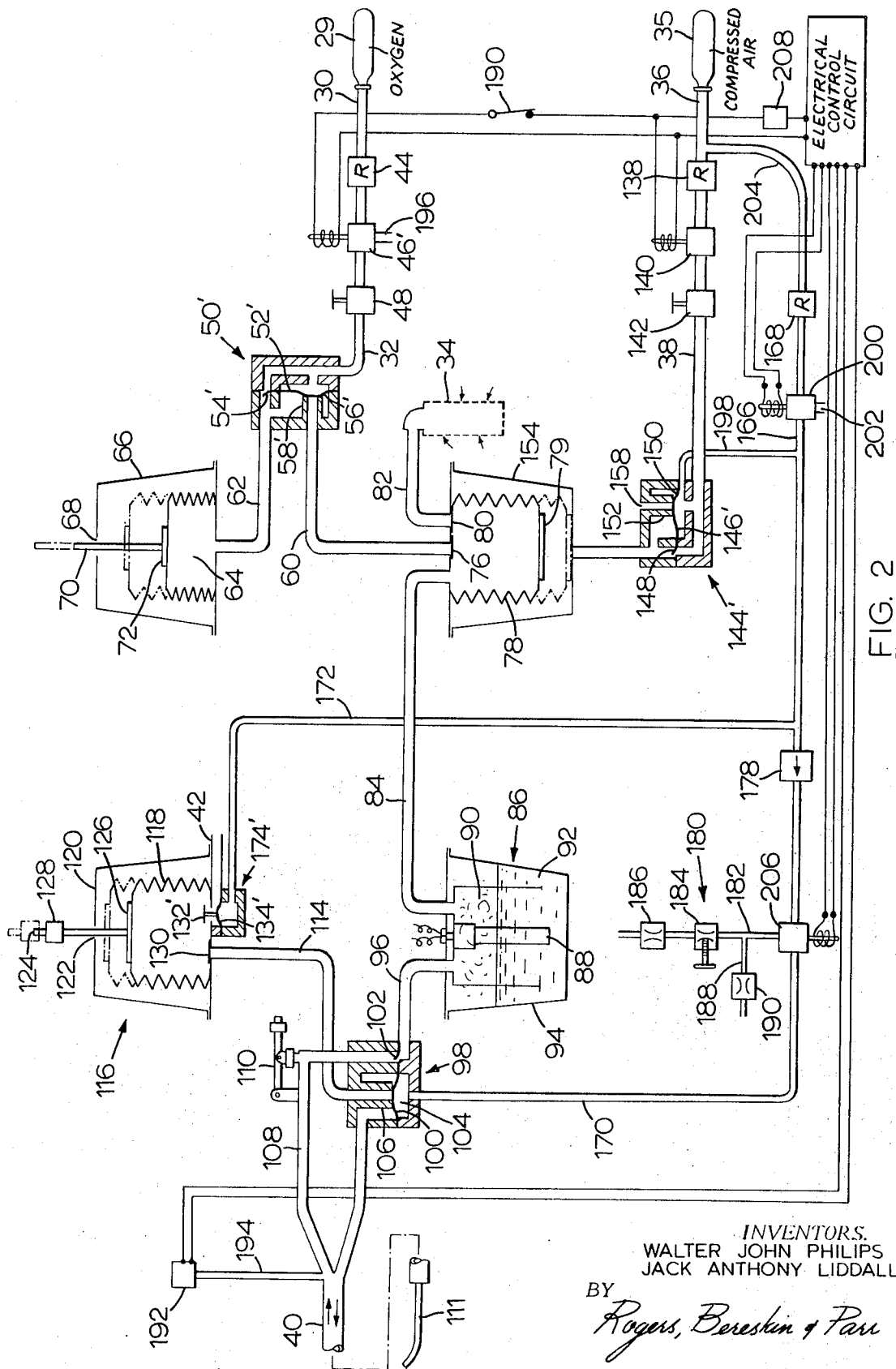


FIG. 1

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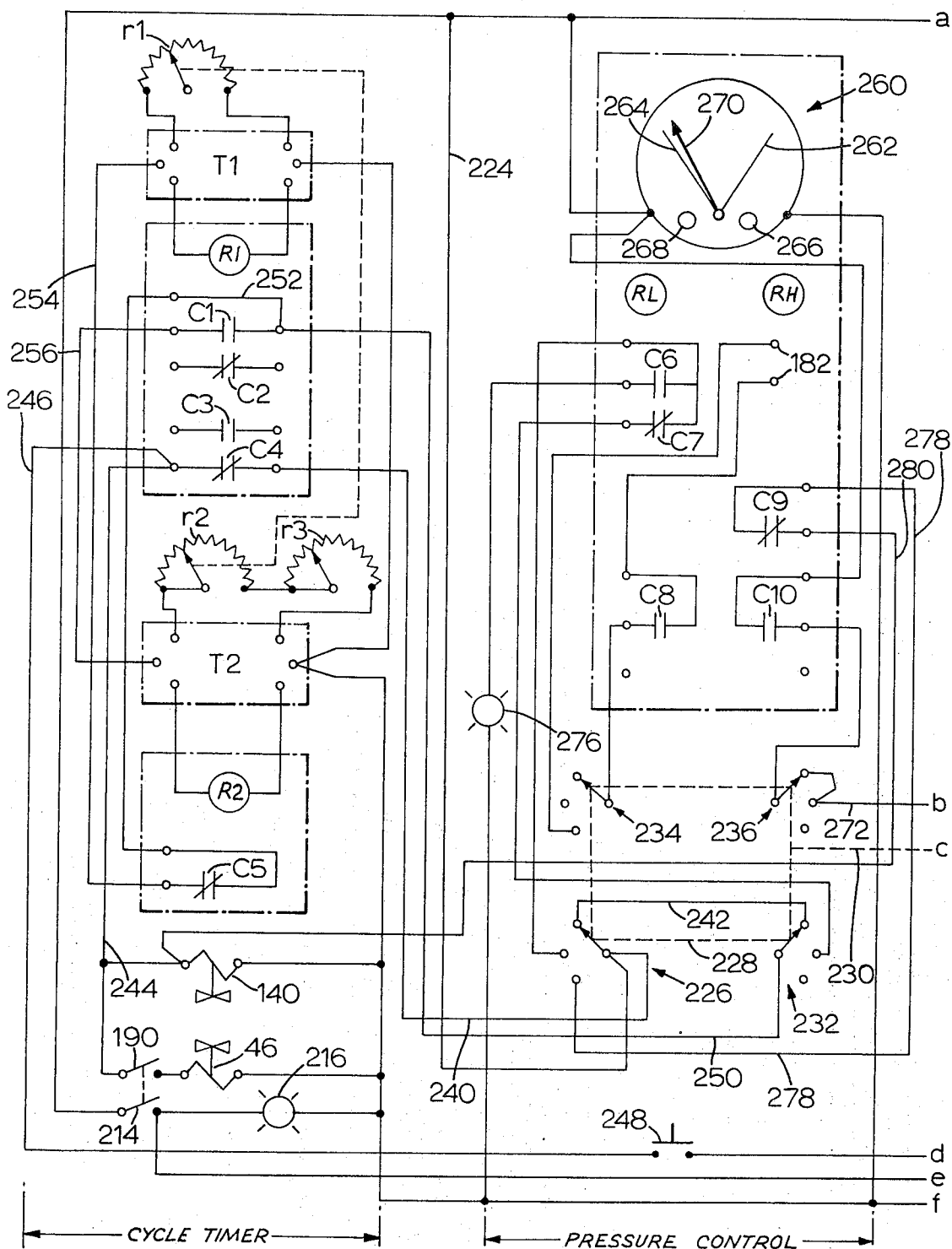


FIG. 3
(Part I)

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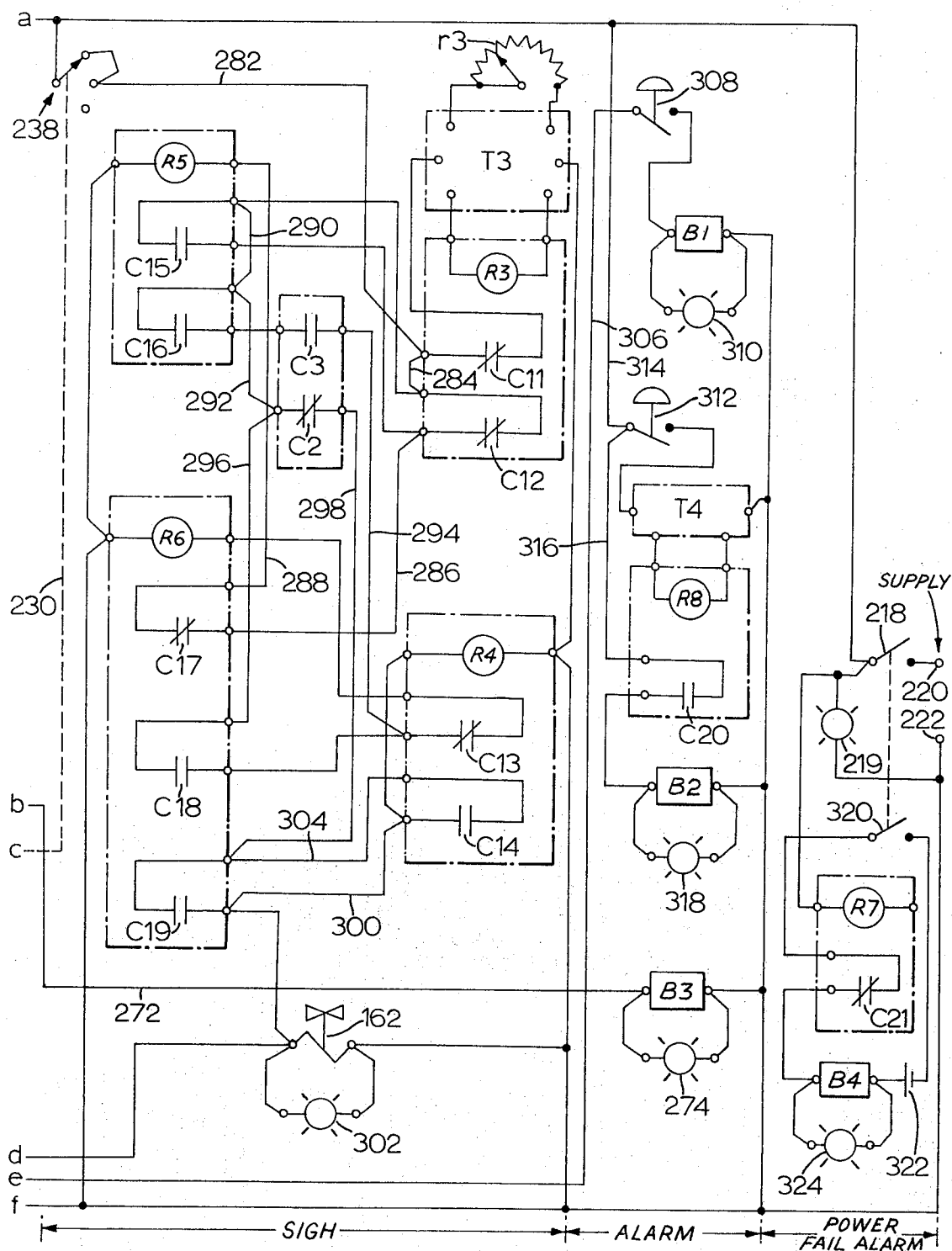


FIG. 3
(Part II)

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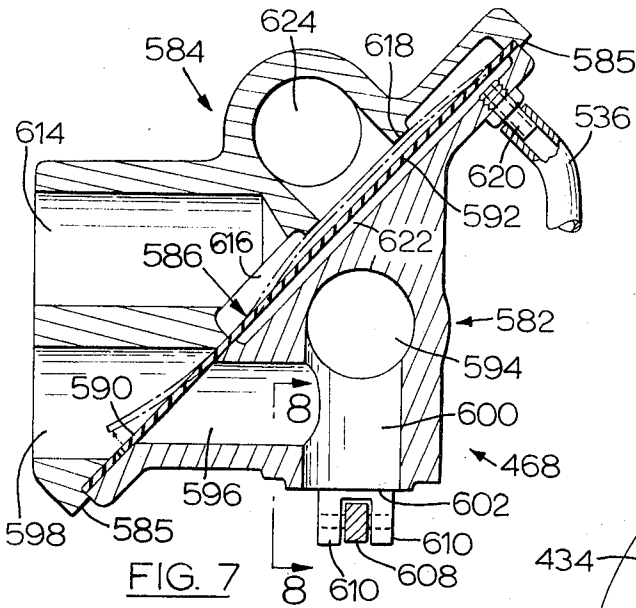


