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THE ANESTHESIA SYSTEM

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THE ANESTHESIA SYSTEM

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FOREWORD

The material contained in this handbook is intended for a broad audience including: practicing clinicians; students; technicians; and biomedical engineering personnel. One particularly exciting aspect of the format chosen for this handbook, is the ability to add supplementary material as needed for particular groups, and to add updates as new pieces of equipment or new techniques evolve.

The importance of this type of material to the anesthesia community cannot be overstated, because we expect many levels of the anesthesia team, from providers to technical support staff, to be able to rapidly assess the functionality of the anesthesia delivery system. A handbook with diagrams of gas flow paths, functional aspects of valves, regulators, vaporizers, breathing circuits and ventilators is an extremely useful resource to enhance understanding of the equipment and to assist in rapidly assessing problems and developing solutions. This handbook was written to be read cover to cover, or as a reference that addresses specific questions.

Read this material with the intention of broadening your knowledge base in the functional aspects of the anesthesia equipment that you use everyday, and also with the expectation that supplements will be forthcoming to update and further enhance the material contained in this version of the handbook.

We invite you to Explore!

David A. Paulus, M.D.
Professor of Anesthesiology and Mechanical Engineering
University of Florida College of Medicine
Gainesville, Florida

A. William Paulsen, MMSc (Anesthesiology), PhD, CCE, AAC
Associate Professor, Department of Anesthesiology
Emory University School of Medicine
Atlanta, Georgia

FOREWORD

A picture is worth a thousand words! Indeed, this remarkable addition to the Ohmeda Educational Series will be welcomed with open arms by the anesthesia community. “EXPLORE! The Anesthesia System” is a meticulously routed, graphically explicit journey through the anatomy of an Ohmeda anesthesia machine. It offers the anesthesia professional a vivid, enduring image of the complex interrelationships inside this machine. The presentation provides an essential resource for the practitioner as well as the educator, student and technician. No one should feel intimidated by this manual. The ring binder and single-side printing create a pleasant breeze as the pages rush by. Readers might complete this journal in a single sitting.

Each chapter clearly outlines the learning objectives, directing the reader through colorful displays and legible descriptions. This pathway follows the course of oxygen as it originates from the central supply. We learn how the oxygen pressure activates a multitude of valves and sensors as it travels to the vaporizer. Directional flow of gas through the absorber is vividly displayed on schematic diagrams, giving the reader a clear understanding of its function. The complex arrangement of pneumatics and electronics within the ventilator is geographically simplified and will lead to a more intuitive application in clinical practice.

Why is this manual a service to our profession? First, it provides a visual impact, stimulating self-study of complex equipment. Second, the design of this presentation enables and encourages the reader to complete the entire lesson promptly. Third, by understanding the multitude of safety features and alarms, we become allied with the machine as a sentinel for patient safety. “EXPLORE” is aptly named and I encourage you to do so.

Michael A. Olympio, M.D.
Associate Professor of Anesthesiology
Bowman Gray School of Medicine
Wake Forest University
Winston-Salem, North Carolina

PREFACE

In today's climate of everchanging technology, anesthesia practitioners are thrust into an array of systems, circuits, techniques, check lists, and machines of all types.

The text and illustrations presented in this book were designed to hasten the adjustment to a new system, to provide the opportunity to look inside the anesthesia machine and to help in understanding how this important tool functions. In addition to the anesthesia machine, information has also been included on the oxygen monitor, tidal volume monitor, waste gas system, and ventilator. One must know how the essential components operate in unison in order to be able to identify problems, correct or prevent them, and have the confidence to make decisions and alterations in the shortest amount of time.

We sincerely hope this book will be a valuable resource for the new and experienced practitioner as they work to improve the effectiveness and quality of patient care.

Richard Atkins
President & CEO
Datex-Ohmeda
North America

ACKNOWLEDGMENT

Ohmeda wishes to acknowledge the many people who have contributed to the production of the book, Explore! The Anesthesia System. The people involved with this project have contributed many hours of research, writing, and editing to present a book that will enhance the reader's understanding of an Ohmeda anesthesia system.

Authors

Janis Rice, Ohmeda Service Education Instructor

Bob Kolek, Ohmeda Service Education Instructor

Editors

Julie Mills, Ohmeda Technical Writer

John Wolf, Consulting Editor

Graham Lukey, Manager, International Regulatory Affairs

Chalmers Goodyear, Manager, Special Projects

Dan Kosednar, Ohmeda Documentation Specialist

Illustrations

Bob O'Donnell, Ohmeda Service Education Instructor

Cary Tietz, Ohmeda Graphics Illustrator

Mary Buckland, Ohmeda Graphics Illustrator

Graphics

Mary Brandes, Ohmeda Graphics Systems/Departmental Coordinator

We extend special thanks to the practitioners and educators who kindly reviewed the clinical and technical scope of this text: Dr. David A. Paulus, University of Florida College of Medicine; Dr. A. William Paulsen, Emory University School of Medicine and Dr. Michael A. Olympio, Bowman Gray School of Medicine.

We also thank all the members of the Ohmeda team who had involvement in this project and who supported the project members.

NOTE FROM THE AUTHORS

We also wish to especially thank:

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Janis Rice and Robert Kolek
Instructors, Ohmeda Service Education

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THE ANESTHESIA SYSTEM

TABLE OF CONTENTS

INTRODUCTION

"BASIC ANESTHESIA SYSTEM" OVERVIEW

A basic anesthesia system includes the:

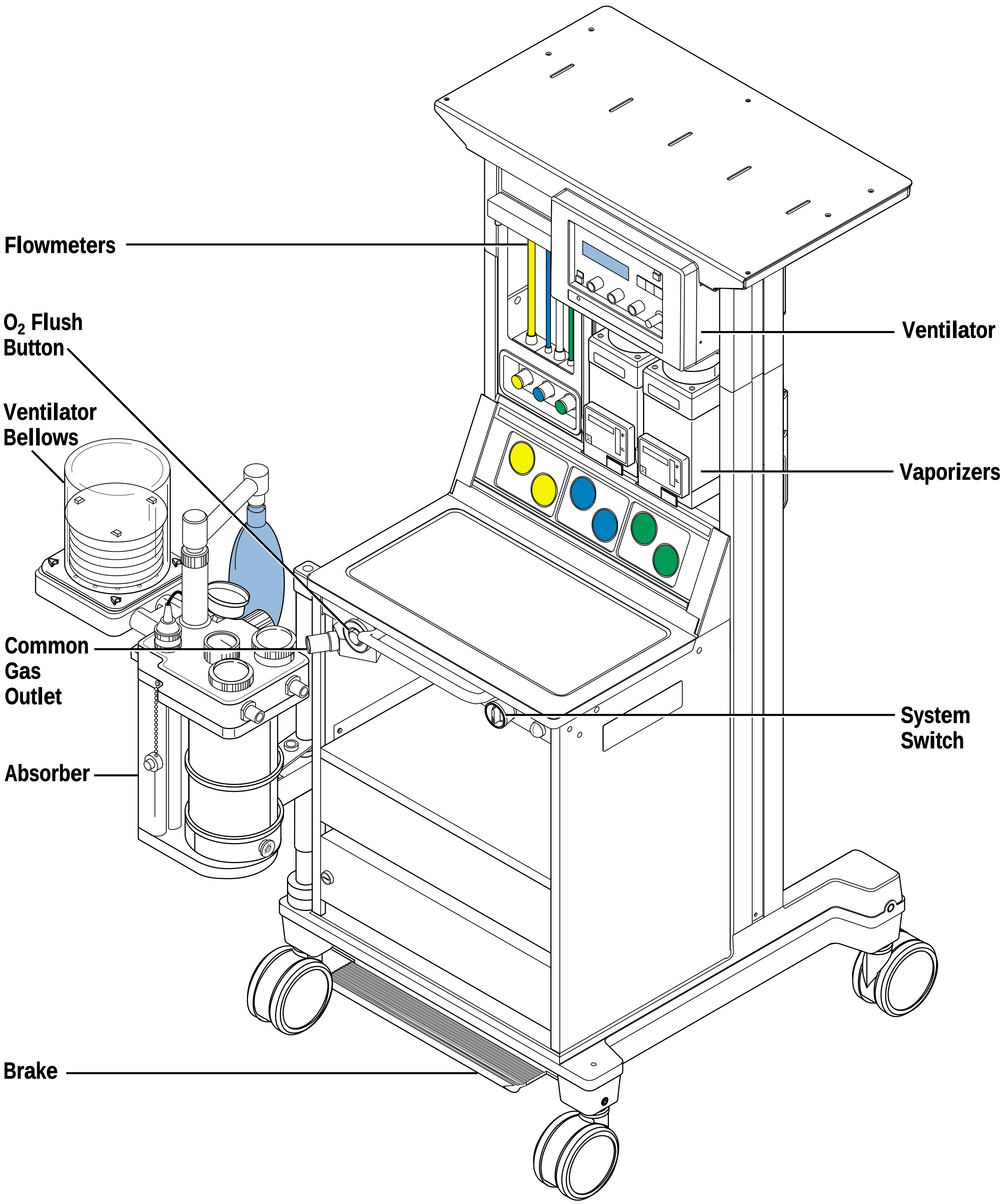
- Anesthesia machine.
- Pipeline and cylinder gas supplies.
- Anesthetic vaporizers.
- Carbon dioxide absorber and gas management system.
- Gas scavenging system.
- Ventilator.
- Monitors and displays.

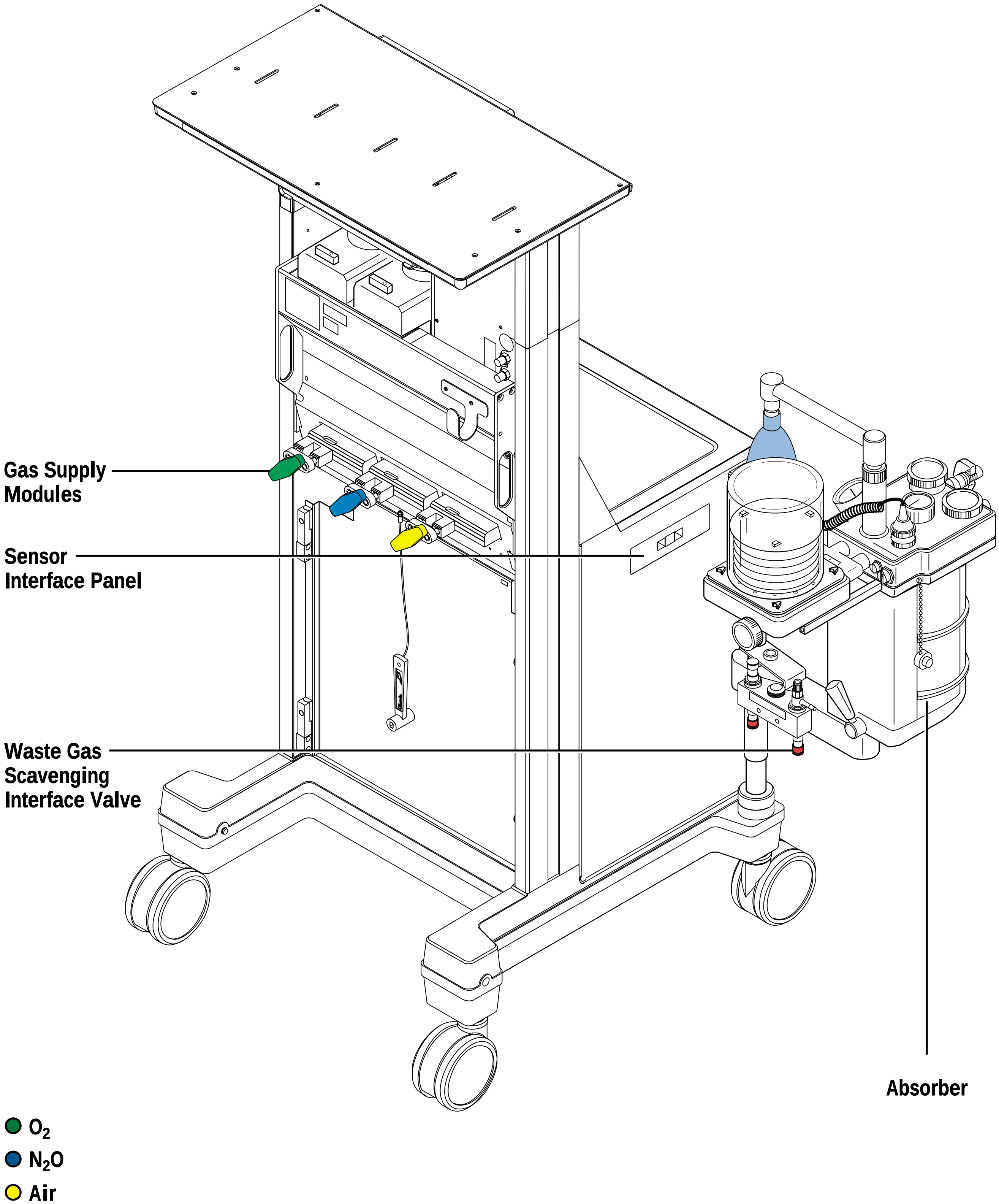
An anesthesia system:

- Supplies set mixtures of gases and anesthetic vapors to the patient.
- Helps the clinician control patient breath rates, volumes, and pressures.
- Monitors gas concentrations from the anesthesia machine.
- Provides patient monitors.
- Includes safety features to help protect the patient.
- Removes excess gas from the breathing system.

Illustration 1

The Excel SE Anesthesia Machine




Gas Supply
Modules
Sensor
Interface Panel
Waste Gas
Scavenging
Interface Valve
Absorber
O2
N2O
Air

INTRODUCTION

The anesthesia system uses two types of gas supplies:

- Gas cylinders that connect directly to the anesthesia machine.
- A central pipeline system that connects to wall and ceiling outlets.

This section tells about the different types of gas supplies. By the end of this section, you should know:

- How much gas is held by cylinders of different sizes.
- How cylinder pressure is related to the volume of gas compressed into the cylinder.
- What the average pipeline pressures are.
- How safety systems help prevent incorrect gas connections.

CYLINDERS

Cylinders contain gas in a compressed form, either high pressure gas or liquid. The high pressures in the cylinder permit each cylinder to hold a large volume of gas in a compressed state. A gauge connected to the cylinder shows the pressure in pounds per square inch gauge (psig) or kilopascals (kPa).[1] A regulator connected to the cylinder is used to reduce the pressure of gas as it leaves the cylinder. A full E size cylinder of compressed oxygen usually contains 660 liters (L) at a pressure of approximately 2000 psig. A full E size cylinder of compressed nitrous oxide usually contains 1590 L at a pressure of approximately 745 psig. Larger cylinders, such as an H size, contain more volume but at approximately the same pressure as in smaller cylinders.

Gas cylinders that connect directly to the anesthesia machine are usually the secondary, or emergency gas supply to the anesthesia system. They provide a gas supply when the pipeline supply is low or inoperative.

When the cylinders are part of a central pipeline system, the gauge and the regulator are part of the pipeline system. When a cylinder is connected directly to the anesthesia machine, the gauge and regulator are part of the anesthesia machine.

CYLINDER VOLUME AND PRESSURE

The quantity of gas at in a cylinder is known as the cylinder volume. This volume is measured in liters at standard temperature and pressure (STP). The volume of gas in a full cylinder changes with the size of the cylinder and the type of gas: liquid or compressed.

With a compressed gas, the cylinder gauge displays the pressure of gas in the cylinder in psig and will give an indication of the volume of gas remaining in the cylinder. This is true for oxygen, air, and heliox (gases at cylinder pressures). As gas flows out of the cylinder, the pressure indicated on the gauge decreases. If a cylinder is half full, its pressure is half that of a full cylinder.

Nitrous oxide and carbon dioxide cylinders contain compressed gas and liquid. The volume of nitrous oxide in a full cylinder, for instance, is mostly in a liquid state, with a smaller amount in a gaseous state. When gaseous nitrous oxide leaves the cylinder during use, some of the liquid nitrous oxide changes to a gas.

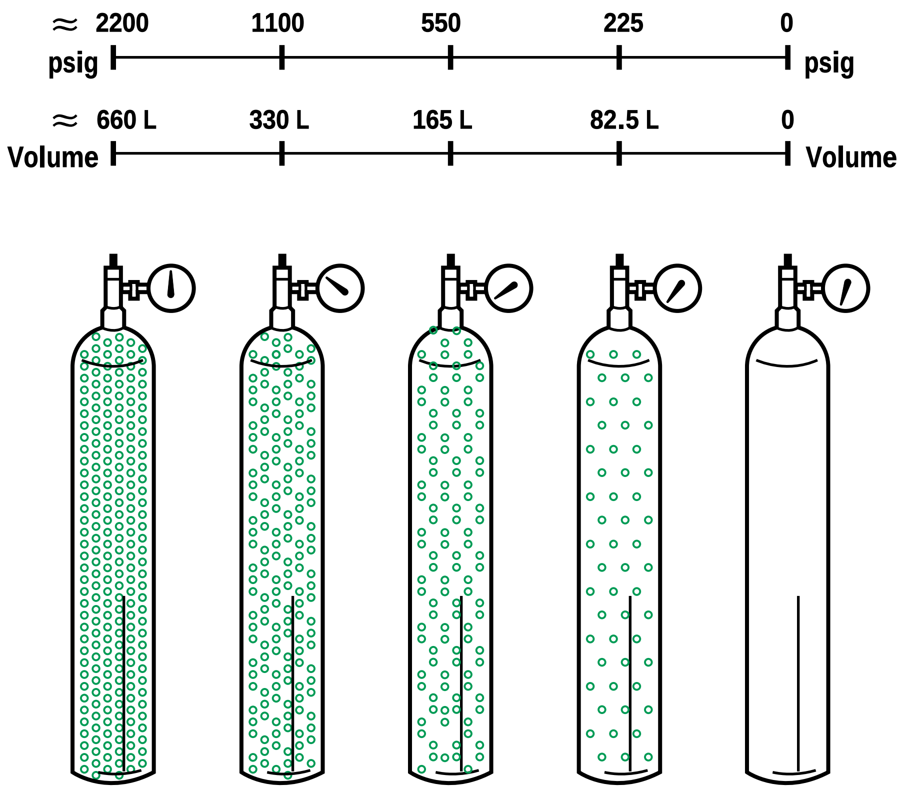
As gases change from liquid to gas, the pressure indicated on the gauge remains relatively constant until all of the liquid has been converted to a gas. The pressure gauge will indicate a decrease in pressure only after all the liquid is gone and the cylinder volume is almost empty. At this point, an E size nitrous oxide cylinder contains approximately 300 L.

The illustration on the facing page shows cylinder volumes and pressures for E size cylinders of oxygen and nitrous oxide. Notice how the pressure gauge on the oxygen cylinder changes as the volume in the cylinder decreases. Compare this to the pressure gauge on the nitrous oxide cylinder. The pressure of the nitrous oxide stays the same until all of the liquid has changed to a gas.

