United States Patent

[11] **3,527,206**

[72] Inventor **William C. Jones**
16 W. 328 Walnut Lane, Timber Trails, Elmhurst, Illinois 60126

[21] Appl. No. **751,475**
[22] Filed **Aug. 9, 1968**
Continuation-in-part of Ser. No. 718,029, Apr. 2, 1968.
[45] Patented **Sept. 8, 1970**

[54] **RESPIRATION TESTING APPARATUS**
10 Claims, 11 Drawing Figs.

[52] **U.S. Cl.** **128/2.08**
[51] **Int. Cl.** **A61b 5/08**
[50] **Field of Search** 128/2.07, 2.08

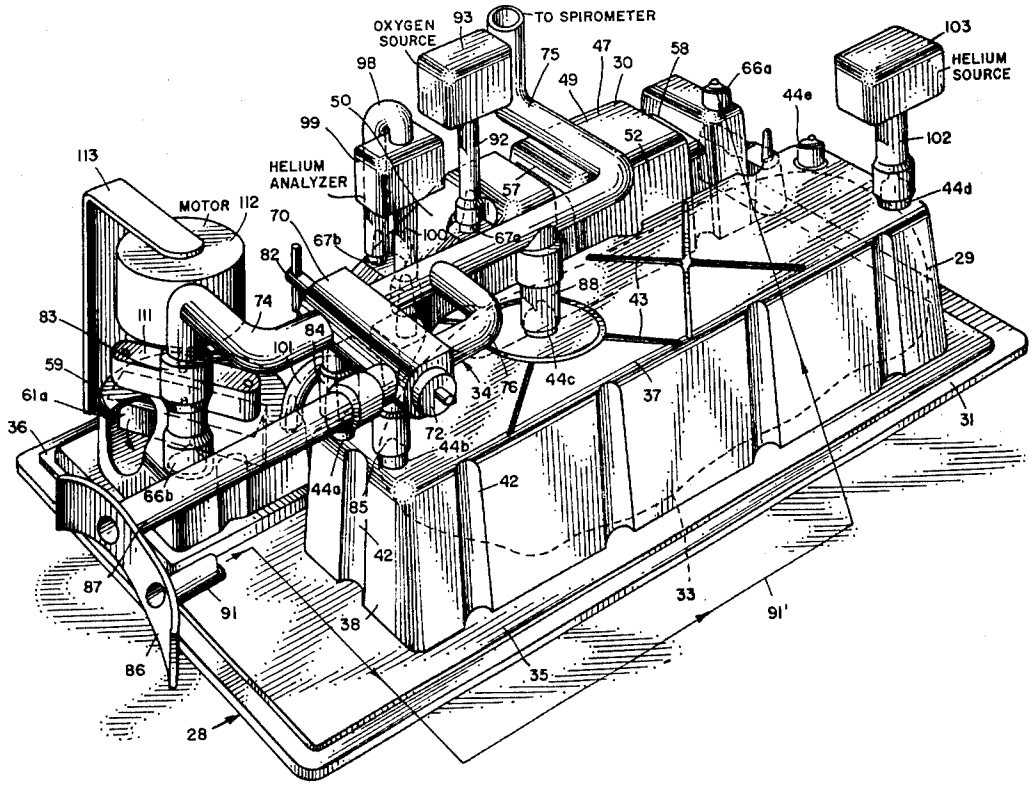
[56] **References Cited**

UNITED STATES PATENTS

2,592,694	4/1952	Heidbrink	128/2.07
2,707,947	5/1955	Traugott	128/2.07
2,709,430	5/1955	Traugott	128/2.07
2,792,828	5/1957	Engelder	128/2.07
3,129,705	4/1964	Nemec et al.	128/2.07
3,467,078	9/1969	Bird et al.	128/2.08

Primary Examiner—Richard A. Gaudet
Assistant Examiner—John B. Mitchell
Attorney—Dawson, Tilton, Fallon and Lungmus

ABSTRACT: A compact, lightweight disposable apparatus for respiration testing particularly suitable for measuring lung volume and capacity which may be shipped as a sealed aseptic unit. The apparatus includes a first sealed housing providing a chamber, a sealed bag within the chamber, and a second sealed housing providing a carbon dioxide absorption chamber and a blower chamber. A bag access conduit communicates with the bag and extends outwardly from the first housing, and two access conduits which communicate with the first housing chamber extend outwardly from the second housing at the upstream and downstream ends thereof. The outer ends of the access conduits are closed but are adapted to be readily slit or snipped open. A valve and hose assembly is adapted to connect the housings, a spirometer, and a mouthpiece. A breathing circuit is thereby formed from the mouthpiece to the upstream end of the second housing, and from the downstream end of the second housing to the mouthpiece, and the valve selectively includes either the spirometer or the chamber of the first housing in this breathing circuit.