FIG. 7

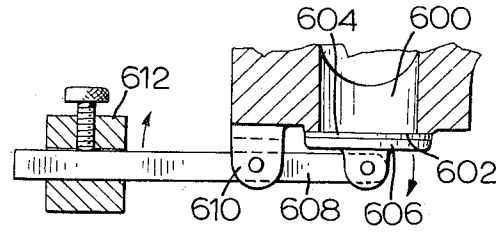


FIG. 8

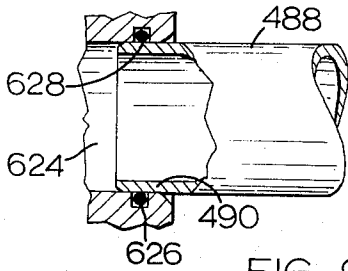


FIG. 9

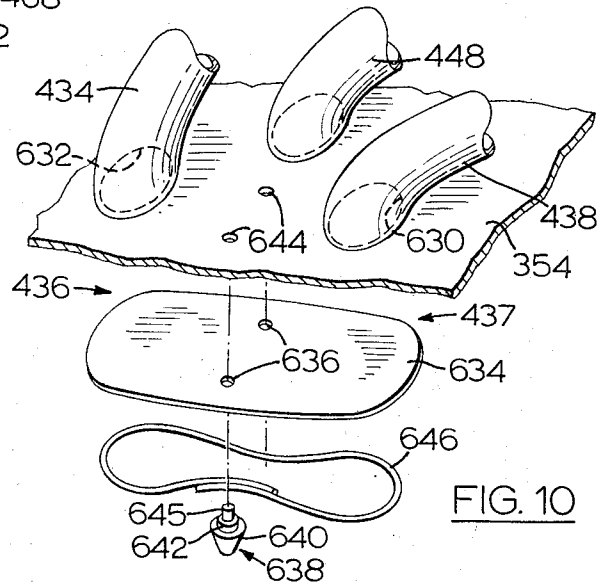


FIG. 10

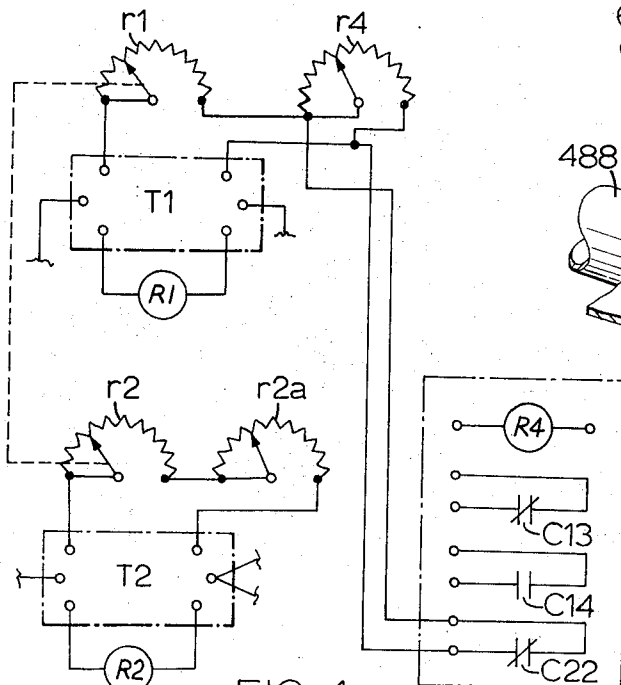


FIG. 4

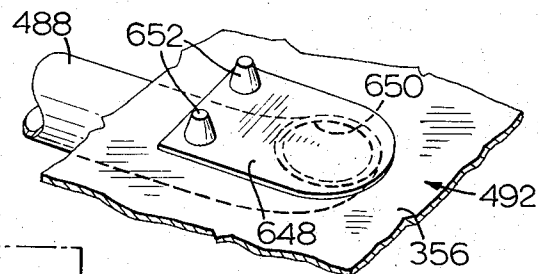


FIG. 11

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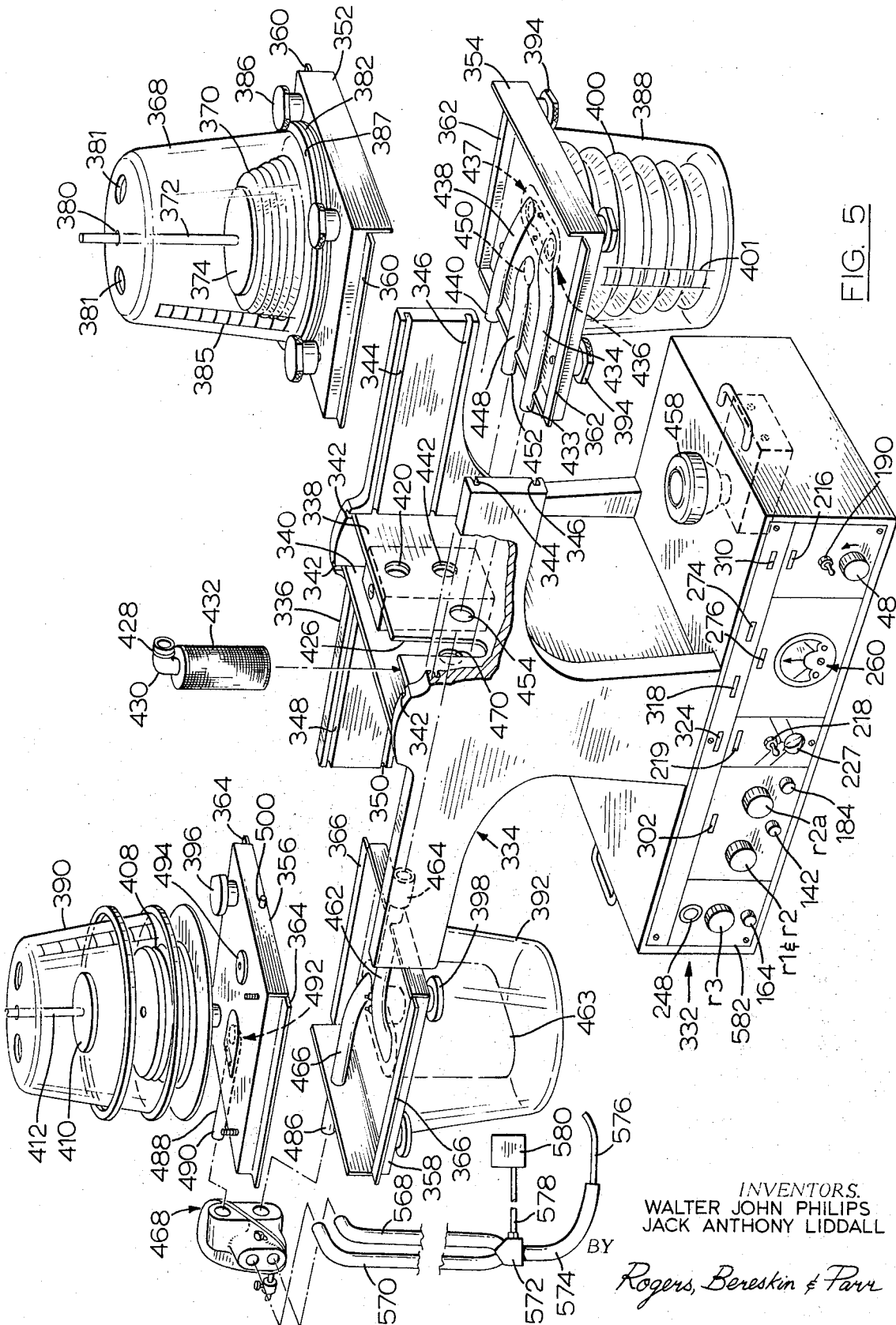


FIG. 5

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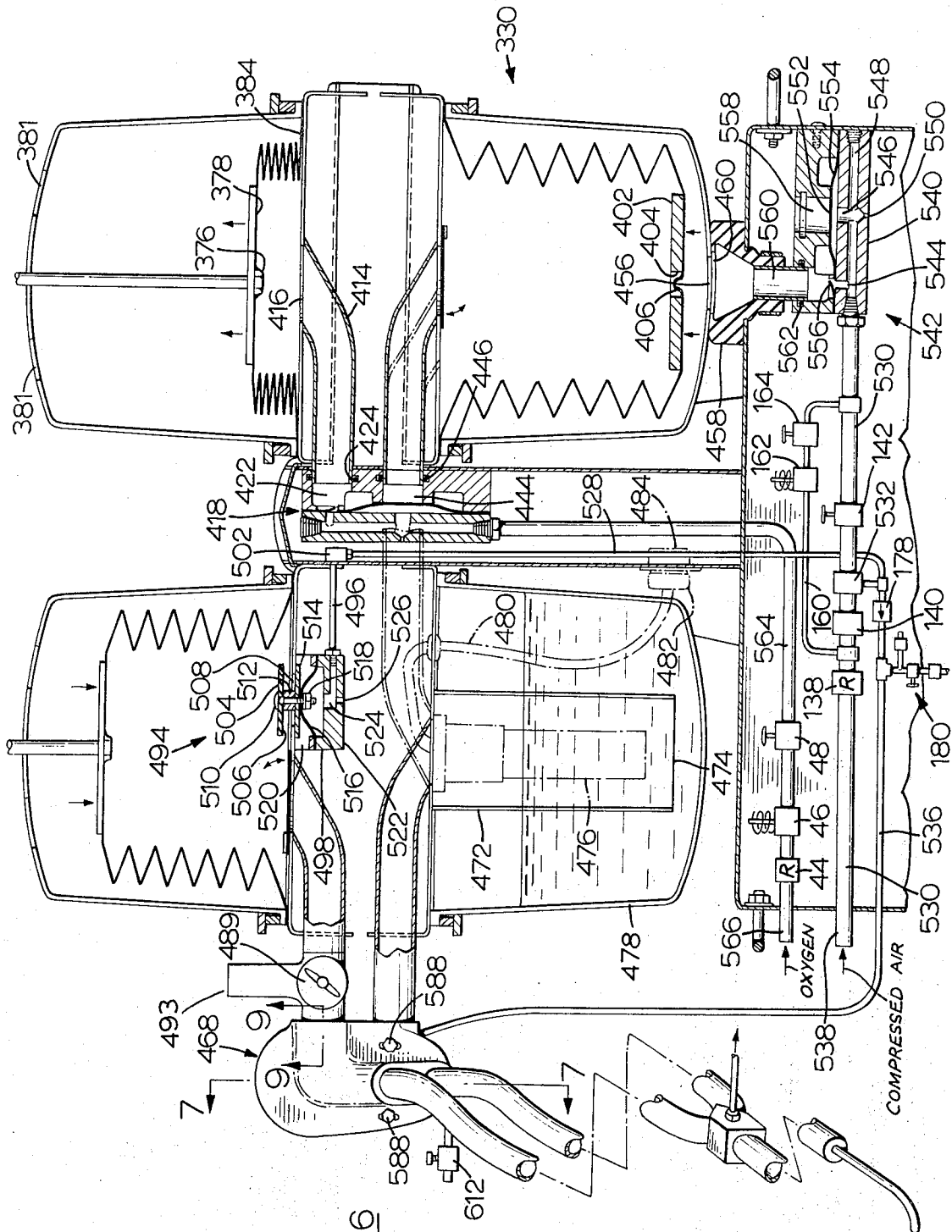


FIG. 6

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AUTOMATIC THERAPEUTIC VENTILATOR

This invention relates to a therapeutic ventilator for automatically forcing a humidified breathing mixture into a patient's lungs during an inhalation period, and for then permitting the lungs to exhale into a spirometer during an exhalation period preparatory to the commencement of a new inhalation period.

Various lung conditions and associated health problems cause difficulty in breathing, and in extreme cases breathing can cease unless the patient is ventilated artificially. Ventilators are available for effectively taking over the breathing function of a patient and forcing breathing mixture into his lungs to ensure an adequate supply of oxygen. The ventilators should be capable of three modes of operation, namely: fully automatic operation for ventilating patients who have ceased breathing for themselves; semi-automatic operation for assisting patients who are breathing intermittently and weakly; and a patient triggered operation in which mode the ventilator responds to attempts made by the patient to breathe for himself. The breathing mixture is usually oxygen-enriched air which is passed through a humidifier to pick up moisture so that when the breathing mixture is forced into the patient's lungs, the moisture ensures that mucus and tissue in the patient's breathing system is not dried out. After each inhalation period, the patient's lungs are allowed to collapse so that exhaled breath passes back to a spirometer in the ventilator and the cycle is then repeated.

There are many types of ventilators available. However, present ventilators tend to be relatively large, unwieldy and expensive, have many delicate parts for metering oxygen and air, and the circuit carrying the breathing mixture is inaccessible and not readily removed for autoclaving.

In one of its aspects, the present invention provides a relatively small, simple and compact automatic therapeutic ventilator which is readily dismantled and affords a visual inspection of its operation. Oxygen is fed into a bellows which is expanded until a predetermined volume of oxygen is collected. This oxygen is then passed from the oxygen bellows into a further bellows which collects the oxygen and contemporaneously inspires a predetermined volume of air so that the air and oxygen mix thereby creating a breathing mixture. A casing around the bellows is filled with compressed air to collapse the bellows and force the breathing mixture through a humidifier to the patient. The breathing mixture bellows and oxygen bellows are visible to the operator so that he has an immediate visible indication of the operation of the ventilator as well as an indication of the relative volumes of oxygen and air in the breathing mixture.

In a second of its aspects, the present invention provides a ventilator having a breathing mixture bellows and humidifier arranged so that trays carrying the bellows and the humidifier can be slidably removed for autoclaving thereby removing completely the circuit between the patient and the air intake.

In a third of its aspects, the invention provides an automatic therapeutic ventilator in which the flow of oxygen into and out of the oxygen bellows is controlled by the pressure of the oxygen; the flow of compressed air for compressing the breathing mixture bellows, the flow of exhaled breath out of a spirometer, the flow of breathing mixture from the humidifier to the patient, and the return flow of exhaled breath from the patient

to the spirometer are controlled automatically by compressed air pressure.

In a fourth of its aspects, the present invention provides an automatic therapeutic ventilator having adjustable electrical timers for controlling inhalation and exhalation periods such that the exhalation period is substantially equal to or greater than the inhalation period.

