Oct. 27, 1942. K. CONNELL 2,300,273

RESPIRATOR

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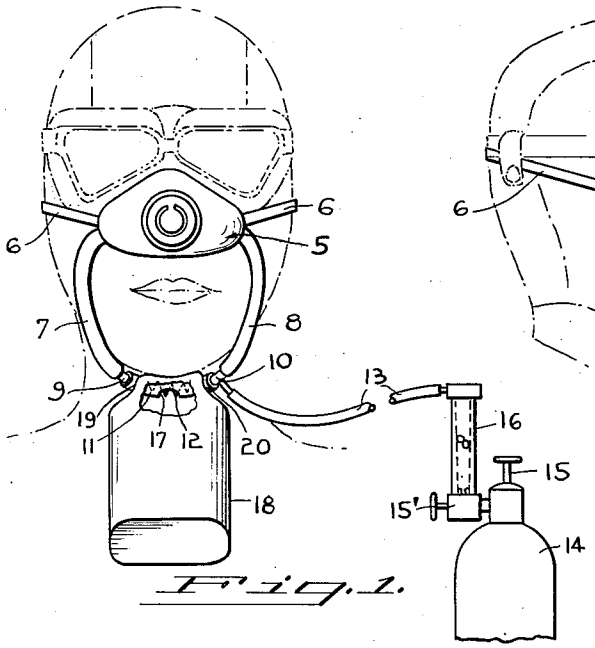


Fig. 1.

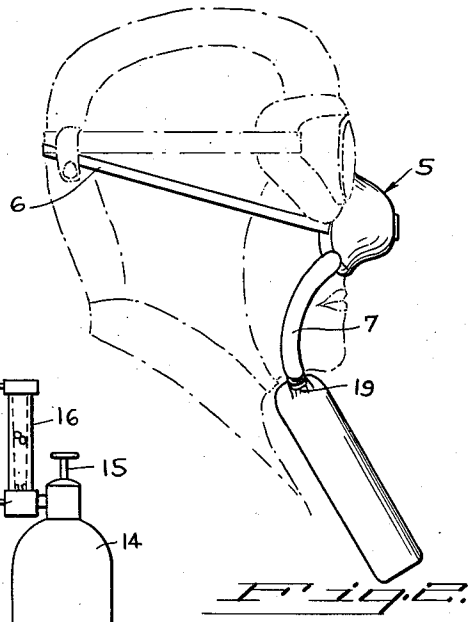


Fig. 2.

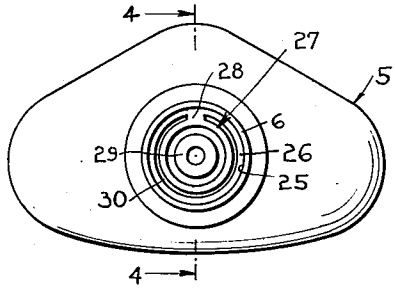


Fig. 3.

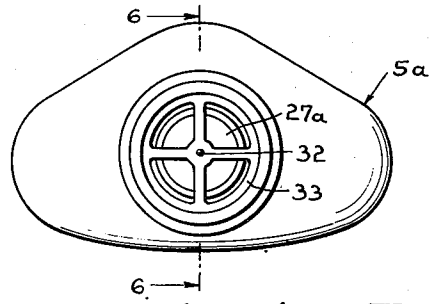


Fig. 5.

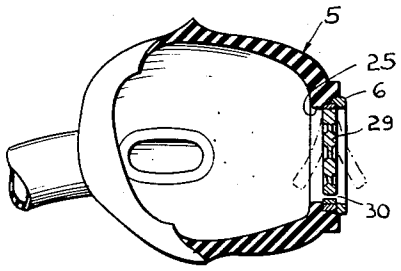


Fig. 4.

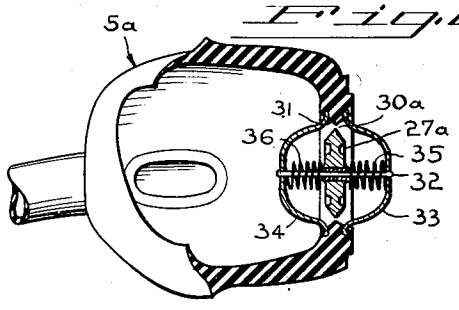


Fig. 6.