Patented Sept. 8, 1970 3,527,206

FIG. 1

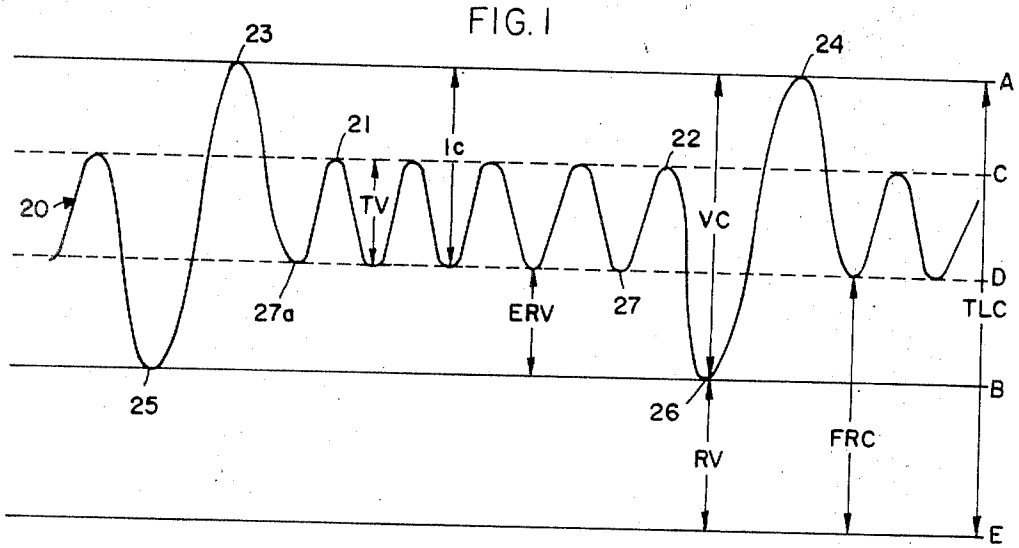
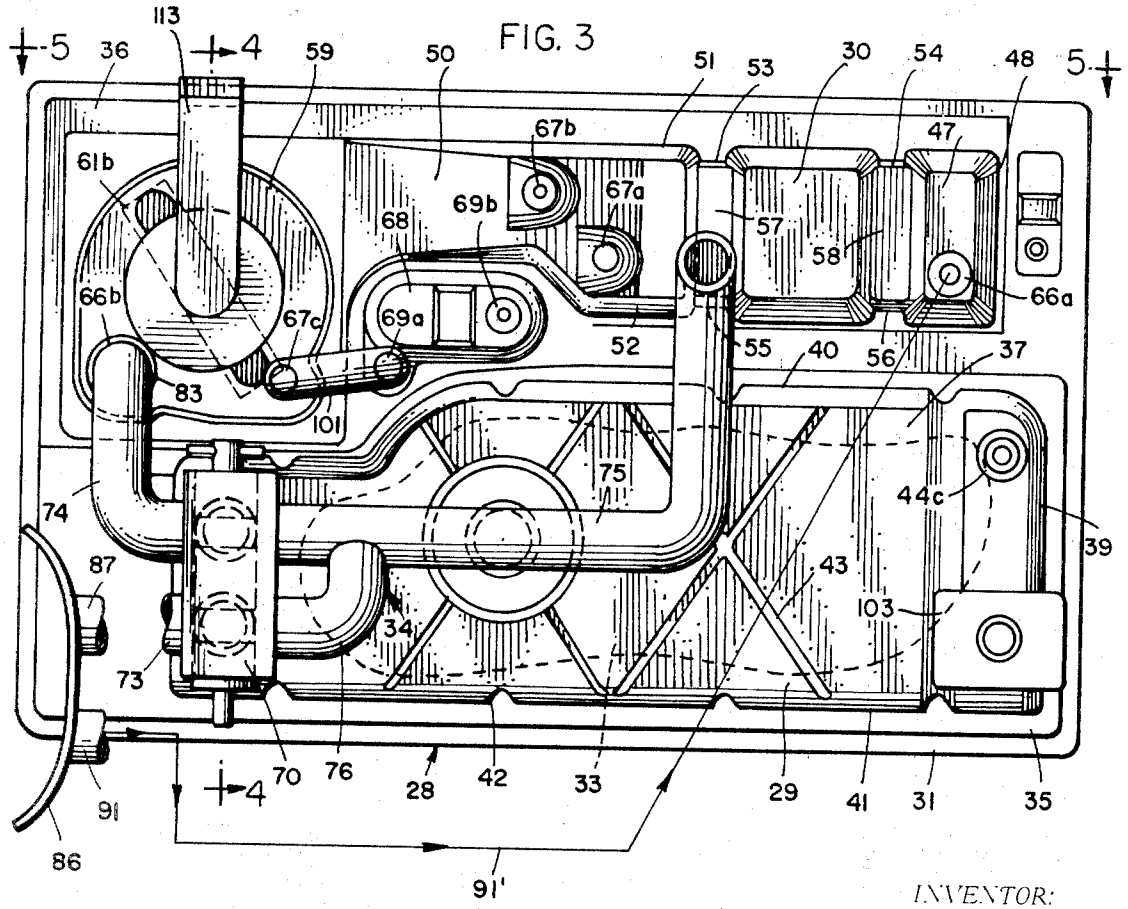