According to one further aspect of the invention a sigh circuit is provided for automatically and periodically increasing the volume of breathing mixture fed to the patient during a breathing cycle, the sigh circuit being arranged to increase the inhalation period so that the oxygen to air ratio in the breathing mixture remains substantially constant before, during and after the sigh cycle.

These, and other aspects of the invention will be better understood with reference to the following description and drawings wherein:

FIG. 1 is a diagrammatic representation of a pneumatic circuit for mixing oxygen and air into a breathing mixture and applying compressed air to force the breathing mixture into a patient's lungs;

FIG. 2 is a diagrammatic representation of an alternative embodiment of the pneumatic circuit;

FIG. 3 (on two sheets identified as Parts I and II) is a diagrammatic representation of an electrical circuit which controls the flow of compressed air and oxygen according to timing characteristics built into the electrical circuit;

FIG. 4 is a diagrammatic representation of an alternative embodiment of a part of the electrical circuit;

FIG. 5 is an exploded perspective view of an automatic therapeutic ventilator built according to the invention;

FIG. 6 is a front sectional view of the ventilator shown in FIG. 5;

FIG. 7 is a sectional view of a breathing control valve assembly taken on lines 7—7 of FIG. 6;

FIG. 8 is a sectional view of part of the valve assembly taken on lines 8—8 of FIG. 7;

FIG. 9 is a sectional view of a part of the valve assembly taken on lines 9—9 of FIG. 6;

FIG. 10 is an exploded perspective view of a flap valve assembly; and

FIG. 11 is a perspective view of a further flap valve assembly.

For the purposes of description, the invention falls into three parts. A first part is a pneumatic circuit which receives air and oxygen, mixes the air and oxygen to form a breathing mixture and then forces the mixture through a humidifying device to the patient. Exhaled breath from the patient is collected in a spirometer. A second part is a control circuit for timing and sequentially operating the pneumatic circuit, and a third part is a structural embodiment of the pneumatic circuit. The three parts will be described in the order in which they were introduced.

Reference is first made to FIG. 1 which illustrates a first embodiment of the pneumatic circuit. A pressurized oxygen supply 29 is connected to an inlet 30 at the end of an oxygen input conduit 32 and air enters through an air filter 34 to mix with the oxygen thereby creating a breathing mixture. A compressed air supply 35 is connected to an inlet 36 on the end of a feed pipe 38 for forcing the breathing mixture through the circuit and out by way of a tube 40 to the patient. The breath-

ing mixture is driven with sufficient pressure to inflate the patient's lungs. Upon removing the compressed air pressure from the breathing mixture, the patient's lungs collapse driving exhaled breath back through the tube 40 and eventually out through an outlet tube 42.

For convenience, the pneumatic circuit will be described firstly with reference to the formation of a breathing mixture and its passage to the patient; secondly with reference to the exhaled breath; and then finally with reference to the compressed air and associated valving for controlling the flow of breathing mixture and exhaled breath. In general, ducts carrying air, oxygen or breathing mixture will be referred to as conduits, ducts carrying exhaled breath as tubes, and ducts carrying compressed air as pipes.

On entering the inlet 30, oxygen first passes through a pressure regulator 44 which reduces the pressure from the oxygen supply 29 and holds it within close limits, and then through a solenoid valve 46 which can be actuated to shut off the flow of oxygen through the conduit 32 as will be described. Next, the oxygen passes through a flow valve 48 which determines the rate of flow of oxygen through the conduit 32 and then on to an oxygen control valve assembly 50. A single diaphragm 52 incorporates a flap valve 54 which opens in response to pressure when oxygen is passing through the conduit 32 and a flexible portion 56 which is free to move against a valve seat 58 under the influence of the oxygen pressure to thereby prevent oxygen escaping down an oxygen output conduit 60. At the instant depicted by the drawing, oxygen is passing through conduit 32, past flap valve 54, and on through intermediate oxygen conduit 62 into an oxygen bellows 64. A transparent casing 66 protects the bellows 64 and defines an opening 68 for guiding a rod 70 attached to a metal disc 72 coupled to the top of the bellows 64. As oxygen flows through the conduits 32, and 62, the bellows 64 is expanded from a collapsed position, through the position shown in FIG. 1 and on to the position shown in broken outline. At this point the solenoid valve 46 closes and oxygen bleeds through an orifice 74 in the oxygen control valve assembly 50 thereby reducing the pressure in the valve assembly 50 and conduit 32. The resulting pressure differential across the diaphragm 52 causes the flap valve 54 to close and the flexible portion 56 to lift off the seat 58.

The combined weight of the rod 70 and disc 72 acts on the bellows 64 and forces oxygen back through the intermediate oxygen conduit 62 where it meets the closed flap valve 54 and is diverted past the valve seat 58 and on through the oxygen output conduit 60 where it meets an oxygen input valve 76. A light spring is associated with valve 76 to maintain it in the closed position against gravity until the pressure of the oxygen opens the valve 76 so that oxygen enters a bellows 78 where the oxygen will be mixed with air drawn in through air filter 34 by the gravitational action of a metal disc 79 on the bottom of bellows 78. A similar valve 80 is provided adjacent valve 76 at an end of an air inlet conduit 82 which connects the filter 34 to the inside of the bellows 78. In the position shown, the valves 78 and 80 are closed because no oxygen or air is passing through respective conduits 60 and 82. However, the bellows 78 already contains a quantity of breathing mixture from a previous oxygen and air input and is being collapsed by compressed air fed from inlet 36. As a result the breathing mixture is forced from bellows 76, through a

connecting conduit 83, and into a humidifier 86. An electrical heating element 88 is suspended within a humidifier chamber 90 which opens downwardly into water 92 contained in an outer casing 94. The element 88 slowly vapourizes the water 92 to humidify the breathing mixture as it leaves the connecting conduit 84 and passes through the chamber 90 before leaving by a humidifier outlet conduit 96.

A breathing control valve assembly 98 has a diaphragm 100 defining a flap valve 102 and a flexible portion 104 adapted to be moved against a valve seat 106. The portion 104 is held against seat 106 by compressed air fed from the inlet 36 until such time as the compressed air flow is interrupted as will be described. As shown in the figure, breathing mixture is being forced past the flap valve 102 into a breathing mixture outlet conduit 108 which incorporates an adjustable blow-off valve 110 to ensure that the breathing mixture is not pressurized excessively. Tube 40 then receives the breathing mixture from the conduit 108 and delivers it into a tracheal tube 111 to inflate the patient's lungs. The breathing mixture will continue to flow through the tube 40 only as long as the compressed air is allowed to collapse the bellows 78. As a result, once the rate of flow through valve 142 is set, the volume of breathing mixture being fed to the patient from the bellows 78 can be controlled by varying the time period that the compressed air is used to collapse bellows 78. Further, by occasionally permitting more compressed air to be fed for the same time period, a sigh can be developed to further inflate the patient's lungs and ensure that his lung cells are opened. This will be described later.

The next part of the pneumatic circuit to be described is the part concerned with the exhaled breath. After the patient has received sufficient breathing mixture for a single inhalation the solenoid valve 140 cuts off the supply of compressed air. The patient's lungs are then at a higher pressure than the pressure inside the humidifier outlet conduit 96 because the compressed air pressure is reduced as will be described. Consequently, the flap valve 102 closes. Compressed air is also applied to the underside of flexible portion 104 of diaphragm 100, so that when the solenoid valve closes, the flexible portion 104 moves away from valve seat 106 as will be described with reference to the part of the circuit associated with the compressed air supply. The patient's exhaled breath then passes back down tube 40 and enters an exhalation input tube 112 which feeds exhaled breath into the valve assembly 98. The flexible portion 104 is remote from valve seat 106 so that the exhaled breath continues on past valve seat 106 and out through a connecting tube 114.

An optional spirometer 116 includes a bellows 118 surrounded by a casing 120 defining an opening 122 for guiding a rod 124. The rod is attached to a metal disc 126 coupled to the top of bellows 118 and has a removable attachment 128 which is one of a series of different attachments for adding to the rod 124 to change the total weight of rod 124, disc 126 and attachment 128 as required in special circumstances where complete lung collapse is undesirable. A minimum total weight excluding attachment 128 is needed for collapsing bellows 118 to expel exhaled breath from the spirometer. Sufficient weight must be provided to ensure that all of the exhaled breath leaves the spirometer before the next breath begins to enter the spirometer. The base of

the spirometer includes a flap valve 130 associated with the end of connecting tube 114 for opening automatically when exhaled breath is being forced by the collapsing patient's lungs through tube 114 and into bellows 118 to expand the bellows. In the position shown, the bellows 118 contains exhaled breath and is in the process of collapsing thereby forcing exhaled breath out past a poppet valve 132 attached to a diaphragm 134. Compressed air is fed to the under surface of the diaphragm 134 while exhaled breath is leaving the bellows 118 to hold the poppet valve 132 open.

There are several design considerations to be satisfied by the third part of the pneumatic circuit, namely that part containing compressed air. Firstly, the patient must alternatively receive breathing mixture and exhale his breath. Secondly, the bellows 78 must be collapsed by the compressed air once every cycle. Thirdly, the compressed air must be applied to poppet valve 132 and valve assembly 98 to control these valves.

At an instant when the bellows 64 is expanding, the bellows 78 is collapsing to feed a breathing mixture to the patient, and the bellows 118 is also collapsing to expel the previous exhaled breath from the patient. As the cycle of operation continues, an instant will occur when the oxygen bellows 64 is collapsing at which time the breathing mixture bellows 78 will be expanding to receive oxygen from bellows 64, and the bellows 118 will be receiving the exhaled breath from the patient. The compressed air supplies the energy to the pneumatic circuit necessary in meeting these requirements and the timing of the supply of compressed air is controlled by the electrical circuit which will be described with reference to FIG. 3.

Dealing first with the physical connections from the compressed air supply 35, the inlet pipe 38 receives compressed air from inlet 36 and guides the air through a pressure regulator 138, through a solenoid valve 140 and then through an adjustable flow valve 142. The solenoid valve 140 is selectively coupled electrically to oxygen valve 46 so that both valves may be opened contemporaneously for a predetermined time interval. The quantity of compressed air passing through pipe 38 can be varied by adjusting flow valve 142. The pipe 38 feeds the compressed air to compressed air valve assembly 144 which is similar in construction to the oxygen control valve assembly 50 and incorporates a diaphragm 146 defining a flap valve 148 and a flexible portion 150. Pressure from the compressed air supply moves the flexible portion 150 against a valve seat 152 and opens the flap valve 148 permitting compressed air to enter casing 154 about bellows 78 to collapse the bellows and force breathing mixture to the patient. After a time set by the electrical control circuit, the solenoid valve 140 is closed and the compressed air trapped in the feed pipe 38 adjacent the valve assembly 144 bleeds off through orifice 156. As a result there is a differential created across the flap valve 148 and flexible portion 150 resulting in the flap valve closing and the flexible portion moving off the valve seat 152. Compressed air then exhausts from casing 154 to atmosphere and the bellows 78 opens under the influence of the weight of disc 79 to refill the bellows with breathing mixture.

A bypass pipe 160 having a solenoid valve 162 and flow valve 164 is provided to supplement the flow of compressed air through solenoid valve 140 and valve 142 to provide a sigh, when the valves 162, 164 are

opened, more compressed air passes into casing 154 during the time interval set for inhalation. As a result the patient receives a larger volume of breathing mixture.

A control pipe 166 carries compressed air from a point in the feed pipe intermediate solenoid valve 140 and flow valve 142 for controlling the breathing control valve assembly 98 and the poppet valve 132. A pressure regulator 168 in the pipe 166 further reduces the pressure of the compressed air which passes on to the junction of a breathing control pipe 170 and a spirometer control pipe 172. Pressure is applied directly from pipe 172 to the underside of diaphragm 134 in a poppet valve assembly 174 which also has an orifice 176 for bleeding compressed air.

Compressed air entering the pressure control pipe 170 must first pass through a one-way valve 178 which prevents flow in a direction from pipe 170 into pipes 172 and 166. An orifice assembly 180 is coupled to pipe 170 for bleeding compressed air from pipe 170. The assembly 180 includes a main branch pipe 182 feeding an adjustable orifice 184 and a fixed orifice 186. A secondary branch pipe 188 feeds a further fixed orifice 190. The arrangement of the orifices 184, 186 and 190 is such that if the adjustable orifice 184 is closed, then the rate of pressure bleeding from pipe 170 is fixed by the orifice 190. If the orifice 184 is fully open, the rate is fixed by the combined effect of orifices 186 and 190. At any position between fully open and fully closed, the orifice 184 has the effect of providing an adjustable rate of pressure bleed from pipe 170.

The control pipes 166, 170 and 172 provide pressure control of the poppet valve 132 and flexible portion 104 of diaphragm 100 in breathing control valve assembly 98. When the solenoid valve 140 is open, the poppet valve is open to permit exhaled breath to escape from bellows 118 and the valve seat 106 is sealed by flexible portion 104 to prevent breathing mixture from finding its way into the spirometer 116. While the valve 140 is open, compressed air is bleeding through orifice 176 and through orifice assembly 180. As soon as the valve 140 is closed, the pressure in pipes 166 and 172 begins to drop due to air bleeding through orifice 176, and the orifice assembly 180 permits controlled bleeding so that the pressure in pipe 170 begins to drop. The sizes of orifices 190, 184 and 186 are chosen so that the flexible portion 104 moves more or less slowly off valve seat 106 as required so that the breathing mixture may be held in the lungs for a short finite period. This is desirable in cases where the lungs may be inflated differentially because of internal restrictions associated with the lungs.