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Fig. 7.

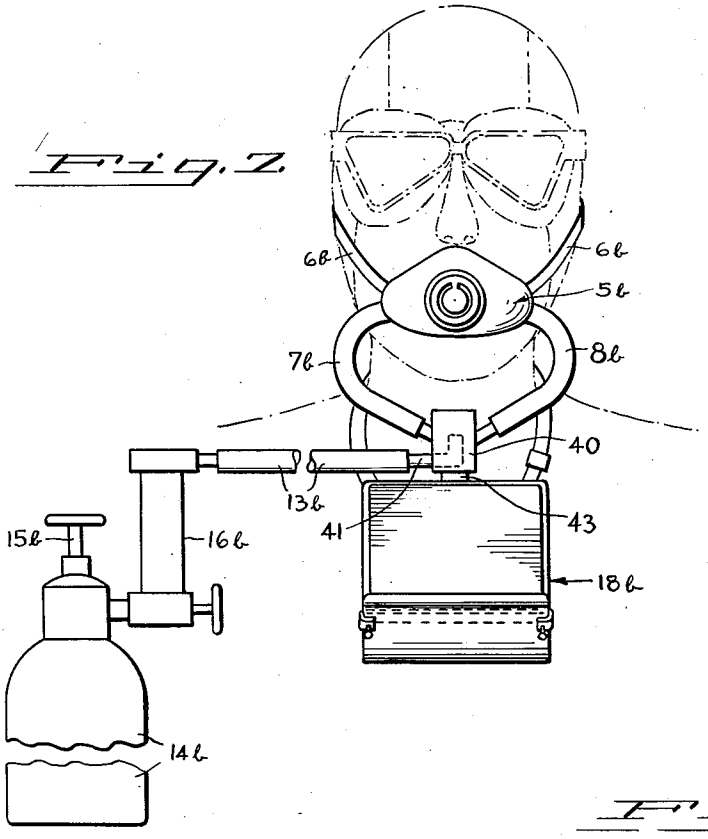
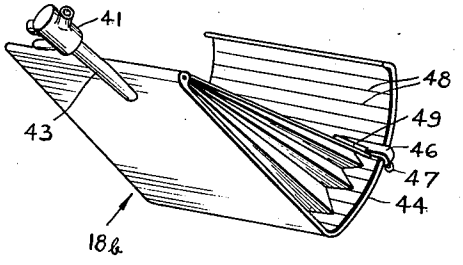


Fig. 9



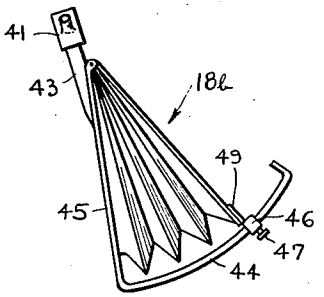


Fig. 8.

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UNITED STATES PATENT OFFICE

2,300,273

RESPIRATOR

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Application March 13, 1940, Serial No. 323,640

9 Claims. (Cl. 128—203)

This invention relates to the administration of gas, and more particularly to respirator systems for use in aviation and in therapy.

An object of the invention is to provide improved means and methods for the administration of gas, as in the administration of oxygen in therapy and in altitude flying.

More specifically, it is the object of the invention to provide a respirator system for the effective and efficient enrichment of oxygen in the tidal breathing and the rejection of carbon dioxide therefrom in a system of partial rebreathing.

A further object of the invention is the provision of simple, comfortable, effective, and efficient apparatus for the administration of oxygen as in therapy and in altitude flying.

Other objects of the invention will in part be obvious and will in part appear hereinafter.