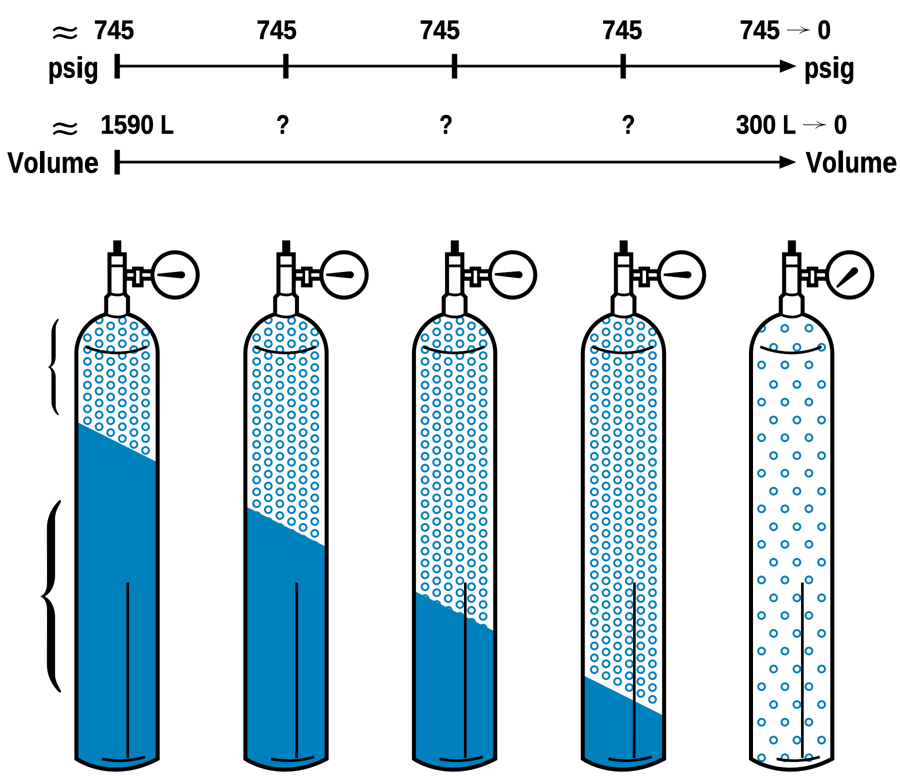
[1] Required by American National Standards Institute

Illustration 2

E size cylinder volumes and pressures



Oxygen Cylinders



Nitrous Oxide Cylinders

CYLINDER SAFETY

Cylinders must be stored securely. If a valve stem breaks, the sudden release of pressure from the cylinder can propel it across a room and force it through walls.

Cylinders must be kept away from flammable materials, including oils and lubricants. The heat caused by a sudden pressure release from a cylinder can ignite flammable materials. Gases such as oxygen, nitrous oxide, and heliox can support violent burning of flammable materials. Only lubricants approved for contact with high pressure gas should be used.

CENTRAL PIPELINE SYSTEMS

The central pipeline system is usually the primary gas supply for the anesthesia system. Tanks of liquid gas or large cylinders supply the gas for the central pipeline. These tanks or cylinders, and their pressure regulators, are located in an area outside the hospital or in a utility area.

Standards specify 45-55 psig for oxygen pipeline systems.[2] Gas at this pressure flows through the pipeline system to outlets throughout the hospital. In this book, when the pipeline system is mentioned, we are discussing the gas available at these outlets.

The central pipeline system is supplied by a liquid storage tank or a gas cylinder manifold. A basic gas manifold includes a control cabinet housing a manifold with multiple connections. The cylinders are divided into a left bank and a right bank, as shown in the illustration on the facing page. They are connected to the control cabinet by copper tubing called “pigtails.”

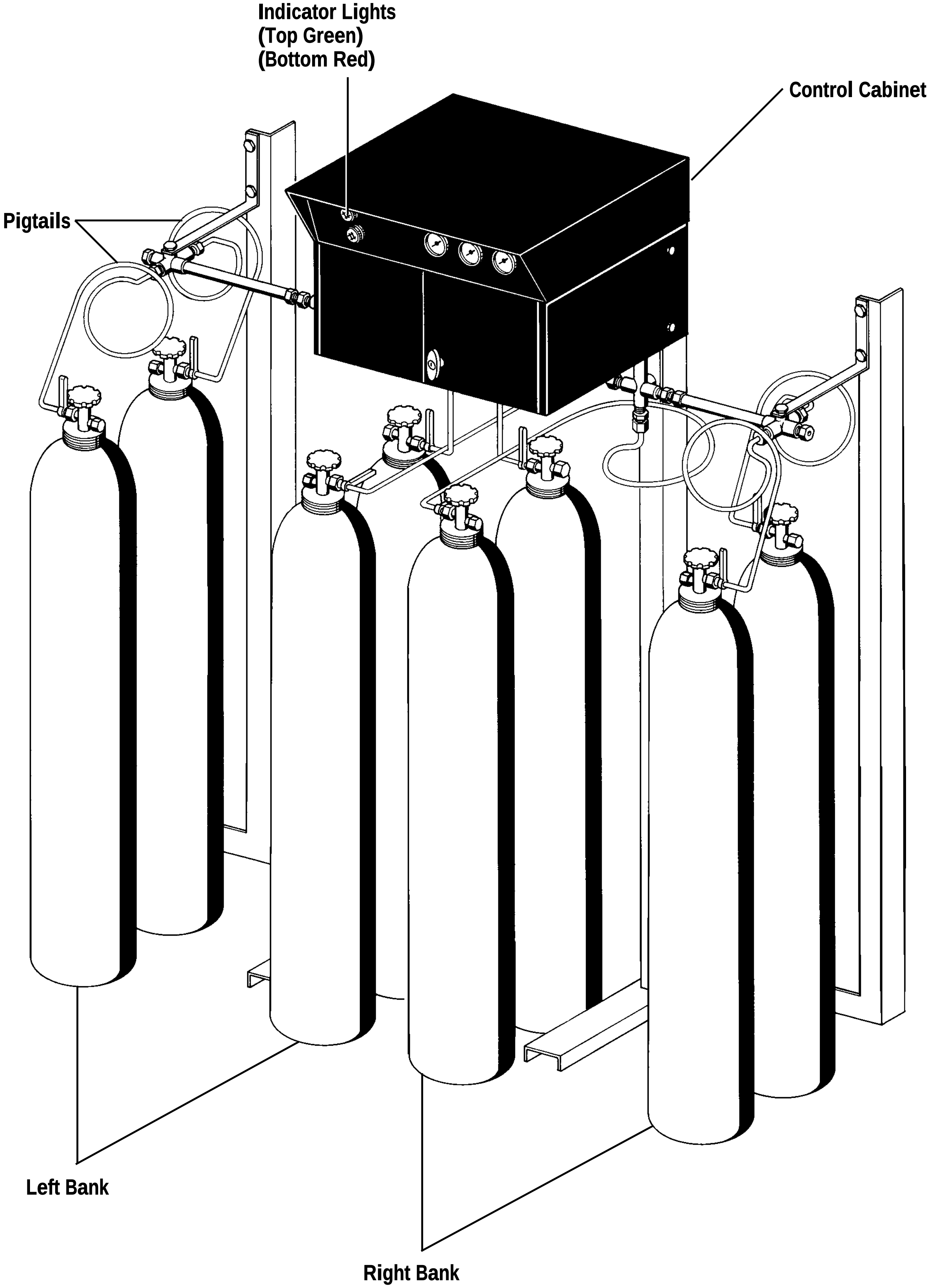
When the bulk supply or one bank is exhausted, the manifold automatically switches to supply gas from another bank. Indicator lights on the control cabinet indicate the switchover.

A central pipeline system includes sensors wired to an alarm system. This alarm system has visual and audible alarms to indicate when cylinders or bulk supplies need to be replaced. They can also alert the user when the pressure in the gas supply line is too high or too low.

[2] Required by National Fire Protection Agency (NFPA 99)

Illustration 3

Gas manifold



SAFETY SYSTEMS

Safety systems help prevent incorrect gas connections. These systems include:

- Color coding.
- Pin indexing.
- Diameter indexing.

Cylinders, labels, and some hoses are color-coded. The color of a cylinder specifies what kind of gas is in the cylinder. The color of a label on a control or a pressure gauge also identifies the gas. The color of a hose indicates what gas fitting to use. Different countries use different color codes.

The illustration on the facing page shows the valve stem at the top of the cylinder. This opens the outlet for the gases in the cylinder. Connections to the anesthesia machine or the central pipeline system are made at the valve outlet.

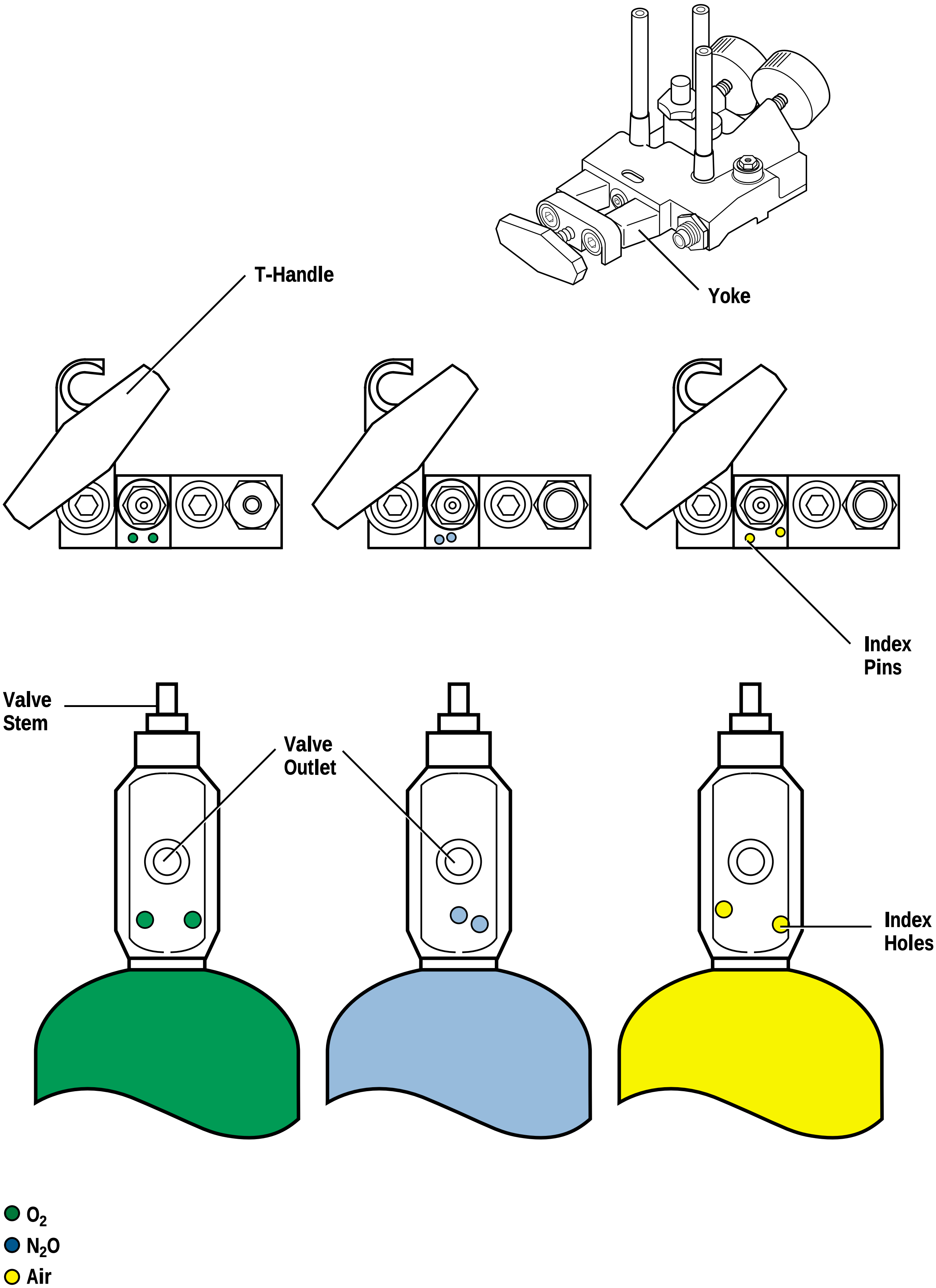
Cylinders that connect directly to the gas machine use a pin index system. Holes in the cylinder valve body align with pins on the anesthesia machine. The illustration on the facing page shows the holes and pin positions for the most frequently used gases.

Gas	Color (ANSI)	Color (Canada - ISO)
Oxygen	**Green**	**White**
Nitrous Oxide	**Blue**	**Blue**
Air	**Yellow**	**Black and White**
Heliox[3]	**Green and Brown**	**Brown and White**

[3] Different heliox mixtures are available. All indexing information in this book refers to heliox mixtures that contain 25% oxygen. The heliox flowmeter is calibrated for 25% oxygen, 75% helium.

Illustration 4

Valve stems and yokes

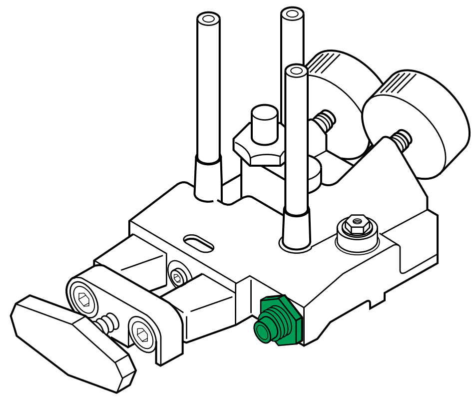


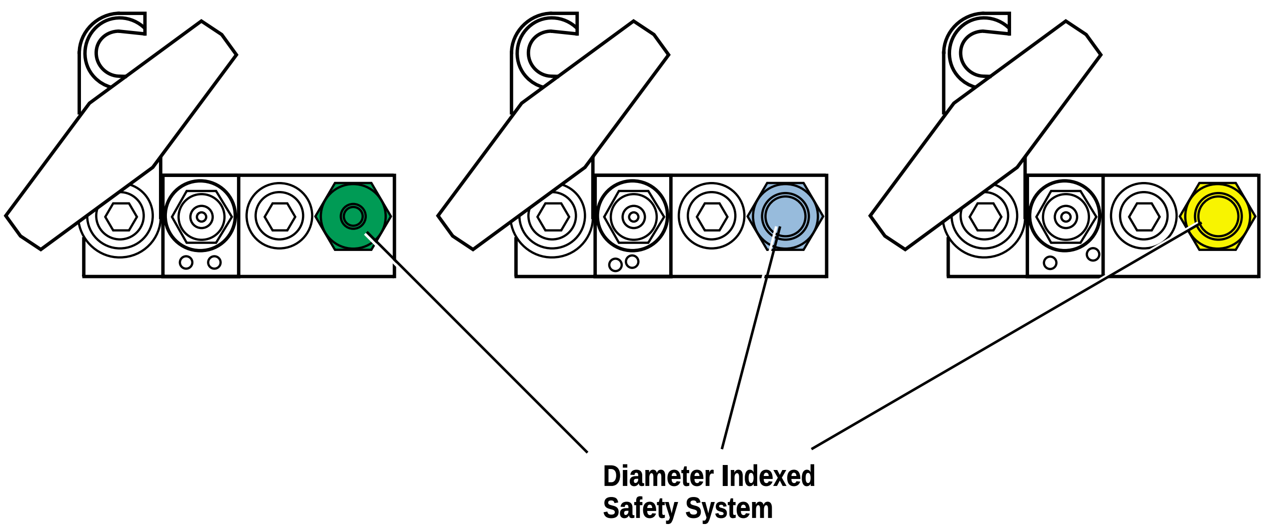
Pipeline connections to the anesthesia machine use a diameter indexed safety system (DISS) [4] to help prevent incorrect connections. The fitting for each gas has a different diameter. Each fitting is also internally keyed so that the operator cannot make a loose connection with a slightly larger fitting.

[4] Used in United States in accord with the Compressed Gas Standards

Illustration 5

DISS inlet connections on the anesthesia machine





INTRODUCTION

ANESTHESIA SYSTEM

The first part of this section explains how gas flows through the anesthesia machine and provides background for understanding how the anesthesia machine operates. The second part of this section describes the individual components of the anesthesia machine.

By the end of this section, the reader should know:

- Where oxygen is always available.
- What occurs when the system switch is set to ON, a flow control is adjusted, or the oxygen flush button is pushed.
- What safety devices the anesthesia machine includes.
- How to install a cylinder.

FLOW THROUGH THE ANESTHESIA MACHINE

The illustration on the facing page shows the flow of gases through the anesthesia machine. It uses the American National Standards Institute (ANSI) color code.

When the oxygen wall supply is connected to the pipeline inlet, or the cylinder is open, oxygen is always available at the pneumatic outlets and the oxygen flush button.

When the system switch is set to ON:

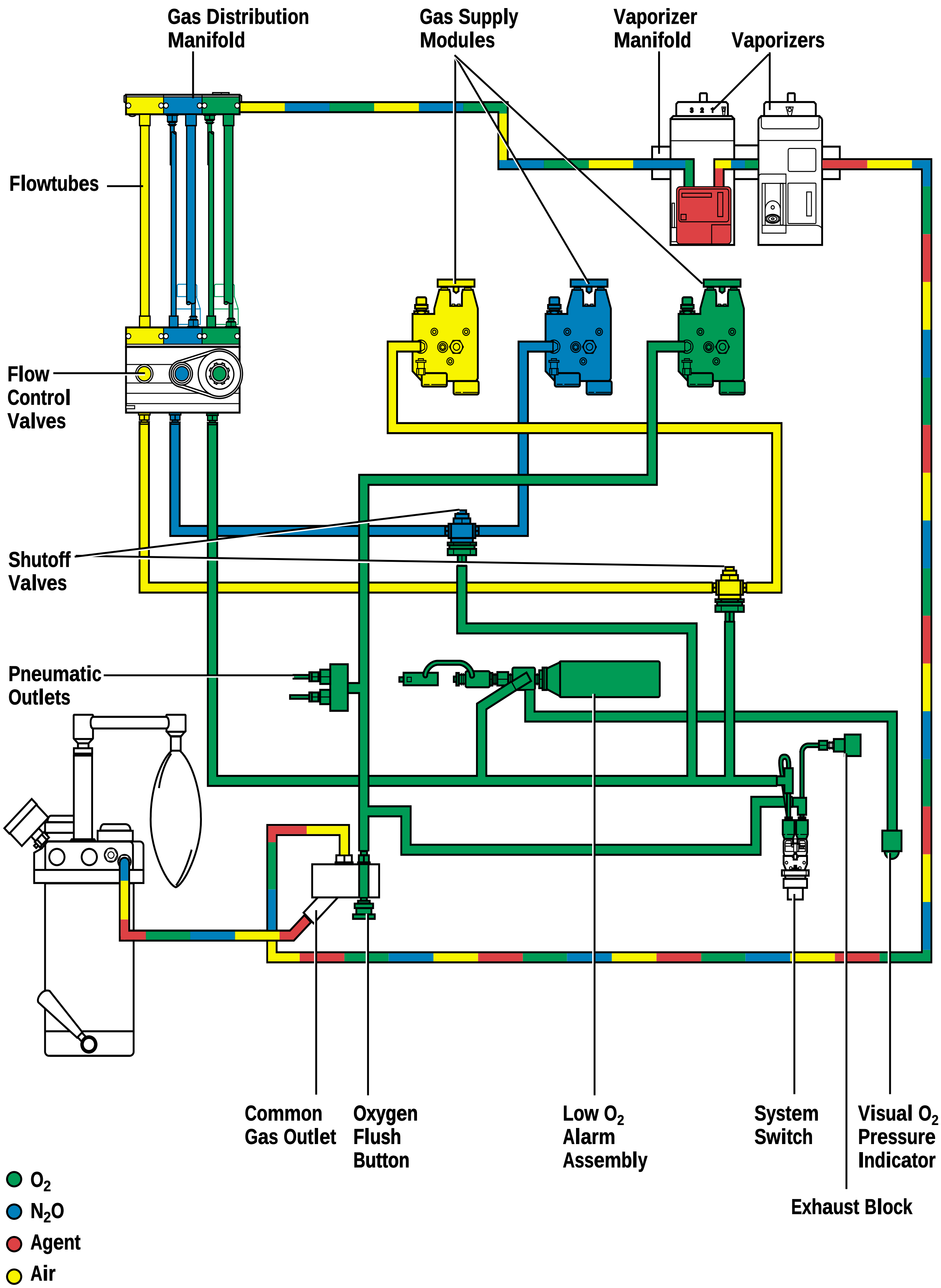
- Oxygen pressure connects to the low oxygen supply alarm and the shutoff valves.
- Oxygen pressure opens the shutoff valves and permits the flow of other gases to their flow control assemblies.
- Oxygen and secondary gases flow through the flowmeters at the set flow rates.
- Mixed gas flows through the vaporizer manifold, through the vaporizer that is ON, and to the common gas outlet.