Turning now to the sequence of operation of the valves in the circuit, the order of events will be described with reference to a patient inhaling and exhaling. The breathing mixture is first prepared as previously described by feeding oxygen to the bellows 64 to collect a predetermined volume of oxygen in the bellows. This oxygen is then fed into the bellows 78 where it is mixed with air. At this point, the bellows 64 has collapsed and the bellows 78 is fully extended with the bottom of bellows 78 resting on the bottom of casing 154. Solenoid valves 46, 140 and 162 are all closed and the patient has just finished exhaling into the spirometer 166. Next the valves 46 and 140 are opened so that oxygen begins to flow into the bellows 64 to supply a fresh charge of oxygen for the next breath. Simulta-

neously, compressed air enters the casing 154 and collapses the bellows 78 thereby forcing a breathing mixture through the connecting conduit 84, humidifier 86, breathing control valve assembly 98, exhalation input tube 112, and finally through tube 40 to the patient. The quantity of breathing mixture fed to the patient depends upon the setting of the flow control valve 142 and the time that the solenoid valve 140 is open. Solenoid valve 46 and flow valve 48 similarly control the quantity of oxygen supplied to the bellows 64. Valves 46 and 140 are electrically operated in parallel so that oxygen is fed through conduit 32 and compressed air is fed through feed pipe 38 for a predetermined length of time. As a result, the flow control valves 48 and 142 must be set to ensure that the required relative volumes of oxygen and compressed air are fed to the respective bellows 64 and casing 154. While the breathing mixture is being fed to the patient, the control pipe 166 and associated pipes 170, 172 are supplied with compressed air. As a result the spirometer 116 is permitted to pass previously exhaled breath out through outlet tube 42 while the breathing mixture is being fed to the patient. The compressed air is permitted to collapse bellows 78 until a point is reached where the volume to be supplied to the patient has left the bellows 78. Normally the bellows will not be fully collapsed at this point. Both solenoid valves 46 and 140 are then de-energized so that oxygen begins to flow from the bellows 64 into the bellows 78 and is followed by air which enters the bellows 78 from the filter 34. Simultaneously, the patient begins to exhale and the pressure in the pipe 170 is reduced as compressed air bleeds through the orifice assembly 180. The patient's exhaled breath then passes into the spirometer and because the pressure in pipe 172 has bled through the orifice 176 in the poppet valve assembly 174, the valve 132 closes, trapping the patient's exhaled breath in the bellows 118. After a predetermined time which is at least as long as the time taken to force breathing mixture into the patient, the bellows 78 is again full of breathing mixture, the bellows 118 is full of exhaled breath and the bellows 64 contains a fresh charge of oxygen. The patient is then ready to receive a new charge of breathing mixture and the breathing cycle is repeated.

For physiological reasons (believed to be to eliminate errors in the volume of air inhaled to oxygenate the blood) it is necessary to occasionally prepare a sigh for the patient. The electrical timing circuit which will be described later, incorporates a circuit for connection to the solenoid valve 162 in the bypass pipe 160. At intervals selected by the operator and timed electrically, solenoid valve 162 will open with the solenoid valves 46 and 140 to thereby permit an extra charge of compressed air to pass around the bypass pipe 160. This results in collapsing the bellows 78 further than it is collapsed for a normal breath so that the patient receives an extra charge of breathing mixture. At the next breath, the patient will receive a breathing mixture in which the oxygen content is slightly reduced because a fixed volume of oxygen is fed into the bellows 78 on every cycle and the bellows 78 was collapsed further for the sigh. However, the mixture will be restored to substantially the desired proportions within several cycles.

The oxygen supply can be increased or completely stopped. Flow valve 48 can be operated manually to increase the volume of oxygen, and if desired, a switch

190 in the line to the solenoid of the solenoid valve 46 can be opened so that valve 46 remains in a closed position. As a result, no oxygen will be fed to the bellows 64. The flap valve 76 inside bellows 78 then prevents flow of breathing mixture back through oxygen output conduit 60.

A pressure sensing device 192 is coupled by a branch pipe 194 to the junction of tube 40, conduit 108 and tube 112. The device 192 is coupled electrically to the electrical control circuit which will be described.

In situations where the supply of compressed air is limited, it would be preferable not to waste compressed air. In the pneumatic circuit just described, air is bled through orifice assembly 180 and orifice 176 while maintaining the diaphragm 100 against the valve seat 106 and holding the poppet valve 132 open. Further, in some instances it may be desirable to ensure that the ratio of oxygen to air is maintained substantially constant after a sigh and that a minimum of oxygen is vented. A pneumatic circuit which will satisfy these requirements is illustrated in FIG. 2.

Reference is now made to FIGS. 1 and 2 with particular reference to FIG. 2. Parts appearing in FIG. 1 which are identical with those already described with reference to FIG. 1 are given the same numerals, and parts which are similar to corresponding parts in FIG. 1 are given primed numerals. The main difference between the FIG. 1 and FIG. 2 embodiments lies in the arrangement for permitting the pressures in pipes 170, 172, conduit 32 and feed pipes 38 to become atmospheric. Dealing first with the oxygen supply through conduit 32, a control valve assembly 50' is similar to valve 50 with the exception that the orifice 74 in valve 50 is removed. Oxygen is vented through a solenoid valve 46' positioned to replace solenoid valve 46 and including an outlet 196. Solenoid valve 46' has a first position in which oxygen is free to pass through the valve from the inlet 30 and into the valve 50' and there is no flow through the outlet 196. Upon de-energizing the valve 46', the valve takes up a second position in which oxygen is prevented from passing from the inlet 30 through to the conduit 32. However, in the second position oxygen from conduit 32 is free to pass through the valve 46' and out to atmosphere by way of outlet 196. This arrangement minimizes the loss of oxygen because unlike the previous embodiment shown in FIG. 1, the oxygen vents to atmosphere only after valve 46' shuts off the oxygen supply. In the FIG. 1 embodiment the oxygen vents continuously through orifice 74 when valve 46 is open.

A compressed air valve assembly 144' is similar to valve assembly 50' with the exception that the underside of diaphragm 146' is connected by a branch pipe 198 coupled to control pipe 166. A solenoid valve 200 is provided in control pipe 166 and operates in a similar manner to valve 46' to selectively either permit compressed air to pass from pressure regulator 168 to control pipe 166 or, when de-energized, to permit compressed air to exhaust through outlet 202 from the underside of diaphragm 146' and branch pipe 198. Valve 200 also permits the pressure in pipe 172 and in the underside of poppet valve diaphragm 134' to bleed to atmosphere. As a result there is no orifice in the poppet valve assembly 174'.

Because the control pipe 166 now has a control valve 200, pressure regulator 168 can be fed from inlet 36 directly by a feed pipe 204.

Valve 200 can not be used to permit the pressure on the underside of diaphragm 100 to be relieved by permitting compressed air from pipe 170 to pass through outlet 202. This is because as previously mentioned the pressure in pipe 170 and the underside of diaphragm 100 is relieved relatively slowly and is prevented from returning to pipe 166 by a one-way valve 178 in the pipe 170. However, this part of the circuit differs from the circuit shown in FIG. 1 in that a further solenoid valve 206 is included at the junction of pipe 170 and main branch pipe 182. The valve 206 is also similar to valves 200 and 46' and selectively permits compressed air to pass along pipe 170 without access to branch pipe 182 and then to pass from the underside of diaphragm 100 along pipe 170 and out through the branch pipe 182 and orifice assembly 180.

The arrangement of valves shown in FIG. 2 reduces the loss of oxygen and compressed air when compared with the FIG. 1 circuit. Further, when compressed air is needed to collapse the bellows 78 in the embodiment shown in FIG. 1 there was a loss of compressed air because it was bleeding through orifice 176, through orifice assembly 180, and through orifice 156. In the FIG. 2 embodiment, when the compressed air is collapsing the bellows 78, there is no loss of compressed air pressure at any other part of the circuit.

The FIG. 2 embodiment also differs from the FIG. 1 embodiment in that the sigh is provided in a different manner. The electrical circuit feeding the solenoid valves 46' and 140 includes a relay and resistance indicated diagrammatically at 208. When a sigh is to be produced, the relay brings the resistance into the circuit feeding the solenoid and thereby holds the solenoid valves 46' and 140 open for a longer period. As a result the patient receives more breathing mixture. An advantage of this sigh arrangement is that while the sigh breathing mixture is being forced to the patient, the bellows 64 is receiving oxygen for the same period. When this oxygen is drawn into bellows 78 it is sufficient to ensure that the resulting air to oxygen ratio in the breathing mixture remains at the desired setting after a sigh cycle.

Although two embodiments of the pneumatic circuit have been described, it is of course possible to delete part of one circuit and incorporate parts of the other. For instance, the valve 206 which supplies the orifice assembly 180 could be deleted if preferred to obviate the possibility that valve 206 will stick and hold the patient in an inflated position. Also, if adequate supplies of compressed air are available the circuit shown in FIG. 1 may be preferred in order to reduce the cost incurred in using the solenoid valves 46' and 200 described with reference to FIG. 2.

This completes the description of two embodiments of pneumatic circuits suitable for use in the invention. Next, the electrical circuits associated with the control of the pneumatic circuits will be described.

Reference is made to FIG. 3, which shows an electrical circuit suitable for controlling the pneumatic circuit shown in FIG. 1. The electrical circuit is required to open and close the solenoid valves 46, 140 and 162 at predetermined intervals in a breathing cycle. Once the solenoid valves have been opened, the compressed air supply and the oxygen supply are applied to the pneumatic circuit as previously described.

The electrical circuit consists of five sub-circuits which are indicated along the bottom of FIG. 3. The

sub-circuits are: a cycle timer circuit which is adjustable for controlling both the inhalation period during which breathing mixture is supplied to the patient, and the exhalation period during which the patient exhales; a pressure control circuit which can be adjusted to set the upper and lower pressure limits of the pneumatic cycle as applied to the patient; a sigh circuit which is adjustable for controlling the time between sighs and is adapted to periodically activate solenoid valve 162 (FIG. 1) at an instant when the solenoid valve 140 is activated; an alarm circuit for indicating low oxygen pressure, prolonged low pressure at the tube 40 (FIG. 1), and excessive breathing mixture pressure; and a power fail alarm circuit which indicates to the user that the power supply to the main circuit has failed. The sub-circuits will be described in the order in which they were introduced, i.e., from left to right of FIG. 3.

A cycle timer circuit includes timers T1 and T2 for respectively controlling the inhalation period during which breathing mixture is forced to the patient and the exhalation period. The timers T1, T2 have respective potentiometers $r1$ and $r2$ which are ganged together and so arranged that for similar settings of $r1$, $r2$, the timers T1 and T2 produce substantially equal time delays. A further potentiometer $r2a$ is in series with potentiometer $r2$ so that the exhalation period can be increased relative to the inhalation period by adjustment of potentiometer $r2a$.

Respective relays R1 and R2 are activated by timers T1 and T2 such that when electrical power is initially applied to one of the timers, there is a delay followed by activation of the associated relay. Each of the relays R1, R2 remains activated until the power is disconnected by its associated timer at which time the relay drops out. Four contacts C1, C2, C3 and C4 are associated with relay R1 and relay R2 is associated with contact C5.

The cycle timer circuit is coupled to compressed air solenoid valve 140 and oxygen solenoid valve 46 previously described with reference to FIG. 1. Switch 190 which was described in FIG. 1 for selectively introducing oxygen supply into the pneumatic circuit is ganged with a further switch 214 for energizing light bulb 216 to give a visual indication that the oxygen supply 29 is connected to the pneumatic circuit.

For the purposes of describing the cycle timer circuit in detail, it will be assumed that the switches 190, 214 are closed. When a main switch 218 adjacent the supply terminals 220, 222 is closed, a bulb 219 indicates that the electrical circuit is energized. For simplicity of description it will be assumed that electrical current flows from terminal 220 to terminal 222, so that initially, current flows to the light bulb 216 to indicate that electrical power is available. At this instant current also flows to conductor 224 which is connected to a first part 226 of a ganged selector switch 227 (FIG. 5) having five parts. Broken lines 228, 230 indicate that the part 226 is ganged to respective second, third, fourth and fifth parts 232, 234, 236 and 238 of the selector switch. Each part can selectively connect a respective centre contact to one of three outer contacts. In each case, the upper of the three contacts indicates connection to a fully automatic cycle, the intermediate contact indicates connection to a semi-automatic cycle, and the lower contact indicates connection to a cycle triggered by the patient. As drawn, the switch parts 226, 232 are in the "automatic" position so that

the cycle timer circuit will control the inhalation and exhalation periods.

Conductor 224 terminates at switch part 226 and is electrically coupled to conductors 240 and 242. Considering first conductor 240, this conductor terminates at a closed contact C4 where it meets further conductors 244 and 246. A manual switch 248 in conductor 246 is provided for calibrating the sigh circuit (as will be described) and is normally open so that no current is flowing in conductor 246. Conductor 244 however, carries current to solenoid valves 46 and 140 thereby energizing the valves and permitting oxygen and compressed air to flow into the pneumatic circuit. Considering now the other conductor, 242, current flows from conductor 242 through selector switch part 232 and then by way of conductor 250, conductor 252, closed contacts C5 and conductor 254 to timer T1 thereby energizing the timer and starting the inhalation time delay. During this delay, breathing mixture is being forced to the patient by compressed air introduced to the pneumatic circuit through open solenoid valve 140. At the end of the inhalation delay, the relay R1 is energized thereby closing contact C1 and permitting current to flow from conductor 250 through conductor 256 to energize timer T2. At the same time as the contact C1 closes, the contact C4 opens cutting off current to the solenoid valves 46, 140 whereupon both valves close cutting off oxygen and compressed air from the pneumatic circuit. The patient's inhalation period has now ended and the exhalation period has begun, the duration of the exhalation period being determined by the delay of timer T2. Eventually, relay R2 is energized thereby opening contacts C5 and cutting off power to timer T1. Contacts C1 and C4 then return to their original position as drawn and the valves 46, 140 are again opened and the cycle is repeated.