In certain pathological conditions, such as choked airway or lessened alveolar absorptive capacity, as for example in pneumonia, an enrichment of oxygen in the tidal air from the normal atmosphere content of 20% up to 70% or more, is at times useful to adequately oxygenate the patient. In certain environments of low barometric pressure, such, for example, as those commonly encountered in aviation, particularly at altitudes above 12,000 feet, an enrichment of oxygen in the tidal air of normal subjects is necessary for human efficiency. At a barometer of 500 mm. of mercury (at about 12,000 feet of elevation), the normal sea-level alveolar content of oxygen, which is about 100 to 105 mm. of oxygen pressure, falls to about 60 mm. and results in a certain degree of anoxemia especially manifest in unaccustomed subjects by a mild degree of dyspnoea and hyperpnoea, lethargy and vomiting known commonly as the mountain sickness complex. At 18,000 feet the alveolar content of oxygen falls to below 50 mm. of pressure, and mental aberration of trained air pilots becomes at times serious, and oxygen reinforcement of the tidal breath intake has become customary. The oxygen content is usually provided by delivering pure oxygen from a source of oxygen under pressure, such as a pressure cylinder, thru a partially-closed breathing system; in order to enrich the tidal breathing by maintaining an adequate supply of oxygen in the alveolar air, a certain amount of expiration products being allowed to escape into the outer atmosphere so as to diminish the building up of carbon dioxide in the air which is breathed. As set forth in my Patent 2,073,192, dated March 9, 1937 (in which a general discussion of breathing conditions will be found), only the first portion of the air taken in on inspiration actually reaches the alveolar passages, and accordingly it is important that this portion contain a high proportion of the gas, for example oxygen, being administered. Conversely, on expiration, the last portion of gas expired is the most heavily laden with carbon dioxide, and it is important in spilling gas from the system that this be the portion spilled. It is likewise important, in many instances, and particularly in aviation, that as simple a form of system as possible be provided.

With the foregoing and other considerations in view, the present invention contemplates the provision of a partially-closed breathing system of such character that delivered oxygen will be disposed in that portion of the tidal air wherein it will most profoundly enrich the oxygen content of the alveolar air on inspiration and that the portion of the tidal breath most profoundly polluted with carbon dioxide will be rejected, while the major portion of the tidal air is retained for rebreathing.

More specifically, the invention in certain of its aspects contemplates the provision of a respirator system comprising means such as a mask or other breathing member adapted to coapt the respirator tract, valve means proximal to the coapting means and adapted to admit air to and release gaseous fluid from the respirator system when given differentials in external and internal pressure exist, a variable-capacity reservoir, fixed-capacity means for connecting said variable-capacity reservoir with said coapting means, and means to introduce gas to said system at a point spaced from said valve means and between said valve means and said variable-capacity reservoir, the capacity of the variable-capacity reservoir and the resistance of this reservoir to expansion and the resistance of the valve means to opening being suitably correlated, whereby a gas such, for example, as oxygen, may be stored for rebreathing between expiratory and inspiratory periods of the breathing cycle so that it will be inspired first, followed by gaseous fluid stored in the reservoir and followed thereafter by air admitted thru the valve means, and whereby the last portion of an expiration will be released to the outer air by the valve means.

As above noted, one's oxygen requirements increase with decrease in barometric pressure. In aviation a ceiling is reached at about 31,000 feet where normally the alveolar content of oxygen is 12 mm. of pressure, and human efficiency is not

supported except in an atmosphere of pure oxygen. The higher an airplane climbs toward this ceiling the greater are the oxygen requirements, and accordingly a greater proportion of oxygen and a smaller proportion of diluents should be inspired. To this end, the present invention in certain of its more specific aspects, contemplates the provision of means for regulating the amount of tidal air which may be stored in the variable-capacity reservoir, so that on expiration a greater proportion of expiration products will be released to the atmosphere to assure that a greater proportion of oxygen will reach the alveolae of the lungs on inspiration. In accordance with this aspect of the invention, an adjustable means may be provided for limiting the maximum capacity of the variable-capacity reservoir.

The invention accordingly comprises the features of construction, combinations of elements and arrangement of parts, and the several steps and the relation and order of one or more of such steps with respect to each of the others thereof, all of which will be exemplified hereinafter and the scope of the application of which will be indicated in the claims.

For a fuller understanding of the nature and objects of the invention reference should be had to the following detailed description taken in connection with the accompanying drawings, in which:

Figure 1 is a front view of one form of apparatus embodying the invention;

Fig. 2 is a side view of a portion thereof;

Fig. 3 is an enlarged detail front view of the breathing member;

Fig. 4 is a sectional view along the lines **4—4** of Fig. 3;

Fig. 5 is a view similar to Fig. 3 showing a modified form of valve means;

Fig. 6 is a sectional view along the lines **6—6** of Fig. 5;

Fig. 7 is a view similar to Fig. 1 showing a modified form of apparatus embodying the invention;

Fig. 8 is a side view of a portion thereof;

Fig. 9 is a perspective view thereof.