FIG. 3



INVENTOR:
WILLIAM C. JONES
BY
Dawson, Tilton, Fallon & Lungmus
ATT'YS

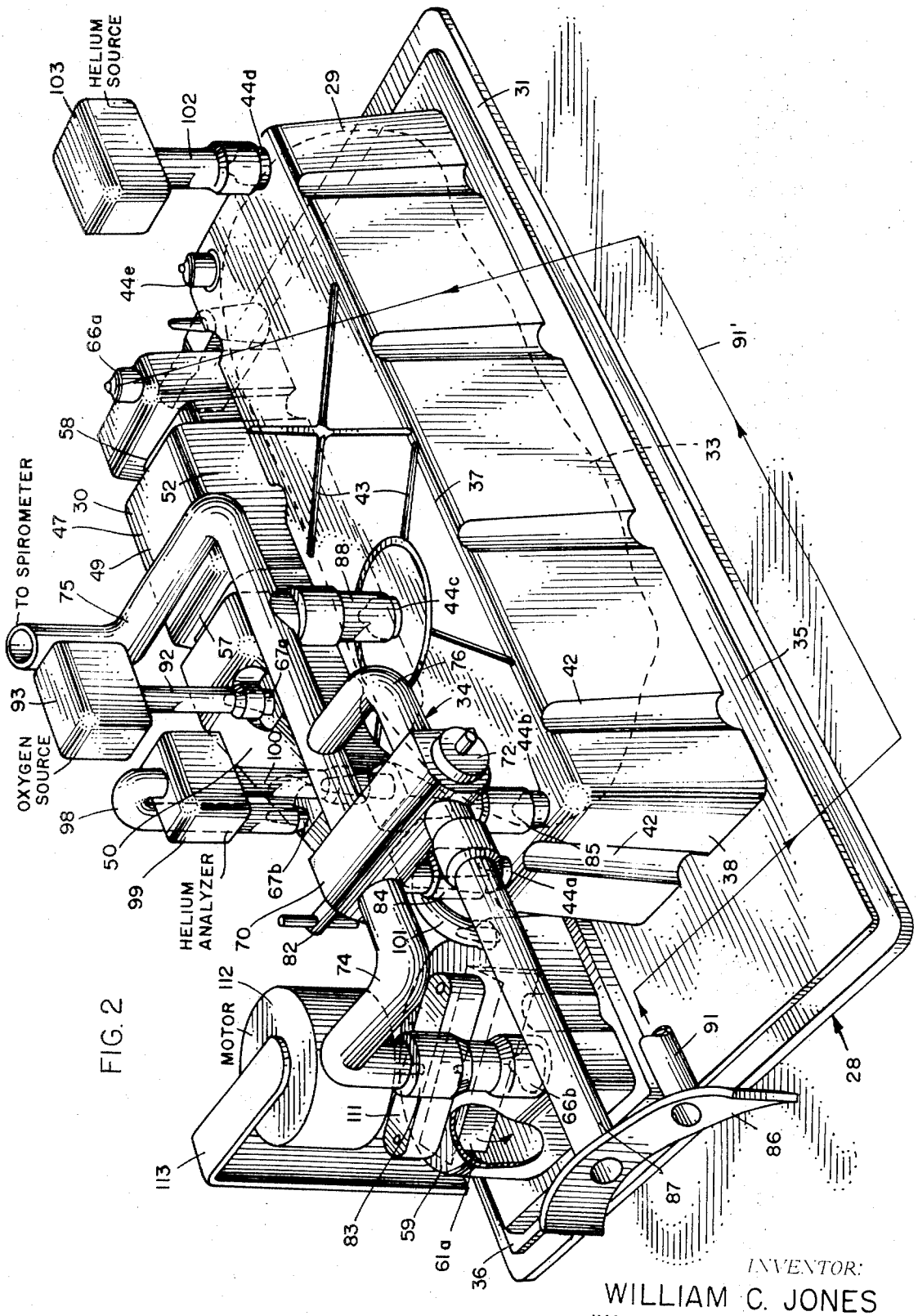


FIG. 2

INVENTOR:
WILLIAM C. JONES
BY
Dawson, Tilton, Fallon & Lungmus
ATT'YS

FIG. 4

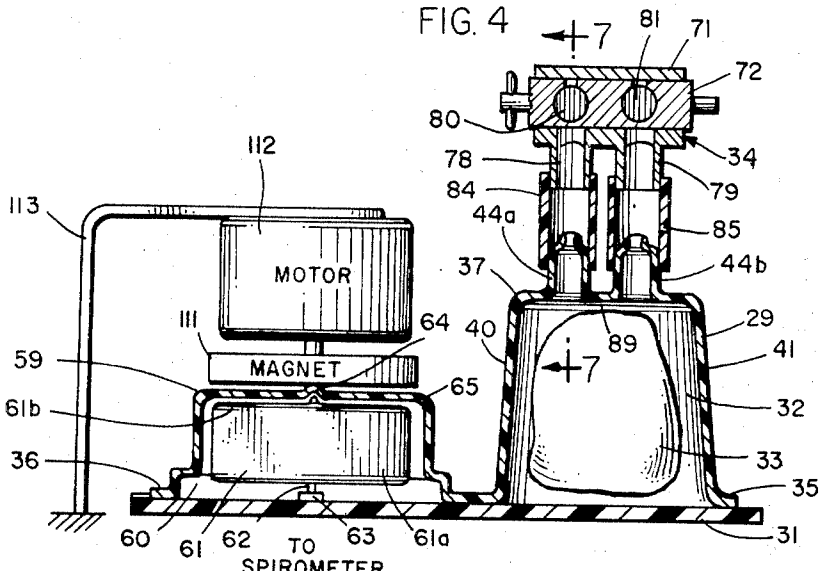


FIG. 5

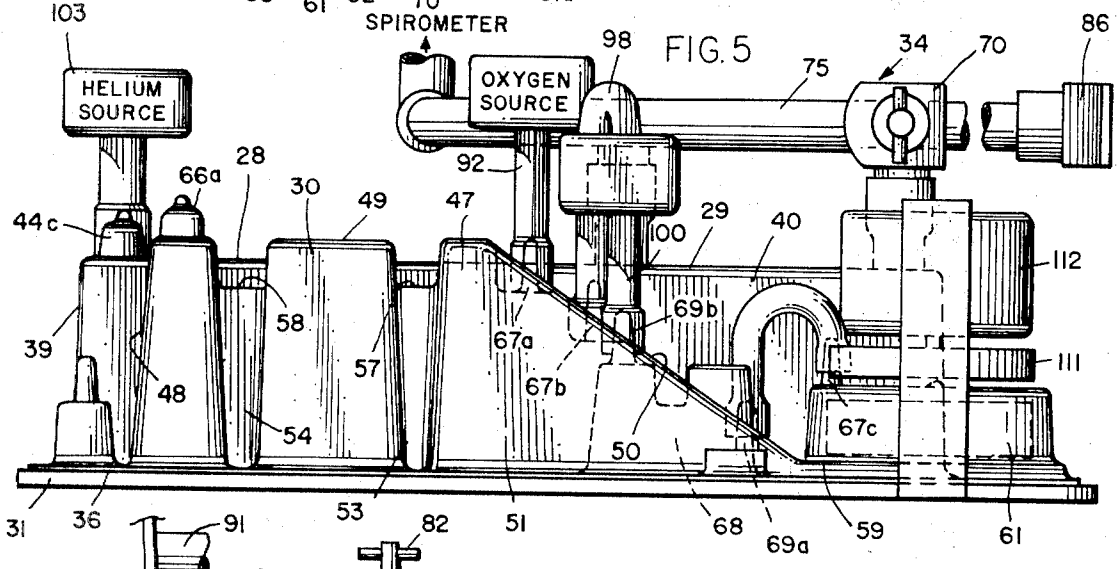
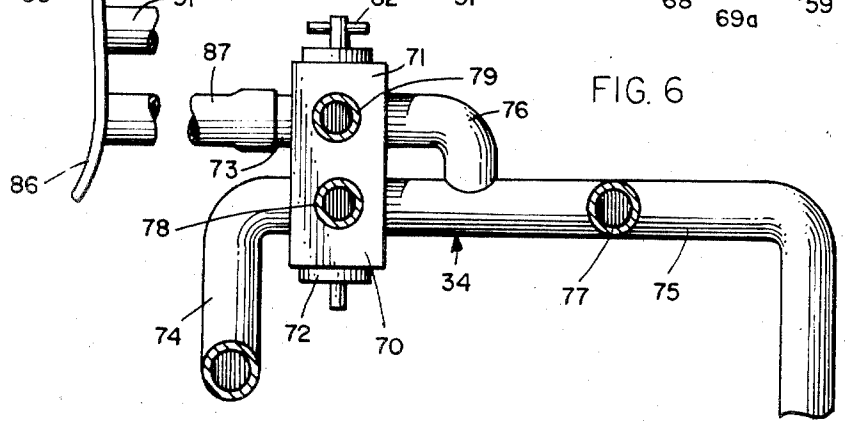