The first delay during which breathing mixture is forced to the patient will be substantially equal to the second delay during which the patient exhales if the potentiometer *r2a* is set at zero resistance. As potentiometer *r2a* is introduced into the circuit the exhalation delay increases.

In the automatic cycle, the patient does not trigger any of the functions. The complete cycle is controlled by timers T1 and T2. However, in the semi-automatic cycle the patient may trigger a new cycle by attempting to inhale. If he does not inhale however, the cycle reverts to automatic thereby ensuring that the patient receives breathing mixture. In order to provide the semi-automatic cycle the pressure control circuit must be coupled to the cycle timer circuit.

The pressure control circuit is associated with a pressure control meter 260 which receives signals from sensing device 192 (FIG. 1). The meter 260 has adjustable upper and lower limit indicators 262, 264 associated with respective control knobs 266, 268. A needle 270 is responsive to pressure fluctuations relayed from pressure sensing device 192 (FIG. 1). Relays RL and RH are coupled to the meter 260 and are respectively actuated as needle 270 sweeps over limits 264, 262 in a clockwise direction (as drawn). As the needle returns in an anti-clockwise direction, the relays RH, RL are de-energized when the needle passes over respective limits 262, 264. As drawn, contacts associated with relays RL and RH are shown in the position they would be in when the needle is between limits 262, 264. Relay RL controls contacts C6, C7 and C8, and relay

RH controls contacts C9 and C10. Respective third and fourth parts 234, 236 of the control switch determine the mode of operation of the pressure control circuit.

With the control switch in the "automatic" position as drawn, the lower limit 264 is set well below atmospheric pressure and the upper limit 262 is set slightly above the pressure developed by the preset volume delivered to the patient's lungs. As the ventilator cycles, the needle 270 will sweep back and forth responding to pressure fluctuations. If for any reason the needle should pass the upper limit 262, the relay RH will be energized and contact C10 will close. As a result, current will flow from contact C10 through switch fourth part 236 and by way of conductor 272 to alarm buzzer B3. An alarm bulb 274 is wired in parallel with buzzer B3 to give a visual indication that a high pressure condition exists. Once the needle 270 falls below upper limit 262, the relay RH is de-energized and the contacts C10 open thereby cutting off buzzer B3 and bulb 274. The contact C9 which is also operated by relay RH receives current only when the switch first part 226 is in the "patient triggered" position.

Should the needle 270 fall below the limit 264 it indicates that the patient has attempted to take in a breath and has reduced the pressure below limit 264. As a result, contact C6 is closed by the de-activation of relay RL and an assist bulb 276 is illuminated to indicate that the patient has attempted to take a breath. At the same instant contact C8 is closed and the contact C7 is opened. However, these three contacts have no effect with the selector switch in the automatic position. Thus with the selector switch at "automatic" should the needle 270 pass the upper limit 262, buzzer B3 and bulb 274 are energized.

Consider next the situation when the control switch is in the "semi-automatic" position and the needle 270 is in the position shown in the drawing and moving toward limit 262. The patient is receiving a breathing mixture controlled by timer T1. However, should the patient attempt to breathe he may do so in such a fashion that the needle 270 would pass the upper limit 262 and the buzzer B3 and light 274 would then be actuated as previously described. It is therefore preferable to set the upper limit slightly higher than in the automatic cycle to avoid unnecessary activation of buzzer B3 and light 274. After the inhalation period set by timer T1, timer T2 commences the exhalation period and the needle falls to lower limit 264 ready to commence a new cycle after timer T2 is de-activated. However, a new cycle can be triggered by the patient as will now be explained.

As the needle sweeps towards limit 264, the timers T1 and T2 are both energized and the exhalation delay period is in progress, the contacts C1 to C5 being in the opposite mode to that drawn. Current is flowing through contact C1 to timer T2 and through contact C5 to timer T1. Should the patient try to take a breath at this point he will reduce the pressure and needle 270 will fall past the pre-adjusted limit 264 so that relay RL will be de-activated and contact C7 will open. Current to timer T1 was passing from switch first part 226 through contact C7 and then by way of switch second part 232, conductor 252, contact C5, and conductor 254 to timer T1. When contact C7 opens, current is no longer flowing to timer T1 and the cycling circuit resets. As a result contact C4 closes and current flows from switch first part 226 by way of conductor 240 and

contact C4 to open the solenoid valves 46, 140. The pressure then rises to bring needle 270 above lower limit 264 whereupon contact C7 again closes and current is available at timer T1 for an automatic cycle. Thus, the difference between the automatic and semi-automatic cycles is that the patient is allowed to commence a new cycle by attempting to take a breath. However, if he fails to attempt to breathe before the set exhalation period is complete, the automatic cycle begins a new breathing cycle.

Next, the "patient triggered" position of the selector switch will be described. The cycle is now controlled by the patient without using timers T1 and T2. Commencing with the needle 270 in the position shown, and the patient about to attempt to inhale. Upon inhaling, pressure drops until needle 270 reaches lower limit 264 which is set so that the patient must attempt to inhale in order to bring needle 270 below lower limit 264. Relay RL is now de-energized so that contact C8 is closed. Switch third part 234 and contact C8 together form a switch across latch terminals 182 of relay RH so that relay RH is energized thereby closing contact C9 to commence a pressure cycle. The valves 46 and 140 are then opened as a result of current passing from switch part 226 through conductor 278, and then by way of contact C9 and conductor 280 to the valve 140 and 46. As soon as needle 270 passes upwardly across limit 264 the contact C8 opens and contact C9 remains in position until it is disturbed by needle 270 passing upper limit 262. When the needle 270 reaches the upper limit 262 the relay RH opens contacts C9 thereby de-energizing the solenoid valves 46, 140. Contact C10 although closed, is not in the circuit. The pressure then begins to drop but the contact C9 remains open, this contact being of a type having no preferred position. This mode is of use only if the patient is capable of initiating breathing and simply requires assistance.

Next the sigh circuit will be described. Power for the sigh circuit is drawn through the selector switch fifth part 238 which is arranged so that the sigh circuit will be operational when the switch is in either the "automatic" or "semi-automatic" positions. The sigh circuit is isolated when the selector switch is in the "patient triggered" position.

The sigh circuit includes a timer T3 having a potentiometer r3 and associated with a relay R3 having contacts C11 and C12, a relay R4 associated with contacts C13, C14, a relay R5 associated with contacts C15, C16, and a relay R6 associated with contacts C17, C18 and C19. Contacts C2 and C3 of relay R1 in the cycle timer circuit are associated with the sigh circuit and for simplicity of drawing, these contacts are duplicated in the sigh circuit between relays R5 and R3.

The sigh circuit has a timer T3 and associated potentiometer r3 for adjusting the timer to give delays of the order of 1 to 7 minutes. For proper timing, the sigh circuit must be arranged to commence supplying an extra volume of compressed air through solenoid valve 162 (also shown in FIG. 1) at the same time that valve 140 associated with the cycle timer circuit begins to open. The timer T3 is of a type which when actuated immediately actuates the relay R3 and when the power is no longer applied to the timer T3 there is a time delay before the relay R3 is de-energized.

It will be convenient for the purposes of description to consider an instant in the cycle at which the timer T3

has actuated relay R3. As a result both contacts C11, C12 will be open and there is no complete circuit through which current can flow from conductor 282. After the time delay set by T3, the relay R3 will be deactivated and contacts C11, C12 will close. As a result, current will flow through contact C11 thereby energizing timer T3. However, before relay R3 can open contacts C11 and C12, current passes from conductor 282, through conductor 284 and then by way of contact C12, conductor 286, closed contact C17 and conductor 288 to energize relay R5. This closes contact C15 so that current from conductor 284 now passes to conductor 286 by way of contact C15 rather than by way of contact C12 which now opens under the influence of relay R3.

Relay R5 now maintains contacts C15, C16 in a closed position irrespective of the timer T3. If relay R1 is not energized, contact C3 prevents current flow from conductor 290 and closed contacts C16. A conductor 292 coupled to conductor 290 also leads to open contacts C18, C19 and C14. As a result, the sequence is stopped until such time as relay R1 is activated after an inhalation period.

Upon activation of relay R1, conductor C3 closes and current flows through conductor 294, closed contact C13 and on to energize relay R6. At the same instant, contact C2 opens thereby cutting off current to contact C19 which at this instant is closing because relay R6 is energized. However, current from conductor 292 passes by way of conductor 296 to closed contact C18 which permits current to flow through contact C13 and back to relay R6. Relay R6 is now maintained in the activated position irrespective of relays R3 and R5 and timer T3. C17 has now opened thereby de-energizing relay R5.

The cycle can progress no further until the relay R1 is again de-energized signifying the commencement of a new inhalation period. Upon de-energizing relay R1, contact C3, which is now isolated by open contact C16, opens, and contact C2 closes. As a result current flows through contact C2 and then by way of conductor 298 and closed contact C19 both to solenoid valve 162 and conductor 300 which energizes relay R4. A warning light 302 is wired in parallel with the solenoid valve 162 to indicate that the valve is now open. Upon energizing relay R4, contact C13 is opened thereby cutting off current supply to relay R6. However, because contact C14 is now closed current passes by way of contact C2, conductor 298 and conductor 304, contact C14 and conductor 300 to the solenoid valve 162. As a result, the valve 162 will remain open until R4 is de-energized.

At the end of the inhalation period, relay R1 is again energized and contact C2 is opened. This cuts off the supply of current to the valve 162 and to relay R4. Contacts C13 and C14 then return to their original positions and the circuit has completed the sigh. While the sigh has been in progress, the timer T3 has started a new cycle and after a significant delay, it will again trip the relay R3 and begin a new sigh cycle.

The next part of the electrical circuit is the alarm circuit. Beginning at the top of the alarm circuit, a conductor 306 connects the back of switch 214 in the cycle timer to a pressure switch 308 which responds to low oxygen pressure to set off a buzzer B1 and alarm bulb 310, provided that the switch 214 is closed.

The next part of the alarm circuit is concerned with low pressure at the tube 40 (FIG. 1). A pressure switch

312 closes if the pressure drops and remains below a minimum (typically 7 cms. of water) for more than a predetermined period set by a timer T4. A conductor 314 carries current to the switch 312 and upon the pressure dropping below the predetermined figure, the timer T4 will be energized. After the time delay built into the timer, (typically about 7 seconds) the relay R8 will be energized to close contact C20. A conductor 316 then carries current from conductor 314, through closed contact C20 to energize a buzzer B2 and alarm bulb 318. This alarm will be energized should there be a major leak in the supply of breathing mixture to the patient, or if the patient fails to trigger a new cycle when the selector switch is in the "patient triggered" position.

The alarm circuit also consists of the buzzer B3 which as previously described will be energized should the pressure of the breathing mixture supplied to the patient exceed the upper limit 262.

The last part of the electrical circuit consists of a power fail alarm. The switch 218 is ganged to a further switch 320 in a separate circuit containing a battery 322. When switches 218, 320 are closed, a relay R7 is energized and a contact C21 is opened to prevent flow of current around the low voltage circuit. Should the power fail, relay R7 releases contact C21 which completes the low current circuit and activates a buzzer, B4 and warning light 324. As soon as power is restored, the relay R7 is again activated and the lower power circuit is broken.

Although the electrical circuit has been described with reference to three modes, i.e., automatic, semi-automatic and patient triggered, the electrical circuit can be simplified should it be desired to simply incorporate one of these modes of operation. Further if it is not necessary to include the sigh circuit, this can be deleted.

As previously discussed with reference to FIGS. 1 and 2, it is sometimes desirable to incorporate solenoid valves 46', 200 and 206 in order to limit compressed air and oxygen losses. In such a case, the electrical circuit would incorporate solenoids 46', 140, 200 and 206 in parallel in place of the solenoids 46 and 140 shown in parallel in FIG. 3. The sigh circuit described with reference to FIG. 3 is specifically for use with the FIG. 1 embodiment. However, the FIG. 1 circuit can be modified to match the FIG. 2 pneumatic circuit embodiment. As shown in FIG. 2, the FIG. 1 bypass pipe and valves 162 and 164 have been removed, regulator 168 is coupled directly to the compressed air supply 35 and solenoid valve 200 is introduced into the compressed air control pipe 166. The length of the inhalation period is increased when a sigh is to be produced by introduction of a resistance into the electrical circuit at 208.

Reference is now made to FIG. 4 which shows a modification to be made to the FIG. 3 circuit in order to increase the length of inhalation period when a sigh is being produced to match the FIG. 2 embodiment. Parts common to those already described have the same numerals in order to relate the FIG. 4 change to the circuit already described with reference to FIG. 3. In FIG. 3, the potentiometer r1 is connected directly to the timer T1, and the potentiometers r2 and r2a are connected in series across timer T2. In FIG. 4 the potentiometer r1 is connected to a normally closed contact C22 in parallel with a potentiometer r4. As previously described potentiometers r1 and r2 are ganged to-

gether to move in unison so that if potentiometer r2a is at zero resistance the inhalation and exhalation times are substantially equal. Contact C22 is added to relay R4 shown in FIG. 3 so that when the sign is about to take place the contact C22 is opened by relay R4 and potentiometer R4 is brought into the timer circuit T1. As a result, the inhalation period is extended with a proportionate increase in the volume of breathing mixture received by the patient together and in the volume of oxygen entering the oxygen bellows. Potentiometer r2a continues to dictate whether or not the inhalation and exhalation periods will be equal or whether the exhalation period will be longer than inhalation period except when, there is a sigh inlation.