In Figs. 1 thru 4, there is illustrated a respirator or breathing system comprising a breathing member, which may be a mask which fits over both the nose and mouth of the user, or may be a means for breathing either thru the nose or thru the mouth while the other is left free. The exemplified form of breathing member is a type of mask **5** which the user may fit over his nose, but which he may optionally fit over his mouth, and which may be secured in place on his head, as by suitable strips **6**. This mask is adapted to coapt the respiratory tract and to receive and deliver the tidal volume of breathing, and, as exemplified, is formed of soft rubber or other pliable material with its edge turned in to provide a smooth pliable coapting surface for comfort and latitude of adjustment. As shown, the mask is particularly adapted for aviation use, being so short above so as to permit goggles to be worn, and so ovoid in opening as to serve optionally as a mouth mask in subjects where nasal breathing is obstructed. From the mask **5** there extends one or more tubes, two tubes **7** and **8** being exemplified. The tubes **7** and **8** are formed of flexible rubber tubing adapted to extend toward the chin of the user; the tube **7** carrying a metallic fitting **9**, and the tube **8** carrying a metallic T fitting **10**, the two fittings being connected by a piece of flexible rubber tubing **11** adapted to fit under the chin of the user and containing, in the present instance, a coil spring **12** to assure against its collapse. From the stem of the T-fitting there extends a flexible rubber tube **13** thru which a gas, such, for example, as oxygen, may be supplied to the breathing system. Suitably such gas is supplied from a source of gas under pressure, such as an oxygen tank **14**, which, desirably is equipped with a main valve **15**, a decompression valve **15'**, and a flow gage **16** which preferably is of a character described in my Patent No. 1,965,333, dated July 3, 1934. The interior of the mask **5** and of the tubes **7**, **8**, and **11** forms a fixed-capacity accumulator having a capacity, for example, 60 c. c. equal to only a minor part of the tidal volume of average normal breathing (about 800 c. c. to 1,000 c. c.). The tube **11** is formed with a cut-away portion providing an opening **17**, and over this opening there is fitted one end of a variable-capacity accumulator or reservoir consisting in the present instance of a collapsible rubber bag **18** formed with openings **19** and **20** of smaller diameter than the exterior diameter of the tube **11**, so as to tightly fit over the tube. The exemplified bag is adapted to collapse substantially completely when air is drawn therefrom and to receive up to 700 c. c. of gas without stretching. The bag is preferably formed of rubber which is thin enough to collapse readily, but thick enough so that it will not tend to stretch substantially under an internal pressure of ½ mm. of mercury, or less; though other material which is collapsible, substantially impervious to gas flow, and suitably resistant to over-expansive tendencies may be employed in most instances, and, in some cases, a piston-type reservoir may be employed. At the end of the respirator system proximal to the coaptive opening, there is provided, in accordance with the invention, valve means adapted to communicate with the atmosphere. This valve means is preferably in the form of a two-way seatless valve, and, as exemplified, is formed in the mask **5**. In the front of the mask there is formed an opening **25** surrounded by a rigid ring **6** molded into the body of he mask, and within this ring there is vulcanized a soft rubber disc **26**, the central portion of which is separated from the body of the disc thruout the major part of its periphery to provide a flapper valve **27** suspended by an elastic hinge **28** which connects it to the top of the body of the disc. As exemplified, the valve **27** is formed with concentric raised annular portions **29** to assure against warping. As will be observed, the valve **27** is a seatless two-way valve normally obturating an opening **30** in the body of the disc **26**. For ease of opening in either direction and to get sufficient airway, the valve should be not less than 0.75 sq. cm. in effective area and should open on a pressure in either direction of ½ mm. or less. In the present instance, (when correlated with a bag having a resistance to distension of ⅛ mm.) the valve should desirably have a resistance of not less than ¼ mm. at slight opening, nor more than ½ mm. at an opening adapted for the quantitive passage of 25 liters of gas per minute. For delicacy of action the obturator valve **27** should be spaced from the body of the disc **26** by not less than 0.002 inch. A spacing up to .015 inch is tolerable without material loss of gas under the collapsing pressure of the bag **18** exemplified in the time interval of the breathing cycle. The closed capacity of mask **5** and of the tubing **7**, **8**, and **11** connecting the mask with the gas inlet is preferably not less than about 50 c. c., nor more than about 100 c. c., and,

as exemplified, in 60 c. c., a desired capacity for the fixed-capacity portion. It is to be noted that the incoming gas enters this portion, so that during the idle and inspiration phases the gas will flow thru the tubes 7 and 8 toward the breathing member, pushing the previously expired gas ahead of it without any substantial tendency to mix with the expired gas.