When the system switch is set to OFF, oxygen in the circuit downstream of the switch vents through an exhaust block. As the oxygen pressure decreases:

- A low oxygen supply alarm is activated.
- All shutoff valves close.

Illustration 6

Gas flow through the anesthesia machine



INDIVIDUAL COMPONENTS

This discussion follows the flow of gas through the anesthesia machine. First, a look at the high pressure section of the machine. These parts are always connected to cylinder or pipeline supplies. Next, a look at the parts that are connected when the system switch is set to ON.

GAS SUPPLY MODULE

Gas pipelines and cylinders are connected to the anesthesia machine's gas supply modules. Each gas enters the anesthesia machine through gas specific supply modules. These modules are labeled and color-coded for each gas.

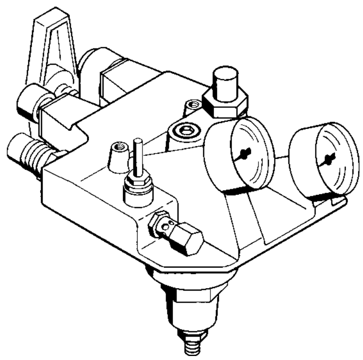
A gas supply module includes:

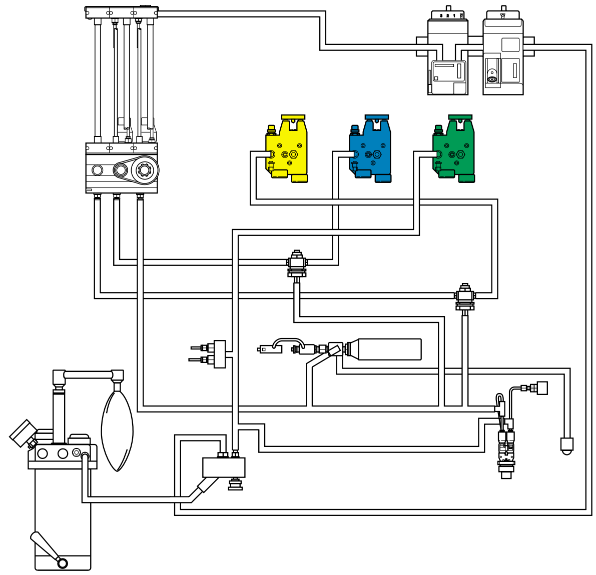
- A pipeline branch.
- A cylinder branch.
- Pressure gauges for pipeline and cylinder supplies.

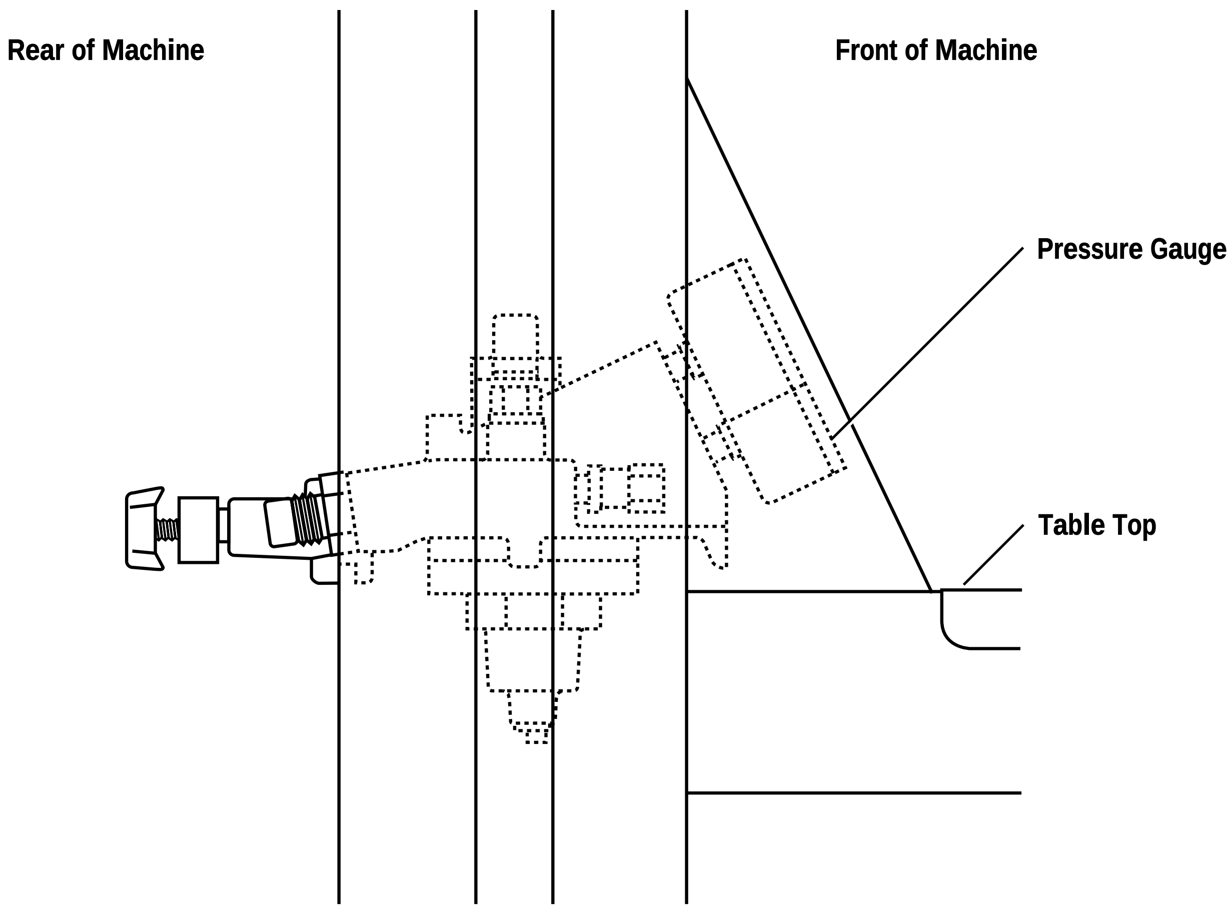
The gas supply connections are located at the rear of the anesthesia machine (shown on the facing page) and the pressure gauges can be seen from the front of the machine.

Illustration 7

The gas supply modules







- O_2
- N_2O
- Air

The pipeline gases go through:

- A pipeline inlet.
- An inlet filter.
- A pressure gauge.
- A check valve.

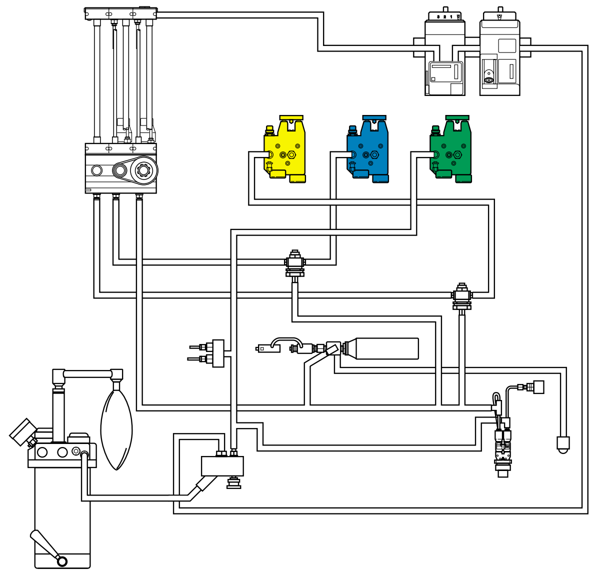
The cylinder gases go through:

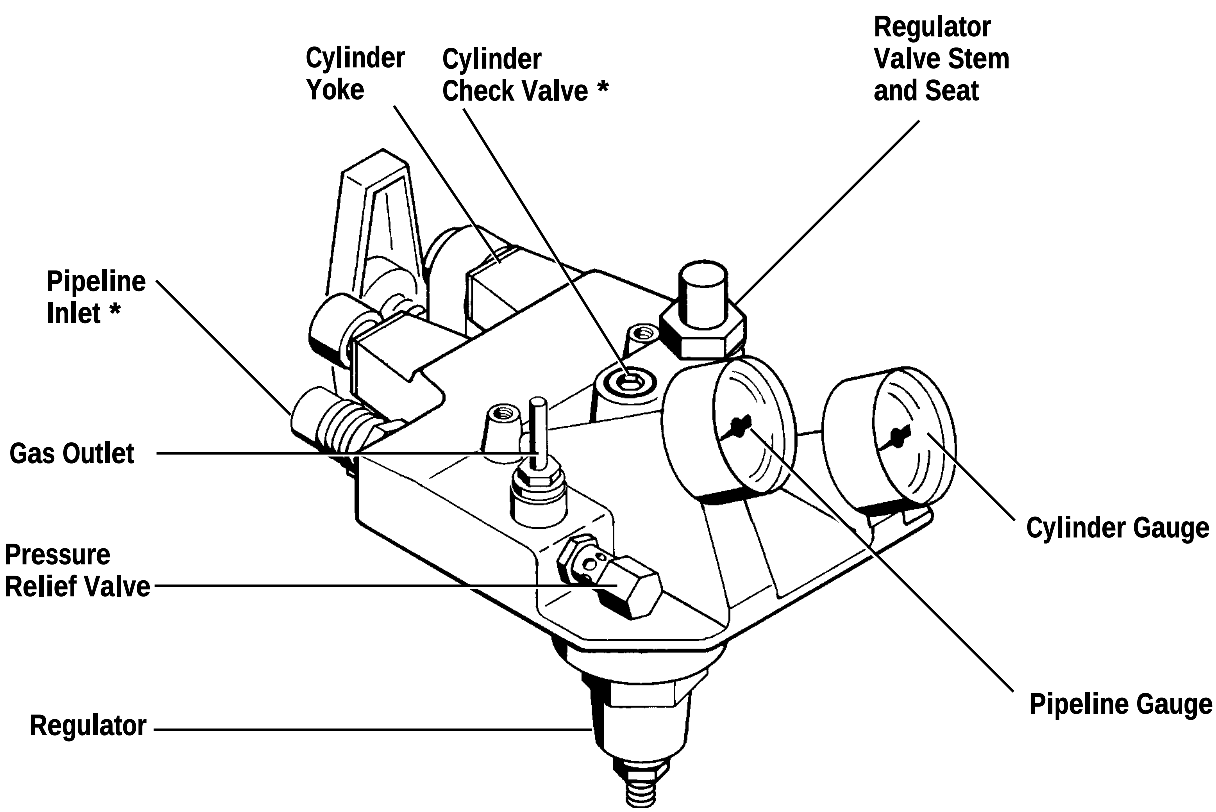
- A cylinder yoke.
- An inlet filter.
- A pressure gauge.
- A check valve.
- A high pressure regulator.

A pressure relief valve vents to atmosphere if the pipeline pressure or the regulated cylinder pressure is too high (approximately 65-75 psig).

Illustration 8

The different components of the gas supply module





- O_2
- N_2O
- Air

* Note: The pipeline inlet filter and check valve are internal.

Pipeline inlets

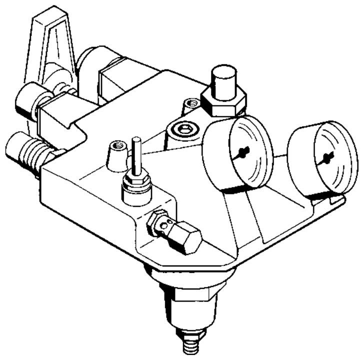
The central pipeline hose connects to the gas supply module at the pipeline inlets. These inlets use DISS fittings. The pipeline hose uses two different fittings: a DISS fitting on one end and a fitting for the central pipeline system on the other end. Different hospitals use different types of pipeline connections. When assembling a pipeline hose, the operator must be sure to use the correct fitting on each end to help prevent incorrect gas connections.

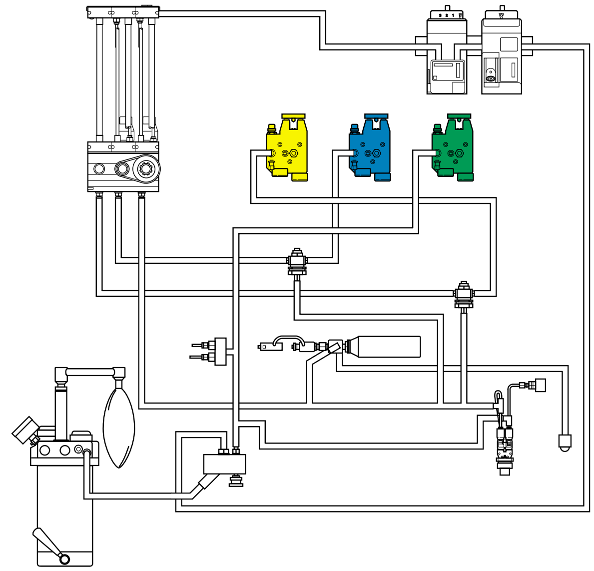
Cylinder yokes

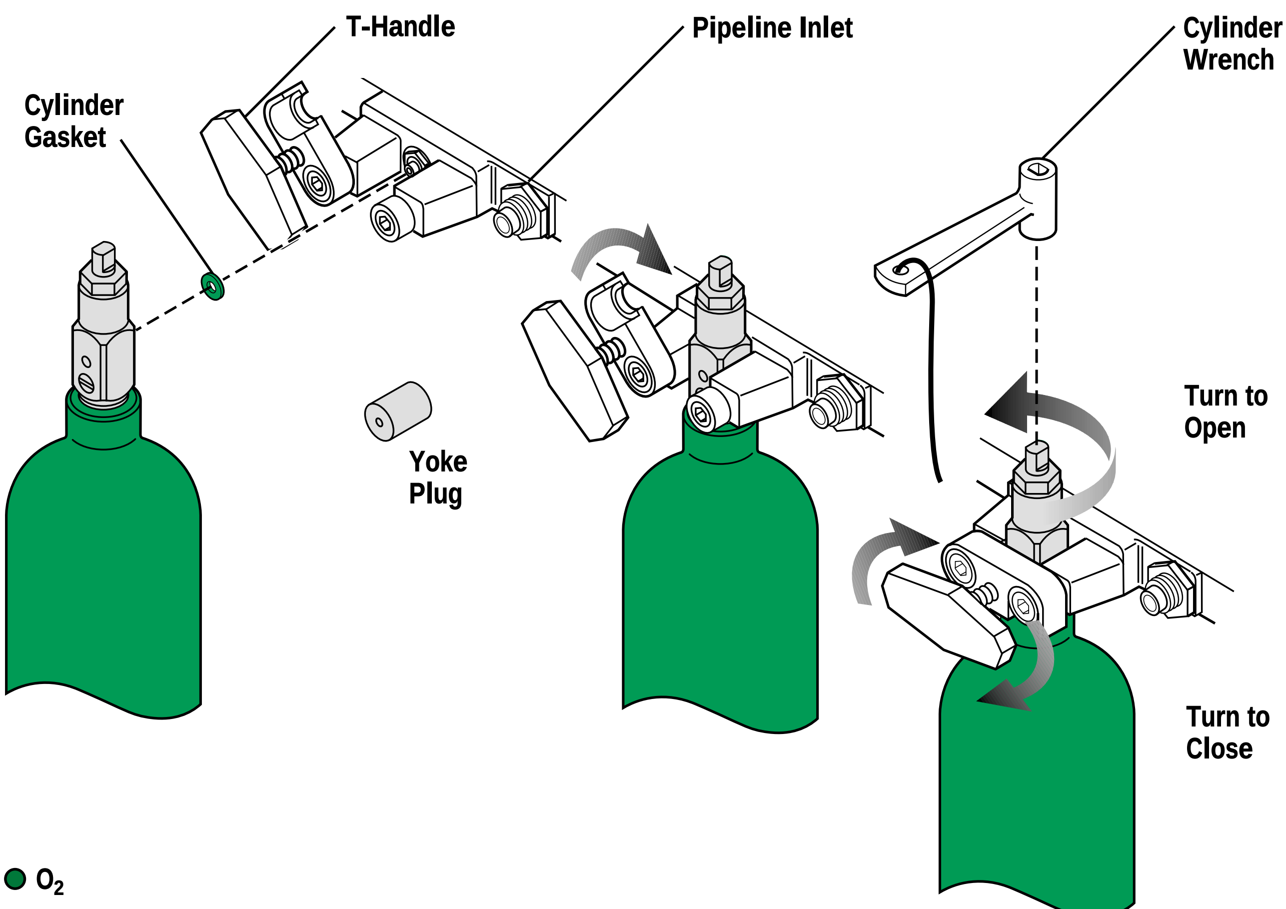
E size cylinders connect to the cylinder yoke of the gas supply module. The illustration on the facing page shows you how to install a cylinder in the yoke. A cylinder gasket must be used to help prevent leaks. Always replace the gasket each time the cylinder is replaced. If more than one gasket is used, this can create a leak or increase the space between the cylinder valve and yoke and defeat the pin index system. A yoke plug and gasket should always be installed in an unused cylinder yoke. The T-handle must be tightened to hold the cylinder in position.

Illustration 9

How to install a cylinder or a yoke plug







- O_2
- N_2O
- Air

Pipeline and cylinder inlet filters

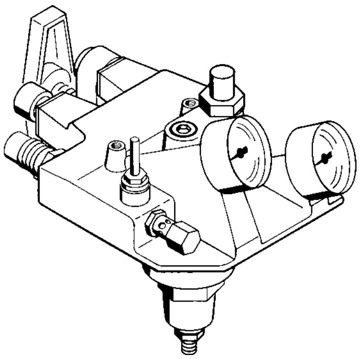
At the inlet, gas supplies flow through filters and into the gas supply module. The filters are made of compressed bronze particles. Pores in the filter trap dust, dirt, and other particles.