As previously described, in this embodiment a sigh increase the length of time during which oxygen solenoid valve 46 and the compressed air solenoid valve 140 are open. The concentration of oxygen in the breathing mixture therefore remains substantially constant in the subsequent inhalation.

Reference is now made to FIGS. 5 and 6 which show an automatic therapeutic ventilator 330 built according to the invention. The ventilator incorporates the pneumatic circuit described with reference to FIG. 1, and in FIG. 6, the parts of the ventilator are shown in the same position as the diagrammatic parts of FIG. 2.

Ventilator 330 consists of a base 332 supporting T-shaped end members 334, 336 disposed at the front and back of the base 332. Upright panels 338, 340 are located in slots 342 and extend rearwardly in spaced-apart relation between end members 334, 336. The members 334, 336 also define four pairs of opposed grooves 344, 346, 348 and 350 for respectively receiving oxygen tray 352, breathing mixture tray 354 spirometer tray 356, and humidifier tray 358. The trays have respective outwardly turned lips 360, 364 and 366 for slidably engaging in the grooves.

The oxygen tray 252 supports a generally bell-shaped transparent plastic casing 368 containing an oxygen bellows 370 and a rod 372 coupled to a disc 374 for compressing the bellows 370. As better seen in FIG. 6, the rod 372 extends through the disc 374 and projects into a shallow depression 476 in end wall 378 of bellows 370. Casing 368 defines an opening 380 providing guidance for the rod 372 and openings 381 to permit the bellows 370 to expand as oxygen is forced into the bellows. The casing 368 has an outwardly-extending rim 382 which traps an outwardly-extending flange at the mouth of bellows 370 against tray 352 to seal the bellows. Casing 368 is held in place against the bellows flange 384 by four rotary latches 386 engaging a pressure ring 387 on the casing rim 382 and a scale 385 indicates the volume of oxygen in bellows 368.

Trays 354, 356 and 358 have respective casings 388, 390 and 392 attached to them by respective rotary latches 394, 396 and 398.

A bellows 400 for receiving oxygen and air is contained in casing 388 and held in place in similar fashion to bellows 270 with which it is interchangeable. However, bellows 400 contains a disc 402 for extending the bellows. The disc 402 has a central opening 404 providing clearance for shallow depression 406 in the end wall of the bellows 400 for locating the disc 402 centrally of the bellows end wall. A spirometer bellows 408 is contained in casing 390 and is associated with a disc 410 and rod 412 for collapsing bellows 408. Bellows 408 is also interchangeable with bellows 380 and 400.

As better seen in FIG. 6, an oxygen conduit 414 extends downwardly and horizontally from an opening 416 in tray 352 to connect the bellows 370 to an oxygen control valve assembly 418 attached to panel 338. Conduit 414 extends through an opening 420 in panel 338 and into an oxygen port 422 in valve assembly 418. The port 422 defines an annular groove containing an elastomeric O-ring 424 which seals about a projecting end of conduit 414.

An elongated slot 426 extends downwardly from the top of panel 338 and is adapted to engage in an annular groove 428 adjacent an end of an elbow 430 attached to air filter 432. Once in position in slot 426, the open end of elbow 430 is positioned for receiving an end of an air inlet conduit 434 attached to tray 354. The conduit 434 leads air from filter 432 through a flap valve 436 into bellows 400. A similar flap valve 437 is associated with an end of an oxygen output conduit 438 which terminates at an end 440 aligned with an opening 442 in panel 338. An oxygen outlet port 444 is in registration with opening 442 and defines an annular recess containing an elastomeric O-ring 446 which seals about end 440 of conduit 438.

A connecting conduit 448 extends from an opening 450 in tray 354 terminating at an end 452 for engaging in opening 454 in panel 338.

Ends 433, 452 and 440 of respective conduits 434, 448, and 438 extend in generally parallel relation so that when the tray 354 engages in the grooves 346, the end 433 engages in the end of air filter elbow 430, the end 448 projects through opening 454 in panel 338, and end 440 engages in O-ring 448 of port 444.

Casing 388 includes an opening 456 for registration over a resilient seal 458 associated with the compressed air supply. The seal is located in the top of base 332 and has an inwardly projecting radial lip 460 adapted to flex upwardly under the influence of compressed air to sealingly engage against the casing 388 about the opening 456. When the tray 354 is engaged in the grooves 346, the casing 388 slips into place over the seal 458 and is in correct registration over the seal when the tray is fully engaged with the grooves 346.

Humidifier tray 358 has a conduit 462 for carrying breathing mixture into a humidifier 463. The conduit 462 terminates at its end in a cylindrical coupling 464 for receiving end 452 of connecting conduit 448. Tray 358 also includes a humidifier outlet conduit for transporting humidified breathing mixture from humidifier 463 to a breathing control valve assembly 468. When tray 358 is engaged in grooves 350, the coupling 464 projects through an opening 470 in panel 340 and engages over end 452 of connecting conduit 448 in an air tight joint.

The humidifier 463 consists of an oval housing attached by its upper end to the tray 358 and extending downwardly to an open lower end 474. An electrical heating element is attached to tray 458 and extends downwardly inside housing 472 for heating water 478 contained in casing 392. A cable 480 extends from the element 475 and terminates in a plug 482 engaging in a receptacle 484 which is coupled conventionally to a power source (not shown).

When the trays 352, 354 and 358 are in place in their respective grooves 344, 346 and 350, the pneumatic circuit for preparing humidified breathing mixture and supply it at an end 486 of humidifier outlet conduit 466 is complete.

Spirometer tray 356 includes a connecting tube 488 having an end 490 for engaging in breathing control valve assembly 468. The tube 488 includes a valve 489 and terminates at its other end in flap valve 492 for permitting exhaled breath to pass through tube 488 and into bellows 408. Valve 489 allows the user to divert exhaled breath through an outlet 493 if the breath is to be collected for analysis.

The exhaled breath can escape from bellows 408 only when a poppet valve 494 is opened. A compressed air control pipe 496 extends from poppet valve assembly 498 terminating at an end 500 projecting beyond tray 356 for automatically engaging in a connecting block 502 when the tray 356 is moved into place along groove 348.

The poppet valve assembly 498 consists of relatively rigid disc 504 for supporting a circular rubber seal 506 adapted to engage about an opening 508 in tray 356. The seal and disc 504 are positioned adjacent a head of a bolt 510 which extends downwardly through a spacer 512, a limit bar 514, a diaphragm 576 and engages in a nut 518. The Bar 514 is relatively narrow and rectangular in plan view so that it does not block passage of exhaled breath through opening 508 when the poppet valve is open. A central portion of the diaphragm 516 is trapped between the limit bar 514 and the nut 518, and the periphery of the diaphragm is trapped between an upper frame member 520 on the underside of tray 356 and a block 522. With the poppet valve 494 open, exhaled breath is free to pass through opening 508 and escape past frame member 520. The poppet valve 494 is held in the open position by compressed air applied through pipe 496 and duct 524 below diaphragm 516. An orifice 526 leads from duct 524 to atmosphere for bleeding pressure from below diaphragm 516 as previously described with reference to FIG. 1. Thus when the compressed air supply is no longer available to pipe 496, pressure in duct 524 and below diaphragm 516 bleeds through orifice 526 and the poppet valve 494 closes.

Compressed air is supplied to the block 502 by way of a control pipe 528 leading from a main compressed air inlet pipe 530. Pipe 528 is coupled by a T-connector 532 to pipe 530 and to a flexible control pipe 536 which is coupled at its other end to the control valve assembly 468, as will be described. An end 538 of compressed air pipe 530 projects outside base 332 for connecting a compressed air supply to the ventilator. The other end of pipe 530 is attached to a lower half 540 of compressed air valve assembly 542. Lower half 540 includes upwardly projecting outlets 544, 546 fed by a main bore 548. An orifice 550 extends downwardly from the main bore 548 for bleeding compressed air from below a flexible portion of a diaphragm 554 which also includes a flap 556 adapted to close outlet 544. The flexible portion 552 seals a vent port 558 when compressed air is applied through outlet 546 to the underside of the flexible portion 552. As previously described, when the flexible portion 552 seals the vent port 558, the flap 556 is opened and compressed air passes through a short pipe 560 set in seal 458 and into casing 388. The lower end of pipe 560 is engaged in an O-ring 562 housed in the upper half of valve assembly 542.

The oxygen control valve assembly 418 is interchangeable with the compressed air valve assembly 542 just described. However, the valve assembly 418 con-

trols flow of oxygen from oxygen input conduit 564 which has a first end 566 outside the base 332 for connection to an oxygen supply. The other end of conduit 564 is coupled to the valve assembly 418 for supplying oxygen through oxygen conduit 414 and then permitting a measured quantity of oxygen to pass from bellows 370 back through the valve assembly 418 and into oxygen output conduit 438 which feeds the oxygen into the breathing mixture bellows 400.

The breathing control valve assembly 468 is a friction fit on the respective ends 490, 486 of connecting tube 488 and humidifier outlet conduit 466. The construction of valve assembly 468 will be described with reference to FIG. 7. A breathing mixture outlet conduit 568 and an exhalation input tube 570 extend from the valve assembly 468 to a Y-connector 572 connecting the conduit 568 and tube 570 to a tube 574. A tracheal tube 576 is attached to end of tube 574 for insertion into a tracheal incision in the patient and branch pipe 578 is connected to the Y-connector for relaying pressure changes to a pressure sensing device 580 which would in practice be within the base 332 but which is shown separately for clarity of drawing. The device 580 is associated with the pressure control circuit shown in FIG. 3.

The pressure regulators, flow valves, solenoid valves, orifice assembly and one-way valve appearing in the base 332 are arranged as described with reference to FIG. 1. In FIG. 6 these parts are given the numerals by which they were referred to in FIG. 1 so that ready reference can be made between FIGS. 1 and 6.

As seen in FIG. 5, the base 332 includes a control panel 582 on which the controls described with reference to FIGS. 1 and 3 are located. In order to simplify description and relate FIGS. 1 and 3 to FIG. 5, the controls are simply numbered according to the numerals they carried in FIGS. 1 and 3.

Reference is next made to FIG. 7 which shows the breathing control valve assembly 468. A first half 582 is located relative to a second half 584 by a peripheral lip 585 on second half 584 which also locates a diaphragm 586. Fasteners 588 (FIG. 6) pass through the halves to compress the diaphragm 586 about a flap 590 and a flexible portion 592. The fasteners 588 permit ready disassembly for autoclaving and for replacing diaphragm 586.

The first half 582 defines an inlet duct 594 for leading from humidifier outlet conduit 466 (FIG. 5) and delivering breathing mixture to an intermediate duct 596 which terminates at the underside of flap 590 for preventing return flow back into duct 596. When the breathing mixture is pressurized, the flap 590 moves into the position indicated in broken outline to permit the mixture to enter an outlet duct 598 in second half 584. The breathing mixture outlet conduit 568 (FIG. 5) is of flexible plastic and can be frictionally engaged in outlet duct 598 for completing the pneumatic path to the patient.

The inlet duct 594 is connected to intermediate duct 596 by a blow-off duct 600. As better seen in FIG. 8, this duct opens out at a valve seat 602 for combining with a rubber disc 604 on a cover 606 to normally prevent loss of breathing mixture out of blow-off duct 600. The cover 606 is pivotally attached to a lever 608 which is pivotally mounted between lugs 610 on the bottom of first half 582. A counter weight 612 is slidably engaged on the lever adjacent its distal end for

holding the disc 604 against valve seat 602 to prevent loss of breathing mixture. However, if the pressure of the breathing mixture becomes excessive, the disc 604 is forced off seat 602 to permit breathing mixture to escape. This ensures that if no one responds to the high pressure alarm, the pressure can not exceed a maximum set by the position and magnitude of counter weight 612.

Exhaled breath from the patient comes from exhalation input tube 570 into inlet duct 614 in second half 584. The tube 570 is of similar construction to conduit 568 and is a friction fit in duct 614. Breath from duct 614 enters an annular chamber 616 about a valve seat 618. The flexible portion 592 of diaphragm 586 is held against the valve seat 618 by compressed air from flexible control pipe 536 which is a friction fit over a stub 620 threaded into first half 584. Compressed air is fed to pipe 536 during the inhalation period thereby creating a pressure in a depression 622 on the underside of flexible portion 592 which forces portion 592 onto valve seat 618.

At the commencement of the exhalation period, the pressure in the depression 622 and pipe 536 is allowed to decrease as previously described by bleeding air from orifice assembly 180 (FIGS. 1 and 6). The flexible portion 592 then leaves valve seat 618 and exhaled breath passes from inlet duct 614, into chamber 616 and out through outlet duct 624. The exhaled breath then passes into connecting tube 488 (FIG. 5) which feeds it to the spirometer.

Reference is now made to FIG. 9 which shows a connection between end 490 of tube 488 and the outlet duct 624. An annular groove 626 is provided adjacent the mouth of duct 624 for containing an elastomeric O-ring 628. Upon pushing the valve assembly 584 (FIG. 5) on to tube 488, the end 490 enters the O-ring 628 and seals the tube 488 into duct 624. Compression of the O-ring provides adequate friction to maintain the assembled position.