FIG. 6



INVENTOR:
WILLIAM C. JONES
BY
Dawson, Tilton, Fallon & Lungmus
ATT'YS

FIG. 7

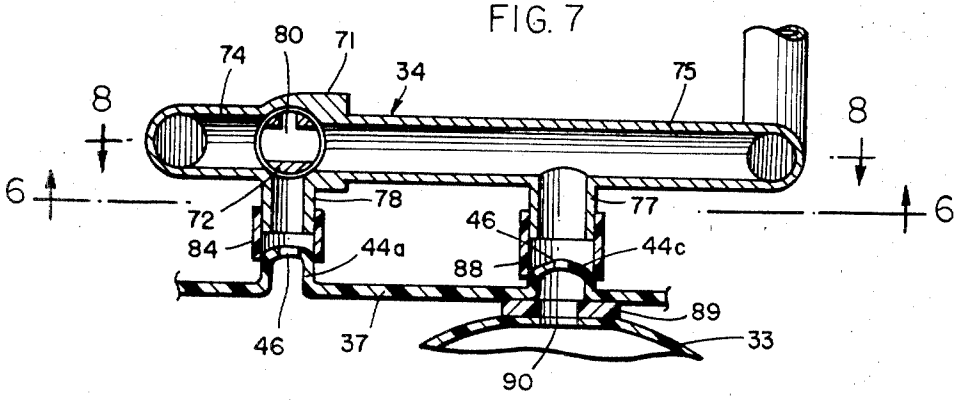


FIG. 8

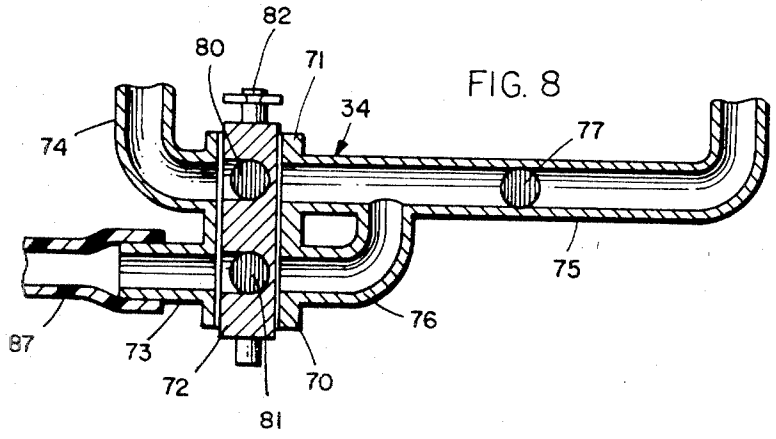


FIG. 9

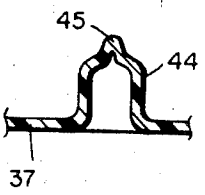


FIG. 10

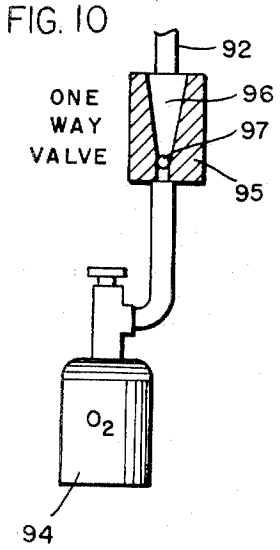
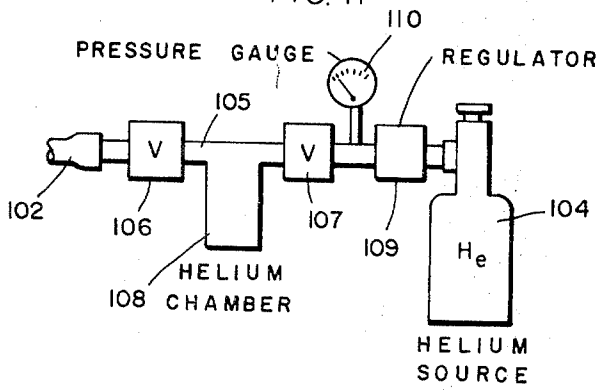


FIG. 11



INVENTOR:
WILLIAM C. JONES
BY
Dawson, Tilton, Fallon & Lungmus
ATT'YS

RESPIRATION TESTING APPARATUS

RELATED APPLICATION

This application is a continuation-in-part of my co-pending application entitled Respiration Testing Apparatus, Ser. No. 718,029, filed April 2, 1968.

BACKGROUND

In the treatment of patients, especially patients suffering from some respiratory disease such as emphysema, it is often desirable to measure the various lung volumes and lung capacities. Some of these pulmonary functions, such as the vital capacity, inspiratory capacity, and expiratory reserve volume, can be measured directly by such instruments as spirometers. My prior patent entitled Respiration Testing Apparatus, U.S. Pat. No. 3,086,515, issued April 23, 1963 and my co-opending application entitled Respiration Testing Apparatus, Ser. No. 739,000, filed June 21, 1968, described in detail two types of spirometers that are suitable for such measurements.

However, some of the important pulmonary functions, such as functional residual capacity, residual volume, and total lung capacity were heretofore required to be measured indirectly by various methods. One of the more widely used methods for measuring these values is the so-called closed circuit helium dilution method, which utilizes a conventional spirometer. Each time this method is employed, the volume or "dead space" of the closed spirometer circuit must be determined. The circuit is filled with air at atmospheric pressure, and a measured volume of helium, also under atmospheric pressure, is introduced into the circuit. By measuring the concentration of helium in the spirometer circuit, the volume or dead space of the circuit can be calculated.

After the dead space of the circuit is determined, the circuit is rinsed with air, and a second measured quantity of helium is introduced. The patient breathes the gas of the spirometer circuit first in a normal manner, and then alternately inspires as much gas as he can and expires as much gas as he can so that the directly measurable pulmonary functions may be determined by the spirometer. The patient may then resume normal breathing, and after the helium concentration in the spirometer circuit reaches an equilibrium level, the patient may be switched out of the spirometer circuit. The remaining pulmonary functions or subdivisions of the total lung capacity must then be calculated indirectly.

The functional residual capacity can be calculated if the dead space of the spirometer circuit, the amount of helium that was introduced into the circuit, and the final or equilibrium concentration of helium in the spirometer circuit are all known. However, not only are the calculations heretofore required in using the helium dilution method bothersome and time-consuming, the values obtained are subject to certain inaccuracies. The method operates on the principle that an unknown volume can be measured by connecting that volume to a known volume and observing the difference in concentration of a known quantity of gas when it is confined in the known volume and when it is in equilibrium with the known and unknown volumes. If the known volume is substantially larger than the unknown volume, the difference between the initial and final concentrations of the gas will be small, and these concentrations must therefore be measured very accurately. The known volume in the helium dilution method is the volume of the spirometer circuit, and this volume is usually considerably larger than the volume of gas inspired and expired by a patient when breathing normally.

This helium dilution method further requires that the patient be switched to the spirometer circuit at the end of a normal expiration, or inaccuracies will arise. It has been found difficult to time this switching maneuver precisely.

Other problems with prior methods of measuring pulmonary functions have also arisen. For example, the apparatus involved is usually rather bulky and may not be readily moved from one location to another. Further, since the patients being tested frequently have some respiration difficulty or disease, there is a good possibility of contamination if the apparatus is used by more than one patient. Heretofore, such testing apparatus was relatively expensive and could not be economically disposed of after each use.

SUMMARY

The inventive apparatus directly and accurately measures the functional residual capacity, residual volume, and total lung capacity of the patient without the necessity of calculations. The helium measuring gas is confined within a volume only slightly larger than the volume of gas that a patient expires and inspires during normal breathing, and, therefore, the change in the initial and final concentrations of the helium is substantial and accurately measurable.

The apparatus is relatively compact, lightweight, and inexpensive, may be kept in a sealed, aseptic condition before use, and may be economically disposed of after each use.

DESCRIPTION OF THE DRAWING

FIG. 1 is an illustration of a graph inscribed by a typical spirometer showing the various pulmonary subdivisions;

FIG. 2 is a perspective view of the inventive testing apparatus;

FIG. 3 is a top plan view of the apparatus of FIG. 2;

FIG. 4 is a sectional view taken along the line 4—4 of FIG. 3;

FIG. 5 is a view taken along the line 5—5 of FIG. 3;

FIG. 6 is a fragmentary sectional view taken along the line 6—6 of FIG. 7;

FIG. 7 is a fragmentary sectional view taken along the line 7—7 of FIG. 4;

FIG. 8 is a fragmentary sectional view taken along the line 8—8 of FIG. 7 showing the valve in an alternative position;

FIG. 9 is a fragmentary sectional view of one of the access nipples;

FIG. 10 is a schematic illustration of an oxygen source for use with the apparatus; and

FIG. 11 is a schematic illustration of a helium source for use with the apparatus.