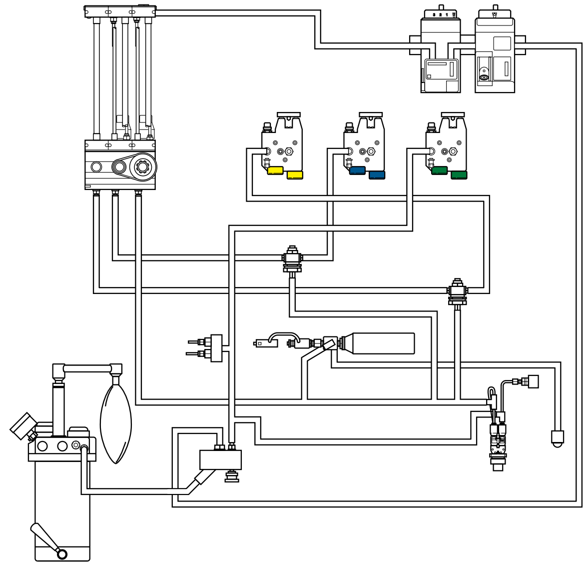
Pipeline and cylinder pressure gauges

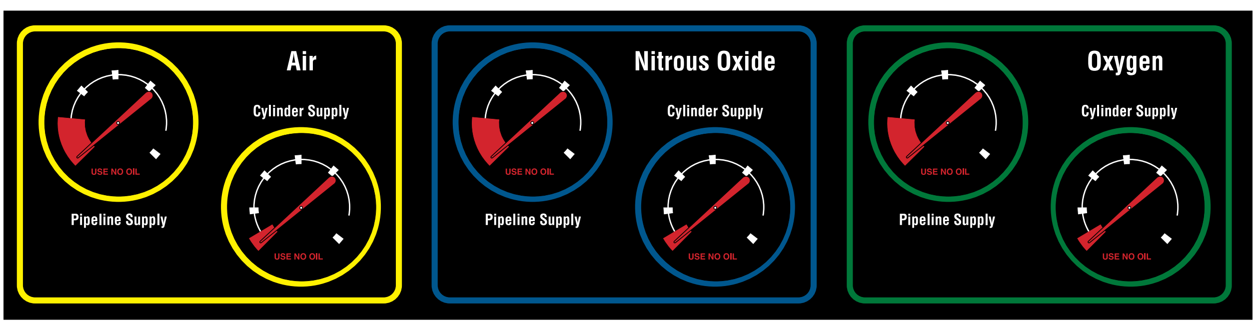
The gas supply module includes pipeline and cylinder pressure gauges to show the two supply pressures. The color code and the label identify each gas. The gauges are located after the inlet filters and before the check valves. The scales on the gauges may have different pressure ranges as appropriate for the different gases. The pressure scales indicate pressure in psig or kPa.

Illustration 10

Pipeline and cylinder pressure gauges





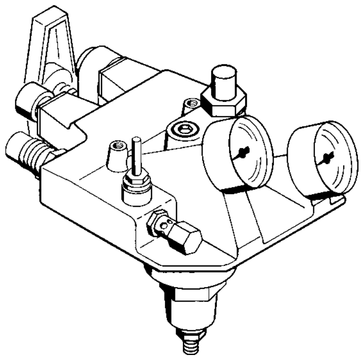


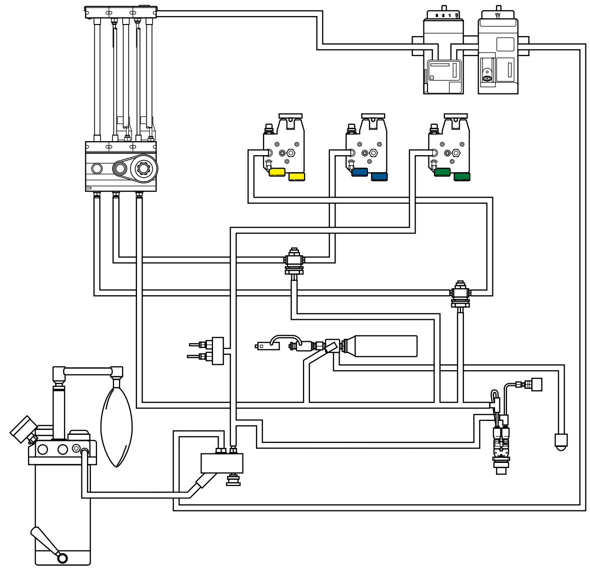
- O_2
- N_2O
- Air

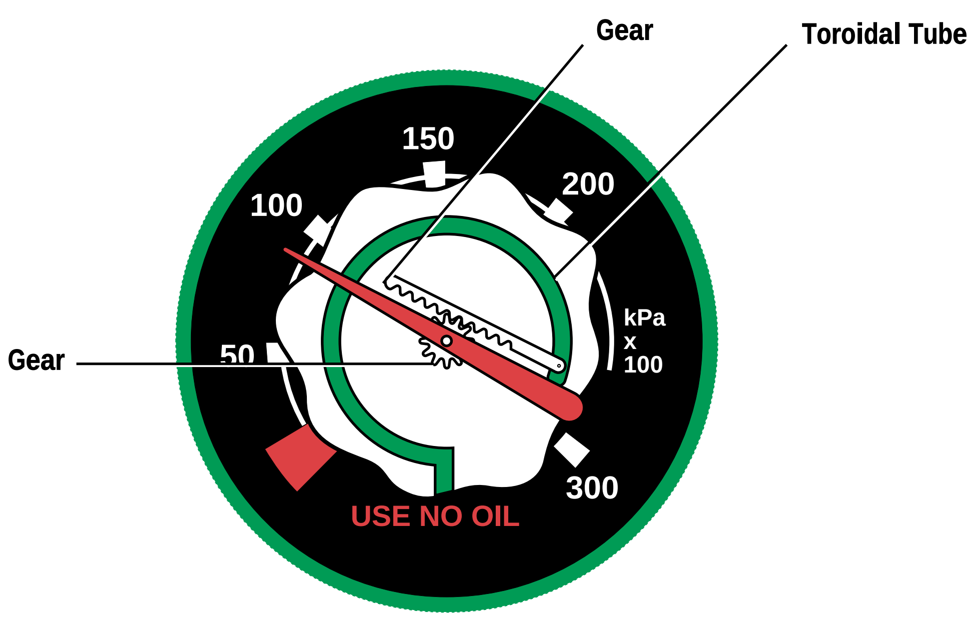
The pressure gauge uses a toroidal-shaped tube (Bourdon) with one end fixed and the other connected to a gear (shown on the facing page). As the pressure increases, the tube straightens. This turns the indicator. Cylinders should be opened slowly to help prevent damage to the gauge.

Illustration 11

How a Bourdon pressure gauge operates







● O_2
● N_2O
● Air

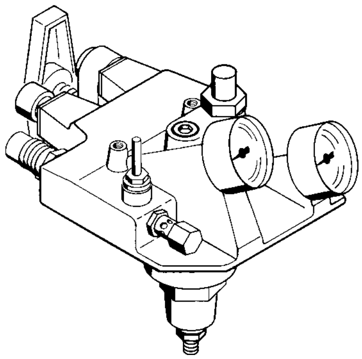
Pipeline and cylinder branch check valves

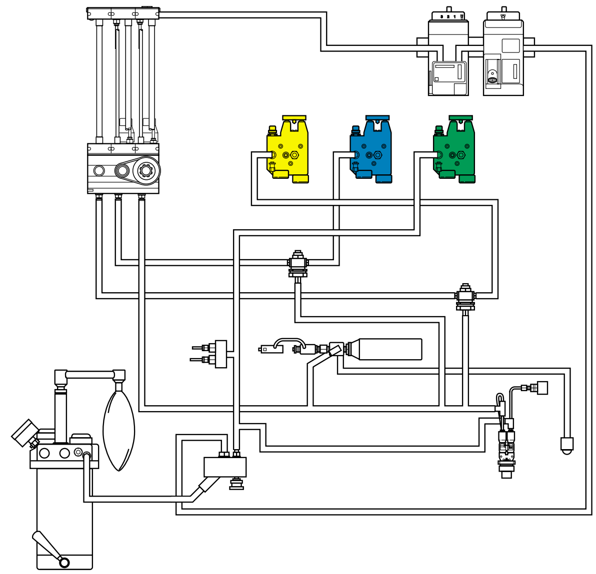
Each pipeline and cylinder branch has a check valve. The check valves permit gas to flow in only one direction. The pipeline check valve helps prevent leaks through the pipeline inlet to the atmosphere when it is not connected to a pipeline supply or when the pipeline pressure is low (Illustration 12). The cylinder check valve helps prevent leaks through the cylinder inlet to the atmosphere when a cylinder is not connected to the cylinder yoke (Illustration 13). With two cylinders connected to a double cylinder yoke and both open (not recommended), the cylinder check valves connect the anesthesia machine to the cylinder supply with the higher pressure (Illustration 14).

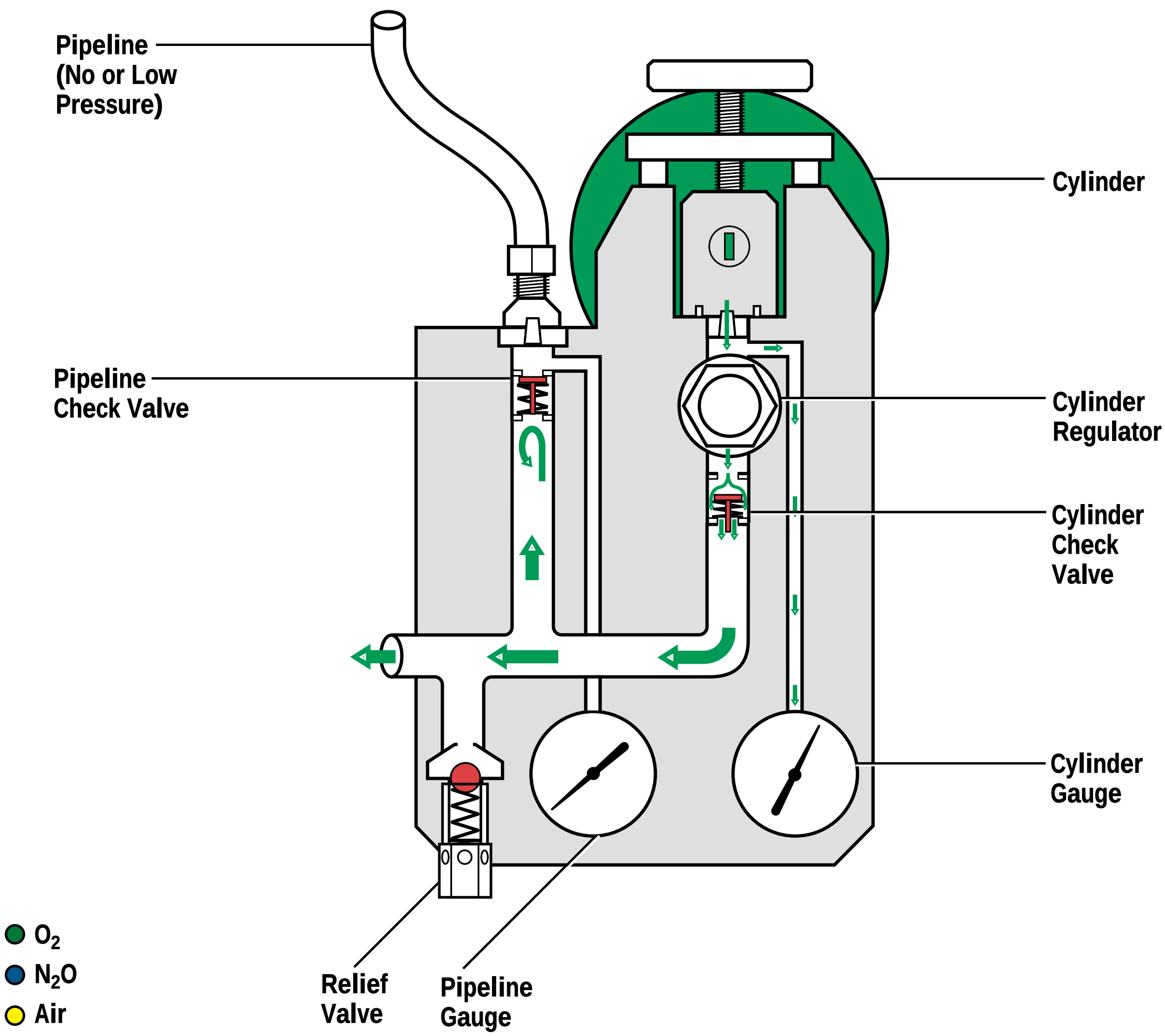
When the regulated cylinder pressure is more than the pipeline pressure, the cylinder check valve opens and the pipeline check valve closes. This helps prevent leaks to the atmosphere if a pipeline supply is not connected.

Illustration 12

Cylinder in use, pipeline check valve closed



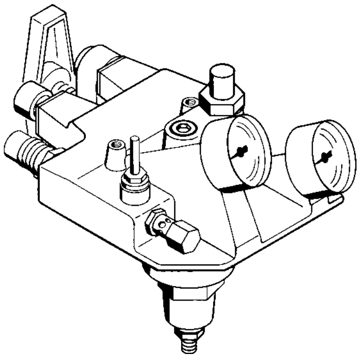


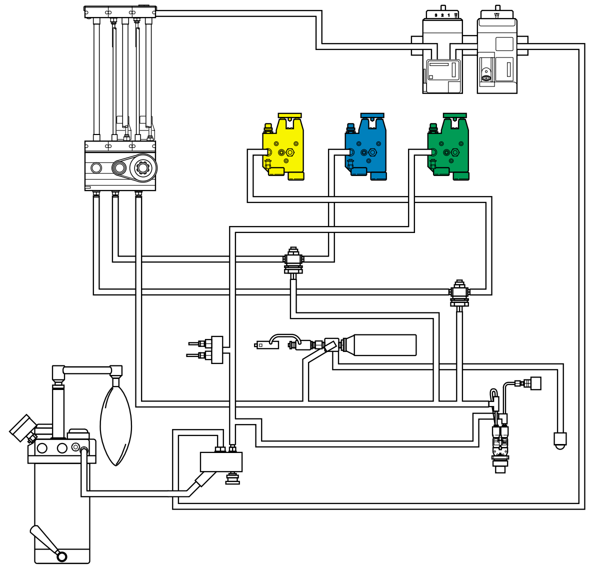


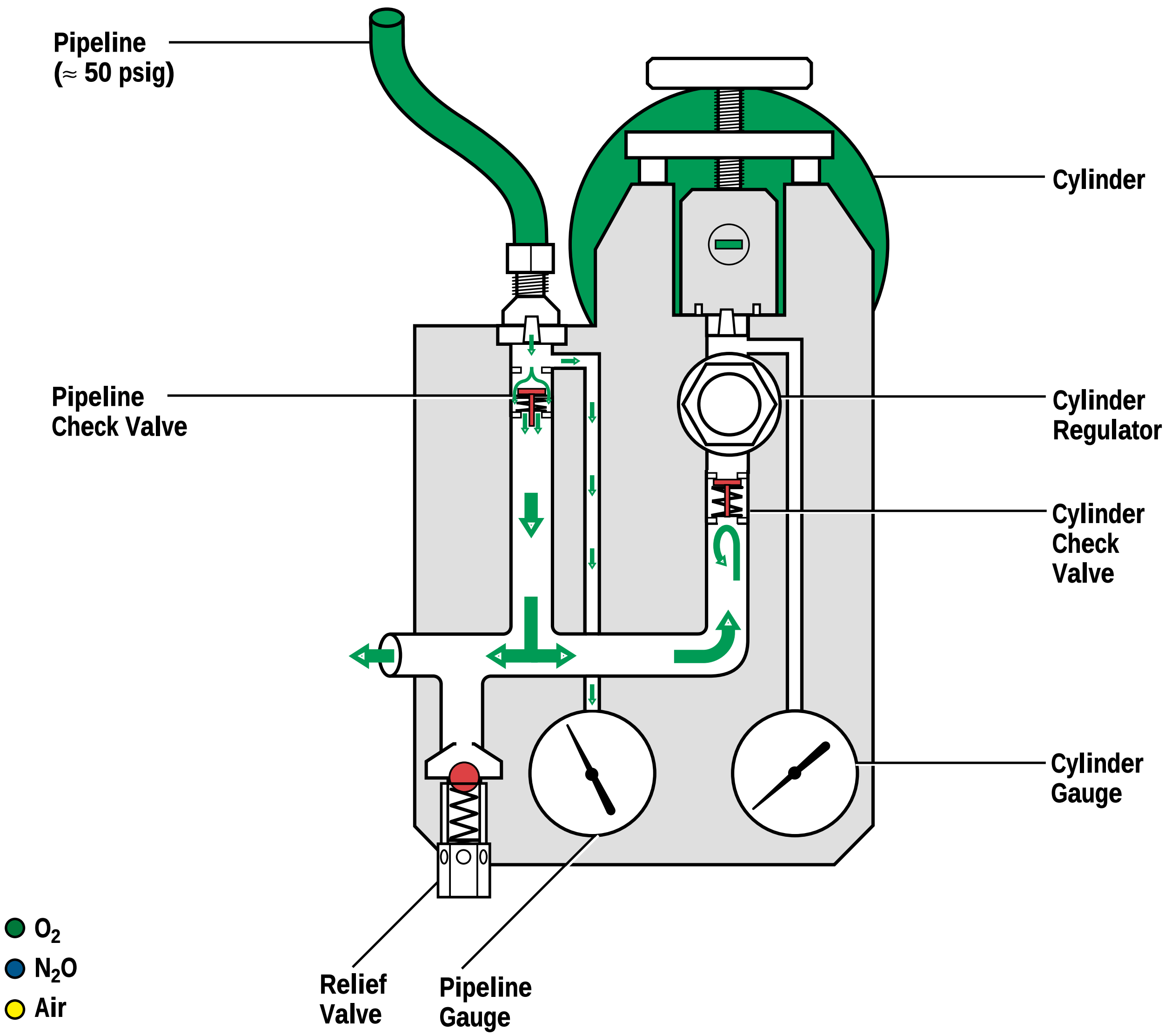
When the pipeline pressure is more than the regulated cylinder pressure, the pipeline check valve opens and the cylinder check valve closes. This helps prevent leaks to the atmosphere if a cylinder or a yoke plug is not installed in the yoke.

Illustration 13

Pipeline in use, cylinder check valve closed







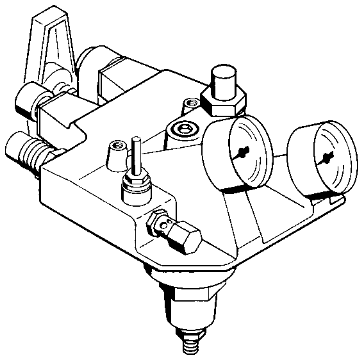
When there are two cylinders for the same gas and both are open (not recommended), the cylinder yoke check valves help to ensure that the cylinder with the higher regulated pressure is used first. In the illustration on the facing page, the cylinder on the left has the higher regulated pressure. This opens the left check valve and closes the check valve for the cylinder on the right.

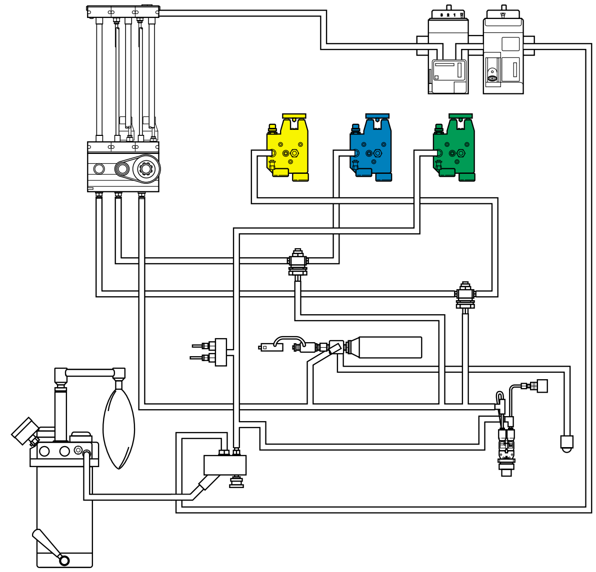
The most important point about inlet check valves is that they are a second line of defense.