FIG. 9 is typical of the pneumatic seals used in the ventilator. A similar seal is used between end 486 of humidifier outlet conduit 46 and inlet duct 594 in first half 582 of valve assembly 468. Also between humidifier coupling 464 and end 452 of connecting conduit 448, and between compressed air control pipe 496 and connecting block 502.

Reference is next made to FIG. 10 which shows the construction of flap valves 436, 437 which respectively permit air and oxygen to enter the breathing mixture bellows 400 during the exhalation period. Oxygen output conduit 438 leads oxygen to an opening 630 in tray 354 and air inlet conduit 434 leads air to an opening 632 in the tray. The openings are covered by an elongated flexible member 634 having central holes 636, for receiving a pair of studs 638 (one of which is shown). Each stud has a conical portion 640, a cylindrical intermediate portion 642 and a cylindrical end portion of reduced diameter for engaging in a corresponding one of a pair of openings 644 in the tray 354. The end portion 645 is sufficiently long to pass through the tray and have its leading end deformed to lock it to the tray. Once in place in the tray, the stud 638 provides a simple connection for the flexible member 634. Holes 636 are of substantially the same diameter as stud intermediate portion 642 so that the flexible member can be pushed over the conical portions 640 of the studs and

snapped into position about the intermediate portions 642.

A light wire spring 646 having a kidney-like shape is adapted to engage under the conical portions 640 of the studs 638 to hold the flexible member 634 in position over openings 630, 632 against gravitational forces.

FIG. 11 shows the flap valve 692 in assembled condition on spirometer tray 356. Valve 492 is similar in construction to valves 436, 437 and indicates how the parts shown in FIG. 10 would appear when assembled.

Flap valve 492 has a flexible member 648 covering an opening 650 in tray 356 for receiving exhaled breath from connecting tube 488. The member 648 is held in place by two studs 652 of similar shape and function to studs 638 (FIG. 10).

Should it be necessary to replace one of the flexible members 634 (FIG. 10) or 648 (FIG. 11) they can be pulled off the respective studs 638, 652 and a new member snapped over the studs as previously described.

Referring again to FIG. 5 it will be seen that the parts of the ventilator which must be autoclaved can be removed quickly and simply without the need for special tools. Further if a set of replacement trays and associated parts is available, the ventilator can be stripped of the old parts and new parts inserted within a relatively short time.

The structural embodiment of the ventilator shown in FIGS. 5 to 11 incorporates the FIG. 1 pneumatic circuit and the FIG. 3 electrical circuit. If the FIG. 2 pneumatic circuit and the FIG. 4 modification to the electrical circuit are to be incorporated, then the valves and other parts would be changed to match those described with reference to FIGS. 2 and 4. The structural features of the embodiment shown in FIGS. 5 to 11 would remain unaffected. It is therefore a matter of expected skill to incorporate the circuits shown in FIGS. 2 and 4, into the FIG. 5 embodiment in place of other parts in the manner described when previously comparing FIG. 1 and 2 and FIGS. 3 and 4.

For simplicity of description, a number of auxiliary devices have been omitted. For instance, it is common to include a water trap after the humidifier to ensure that no water droplets find their way into the patient's lungs. Also, it would be desirable in some instances to include a meter for measuring the concentration of oxygen in the breathing mixture continuously in order to ensure that the desired oxygen percentage is maintained. Devices of this kind are conventional and are not part of the present invention.

In use, the ventilator is first attached to an artificial lung so that the operation of the ventilator can be checked. This is important to ensure that there are no pneumatic leaks and in particular that the spirometer is collecting a volume of exhaled breath equal to the volume of breathing mixture forced into the lung. Once satisfied with the operation of the ventilator, the physician then decides which mode of operation is to be used and whether or not oxygen is to be included. Assuming that the mode is automatic without oxygen, then the physician estimates the volume of air required per minute together with the number of inhalations per minute required. The inhalation and exhalation periods are set on potentiometers $r1$, $r2$, and $r2a$ and the volume per breath is set on the flow control valve 142 (FIG. 1 and FIG. 5). Subsequent re-adjustment of the

potentiometers will not affect the volume rate of flow of air to the patient unless the potentiometer $r2a$ is used to increase the exhalation period. The ventilator is then coupled to the patient. In the foregoing description, a tracheal tube 576 (FIG. 5) was used. However, in practice a face mask can be used in an emergency. When the ventilator is to be used over prolonged periods, the ventilator would be coupled by intubation, that is by insertion of a tracheal tube.

Once the machine is running on "automatic," the physician observes the pressure meter to ensure that the pressure applied to the patient's lungs is not excessive. If the pressure is too high, it can be reduced by increasing the rate of breathing thereby reducing the length of the inhalation period. The upper limit 262 (FIG. 3) is then positioned just above the maximum pressure applied to the lungs so that if there is a reduction in the volume of the patient's lungs due to the collection of secretion and the like, the needle 270 will pass the limit 262 and set off the high pressure alarm. The low pressure limit 264 is set arbitrarily below atmospheric pressure.

It will not be unusual for the physician to alter the number of inhalations per minute once the machine begins to operate. The condition of the patient's lungs together with other problems affecting passage of air into his lungs will dictate to a large degree the rate of inhalations per minute. This is because if there are any restrictions, it is preferable to extend the inhalation period so that the air has a longer period to pass the restriction and enter the patient's lungs. In many cases, the physician will not know the exact condition of the patient's lungs so that his estimate of the required number of inhalations per minute may be subject to correction after the machine has been started.

If a sigh is required, the procedure will depend upon whether the FIG. 1 embodiment or the FIG. 2 embodiment of the pneumatic circuit is in use. In the FIG. 1 embodiment, the flow valve 164 is first closed and then the switch 248 (FIG. 3) is closed to introduce the sigh. Switch 248 is held in the closed position and the flow valve 164 is opened slowly so that its effect upon the volume of air forced into the patient's lungs can be observed on the pressure meter and the bellows volume scales. When the valve 164 is open sufficiently, the switch 248 is released and the period between sighs is set arbitrarily by adjustment of potentiometer $r3$ (FIGS. 3 and 5). Every time the sigh takes place, the needle 270 (FIG. 3) will pass the pressure upper limit 262 setting off the high pressure alarm as an indication that the sigh is operating.

In the FIG. 2 embodiment of the pneumatic circuit, the sigh is obtained by extending the inhalation period using the FIG. 4 electrical circuit. In this case, the ganged potentiometers $r4$, $r5$ are turned to zero so that they have no effect on the inhalation period. Switch 248 (FIG. 3) is then closed and potentiometers $r4$, $r5$ turned to introduce their respective resistances into the timing circuits. The effect of this is again evident on the pressure meter and bellows scales and once a suitable sigh has been developed, the switch 248 is released and the period between sighs is set on potentiometer $r3$ (FIG. 3) as previously described.

Should it be desired at this stage to introduce oxygen into the air supply to the patient, it is done simply by switching an oxygen circuit switch 190 (FIG. 5) and opening the oxygen flow valve 48 (FIG. 1). Because the

breathing mixture bellows 78 (FIG. 1) will draw in a fixed volume each time it extends during the exhalation period, the volume of breathing mixture applied to the patient per minute is set by the control valve 142 and the potentiometer *r1* provided that the exhalation period is not increased with reference to the inhalation period. Consequently, the introduction of oxygen into the oxygen bellows 64 simply reduces the volume of air subsequently drawn into the bellows 78.

The combined weights of disc 374 and rod 372 apply a force on the oxygen bellows so that the oxygen in the bellows is slightly pressurized. When the oxygen begins to flow from the oxygen bellows into the breathing mixture bellows, the oxygen will precede the air into the breathing mixture bellows because the oxygen is pressurized and the air suffers a slight pressure drop in passing through the air filter. This effect can be emphasized by giving the flap valves correspondingly different opening characteristics. The breathing mixture bellows will therefore always receive all of the oxygen before it accepts air to fill up the breathing mixture bellows. Also the oxygen concentration can be increased, decreased or even eliminated without changing the volume of breathing mixture forced into the patient during each inhalation period.

The arrangement of the ventilator places the humidifier quite near to the patient so that as the air passes through the humidifier, it picks up moisture and the air is warmed so that the humidifier effectively replaces the patient's nasal passages which would normally humidify air and warm it before it enters the lungs.

If the ventilator is to be used in the semi-automatic mode, the ventilator is set up as previously described with reference to the automatic mode. However, the inhalation and exhalation periods are chosen so that the patient normally attempts to inhale before the next inhalation period commences. As a result, if he is capable of attempting to breathe he will do so before the end of the automatic exhalation period and trigger the pressure meter to start an inhalation period. Otherwise, the set up is the same as for the automatic mode.

In the case of the patient triggered mode, the patient is in full control of the ventilator. The ventilator will not start a new inhalation until the patient attempts to breathe at which point breathing mixture will be forced to the patient until such time as the pressure in the patient's lungs reaches a maximum set on the upper limit of the pressure meter. If the patient breathes deeply, he will receive more breathing mixture before the upper limit is reached, whereas if he does not breathe so deeply the limit will be reached faster. After exhalation, the patient will then again attempt to breathe whereupon the needle will pass the lower limit and a new inhalation period will begin. As a result, the patient is free to breathe at his own pace, to take deep breaths whenever he feels it is necessary, and to slow down his breathing rate if he so wishes. Further, by progressively increasing the negative pressure required to trigger the inhalation period, the effort required by the patient to initiate an inhalation can be increased as he regains his strength and ability so that a patient who has been dependant upon the ventilator for a prolonged period can be trained and encouraged towards complete recovery.

We claim:

1. A therapeutic ventilator adapted to be connected to a patient adaptor means operable to convey a

breathing mixture to a patient, said ventilator comprising:

support means;

an oxygen bellows coupled to the support means for receiving a predetermined volume of oxygen under pressure during an inhalation period;

a breathing mixture bellows coupled to the support means and to the oxygen bellows for receiving said volume of oxygen during an exhalation period;

air valve means operable to permit air to enter the breathing mixture bellows contemporaneously with the oxygen so that said air and oxygen are mixed in a predetermined volumetric ratio thereby creating a breathing mixture;

oxygen control valve means operably coupled to the oxygen bellows to permit said pressurized oxygen to flow into the oxygen bellows during an inhalation period until the oxygen bellows contains said predetermined volume, and to permit said volume of oxygen to flow from said oxygen bellows into said breathing mixture bellows during said exhalation period; and

control means coupled to said oxygen control valve means and operable to open said breathing mixture bellows during said exhalation period whereby said predetermined volume of oxygen and air are drawn into said breathing mixture bellows until a predetermined volume of breathing mixture is contained in the breathing mixture bellows such that the air and oxygen are in said predetermined ratio and also operable to collapse said breathing mixture bellows during said inhalation period whereby substantially all of said predetermined volume of breathing mixture is forced through said patient adaptor means into a patient's lungs.

2. A therapeutic ventilator as claimed in claim 1 in which said oxygen control valve means comprises: a flap valve operable automatically to open under the force of the pressurized oxygen to permit the oxygen to flow into the oxygen bellows during the inhalation period, and to close upon removing the oxygen pressure from the valve means thereby preventing return flow of oxygen out of the oxygen bellows.

3. A therapeutic ventilator as claimed in claim 1 in which said oxygen control valve means comprises a valve seat and a diaphragm, said diaphragm having a flexible portion for engaging against said valve seat under the influence of the pressurized oxygen to prevent flow of oxygen from said oxygen bellows into said breathing mixture bellows during the inhalation period, and said flexible portion moving off said valve seat upon removing the oxygen pressure from the valve means so that oxygen flows from the oxygen bellows into the breathing mixture bellows during the exhalation period.

4. A therapeutic ventilator as claimed in claim 1 and further comprising an adjustable flow valve operable to control the rate of flow of pressurized oxygen into said oxygen bellows during said inhalation period so that said predetermined volume of oxygen may be varied according to the volume of oxygen required to prepare said predetermined volume of breathing mixture.

5. A therapeutic ventilator as claimed in claim 1 and further comprising: an oxygen weight coupled to said oxygen bellows for collapsing said bellows so that the oxygen bellows is normally in a collapsed condition; and a breathing mixture weight coupled to the breath-

ing mixture bellows for opening the breathing mixture bellows so that the breathing mixture bellows is normally in a fully opened position.

6. A therapeutic ventilator as claimed in claim 1 wherein said control means comprises: a casing containing the breathing mixture bellows; and valve means operable to permit compressed air and the like to enter the casing about the breathing mixture bellows for collapsing the bellows during the inhalation period.

7. A therapeutic ventilator as claimed in claim 6 in which the control means further comprises: an adjustable flow valve operable to permit compressed air to collapse the breathing mixture bellows during the inhalation period until said predetermined volume of breathing mixture has been forced out of the breathing mixture bellows.

8. A therapeutic ventilator as claimed in claim 7 and further comprising an adjustable flow valve operable control the rate of flow of pressurized oxygen into said oxygen bellows during said inhalation period so that said volume of oxygen may be varied as required to prepare said predetermined volume of breathing mixture.

9. A therapeutic ventilator as claimed in claim 8 and further comprising an oxygen supply valve operable to cut off the supply of pressurized oxygen during the exhalation period; and a compressed air supply valve operable to cut off the supply of compressed air during the exhalation period, the supply valves being ganged to operate in unison.

10. A therapeutic ventilator as claimed in claim 9 and further comprising electrical control means; and wherein the oxygen and compressed air supply valves are solenoid operated, the supply valves being electrically coupled to the electrical control means for closing the supply valves during the exhalation period.