The capacity of the collapsible bag 18 is preferably not less than about 500 c. c. nor more than about 1,000 c. c., (depending partly on the conditions of use). As exemplified this has a capacity of 700 c. c. For desirable operation of the respirator the resistance of the bag 18 to inflation must be substantially less than the opening resistance of the obturator valve 27. A resistance of ⅛ mm. of mercury to distension of the bag 18 is desirably correlated with a resistance of the valve of not less than ¼ mm. at slight opening, nor more than ½ mm. at an opening adapted to permit the passage of 25 liters of gas per minute.

As will be appreciated, various forms of valve arrangement may be employed without departing from the invention in its broader aspects. In Figs. 5 and 6 there is shown an arrangement which may be substituted for the central outer portion of the mask shown in Figs. 1–4, similar parts being designated by similar reference numerals distinguished by the subscript *a*. The mask 5*a* is molded, in the present instance, to provide a taper, as at 31, toward the edge of an opening 30*a* across which an obturator valve 27*a* slidably mounted on a guide rod 32 is adapted to extend. The guide rod 32 is supported by brackets 33 and 34, the ends of which are fixed into the mask 5*a*, and the valve 27*a* is movable in either direction against recoil springs 35 and 36, thus providing a seatless two-way valve. A clearance between the periphery of the valve 27*a* and the opening 30*a* should be provided, figures for preferred clearance being similar to those given in connection with the valve 27, and the springs 35 and 36 should provide a resistance to opening similar to those given in connection with the valve 27 when used in an arrangement such as exemplified. Various other forms of valve means may, of course, be provided.

The normal consumption of an average individual at rest is about .3 gram of oxygen per minute abstracted from about 8 liters of tidal air. In aviation it is common practice when flying at 18,000 feet to reinforce the tidal air with about 8 times the basic oxygen requirements or 2.4 grams per minute of oxygen. At higher levels increasing amounts may be required. At sea level the displacement of 2.4 grams of oxygen is approximately 1700 c. c. At 18,000 feet, the displacement of 2.4 grams is approximately 3,200 c. c Since the average tidal rate of breathing is about 16 per minute there will be added to each average tidal volume approximately 200 c. c. of oxygen at a flow rate of 3,200 c. c. per minute when flying at 18,000 feet. Since the respiratory cycle consists of an inspiratory phase, an expiratory phase, and a succeeding rest period each approximating one-third of the cycle, the net action of the disclosed arrangement is as follows:

On expiration, the bag 18 is distended with tidal air with which there is mixed that portion of oxygen delivered during the expiration phase, this amount being about 66.7 c. c. Once the bag becomes full, further expiration results in the opening of the valve 27, and escape of the last portion of the expiration therethru. This terminal residue is that portion of expiration from which oxygen has been most depleted, and also that portion containing the highest proportion of carbon dioxide from the alveolae of the lungs. During the rest period, the oxygen continues to flow, a volume of about 66.7 c. c. entering the fixed-capacity portions of the respirator during this period. The bag 18 being at distension, that portion of the expiration which occupies the 60 c. c. of fixed capacity of the tubes and mask is displaced outwardly thru valve 27 by the incoming oxygen, and the fixed-capacity portion is thus primed substantially with pure oxygen before the next inspiration. The tubes and mask may accordingly be considered as providing an idle-phase accumulator. On inspiration this stored oxygen becomes that portion of the tidal volume first inspired, followed by the contents of the bag, plus the oxygen delivered while the bag is being collapsed; substantially as disclosed in my aforesaid Patent 2,073,192. On further inspiration, the valve opens inwardly, and atmospheric air (plus some admixture due to continued flow of oxygen) is inspired to meet the full inspiratory requirements. It is to be noted in this connection that about every 8th to 16th breath is normally deeper than interim breaths in the respiratory actions of normal persons. Upon expiration, the atmospheric air, (with some admixture) which was last inspired and which did not reach the alveolae and accordingly was substantially unmodified by abstraction of oxygen or addition of carbon dioxide, is first expired and is delivered toward the bag, pushing ahead of it such oxygen and other gaseous fluid as remains in the fixed capacity of the tubes and mask, and such oxygen as is entering the fixed-capacity portion of the respirator. Before the bag reaches its maximum capacity in normal breathing, gaseous expiration products from the respiratory tract down to the bifurcation of the trachea will have been expired. This gaseous fluid will be followed by gaseous fluid containing a higher proportion of carbon dioxide. As the bag reaches distension, further expiration will open the valve 27 so that the gaseous fluid containing the highest proportion of carbon dioxide will escape therethru.