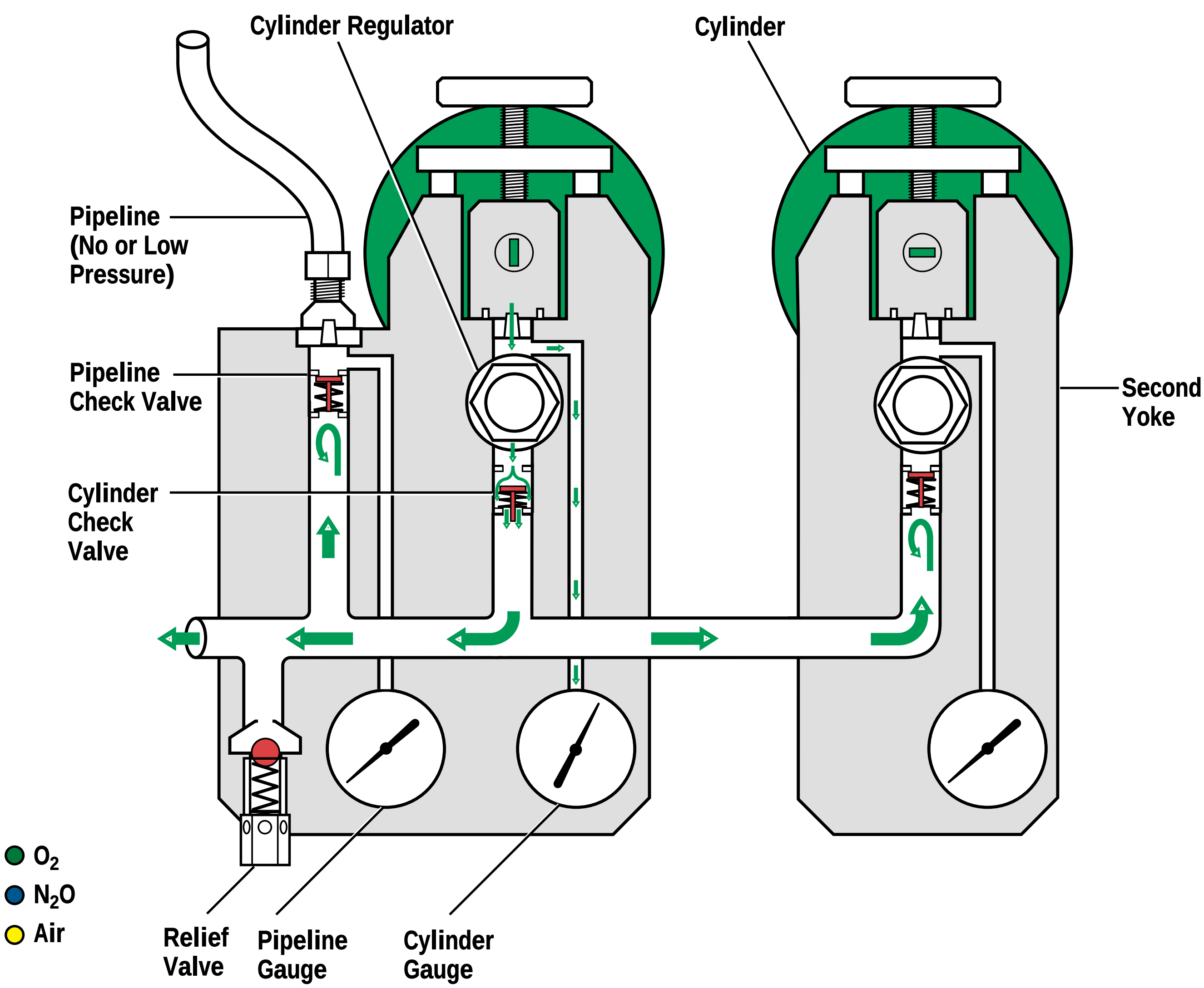
- To prevent leaks to the atmosphere, pipeline supplies must always be connected and yoke plugs and gaskets must always be installed in all empty yokes. If a pipeline hose is not connected, gas can leak out of the pipeline inlet. If a cylinder yoke is empty, gas can leak out of the cylinder inlet.
- To guard against using the pipeline and emergency cylinder supplies at the same time, the cylinder valves must always be kept closed. The pipeline supply pressure changes during the day. If a cylinder is open and the pipeline pressure decreases below the regulated cylinder pressure, the cylinder check valve opens and the cylinder will supply the anesthesia machine.
- To keep a second cylinder for emergencies, only one cylinder should be opened at a time. If two cylinders are open and their regulated pressures are the same, the anesthesia machine uses gas from both of the cylinders.

Illustration 14

Double yoke







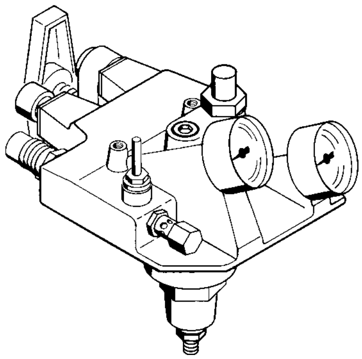
Primary regulator

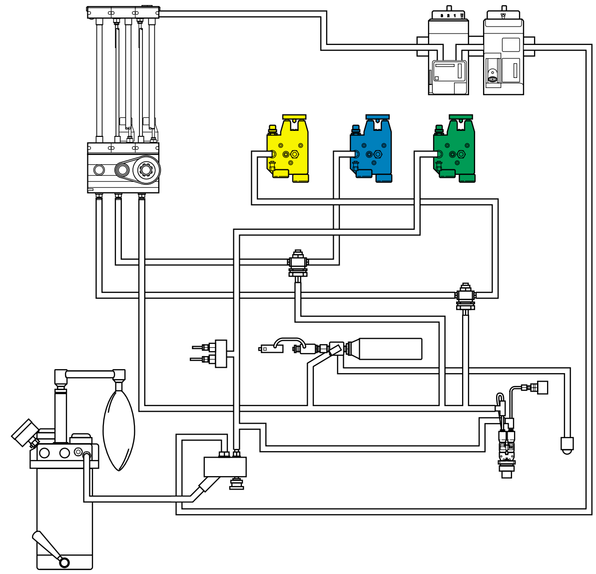
Every gas supply module includes a primary regulator. The regulator is used to adjust the pressure of gas flowing from the cylinder to approximately 40-47 psig. This is lower than the 45-55 psig pipeline pressure and ensures that the check valves connect the anesthesia machine to the higher pipeline supply rather than the cylinder supply.

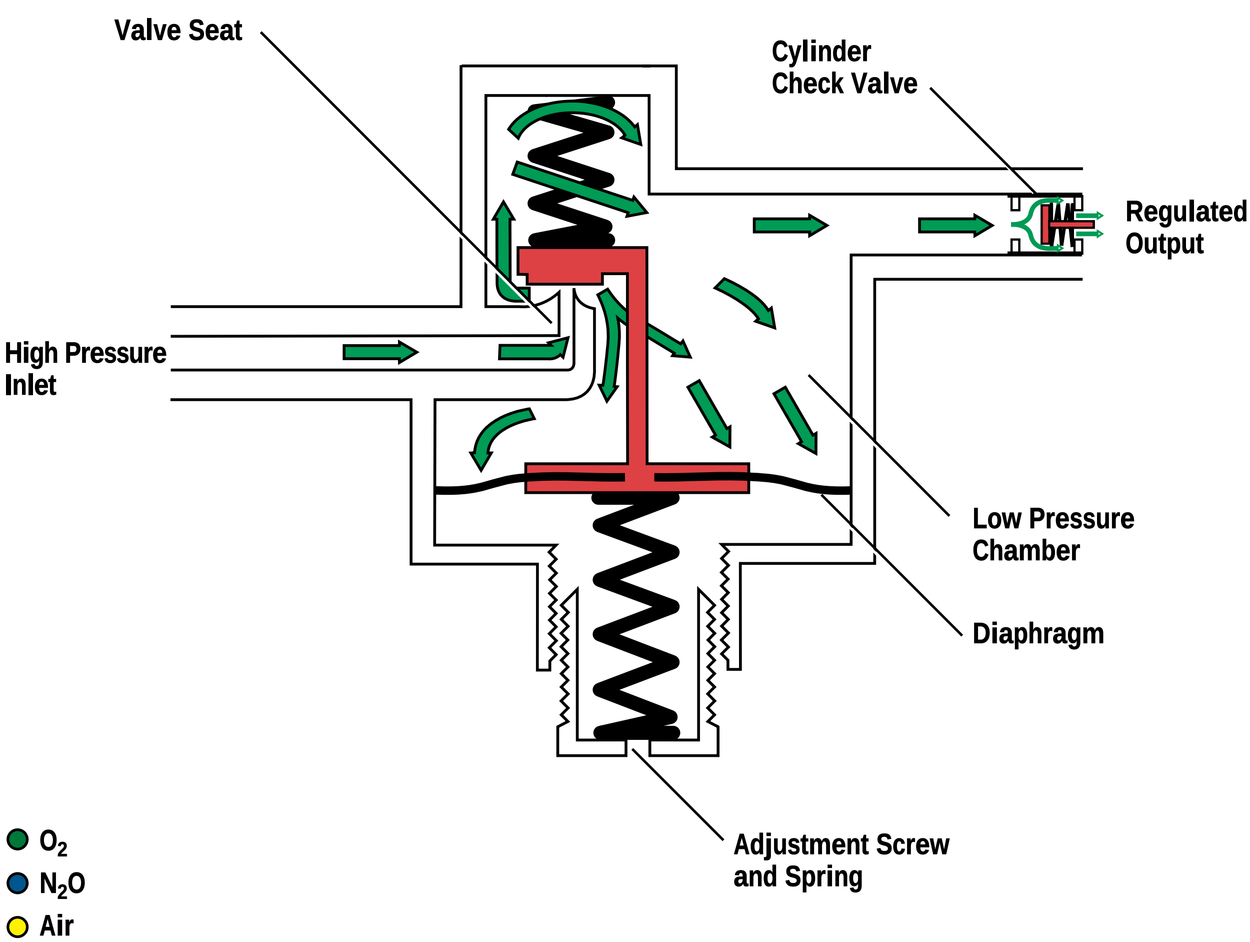
The illustration on the facing page shows how the regulator operates. Gas flows through an opening between the valve seat and the valve. Changing the size of the opening between the valve and the valve seat regulates the flow to keep output pressures constant when different flows are selected. When more flow is necessary, gas pressure against the diaphragm decreases, and the main spring pushes up against the diaphragm. This moves the valve away from the seat and permits more flow through the opening. When less flow is necessary, gas pressure against the diaphragm increases and compresses the main spring. This moves the diaphragm down and decreases the amount of flow through the opening.

Illustration 15

How the primary regulator operates







Pressure relief valve

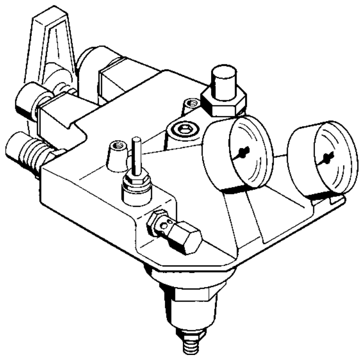
If the pressure in the gas supply module is too high (above approximately 75 psig), the pressure relief valve opens and vents the gas to atmosphere (shown on the facing page). The rapid flow of gas through the relief valve may make a loud sound that is easy to identify. An open pressure relief valve can quickly empty a gas cylinder.

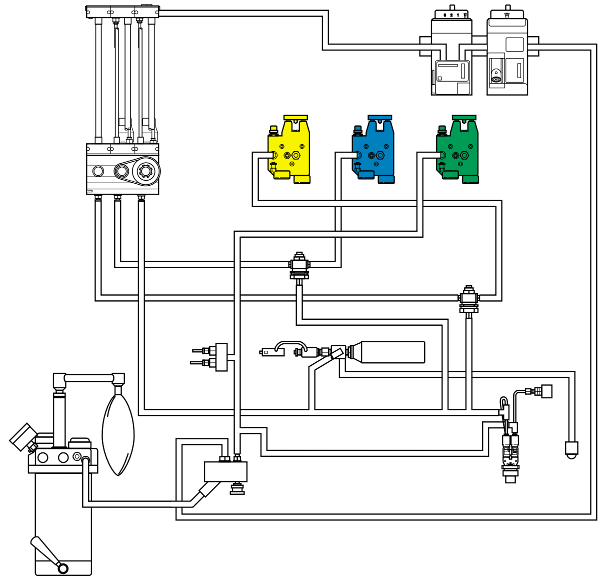
When the pressure relief valve is open, gas continues to flow to the breathing circuit as long as there are sufficient gas supplies. When gas supplies are gone, flow to the breathing circuit stops.

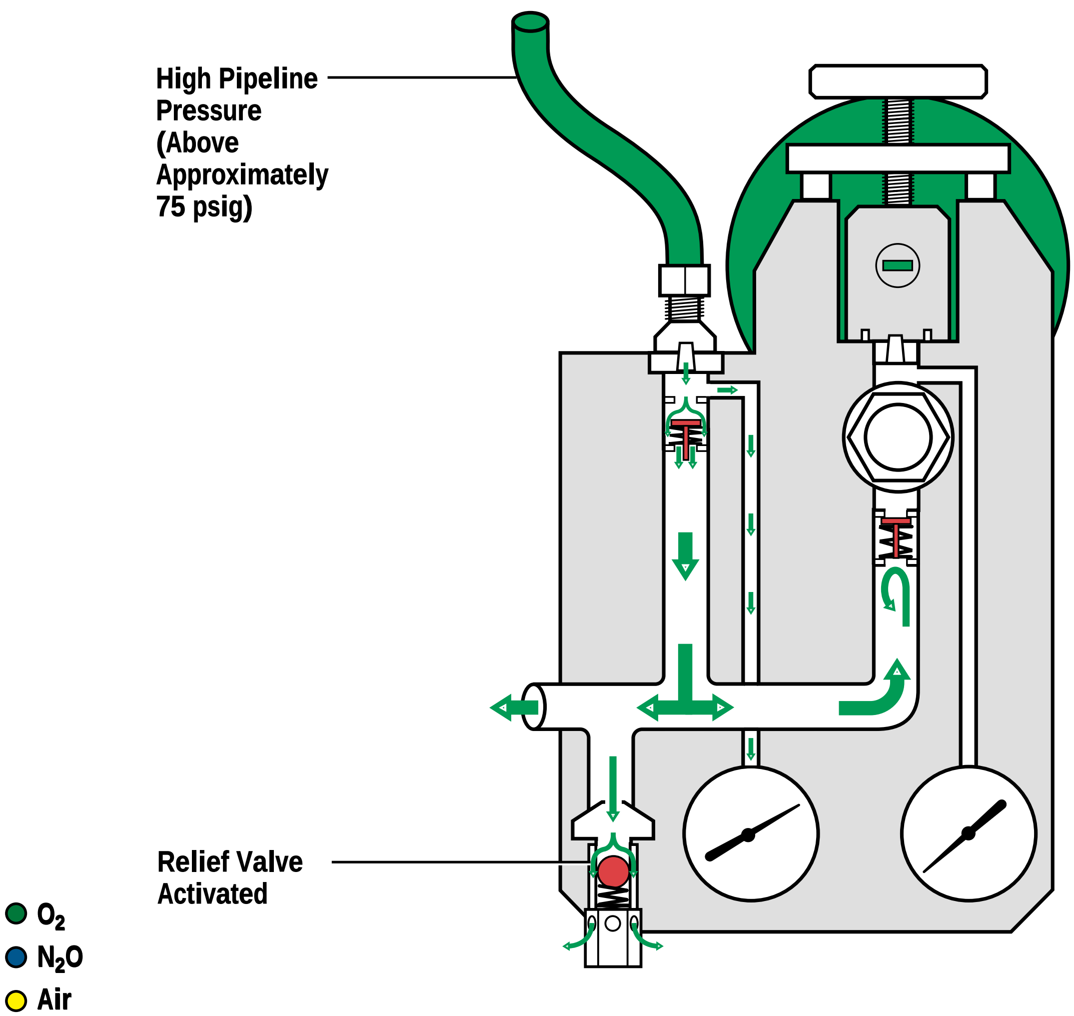
The illustration on the facing page shows how the pressure relief valve operates. This valve includes a ball and spring. The spring holds the ball against the opening. If the pressure in the gas supply module is above approximately 75 psig, the force of the gas pushes the ball away from the opening and the gas vents to atmosphere.

Illustration 16

How the pressure relief valve operates







Pneumatic outlet

The pneumatic outlets supply oxygen for accessories at approximately 50 psig. Oxygen is always available if an oxygen supply is connected to the anesthesia machine.

Items frequently connected to pneumatic outlets include:

- A ventilator.
- An auxiliary oxygen flowmeter.
- Jet ventilation devices.

The accessory connected to an outlet controls how the gas is used. Some accessories, like a flowmeter, supply gas to the breathing system. Others, such as a ventilator, use it for pneumatic power.

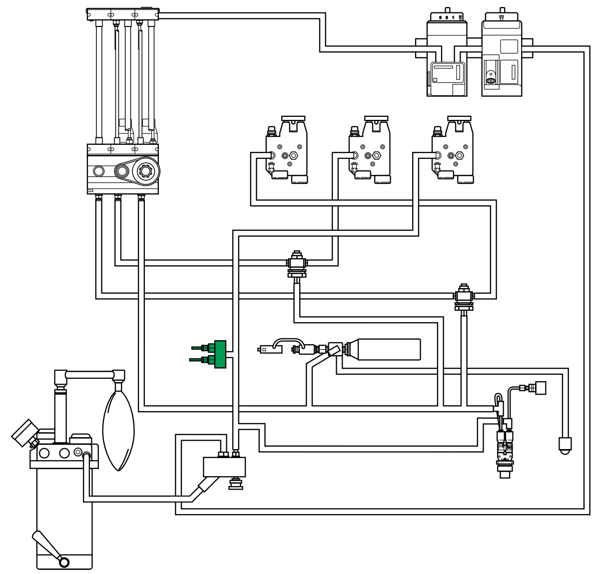
The illustration on the facing page shows how a pneumatic outlet opens when an accessory hose with a DISS adapter is connected and closes when an accessory hose is not connected.