DESCRIPTION OF SPECIFIC EMBODIMENT

Referring now to FIG. 1, the numeral 20 designates generally the line inscribed by the recording means or kymograph of a spirometer. A detailed description of the recording means of a particular spirometer may be found in my prior U.S. patent entitled Respiration Testing Apparatus, Pat. No. 3,086,515, issued April 23, 1963. The generally sinusoidally shaped portion of line 20 between the minor peaks 21 and 22 was inscribed while the patient was breathing normally, or resting. The major peaks 23 and 24 were inscribed while the patient inspired as much gas as he could, and the major valleys 25 and 26 were inscribed while the patient expired as much gas as he could from his lungs. The straight line A may be drawn to connect the major peaks 23 and 24, and line B connects valleys 25 and 26. The dotted lines C and D enclosed the portion of the graph inscribed during normal breathing.

Many of the pulmonary subdivisions can be measured directly from the kymograph. For example, the vital capacity (VC), which is the maximal amount of gas that can be expelled from the lungs following a maximal inspiration, is measured by the distance between the peaks 23 and 24 and the valleys 25 and 26 or the distance between lines A and B. The tidal volume (TV), which is the volume of gas inspired or expired during each normal respiratory cycle may be measured by the distance between lines C and D. The inspiratory capacity (IC) is the maximal volume that can be inspired from the resting expiratory level and is measured by the distance between solid line A and dotted line D. The expiratory reserve volume (ERV), which is the maximal volume of gas that can be expired from resting expiratory level, is measured by the distance between the dotted line D and the solid line B.

After a patient expels all of the gas from his lungs that he can, there is still some gas remaining in the lungs. The volume of this gas remaining in the lungs at the end of a maximal expiration is called the residual volume (RV), and if the solid line E were taken to represent the point which would be reached on the kymograph if the lungs could be completely evacuated, the residual volume would be the distance between lines B and E.

The total lung capacity (TLC), which is the volume of gas contained in the lungs at the end of a maximal inspiration and which is the sum of the vital capacity and the residual volume, is measured by the distance between the lines A and E. The functional residual capacity (FRC), which is the volume of gas remaining in the lungs at the end of a normal rebreathing exhalation and which is composed of the expiratory reserve and the residual volume, is measured by the distance between the dotted line D and the solid line E.

Since the position of the line E cannot be represented on the kymograph, none of the pulmonary subdivisions of residual volume, functional residual capacity, or total lung capacity can be measured directly. In the past, at least one of these subdivisions had to be determined indirectly by time-consuming and error-prone measurements and calculations, and the other two could then be determined from the kymograph. Applicant's inventive respiratory testing apparatus provides a direct read-out of the functional residual capacity, residual volume, and total lung capacity without the formerly required measuring and calculating steps.

Referring now to FIGS. 2—4, the inventive apparatus generally designated by the numeral **28** includes a first box-like housing **29** and a second housing **30** mounted on a base **31**. The first housing **29** provides a breathing chamber **32** therein, and an inflatable, sealed bag **33** is positioned within the chamber **32**. A valve and pipe assembly generally designated **34** is positioned above the first housing **29** and is connected to a conventional spirometer (not shown). The assembly **34** also connects the components of the apparatus **28** in a manner to be described hereinafter.

Each of the housings **29** and **30** may advantageously be formed in the desired shape by vacuum forming a suitable helium-impermeable plastic such as propionate or a high impact styrene. Referring to FIG. **2**, the vacuum forming of the housing **29** provides the housing with a perimetric flange portion **35** around the bottom thereof which is attached by heat sealing to the base sheet **31**, which may be made of a similar plastic. Similarly, the housing **30** includes a base flange **36** which is heat sealed to the base plate **31**.

After the first housing **29** is formed, it has an inverted dish-like shape having a top **37**, front wall **38**, rear wall **39**, and side walls **40** and **41**. The walls of the housing may be formed with generally vertically extending strengthening ribs **42**, and the top **37** is seen to include criss-cross strengthening ribs **43**.

The top **37** of the housing **29** is formed with a plurality of upwardly extending access stub conduits or nipples **44** (FIG. **9**) which include a closed outer end formed by the dimple **45**. A pair of nipples **44***a* and **44***b* are located adjacent the front of the housing, a nipple **44***c* is located in the central portion of the housing, and a pair of nipples **44***d* and **44***e* are located adjacent the rear of the housing. As will be described more fully hereinafter, each of the nipples **44***a*—**44***d* are designed to provide a gas-tight connection with a rubber hose, and before the hose is connected the dimple **45** of each of the nipples is snipped or sliced off with a razor blade, scissors, or the like to provide an opening **46** (FIG. **7**) in the outer end of the nipple.

Referring to FIGS. **2**, **3**, and **5**, the second housing **30** includes a first box-like portion **47** having a substantially vertical rear wall **48**, a top wall **49**, an inclined front wall **50**, and side walls **51** and **52**.

The side wall **51** is provided with a pair of vertically extending ribs **53** and **54**, the side wall **52** is provided with a pair of ribs **55** and **56**, and the top wall **49** is provided with a pair of ribs **57** and **58** joining the ribs on the side walls.

The downwardly sloping front wall **50** of the first portion of the housing **30** merges with a generally cylindrical second housing portion **59** which provides an internal blower chamber **60** (FIG. **4**) therein. A metal vane or rotor **61** is rotatably mounted within the cylindrical blower housing **59** and is generally T-shaped in vertical cross section having a vertical portion **61***a* and a horizontal top portion **61***b*. The rotor **61** is rotatably mounted by means of a pin **62**, the lower end of which is journaled in a bushing **63** secured to the base plate **31** and the upper end of which is received in an upwardly extending dimple **64** formed in the top **65** of the blower housing.

The second housing **30** is also provided with access stub conduits or nipples similar to those heretofore described, a nipple **66***a* being provided adjacent the rear of the housing **30** and a nipple **66***b* being provided in the top of the blower housing **59**. Somewhat smaller nipples **67***a* and **67***b* extend upwardly from the inclined front wall **50** of the first portion of the second housing, and a smaller access nipple **67***c* also extends upwardly from the blower housing **59**.

A third housing **68** (FIGS. **3** and **5**) is secured to the base sheet **31** between the first and second housings, and the housing **68** includes access nipples **69***a* and **69***b*.

The valve and pipe assembly **34** includes a two-position valve **70** comprising a valve casing **71** having a generally cylindrical bore therethrough and a valve core **72**. A stub pipe **73** extends outwardly from the valve casing **71** toward the front of the apparatus, and a pipe **74** extends outwardly and downwardly from the front of the valve casing. A pipe **75** extends rearwardly from the valve casing in general axial alignment with the portion of the pipe **74** which extends from the casing. Similarly, a pipe **76** extends rearwardly from the valve casing in axial alignment with the stub pipe **73**. The pipe **76** is generally L-shaped and connects to the pipe **75**. A stub pipe **77** extends downwardly from the pipe **75** toward the central portion of the first housing **29**. A stub pipe **78** extends downwardly from the valve casing **71** and the axes of the pipes **74**, **75**, and **78** intersect within the valve casing. Similarly, a pipe **79** also extends downwardly from the casing, and the axes of the pipes **73**, **76** and **79** intersect within the casing.