11. A therapeutic ventilator as claimed in claim 10 in which the electrical control means comprises: an inhalation timer having a first potentiometer variable for adjusting the inhalation period; and an exhalation timer having second and third potentiometers in series and variable for selectively adjusting the exhalation period, the first and second potentiometers being ganged to operate in unison and having substantially similar effects upon respective inhalation and exhalation timers such that with the third potentiometer set at zero resistance the inhalation and exhalation periods are substantially equal for all positions of the first and second potentiometers and such that introduction of the third potentiometer resistance increases the exhalation period whereby the exhalation period is never shorter than the inhalation period.

12. A therapeutic ventilator as claimed in claim 1 in which the control means comprises a casing about the breathing mixture bellows for receiving compressed air to collapse the bellows.

13. A therapeutic ventilator as claimed in claim 12 and further comprising: an electrical control circuit including a cycle timer circuit; a solenoid operated oxygen supply valve operable to cut off the supply of oxygen during the exhalation period; and a solenoid operated compressed air supply valve operable to cut off the supply of compressed air to the casing during the exhalation period, the solenoid operated valves being coupled electrically to the cycle timer circuit for contemporaneous operation.

14. A therapeutic ventilator as claimed in claim 12 and further comprising: an oxygen supply valve operable to cut off the supply of oxygen during the exhalation period; a compressed air supply valve operable to cut off the supply of compressed air during the exhalation period; and control means operable to maintain the supply valves open during the inhalation period and to maintain the supply valves closed during the exhalation period.

15. A therapeutic ventilator as claimed in claim 12 and further comprising: an adjustable flow valve operable to control the rate of flow of pressurized oxygen into said oxygen bellows during said inhalation period so that said volume of oxygen may be varied as required to prepare said predetermined volume of breathing mixture and in which the control means further comprises: an adjustable flow valve operable to permit compressed air to collapse the breathing mixture bellows during the inhalation period until said predetermined volume of breathing mixture has been forced out of the breathing mixture bellows.

16. A therapeutic ventilator as claimed in claim 1 and further comprising means providing a sigh periodically and including means operable to adjust the period between sighs, said sigh means being coupled to said control means to further collapse said breathing mixture bellows without increasing said inhalation so that the patient receives a greater volume of breathing mixture during a sigh inhalation.

17. A therapeutic ventilator as claimed in claim 1 and further comprising means providing a sigh periodically and including means operable to adjust the period of the sigh, said sigh means being coupled to the control means to lengthen an inhalation period so that the patient receives a greater volume of breathing mixture during a sigh inhalation.

18. A therapeutic ventilator as claimed in claim 13 in which the electrical control circuit further comprises a sigh control circuit and a sigh bypass pipe having a solenoid operated sigh supply valve, the bypass pipe extending about said compressed air supply valve so that with the sigh supply valve and the compressed air supply valve open the flow of compressed air to the casing is increased during the inhalation period, said sigh control circuit including adjustable timer means for setting the period of the sigh and for operating said sigh supply valve contemporaneously with said compressed air supply valve once every sigh period, the sigh period being substantially greater than the sum of the inhalation and exhalation periods.

19. A therapeutic ventilator as claimed in claim 13 in which the electrical control circuit further comprises a sigh control circuit coupled to the cycle timer circuit and adapted to periodically increase the inhalation period, the sigh control circuit being adjustable for varying the sigh period and for varying the time by which the inhalation period is increased so that the patient receives an increased volume of breathing mixture during a sigh inhalation and the oxygen bellows receives a proportionately larger volume of oxygen whereby the percentage volume of oxygen in the breathing mixture remains substantially constant.

20. A therapeutic ventilator as claimed in claim 18 and further comprising: an oxygen flow valve operable to adjustably set the rate of flow of oxygen through the oxygen supply valve; a compressed air flow valve operable to adjustably set the rate of flow of compressed air

through the compressed air supply valve; and a sigh flow valve operable to adjustably set the rate of flow of compressed air through the sigh supply valve.

21. A therapeutic ventilator as claimed in claim 19 and further comprising flow valves operable to adjustably set the rate of flow of oxygen through the oxygen supply valve, and operable to adjustably set the rate of flow of compressed air through the compressed air supply valve.

22. A therapeutic ventilator as claimed in claim 1 and further comprising: a humidifier coupled to the breathing mixture bellows for receiving breathing mixture and adapted to add moisture to the breathing mixture during the inhalation period.

23. A therapeutic ventilator as claimed in claim 1 and further comprising a breathing control valve assembly operable to permit breathing mixture to be forced to the patient during the inhalation period and to permit exhaled breath to flow from the patient to an outlet during the exhalation period, the breathing control valve assembly comprising: a flap valve operable automatically to open under the force of the breathing mixture to permit the breathing mixture to flow to the patient, and to close after the inhalation period thereby preventing return flow of exhaled breath from the patient into the breathing mixture bellows; a valve seat; a diaphragm having a flexible portion for engaging against the valve seat to prevent flow of breathing mixture into said outlet; and a control pipe coupling the breathing control valve to said supply of compressed air for forcing said flexible portion onto said valve seat during said inhalation period.

24. A therapeutic ventilator as claimed in claim 23 and further comprising an orifice assembly coupled to said control pipe for bleeding off compressed air from said control pipe after said inhalation period so that the pressure in said control pipe drops and said flexible portion moves off said valve seat to permit exhaled breath to leave through said outlet during the exhalation period, said orifice assembly being adjustable so that the rate of bleeding can be varied to ensure that the flexible portion moves away from the valve seat such that the patient's lungs are full of breathing mixture for an adjustable fraction of the exhalation period.

25. A therapeutic ventilator as claimed in claim 1 and further comprising: a spirometer adapted to receive exhaled breath during the exhalation period and including a poppet valve operable to permit the exhaled breath to be vented from the spirometer during the inhalation period; and a control pipe coupling the poppet valve to the compressed air supply for opening the poppet valve during the inhalation period.

26. A therapeutic ventilator as claimed in claim 12 and further comprising an electrical control circuit adapted to shut off the flow of oxygen and compressed air contemporaneously during the exhalation period, the electrical control circuit including a pressure control circuit adapted to respond to a low pressure created by the patient's efforts to breathe whereby an inhalation period begins and adapted to respond to a selected high pressure when the patient's lungs are full of breathing mixture whereby an exhalation period begins.

27. A therapeutic ventilator as claimed in claim 12 and further comprising an electrical control circuit adapted to shut off the flow of oxygen and compressed air contemporaneously during the exhalation period,

the electrical control circuit including a pressure control circuit and a cycle timer circuit, the cycle timer circuit automatically controlling the timing of the inhalation and exhalation periods unless the patient attempts to inhale before the completion of an exhalation period, said pressure control circuit being adapted to respond to a reduced pressure created by the patient's attempt to inhale whereupon an inhalation period is commenced and the cycle timer begins to time a new inhalation and exhalation sequence.

28. A therapeutic ventilator as claimed in claim 27 and further comprising a low pressure alarm adapted to operate should the pressure in a tube feeding breathing mixture to the patient fall below a minimum pressure for a period longer than about two complete breathing cycles.

29. A therapeutic ventilator for forcing a breathing mixture into a patient's lungs during an inhalation period and for permitting the patient to expel exhaled breath during an exhalation period, the ventilator comprising: a pair of end members defining first and second pairs of spaced-apart and parallel grooves, each pair of grooves extending longitudinally of the ventilator; a breathing mixture tray slidable in said first pair of grooves; a breathing mixture bellows releasably coupled to said tray; a connecting conduit coupled to said tray and adapted to receive breathing mixture from the bellows and having a connecting end remote from the bellows; a humidifier tray slidable in said second pair of grooves; a humidifier coupled to said humidifier tray; a humidifier conduit coupled to the humidifier tray and adapted to receive breathing mixture from the connecting conduit and to direct said breathing mixture into the humidifier; and a coupling means attached to an end of said humidifier conduit remote from said humidifier and adapted to slidably receive said connecting end of the connecting conduit whereby the connecting conduit is pneumatically sealed to the humidifier conduit, said conduits being positioned on respective trays such that upon sliding the trays toward one another in the respective pairs of grooves, said connecting end engages in the coupling means.

30. A therapeutic ventilator for forcing a breathing mixture into a patient's lungs during an inhalation period and for permitting the patient to expel exhaled breath during an exhalation period, the ventilator comprising: a pair of end members defining first and second pairs of spaced-apart and parallel grooves, the second pair of grooves being above the first pair and parallel therewith; a breathing mixture tray slidable in said first pair of grooves; a breathing mixture bellows releasably coupled to said tray; an oxygen output conduit coupled to said tray and adapted to receive oxygen from the bellows and having a connecting end remote from the bellows; an oxygen tray slidable in said second pair of grooves; an oxygen bellows releasably coupled to the oxygen tray; an intermediate oxygen conduit coupled to the oxygen tray and adapted to carry oxygen to and from the oxygen bellows, the intermediate oxygen conduit having a connecting end remote from the oxygen bellows; an oxygen control valve assembly coupled to the end members and including means for sealably engaging said connecting ends upon sliding said trays in respective pairs of grooves, the valve assembly including valve means for permitting flow from an oxygen supply into said intermediate oxygen conduit during the inhalation period to expand said oxygen bellows,

and further valve means responsive to the pressure of the oxygen supply for opening automatically after a predetermined reduction of said pressure to direct oxygen from the intermediate oxygen conduit into the oxygen output conduit and hence into the breathing mixture bellows during the exhalation period.

31. A therapeutic ventilator as claimed in claim 30 in which the end members define a third pair of spaced-apart parallel grooves, said pairs of grooves extending longitudinally and said third pair of grooves being spaced longitudinally from said first and second pairs of grooves, the ventilator further comprising: a connecting conduit coupled to said breathing mixture tray and adapted to receive breathing mixture from the breathing mixture bellows and having a connecting end remote from the bellows; a humidifier tray slidable in said third pair of grooves; a humidifier coupled to said humidifier tray; a humidifier conduit coupled to the humidifier tray and adapted to receive breathing mixture from the connecting conduit and to direct said breathing mixture into the humidifier; and a coupling means attached to an end of said humidifier conduit remote from said humidifier and adapted to slidably receive said connecting end of the connecting conduit whereby the connecting conduit is pneumatically sealed to the humidifier conduit, said connecting conduit and said humidifier conduit being positioned on respective trays such that upon sliding the humidifier tray and the breathing mixture trays towards one another in the respective pairs of grooves, said connecting end of the connecting conduit engages in the coupling means.

32. A therapeutic ventilator as claimed in claim 31 in which the end members further define a fourth pair of spaced apart and parallel grooves positioned above said third pair of grooves, said ventilator further comprising: a spirometer tray slidable in said fourth pair of grooves; and a spirometer coupled to the spirometer tray and adapted to receive a patient's exhaled breath.

33. A therapeutic ventilator as claimed in claim 32 and further comprising: a humidifier outlet conduit coupled to the humidifier tray and adapted to receive humidified breathing mixture from the humidifier, the outlet conduit having an outer end remote from the humidifier; a connecting tube coupled to the spirometer tray and adapted to lead exhaled breath into the spirometer, the connecting tube having an outer end remote from the spirometer, said outer ends extending in spaced-apart and parallel relation when the spirometer tray and the humidifier tray are engaged in respective pairs of grooves; and a breathing control valve adapted to selectively provide passage for humidified breathing mixture from the humidifier outlet conduit to the patient and to provide passage for exhaled breath from the patient to the connecting tube, the breathing control valve being a push fit over the said outer ends and including means sealably engaging the outer ends.

34. A therapeutic ventilator for forcing a breathing mixture into a patient's lungs during inhalation period and for permitting the patient to expel exhaled breath during an exhalation period, the ventilator comprising: a pair of supporting end members; a breathing mixture tray adapted to be movably mounted between the end members for assembly between and removal from the end members; a breathing mixture bellows releasably coupled to said tray; an oxygen conduit coupled to said tray and adapted to feed oxygen into the bellows, and having a connecting end; an oxygen tray adapted to be movably mounted between the end members for assembly between and removal from the end members; an oxygen bellows releasably coupled to the oxygen tray; an intermediate oxygen conduit coupled to the oxygen tray and adapted to carry oxygen from the oxygen bellows, the intermediate oxygen conduit having a connecting end; an oxygen control valve assembly fixedly coupled to the end members and including means for sealably engaging said connecting ends upon moving said trays into predetermined positions between the end members, the valve assembly including valve means to direct oxygen from the intermediate oxygen conduit into the oxygen output conduit during the exhalation period.

35. A therapeutic ventilator as claimed in claim 34 and further comprising: a connecting conduit coupled to said breathing mixture tray and adapted to receive breathing mixture from the breathing mixture bellows; a humidifier tray adapted to be movably mounted between the end members for assembly between and removal from the end members; a humidifier coupled to said humidifier tray; a humidifier conduit coupled to the humidifier tray and adapted to receive breathing mixture from the connecting conduit and to direct said breathing mixture into the humidifier; and a coupling means attached to at least one of the connecting conduit and the humidifier conduit whereby the connecting conduit is pneumatically sealed to the humidifier conduit upon moving the humidifier tray and the breathing mixture tray towards one another between the end members.

36. A therapeutic ventilator as claimed in claim 35 and further comprising: a spirometer tray adapted to be movably mounted between the end members for assembly between and removal from the end members; and a spirometer coupled to the spirometer tray and adapted to receive a patient's exhaled breath.

37. A therapeutic ventilator as claimed in claim 36 and which on assembly in the end members, the oxygen tray is above the breathing mixture tray, the spirometer tray is above the humidifier tray, and the humidifier tray and spirometer trays are spaced horizontally respectively from the breathing mixture tray and the oxygen tray.

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