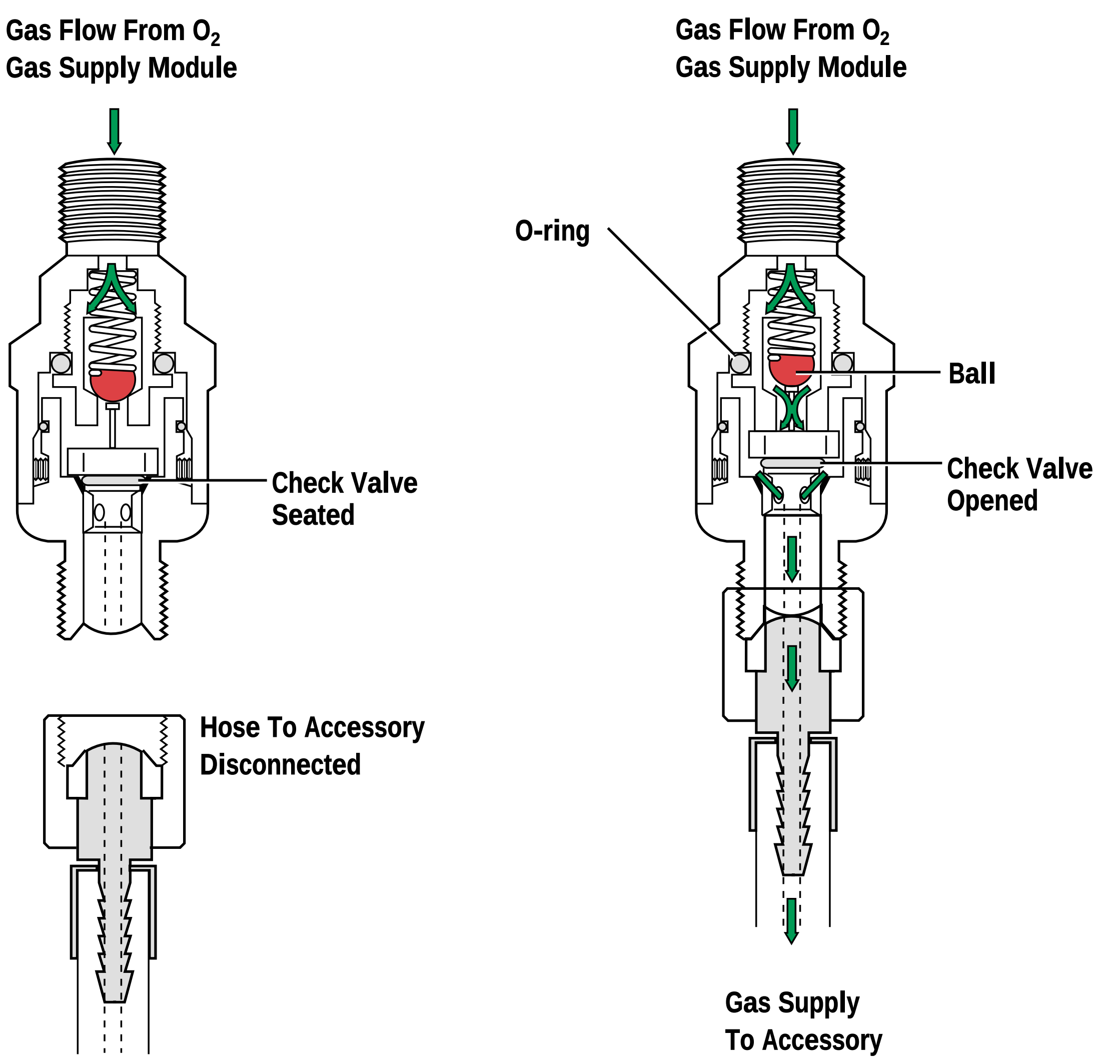
The DISS fitting on the oxygen supply hose connects to the DISS connector on the pneumatic outlet. When the connection is made, the pin in the DISS connector pushes the valve up, away from the seat. This permits oxygen to flow through the pneumatic outlet. As long as the supply hose is connected, the pneumatic outlet is held open. Oxygen flows from the machine through the valve, the supply hose, and to the accessory.

If a hose is not attached a pneumatic outlet, the check valve prevents gas flow to atmosphere. The return spring pushes the valve back on the seat and closes it. This prevents oxygen leaks through the pneumatic outlet.

Illustration 17

Pneumatic outlet with accessory hose connected and disconnected





- O_2
- N_2O
- Air

Oxygen flush button

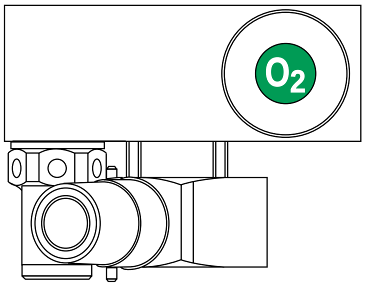
The term “flush” refers to the replacement of anesthetic gases or mixtures in the breathing circuit with a new supply of oxygen. This usually occurs at the end of the case or when the patient’s condition requires 100% oxygen. When oxygen is connected to the machine, the oxygen flush button can be pushed to supply 45 to 75 Liters per minute (L/min) of oxygen flow directly to the common gas outlet.

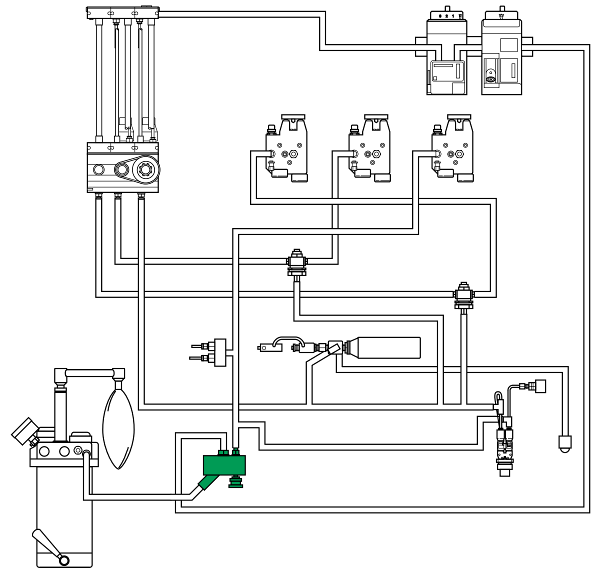
The oxygen flush button is located at the front left-hand side of the tabletop as you face the machine. To help prevent accidental activation, the button is recessed and protected with a collar. Behind the button is a valve and valve retaining spring. The illustration on the facing page shows the flush button in the open position. The valve stays closed until the button is pressed. When the button is pressed, the spring is compressed and moves the valve away from the seat. This permits oxygen from the gas supply module to flow to the common gas outlet. When the button is released, the valve returns to the closed position.

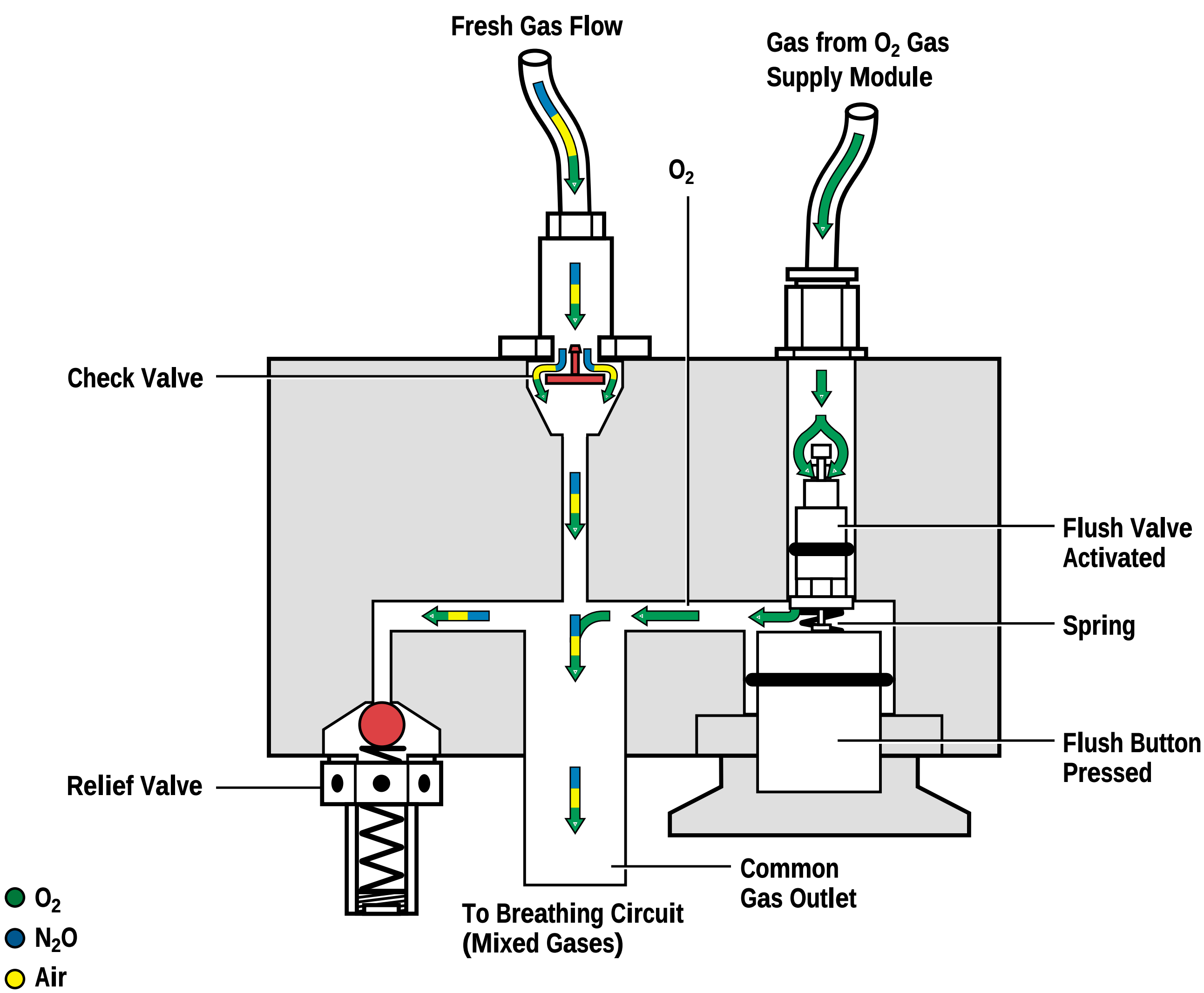
The flush valve is part of the common gas block that includes a relief valve. The relief valve is discussed in detail in the section Common Gas Block.

Illustration 18

Oxygen flush button pressed



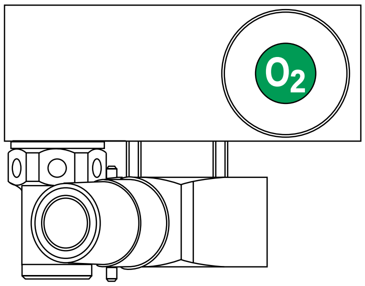


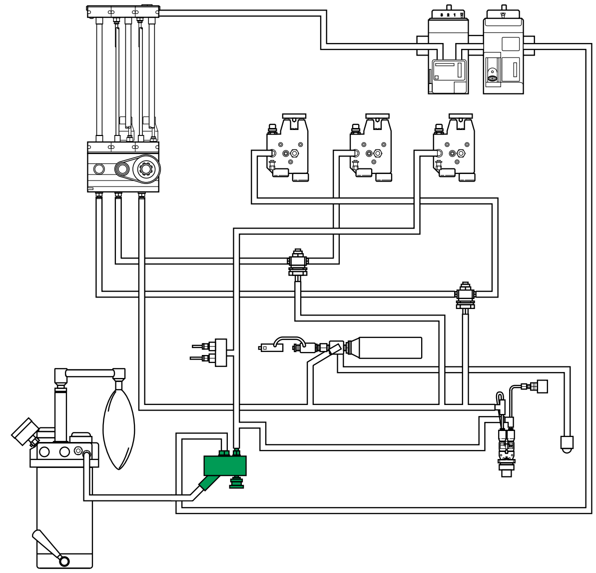


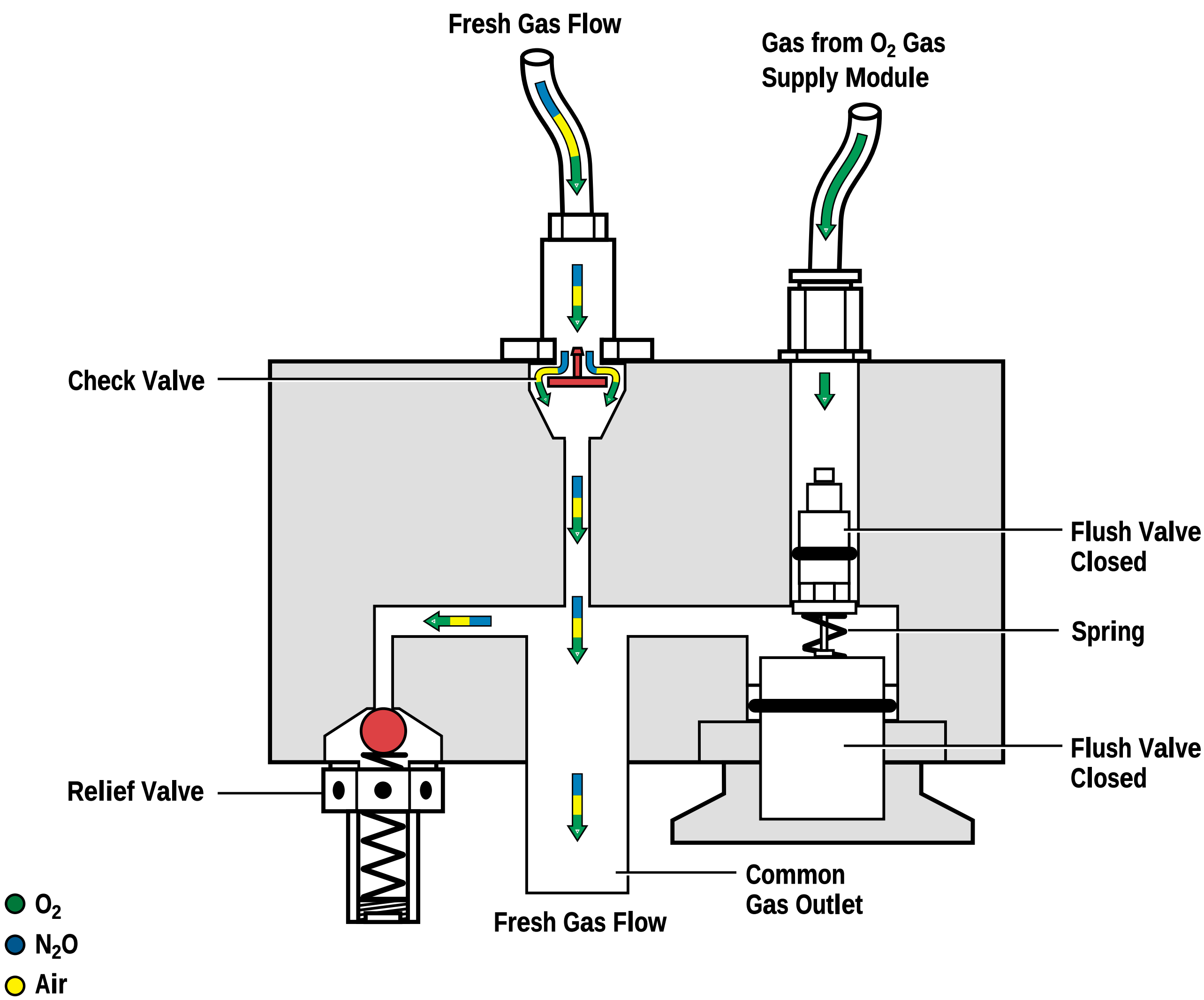
When the oxygen flush button is released, the valve retaining spring returns the valve to its normally closed position.

Illustration 19

When the oxygen flush button is released, the spring closes the valve.







SYSTEM SWITCH

The system switch controls electrical power and gas flow to the anesthesia machine.

In the ON position, the switch:

- Allows electricity to flow to the portions of the machine that are electrically operated, such as the monitor pod and ventilator.
- Connects the oxygen gas supply module to the shutoff valves, the low oxygen supply alarm, and the inlet of the oxygen flow controls.

In the OFF position:

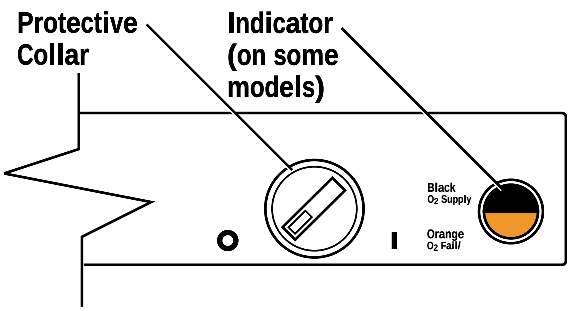
- The electrical portion of the switch cuts off electrical power to the monitors and the ventilator.
- The pneumatic portion of the switch cuts off oxygen flow to the rest of the anesthesia system (oxygen remains available at a pneumatic outlet and the oxygen flush button).
- The pneumatic portion of the switch connected to the downstream oxygen circuit connects to a tube that vents oxygen pressure to atmosphere. This tube includes a check valve that prevents air from being drawn back into the machine and permits a check for leaks in the machine using a negative pressure test (a vacuum is drawn on the machine).

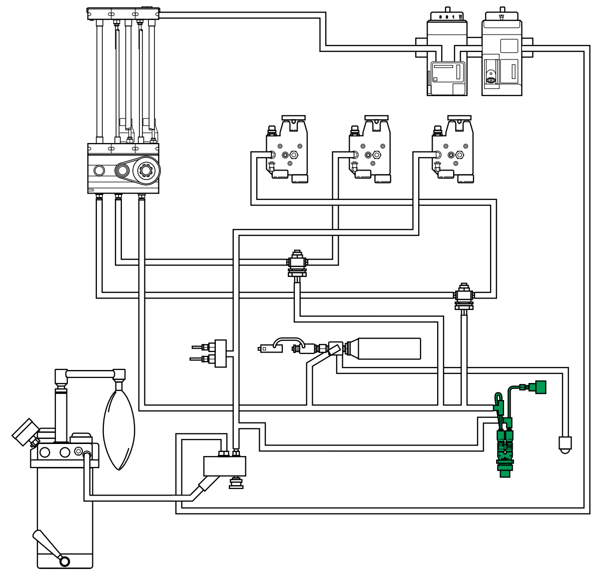
Note: Some machines use the term Standby rather than OFF, because the oxygen flush is still functional if oxygen is connected to the machine. Also, in some machines, a battery may be recharging in the Standby mode.

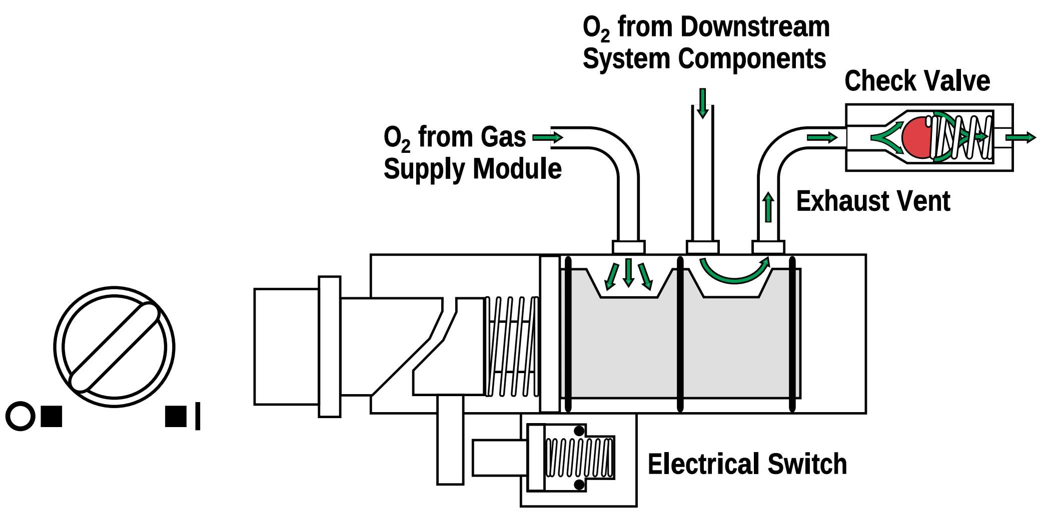
Note: An outlet box may be installed on the machine to provide auxiliary outlets. The outlet box directly connects to an electrical wall supply to supply extra electrical outlets for additional monitors when they are turned ON. The system switch does not control the auxiliary outlet box.