It will thus be seen that of the 200 c. c. of oxygen delivered during a normal breathing cycle one-third will be inspired near the beginning of an inspiration, of the next one-third part will be inspired in admixture with gaseous fluid from the bag and part will remain in the tubes in such admixture, and of the remaining one-third, part will be driven into the bag in admixture with gaseous fluid containing a high proportion of atmospheric air during the first part of the expiration and part will be stored in the fixed capacity when the bag is full and the valve opened during the latter part of the expiration.

By this system of placement of oxygen in the fore part of inspiration, and rejecting carbon dioxide from the hind part of expiration, oxygenation is accomplished with greatest economy of gas, and carbon dioxide is exited without building a material excess of CO_2 in the retained expiratory volume and without excess tidal movement thru the atmospheric valve to maintain the desired normal alveolar balance of about 5.6% of CO_2 content.

Fresh gas, such, for example, as oxygen, is thus delivered at the beginning of the breathing cycle in accordance with my said Patent No.

2,073,192, and, in addition, gaseous fluid most heavily charged with carbon dioxide is discharged from the system, and fresh air is admitted to the system at a period in the breathing cycle such that it does not immediately enter the alveolae.

When higher oxygen enrichment is necessary, as above 18,000 feet, this is readily achieved by increasing the flow of oxygen until, at the ceiling of 31,000 feet, such a volume is delivered as to block ingress of atmospheric air at the end of the inspiratory phase.

It is, however, desirable, with increasing altitude, that a larger proportion of expired gases be released to the atmosphere and to this end there may be provided an arrangement such as shown in Figs. 7, 8, and 9 which show an arrangement which may be substituted for the corresponding portions of the respirator system shown in Figs. 1–4, similar parts being designated by similar reference numerals distinguished by the addition of the subscript *b*. In Fig. 7 the mask is shown in its optional position for oral breathing. In this form of arrangement there is also shown a modified form of bag and connecting means which may be employed instead of that shown in Figs. 1 and 2. In the present form of construction the tubes 7*a* and 8*a* are made somewhat longer than the tubes 7 and 8 and are brought together in a union 40 carrying an upwardly-opening elbow-shaped gas-introduction tube 41 to which the gas inlet tube 13*b* is connected. From the union there extends the neck 43 of a bellows-shaped variable-capacity reservoir 18*b*. This may be formed of rubber similarly to the bag 18, and as exemplified has a similar capacity when expanded. In order, however, that its maximum capacity may be decreased when desirable, as for example, when an airplane climbs to higher altitudes, there is provided adjustable means to limit the amount which the bag 18*b* can expand. This means consists, in the present instance, of an arcuate metallic extension 44 on a plate 45 secured to one side of the bellows 18*b*. The arcuate member 44 lies across the end of the bellows, and slidably mounted thereon is a stop member 46 carrying a set-screw 47 which may secure the member 46 on the member 44 at any suitable point as indicated by a scale 48. The member 46 is formed with an extension 49 adapted to extend over the outer portion of the path of movement of the other side of the bellows to limit its maximum expansion.

Since certain changes may be made in the constructions set forth and in carrying out the above method, and different embodiments of the invention may be provided without departing from the scope of the invention, it is intended that all matter contained in the above description or shown in the accompanying drawings shall be interpreted as illustrative and not in a limiting sense.