The valve casing **71** and the pipes **73**—**79** are joined to form a single piece and are preferably made of metal, such as stainless steel. The valve core **72** is a solid metal block which is provided with a pair of T-shaped bores **80** and **81** (FIGS. **4** and **8**), and the core is accurately ground to be received by the bore of the valve casing to provide a gas-tight seal between the core and the casing.

The valve core **72** may be rotated between the two positions illustrated in FIGS. **7** and **8**. In the position illustrated in FIG. **7**, the core passage **80** connects the pipe **74** to the pipe **75**, and the core passage **81** connects the pipe **73** to the pipe **76**. The downwardly extending pipes **78** and **79** are sealed by the valve core and do not communicate with any of the other pipes. In the position illustrated in FIG. **8**, the passage **80** connects the pipe **74** with the pipe **78**, and the passage **81** connects the pipe **73** with the pipe **79**. The pipes **75** and **76** are sealed by the core from the remaining pipes. The valve core may be provided with a handle **82**, if desired, to facilitate turning of the valve.

The end of the pipe **74** is connected to the access nipple **66***d* of the cylindrical blower housing **59** by flexible hose **83** (FIG. **2**) of rubber or other suitable material, the downwardly extending pipes **78** and **79** are connected to the access nipples **44***a* and **44***b*, respectively, of the housing **29** by hoses **84** and **85**, the pipe **73** is connected to a conventional mouthpiece **86** by hose **87**, and pipe **77** is connected to the access nipple **44***c* by hose **88**. The end of the pipe **75** is connected to a conventional spirometer (not shown). Many commercially available spirometers are suitable, and two such spirometers are described in my prior patent entitled Respiration Testing Apparatus, U.S. Pat. No. 3,086,515 and in my co-pending application entitled Respiration Testing Apparatus, Ser. No. 739,000, filed June 21, 1968.

Referring to FIG. **7**, the inflatable bag **33**, which may be made of Mylar or other helium-impermeable material, is

secured to an annular gasket **89** which in turn is secured to the top wall **37** of the housing **29** below the access nipple **44***c*. The bag is provided with an opening **90** so that the interior of the bag may communicate with the pipe **75** through the nipple **44***c*.

A second mouthpiece hose or conduit **91** extends from the mouthpiece **86** and is connected to the access nipple **66***a* at the rear of the housing **30**. For purposes of clarity, the hose **91** has been illustrated schematically at **91'**.

The first portion **47** of the housing **30** provides an internal chamber which is filled with a suitable carbon dioxide absorbing agent, such as soda lime. The nipple **67***a* of the absorption chamber housing is connected by hose **92** to a suitable oxygen source **93**, which replaces oxygen consumed by the patient during respiration. For example, referring to FIG. **10**, an oxygen tank **94** containing oxygen at about atmospheric pressure may be connected to the hose **92** by a one-way ball valve **95** having a frusto-conical passage **96** which receives ball **97**.

As can be seen in FIGS. **2** and **5**, the nipple **67***b* of the absorption chamber housing **47** is connected by hose **98** to the outlet of a conventional helium analyzer **99**. The inlet of the helium analyzer is connected by hose **100** to the nipple **69***b* of the housing **68**, which contains a suitable gas drying agent. The nipple **69***a* of the front end of the housing **68** is connected to the nipple **67***c* of the blower housing **59** by hose **101**. The oxygen source **93** and helium analyzer **99** are omitted from FIG. **3** for clarity.

The nipple **44***d* at the rear of the housing **29** is connected by hose **102** to a suitable helium source **103**. One such helium source is illustrated in FIG. **11**, in which a cylinder **104** of high-pressure helium is connected to hose **102** by conduit **105**. Solenoid operated valves **106** and **107** are interposed in the conduit **105**, and a helium chamber **108** communicates with the conduit **105** between the valves. A pressure regulator **109** and pressure gauge **110** are interposed in the conduit between the cylinder **104** and the valve **107**. The pressure regulator **109** is designed to measure relative pressures between the air in the hose **102**, which is at atmospheric pressure, and the helium in helium tank **104** in order to admit to the chamber **108** a constant volume of helium at atmospheric pressure regardless of the altitude at which the apparatus is used. This type of regulator is commercially available, and one such regulator is a Bellofram regulator.

The rotor **61** within the blower housing **59** is rotated by means of a bar magnet **111** which is rotated in a horizontal plane by an electric motor **112** supported by bracket **113**. The horizontally extending planar top **61***b* of the T-shaped rotor increases the magnetic attraction between the metal rotor **61** and the magnet **111**, and as the magnet is spun by the motor **112**, the rotor is drawn by the magnet and also spins in a horizontal plane.

OPERATION

After the housings **29**, **30**, and **68** are formed, the volumes or "dead space" of the chambers provided therein are measured. This measurement need be made only after the vacuum forming molds are first made, since subsequently formed housings will have the same volumes. The total volume of these housings minus the volume of soda lime placed in the CO_2 absorption chamber, the volume of gas drying agent placed in the gas drier housing **68**, and the volume of the collapsed bag **33** constitutes the "dead space" of the three housings after they are secured to the base plate **31**. By using a precise amount of carbon dioxide absorbing agent and gas drying agent the dead space of every sealed housing unit will be the same.

The housings can be secured to the base sheet **31** under aseptic conditions, and the apparatus will remain in aseptic condition unitl the dimples **45** of the access nipples **44** are snipped off by the technician prior to testing a patient. When a patient is to be tested, the closed ends of the access nipples are cut off, the associated hoses are positioned thereon, and the motor **112** and magnet **111** are positioned over the blower housing **59**.

The valve core **72** is positioned as illustrated in FIG. **7**, and a measured amount of helium is introduced from the helium source **103** into the breathing chamber **32** within the housing **29**. By using a pressure regulator which measures the difference between atmospheric pressure and the pressure of the helium source, a constant volume of helium will always be introduced regardless of the atmospheric pressure at the time the apparatus is being used. Referring to FIG. **11**, the pressure in the helium chamber **108** is equalized with the pressure in conduit **102**, which is at atmospheric pressure, by switching open the solenoid operated valve **106**, and this valve is then closed. The regulator **109** is opened to introduce a measured amount of helium into the helium chamber **108**, the valve **107** is then closed, and the valve **106** is opened to introduce the helium into the hose **102** and the breathing chamber **32**.

The patient inserts the mouthpiece **86** into his mouth and breathes through the mouthpiece conduits **87** and **91**. While the patient is breathing, the rotor **61** circulates air from the blower housing **59** through the pipes **74**, **75**, **76**, **73**, and mouthpiece conduit **87** into the patient, and from the patient through the mouthpiece conduit **91**, the CO_2 absorption chamber within the housing **47**, and into the blower housing. Air enters the housing **30** through the access nipples **66***a* at the rear end thereof, which is the upstream end, and leaves through the access nipple **66***b* in the blower housing, which is at the downstream end of the housing.