Illustration 20

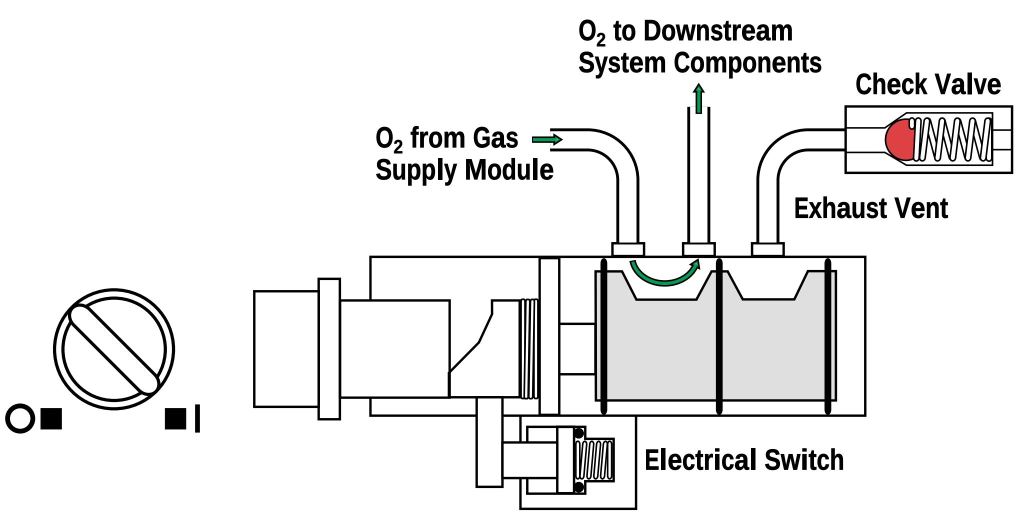
Excel SE system switch







Off Position



On Position

LOW OXYGEN SUPPLY ALARM ASSEMBLY

The low oxygen supply alarm warns the operator when the oxygen pressure in the anesthesia machine is low and must be re-established. The alarm is activated when oxygen pressure falls below approximately 30 psig.

The assembly includes:

- A reservoir.
- A regulator.
- A reed.
- An adjustable flow regulator.

When the system switch is set to ON, the oxygen supply pressurizes the reservoir to approximately 50 psig.

When oxygen pressure is above approximately 30 psig, the regulator prevents oxygen flow to the reed. When the oxygen supply decreases below approximately 30 psig, the regulator opens and oxygen from the reservoir flows through the flow regulator to the reed.

Note: That the oxygen alarm regulator has the gas inlet and outlet connections reversed from a normal regulator to obtain the characteristic where gas only flows when pressure falls below 30 psig.

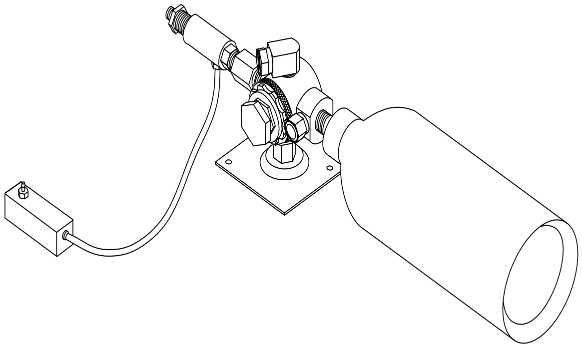
The reed is a metal reed that vibrates as oxygen goes through it and makes the alarm whistle sound. The adjustable flow regulator controls the rate of oxygen flow to the reed. An adjustment on the flow regulator controls how long the alarm will sound. The alarm must sound for a minimum of seven seconds—a standards requirement.

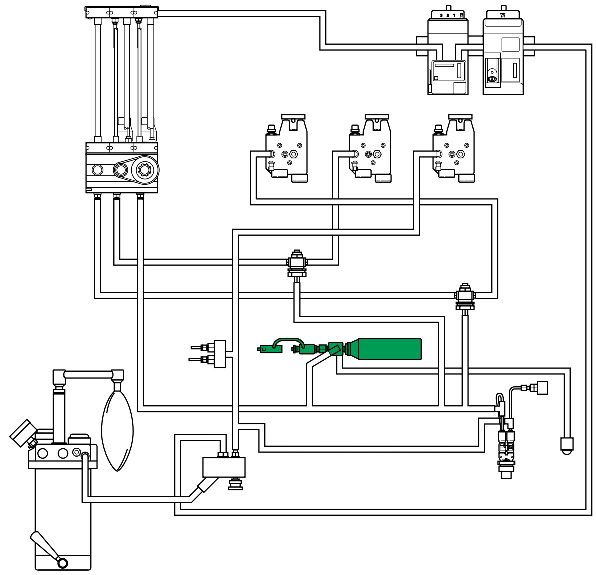
In a pneumatic alarm system, the low oxygen supply alarm stops when the reservoir is empty. This does not always necessarily mean the low pressure condition has ended.

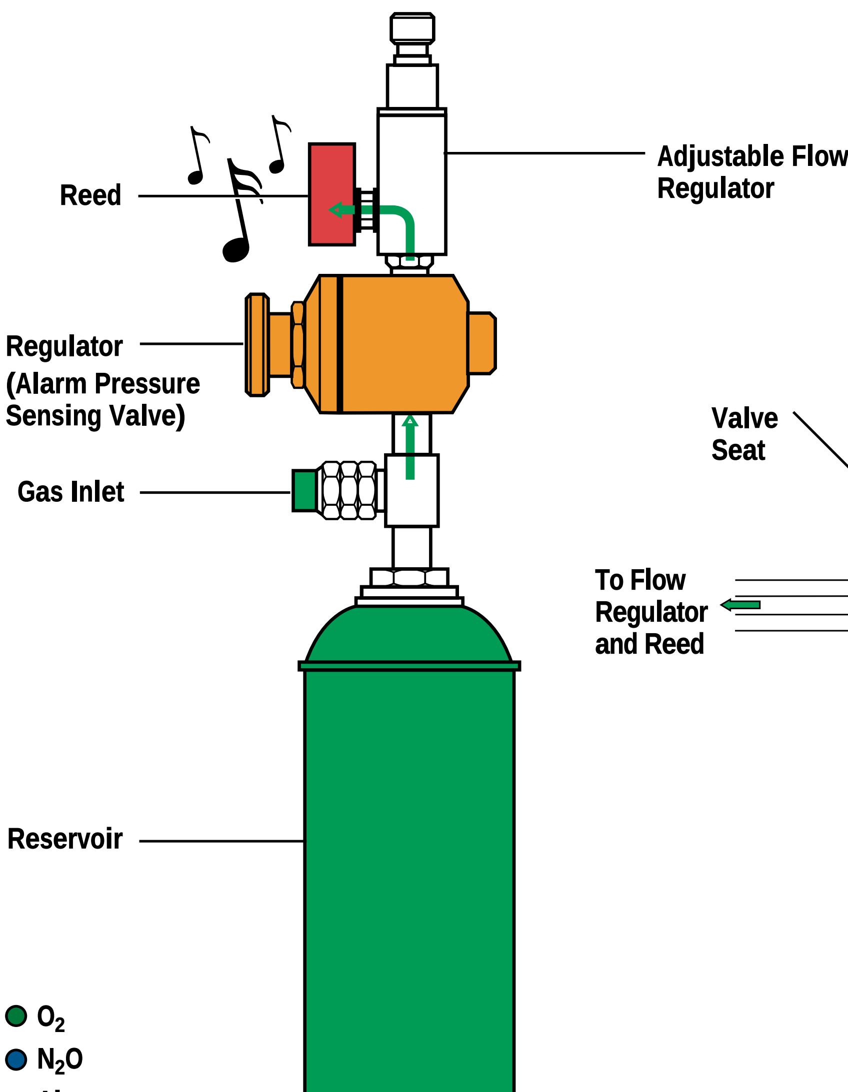
Note: In some models of anesthesia machines, the low oxygen supply alarm may be connected to an anesthesia system's electrical supply. In this case, it includes an electrical switch which sounds an alarm when the system switch is turned ON. If the oxygen supply pressure starts to decrease during operation, the electronic alarm will not stop until oxygen pressure above approximately 30 psig is re-established.

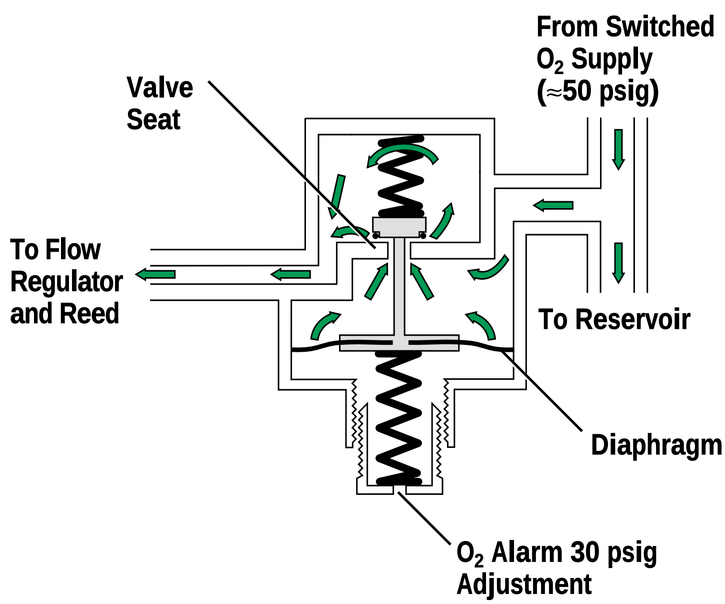
Illustration 21

Low oxygen alarm









- O_2
- N_2O
- Air

SHUTOFF VALVES

The system switch allows oxygen to flow to the remaining parts of the anesthesia machine. Additional gases, such as nitrous oxide, air or heliox are controlled by shutoff valves. As the name indicates, these valves can “shut off” gas flow. A shutoff valve is located between an additional gas supply and a flow control valve.

When an additional gas cylinder is open and/or pipeline supply is connected, gas flows directly to a shutoff valve. Gases other than oxygen are permitted to flow only if sufficient oxygen pressure is present at the valve. If oxygen pressure is too low, the shutoff valve closes and blocks the flow of any additional gas.

All shutoff valves (shown on the facing page) have three ports. In the nitrous oxide line, for instance, the shutoff valve will have;

- An inlet, connected to the nitrous oxide gas supply.
- An outlet, connected to the flow control valve inlet for nitrous oxide.
- A control port, connected to the oxygen supply through the system switch.

When oxygen pressure is above 20 psig at the control port of a shutoff valve (see the illustration on the facing page), the diaphragm, valve, and pin move up and push the valve off the seat. This allows the additional gas to flow to the flow control valve. The valve will stay open and permit the flow of the additional gas from the inlet port through the outlet port.

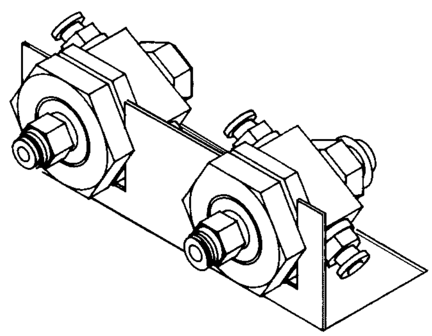
When oxygen pressure at the inlet port of the shutoff valve is less than 20 psig, the pressure on the diaphragm is insufficient to hold the piston, pin and valve off the seat. The return spring will return the valve to its seat and block the flow of the additional gas from the inlet port to the outlet port.

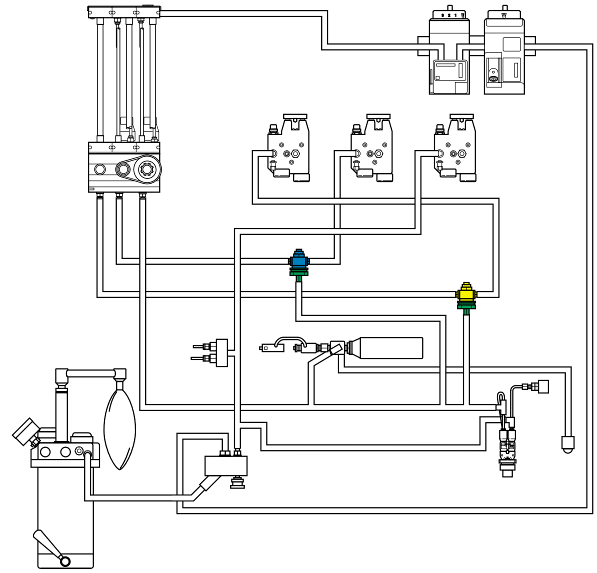
When the system switch is turned OFF, oxygen downstream of the switch is vented to atmosphere through a line connected to the switch. Oxygen pressure at the inlet port of the shutoff valve decreases to less than 20 psig, the valve closes and blocks the flow of any additional gas.

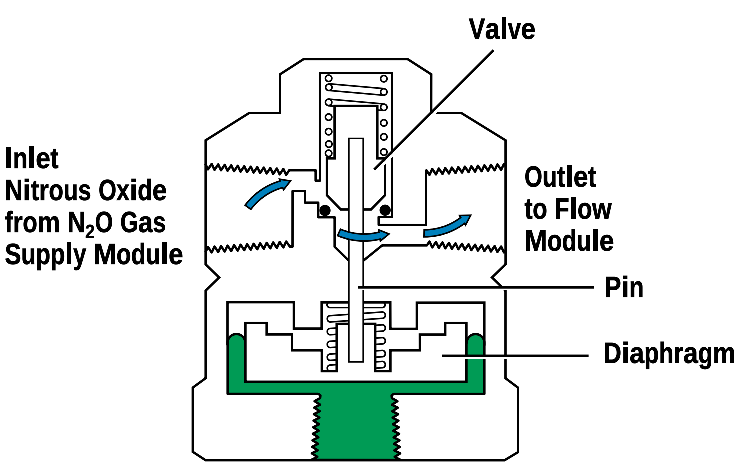
The low oxygen supply alarm will sound as the oxygen pressure decreases below approximately 30 psig. When the oxygen pressure is less than 20 psig, the nitrous oxide float, for instance, drops to the bottom of the nitrous oxide flowtube as the N_2O shutoff valve closes. This is the only indication that nitrous oxide flow is shut off. When the oxygen pressure has decreased to zero, the oxygen float drops to the bottom of the oxygen flowtube.

Illustration 22

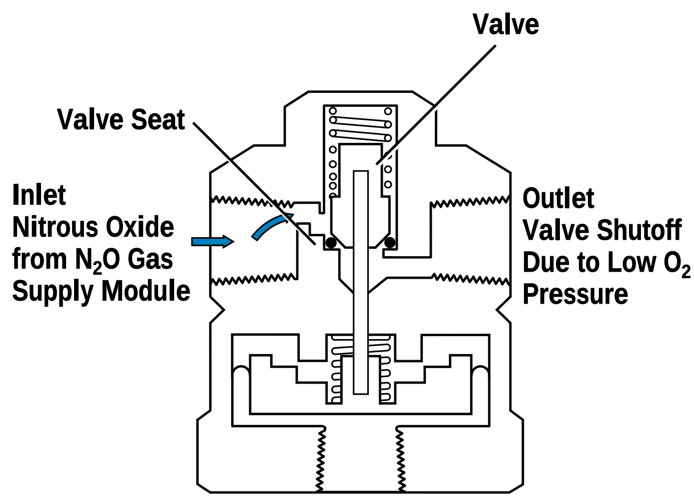
Shutoff valve open and closed







Open Valve



Closed Valve

- O_2
- N_2O
- Air

We have been looking at parts of the anesthesia machine that control gas pressures and flow. In this section, we will investigate how the flow control assembly manages the mixture of gas flows.

FLOW CONTROL ASSEMBLY

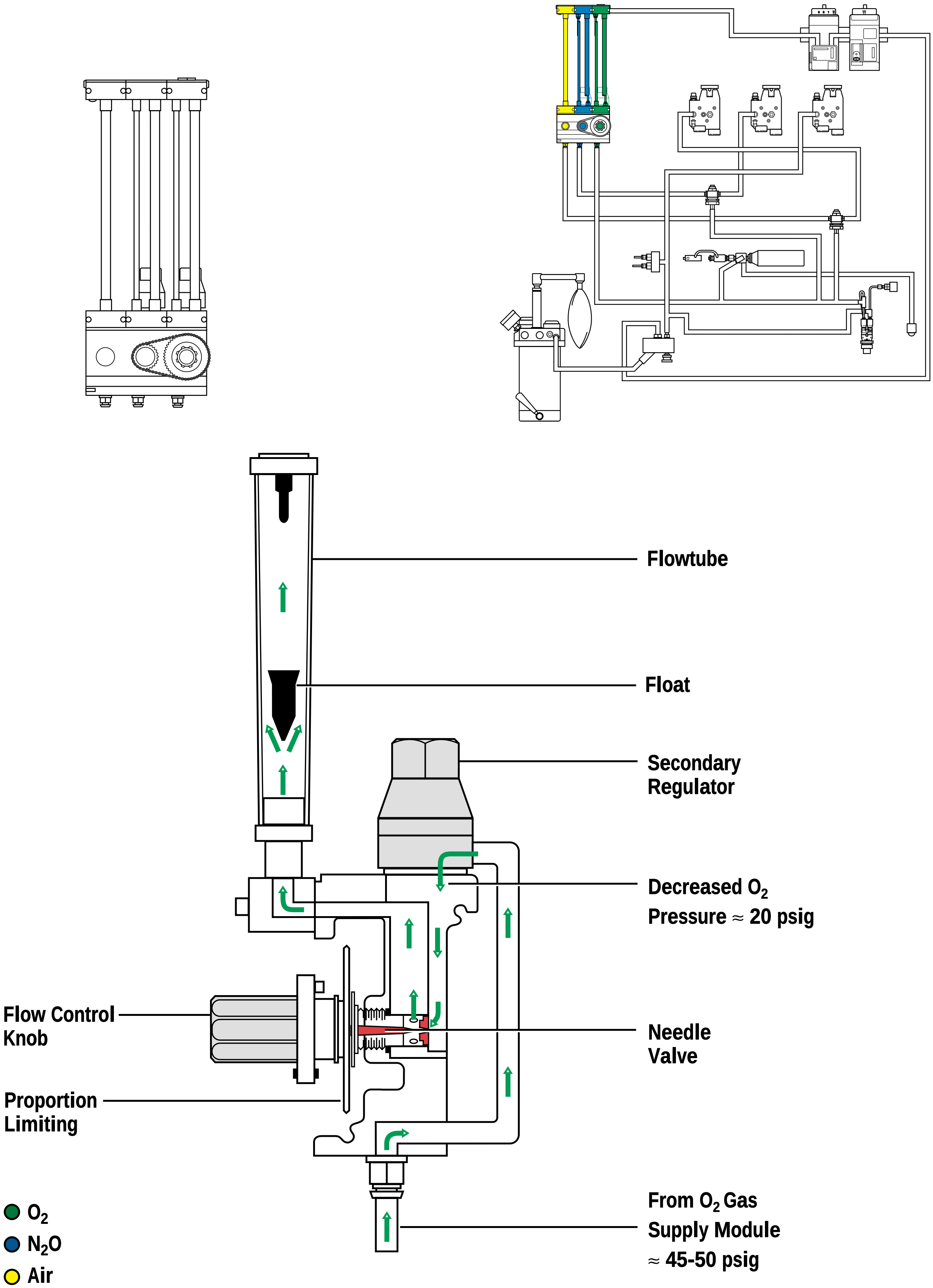
Each gas has its own flow control assembly. Oxygen flows from the system switch to the oxygen flow control assembly. Nitrous oxide and additional gases flow from the output port of a shutoff valve to a flow control assembly.