It is also to be understood that the following claims are intended to cover all of the generic and specific features of the invention herein described, and all statements of the scope of the invention which as a matter of language might be said to fall therebetween.

I claim:

1. Apparatus for the administration of gases, comprising a breathing member, a seatless two-way valve proximal to the breathing member, a variable-capacity reservoir member connected into said system at a point spaced from said breathing member, and means to supply gas to said system at a point spaced from said breathing member, the resistances of said reservoir member and of said valve being so correlated that said valve will open to release gaseous expiration products when said reservoir reaches a given state of distension on expiration and that said valve will open to admit air to said breathing member when said reservoir member reaches a given state of collapse on inspiration.

2. Apparatus for the administration of gases, comprising a breathing member, a seatless two-way valve proximal to the breathing member, a variable-capacity reservoir member connected into said system at a point spaced from said breathing member, and means to continuously supply gas to said system in measured quantity at a point spaced from said breathing member, the resistance of said reservoir member and of said valve being so correlated that said valve will open to release gaseous expiration products when said reservoir reaches a given state of distension on expiration and that said valve will open to admit air to said breathing member when said reservoir member reaches a given state of collapse on inspiration.

3. A respirator system, comprising means to coapt the respiratory tract, valve means adapted to open to the atmosphere, means for the introduction of gas to said system, variable-capacity reservoir means, and means to adjust the maximum capacity of said variable-capacity reservoir means.

4. A respirator system comprising a mask having an opening to the atmosphere, a seatless two-way valve in said opening, an expansible and collapsible bag connected to said system, and means to supply a gas to said system.

5. A respirator system comprising a mask having an opening to the atmosphere, a seatless two-way valve in said opening, an expansible and collapsible bag connected to said system, and means to supply a gas to said system, said valve having a clearance of not less than 0.002 inch and not more than 0.015 inch on each of at least three sides.

6. A respirator system comprising means to coapt the respiratory tract, tubing extending from said coapting means and having therewith a capacity of from about 50 cc. to 100 cc., means to continuously supply gas directly to said tubing near the end thereof remote from said coapting means, a variable-capacity reservoir connected to said tubing near the end thereof remote from said coapting means, said tubing permitting a two-way flow between said variable-capacity reservoir and said coapting means, valve means proximal to said coapting means and adapted to open to release a gaseous fluid to the atmosphere when said variable-capacity reservoir reaches a high capacity.

7. A respirator system comprising means to coapt the respiratory tract, tubing extending from said coapting means and having therewith a capacity of from about 50 cc. to about 100 cc., means to continuously supply gas directly to said tubing near the end thereof remote from said coapting means, a variable-capacity reservoir connected to said tubing near the end thereof remote from said coapting means, said tubing permitting a two-way flow between said variable-capacity reservoir and said coapting means, valve means proximal to said coapting means and adapted to open to admit air from the atmosphere when said variable-capacity reservoir

reaches a low capacity on inspiration and to release a gaseous fluid to the atmosphere when said variable-capacity reservoir reaches a high capacity.

8. A respirator system comprising means to coapt the respiratory tract, tubing extending from said coapting means and having therewith a capacity of approximately 60 cc. means to continuously supply gas directly to said tubing near the end thereof remote from said coapting means, a variable-capacity reservoir connected to said tubing near the end thereof remote from said coapting means, said tubing permitting a two-way flow between said variable-capacity reservoir and said coapting means, valve means proximal to said coapting means and adapted to open to admit air from the atmosphere when said variable-capacity reservoir reaches a low capacity on inspiration and to release a gaseous fluid to the atmosphere when said variable-capacity reservoir reaches a high capacity.

9. A respirator system comprising means to coapt the respiratory tract, tubing extending from said coapting means and having therewith a capacity of from about 50 cc. to about 100 cc., means to continuously supply gas directly to said tubing near the end thereof remote from said coapting means, a variable-capacity reservoir connected to said tubing near the end thereof remote from said coapting means, said tubing permitting a two-way flow between said variable-capacity reservoir and said coapting means, valve means proximal to said coapting means and adapted to open to admit air from the atmosphere when said variable-capacity reservoir reaches a low capacity on inspiration and to release a gaseous fluid to the atmosphere when said variable-capacity reservoir reaches a high capacity, said variable-capacity reservoir having an adjustable maximum capacity.

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