While the patient is breathing with the valve in the position illustrated in FIG. **7**, the patient is connected to the spirometer through the pipe **75**, and the spirometer records the breathing cycle as in FIG. **1**. The patient takes a maximal inspiration and a maximal expiration which are recorded as at **24** and **26**, respectively, in FIG. **1**. The patient then breathes normally, and at the end of a resting expiration as at **27** in FIG. **1** the valve core **72** is switched to its second position illustrated in FIG. **8**. The end of a resting expiration or end tidal volume can be observed on the kymograph so that the valve **70** can be switched at precisely the desired point. Before the valve is switched, the bag **33** communicates with the pipe **75**, but the bag does not inflate because it is contained within the closed housing **29**.

When the valve is switched to its second position, the patient is disconnected from the spirometer and will inhale through the mouthpiece conduit **87** from the breathing chamber **32**. The rotor **61** establishes a gas flow so that the patient inspires the gas from the breathing chamber through the pipes **79** and **73** of the valve and pipe assembly and expires into the absorption chamber through the mouthpiece conduit **91**. Gas passes through the absorption chamber and blower housing and into the breathing chamber **32** through the pipes **74** and **78** of the valve and pipe assembly. As the patient inspires, the bag **33** expands to replace the volume of gas removed from the housing **29**, and as the patient expires the bag deflates. Thus, even though the patient is breathing in a closed system, the inflatable bag permits gas to be withdrawn from and expelled into the system. The bag inflates and deflates by respectively drawing air from and forcing air into the spirometer, and the patient's breathing cycle is recorded on the kymograph even though the patient is not breathing directly into the spirometer.

The patient breathes normally until the helium concentration achieves equilibrium throughout the breathing circuit and the patient's lungs. The blower or rotor **61** facilitates achieving this equilibrium state, and a normal patient may reach equilibrium in about two or three minutes, while a patient suffering from a respiratory disease such as emphysema may require as many as seven or more minutes. The helium concentration is readily observed by means of the gauge of the helium analyzer **99** which is connected to the housing **30** both downstream and upstream of the blower housing.

While the valve is in the second position, the patient is breathing normally as indicated between the points **27** and **21**

in FIG. 1, and it is thus seen that the dead space of the apparatus need not be more than the tidal volume of the patient, which normally is of the order of about two liters. The percentage change of the helium concentration from the initial reference level to the final equilibrium concentration will therefore be about 50 percent. Heretofore, helium dilution systems required a dead space much larger than the patient's tidal volume in order to accommodate the maximal inspiration and maximal expiration of the patient. The accuracy of the system was thereby reduced because the greater the dead space is in relation to the tidal volume of the patient, the less percentage change occurs between the initial and final concentrations of helium.

After the helium concentration as measured by the helium analyzer reaches a constant level, the valve may then be returned to its first position at an end tidal volume as at **27***a*, and the patient again takes a maximal inspiration and maximal expiration, which are indicated at **23** and **25** of FIG. **1**, respectively.

Since the valve **70** was switched back to its first position at the end of a resting expiration, the helium that remained in the patient's lungs at the time was contained in a volume equal to functional residual capacity of the patient's lungs. The equilibrium helium concentration is thus related to the functional residual capacity, the volume of helium introduced by the helium measuring chamber, and the dead space by the equation:

$$C_{He}=\frac{V_{He}}{V_{He}+V_{DS}+FRC}$$

in which:

C_{He} = equilibrium concentration of helium

V_{He} = the volume of helium introduced from the helium measuring chamber

V_{DS} = the dead space of the apparatus

FRC = the functional residual capacity of the patient.

It will be apparent that the factory determined dead space of the sealed housings **29**, **30**, and **68** should be increased by adding the volume of the pipes **73**, **74**, **78**, and **79** of the valve and pipe assembly **14**, the volume of the mouthpiece conduits **87** and **91**, the volume of the lengths of the hoses **83**, **84**, and **85** between the ends of their associated access nipples and the ends of their associated pipes, and the volume of the hoses **92**, **98**, **100**, and **102** associated with the oxygen source, helium analyzer, and helium source. This additional dead space will remain constant for a particular valve and pipe assembly and mouthpiece assembly and need not be calculated each time the apparatus is used.

The functional residual capacity may then be calculated from the above equation:

$$FRC=\frac{V_{He}}{C_{He}}-V_{He}-V_{DS}$$

In the foregoing equation V_{DS} is a known constant, and V_{He} is also a known constant because the helium regulator **109** will always admit a constant volume of helium regardless of the atmospheric pressure at which the apparatus is being used. If V_{DS} and V_{He} are fixed, the functional residual capacity is seen to be related solely to the equilibrium concentration of the helium, and the conventional gauge of the helium analyzer **99** can be calibrated to give a direct read-out of the functional residual capacity.

It is thus seen that the apparatus improves the accuracy of the measurement of the functional residual capacity by reducing the dead space of the measuring apparatus and eliminates the time-consuming step of calculating the functional residual capacity by giving a direct read-out of this value. The apparatus also eliminates the necessity of recalculating the dead space each time the apparatus is used, even if the operating conditions vary.

If it is desired to obtain a direct reading of the residual volume or the total lung capacity rather than the functional residual volume, then the valve **24** is switched back to its first position at the end of a maximal expiration or inspiration rather than at the end of a resting expiration.

After a particular patient has been tested, the plastic housings **29**, **30**, and **68** may be discarded and a new sealed housing unit **28** may be used for the next patient, thereby eliminating any danger of cross-contamination. The sealed housing unit **28** may be maintained in a aseptic condition until the access nipples are snipped open, and there is no danger that a person may become infected by the apparatus. The magnetic connection between the motor **112** and the rotor **61** provides a connection between the power source and the rotor without the danger of creating a helium leak, and also permits the blower housing to be disposable. The mouthpiece and mouthpiece conduits and the valve and pipe assembly **14** and its associated hoses may easily be sterilized by autoclaving or the like and reused again and again.

I have found that further advantages accrue when the plastic used for the housings **29**, **30**, and **68** is transparent, thereby permitting the operation of the rotor and the color of the soda lime and drying agents to be observed. The soda lime will turn from white to blue upon loosing its carbon dioxide absorption effectiveness, while the drying agent will turn from blue to pink as it becomes ineffective.

I have also found that by introducing the measured amount of helium into the first housing **29** rather than the second housing **30**, equilibrium of the helium is obtained much more quickly. This is because a relatively high initial concentration of helium is contained within the breathing chamber **32**, and as soon as the valve is switched to the second position and the patient begins inspiring gas from the breathing chamber through the access nipple **44***b*, the helium is drawn into the patient's lungs and begins travelling through the breathing circuit.

While the patient is breathing the gas contained in the housings **29** and **30**, he is consuming oxygen. The patient can either be disconnected from the circuit before all of the oxygen is consumed, or he can be supplied with oxygen as he breathes. It has been found that the pulmonary functions can be measured more accurately if oxygen is supplied while the patient breathes, but the patient is seldom supplied with only that amount of oxygen that is consumed. If more or less than this amount is introduced to the system, inaccuracies will arise.

The oxygen tank **94** will replace the oxygen that is consumed, and the one-way valve **95** permits oxygen to flow into the second housing **30** without allowing helium to escape from the housing. The oxygen in the tank **94** may be maintained at a pressure slightly greater than atmospheric pressure so that oxygen flows into the breathing circuit at a constant but slow rate. Alternatively, the amount of oxygen supplied by the oxygen source may be more precisely limited to the oxygen consumed by the patient by the use of spring means associated with the spirometer as described in my co-pending application Ser. No. 718,029, filed April 2, 1968.

The nipple **44** on the housing **29** is not snipped opened and remains closed during normal operation of the apparatus. However, the nipple will act as a safety pop-off if the pressure within the housing becomes excessive, as by the addition of too much oxygen from the oxygen source.

While in the specific embodiment illustrated, I have described the spirometer as being connected to the bag **33** and the mouthpiece connected to the housing **29** when the valve is in the second position, these connections may be reversed. That is, the spirometer may connect to the housing **29** and the mouthpiece may connect to the bag. The dead space of the apparatus would be measured when the bag is fully inflated to fill the interior of the housing, and the patient would be switched into the bag at the beginning of an inspiration. The bag would deflate during inspiration, and the spirometer would fill the space created between the bag and the housing. The access nipples **44***a*, **44***b*, and **44***d* would connect to the bag, and the access nipple **44***c* would connect to the housing.

While in the foregoing specification, a detailed description of an embodiment of the invention was set forth for the purpose of explanation, it is to be understood that many of the details hereingiven may be varied considerably by those skilled in the art without departing from the spirit and scope of the invention.

I claim:

1. A sealed unit for use in respiration testing including:
a first substantially gas-tight sealed housing providing a breathing chamber;
a closed, substantially gas-tight inflatable bag within said breathing chamber;
means for connecting the interior of said bag with the exterior of said first housing;
first and second access means on said first housing for connecting said breathing chamber with the exterior of said first housing;
a second substantiallly gas-tight sealed housing providing a carbon dioxide absorption chamber and a gas blower chamber communicating with said absorption chamber, said gas blower chamber including blower means providing the second housing with an upstream end and a downstream end;
first and second access means on said second housing for connecting the upstream end and the downstream end, respectively, of the second housing with the exterior of said housing;
said bag-connecting means adapted to be connected to spirometer means, the first access means of each of the first and second housings being adapted to be connected to a patient whose respiration is to be tested, the second access means of each of the first and second housings being adapted to be connected to each other whereby a breathing circuit may be formed from the patient to the upstream end of the second housing and from the downstream end of the second housing to the breathing chamber and from the breathing chamber to the patient.

2. The apparatus of claim 1 wherein said first and second housings are plastic, each of said access means comprising a nipple communicating with and extending outwardly from the respective housing and providing a closed outer end, each of said nipples being adapted to receive a flexible hose thereon, said bag-connecting means including a nipple communicating with said bag and extending outwardly from the first housing and being adapted to receive a flexible hose thereon.

3. The apparatus of claim 2 including a third access nipple of said first housing adapted to be connected to a helium source.

4. The apparatus of claim 2 wherein a portion of said bag is secured to said first housing adjacent the inner end of the nipple of said bag-connecting means, said bag-connecting nipple communicating with the interior of the bag.

5. The apparatus of claim 1 wherein said second housing includes a generally cylindrical housing portion providing said gas blower chamber therein, said blower means including a metal rotor rotatably mounted within said generally cylindrical housing portion and adapted to be rotated by a magnet outside of said generally cylindrical housing portion.

6. The apparatus of claim 1 including a third sealed housing providing a gas drying chamber therein, said third housing having first and second access means, third access means on said second housing downstream of said gas blower chamber and fourth access means on said second housing upstream of said gas blower chamber, the first access means of the third housing being adapted to be connected to said third access means of the second housing, the second access means of the third housing being adapted to be connected to a gas analyzer, and the fourth access means of the second housing being adapted to be connected to the gas analyzer.

7. The apparatus of claim 1 wherein said first and second housings are formed of vacuum formed plastic heat-sealed to a base sheet of plastic, each of said access means comprising a nipple vacuum formed in the respective housing and extending outwardly therefrom and providing a closed outer end, each of said nipples being adapted to receive a flexible hose thereon, said bag-connecting means including an outwardly extending nipple vacuum formed in said first housing and communicating with the interior of said bag, said bag-connecting nipple being adapted to receive a flexible hose thereon.

8. A respiration testing apparatus including:
spirometer means;
mouthpiece means;
a first substantially gas-impermeable housing providing a breathing chamber therein;
a substantially gas-impermeable inflatable bag within said breathing chamber and sealed therefrom;
a second substantially gas-impermeable housing providing a carbon dioxide absorption chamber and a blower chamber communicating with said absorption chamber;
blower means within said blower chamber providing said second housing with an upstream end and a downstream end;
first conduit means for connecting said mouthpiece means and the upstream end of said housing;
second conduit means for connecting said mouthpiece means to said breathing chamber;
third conduit means for connecting said mouthpiece means to said spirometer means;
fourth conduit means for connecting said bag to said spirometer means;
fifth conduit means for connecting the downstream end of said second housing to said breathing chamber;
and sixth conduit means for connecting the downstream end of said second housing to said mouthpiece means; and
valve means for selectively closing said second and fifth conduit means while opening said third and sixth conduit means, and for opening said second and fifth conduit means while closing said third and sixth conduit means.

9. A respiration testing apparatus including:
spirometer means;
mouthpiece means;
a two-position valve;
a first mouthpiece conduit between said mouthpiece and said valve;
a spirometer conduit between said spirometer and said valve;
a first substantially gas-tight housing providing a breathing chamber therein;
a relatively gas-tight inflatable bag within said breathing chamber and sealed therefrom;
first and second conduits communicating with said breathing chamber and extending outwardly from said first housing to said valve;
a bag conduit communicating with the interior of said bag and extending outwardly from said first housing to said spirometer conduit;
a second housing providing a carbon dioxide absorption chamber and a blower chamber communicating with said absorption chamber, said second housing having an upstream end and a downstream end;
a second mouthpiece conduit joining said mouthpiece and the upstream end of said second housing;
a second-housing conduit between said downstream end and said valve; and
said valve in one position closing said first and second breathing chamber conduits and joining said first mouthpiece conduit and said second-housing conduit to said spirometer conduit, said valve in the other position closing said spirometer conduit and joining said first mouthpiece conduit to one of said first and second breathing chamber conduits and joining said second-housing conduit to the other of said first and second breathing chamber conduits.

10. The apparatus of claim 8 wherein said first and second

housings are plastic, each of said first and second conduits and said bag conduit including a nipple formed in the first housing and extending outwardly therefrom and a flexible hose received thereon, each of said second mouthpiece conduit and

said second-housing conduit including a nipple formed in said second housing and extending outwardly therefrom and a flexible hose received thereon.