A flow control assembly includes:

- Secondary regulators.
- Flow control knobs.
- Flow control needle valves.
- The Link-25 proportion limiting control system.
- Flowtubes.

Illustration 23

Flow control assembly



Secondary regulator

A secondary regulator is used to:

- Decrease the pressure of oxygen and nitrous oxide a second time before these gas flows reach the flow control valves.
- Maintain a difference in gas pressure between oxygen and nitrous oxide.
- Keep nitrous oxide and oxygen flows constant.
- Ensure that oxygen is the last gas to flow from the anesthesia machine.

The secondary regulators reduce the oxygen pressure approximately twice as much as the nitrous oxide pressure. The pressures at the inlets of both the nitrous oxide and oxygen secondary regulators are approximately 50 psig. The pressure at the outlet of the nitrous oxide secondary regulator is approximately 38 psig while the pressure at the outlet of the oxygen secondary regulator is approximately 20 psig. This is a 2:1 ratio of nitrous oxide to oxygen outlet pressures. The difference in pressure between oxygen and nitrous oxide is part of the proportion limiting control that helps to prevent a hypoxic (oxygen-deficient) mixture.

Secondary regulators help to maintain consistent gas flows. They minimize “bobbing” of the floats in the flowtubes during fluctuations in gas supply pressures. It is important to note that oxygen pressure from the pipeline supply is approximately 50-55 psig, but not always. Gas pressure can fluctuate during the day due to changes in demand. For example, in a busy hospital, more oxygen may be used at noon than at 5 a.m. If a gas pressure is not reduced by a secondary regulator, the flow in the flowtube changes as the gas supply pressure changes. This requires the user to make adjustments to a flow control valve each time the gas pressure fluctuates.

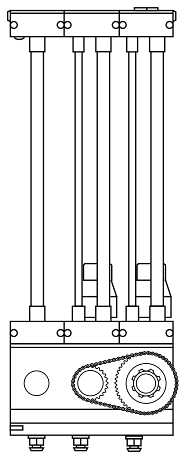
Because the oxygen secondary regulator adjusts the pressure at the oxygen flow control valve to 20 psig, the low oxygen supply alarm sounds before flow decreases in the oxygen flowtube. The pressure at the oxygen flow control is lower than the pressure at other flow controls. This ensures that oxygen is the last gas flow to decrease as the oxygen supply decreases.

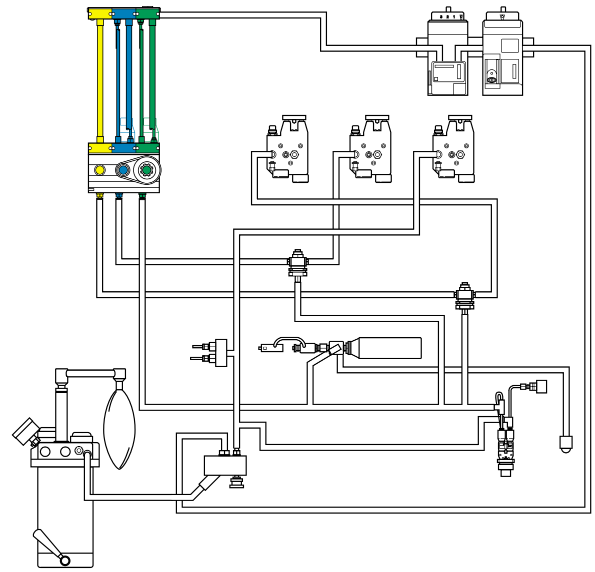
Note: When the shut off valves block the flow of the other gases, the pressure of 20 psig keeps the O_2 float stable even though other flows decrease.

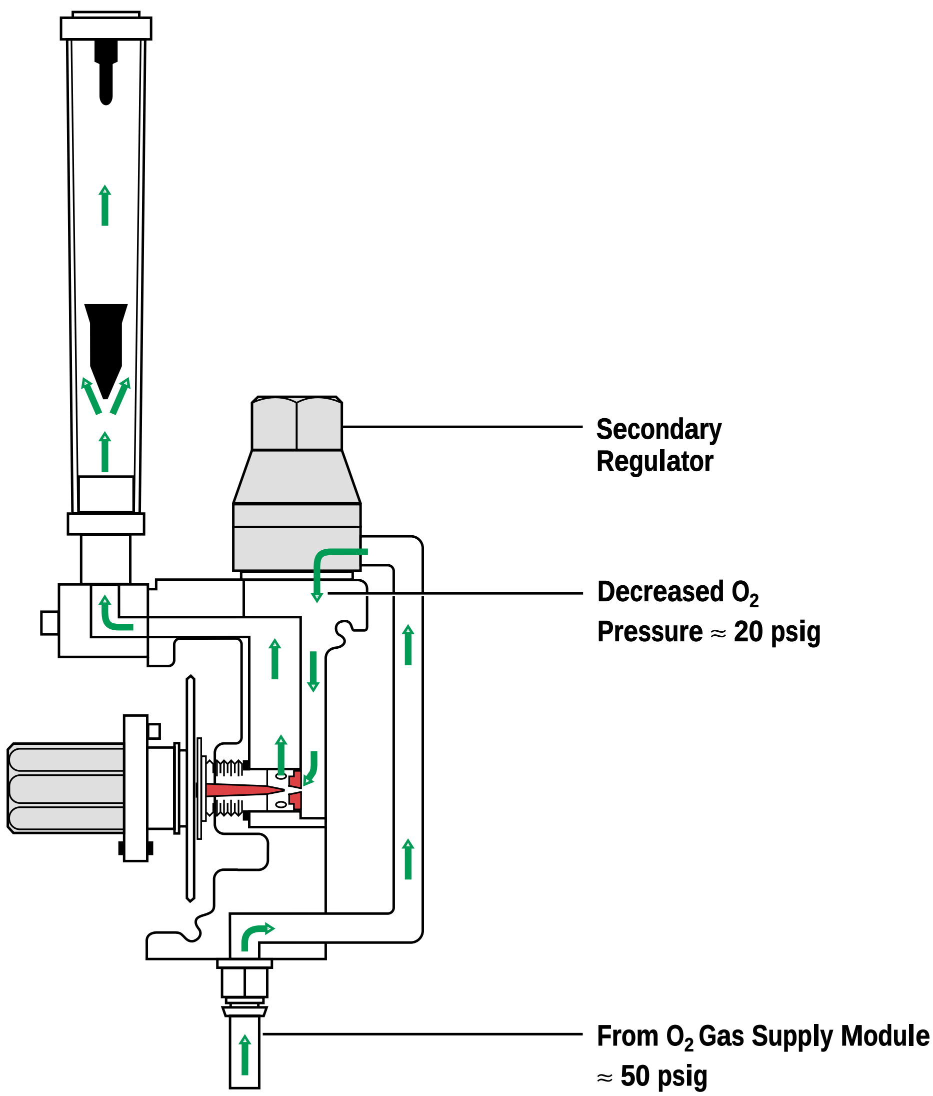
The illustration on the facing page shows how gas flows from the secondary regulator. It is similar to the primary regulator but, because it controls lower pressures, the secondary regulator does not need a relief valve.

Illustration 24

A secondary regulator







- O_2
- N_2O
- Air

Flow controls

Each gas installed on the anesthesia machine has a flow control valve. The flow control valve is an assembly that includes:

- A flow control knob.
- A needle valve and valve seat.

A flow control knob is attached to the needle valve. Each flow control valve is labeled and color-coded to indicate the gas it controls. The oxygen flow control knob can be quickly identified by touch and sight. It is fluted with a smooth finish and is larger in diameter than other gas knobs. The flow control knobs for other gases are smaller in diameter than the oxygen knob and are knurled to provide a different feel to the user.

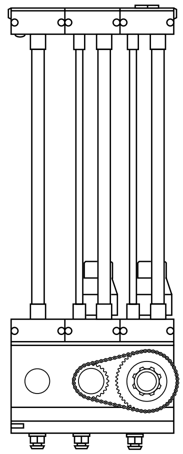
A flow control needle valve has fine screw threads designed to give precision control. Each turn of an oxygen flow control knob, makes a small adjustment of flow in the inlet to the oxygen flow tube. This permits careful selection of the oxygen flow. Turning the oxygen flow control knob counterclockwise moves the needle valve back and away from its seat to open a channel for the flow of oxygen into the flowtube assembly. Turning the knob clockwise closes the space between the needle valve and its seat. This control mechanism permits the operator to adjust the flow supplied to the patient circuit.

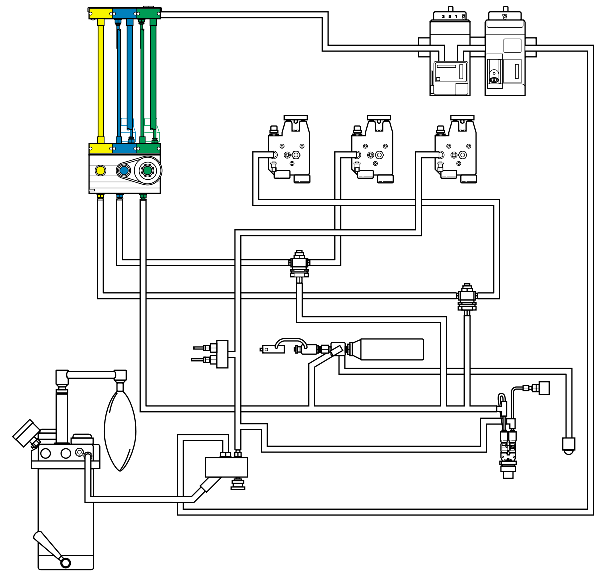
When the valve is closed correctly, the “stop” position feels like a sudden resistance that reminds the operator not to turn this valve any further. When the oxygen flow control valve is set to its “stop” position, the oxygen flow will not be turned OFF. Oxygen flow should be seen in the oxygen flowtube whenever the system switch is ON, even if the oxygen flow control is turned completely clockwise (minimum flow). The minimum flow on most machines is 200 mL. When any other gas flow control valve is set to its “stop” position, flow to the flowtube should be OFF.

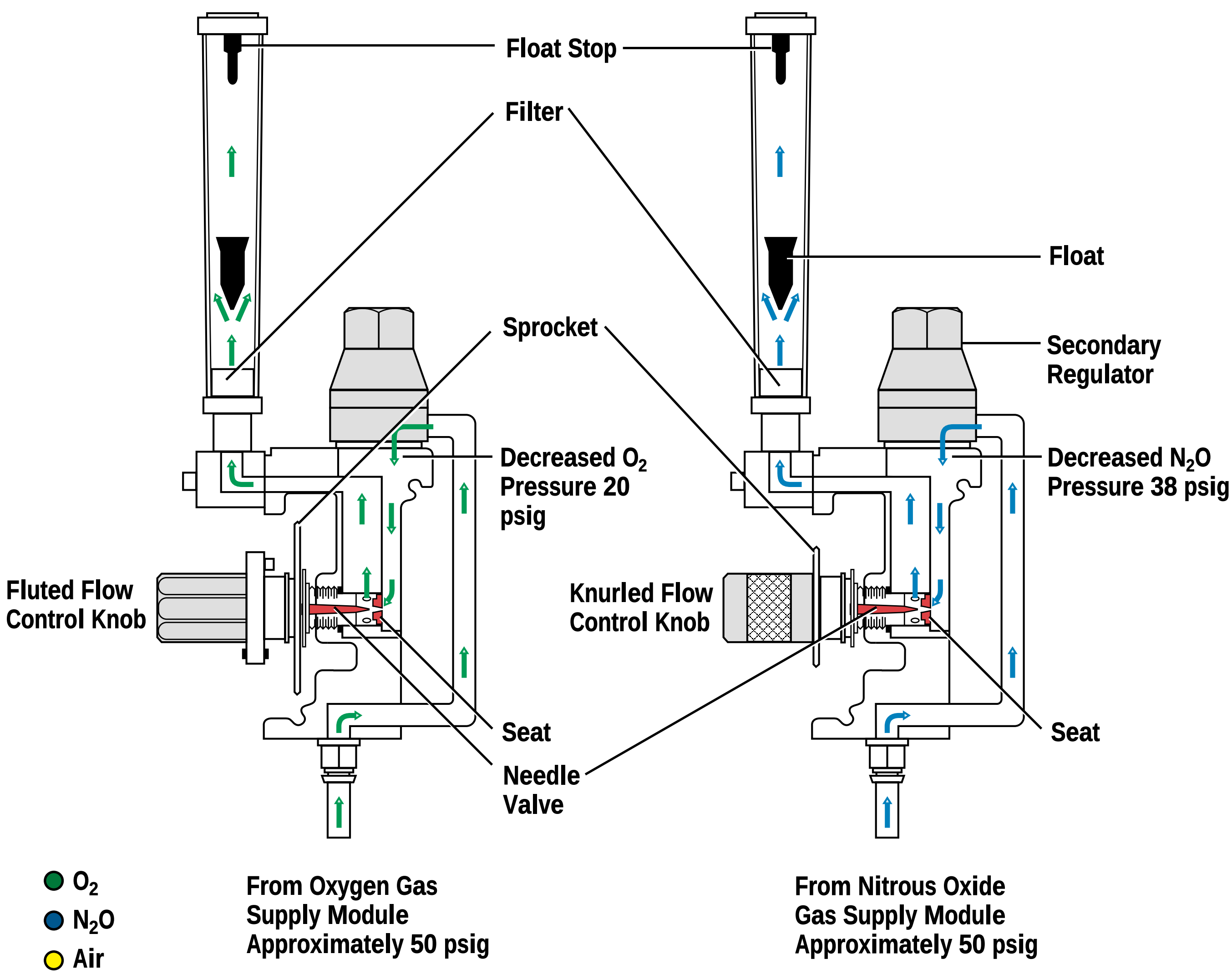
Oxygen flows to the oxygen flow control at about 20 psig. Nitrous oxide flows to the nitrous oxide flow control at about 38 psig. The nitrous oxide flow control includes a flow control knob, a needle valve, and seat. It controls gas flow into the flowtube in the same way the oxygen flow is controlled. When Nitrous Oxide is set to its “stop” position, flow to the flowtube is OFF and the float rests on the filter.

Illustration 25

An oxygen flowmeter and a nitrous oxide flowmeter







The Link-25 proportion limiting control system

The flow controls for oxygen and nitrous oxide are linked together by the Link-25 proportion limiting control system.

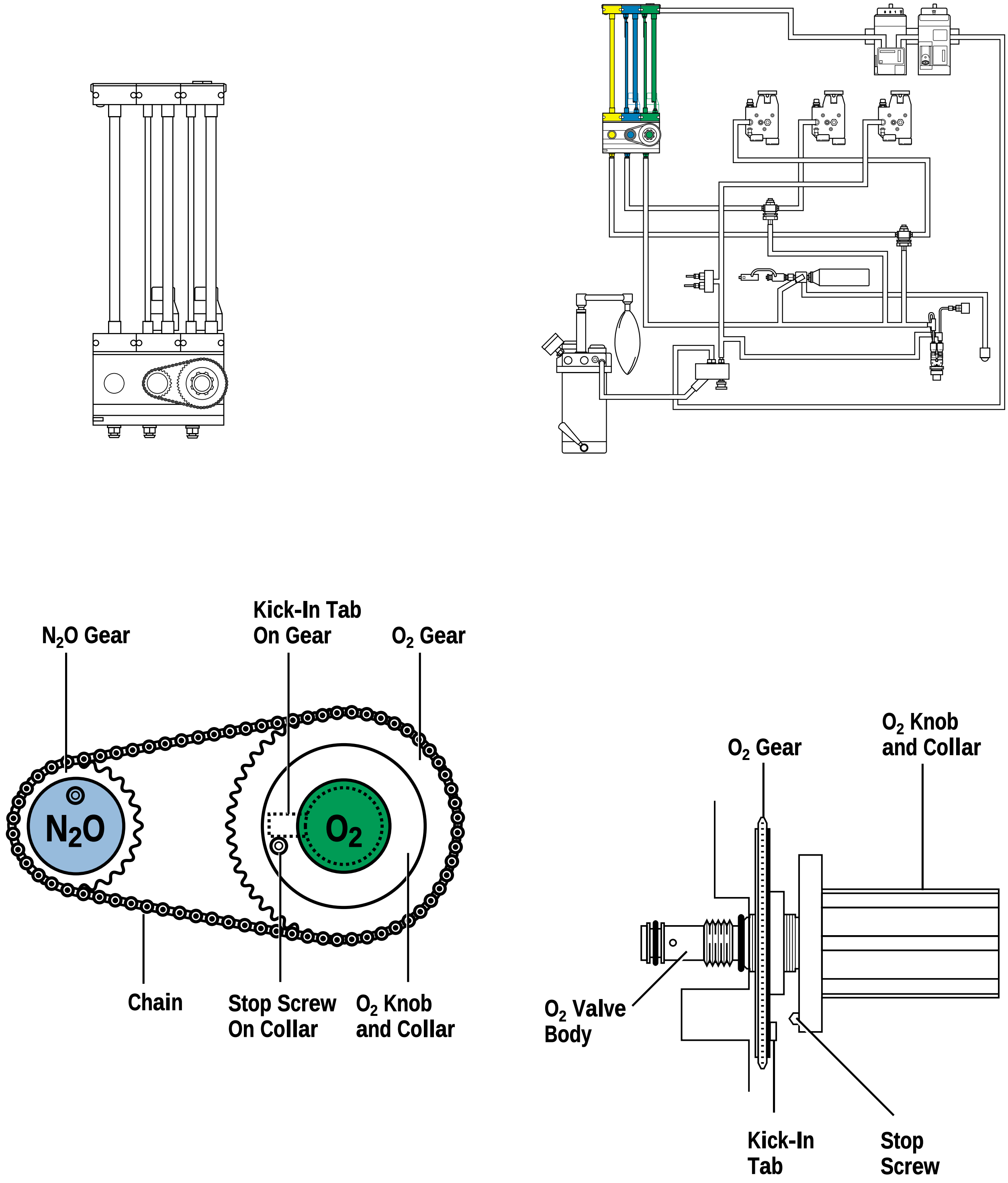
The oxygen and nitrous oxide secondary regulators change the pressures of these gases so that the oxygen pressure is half that of the nitrous oxide pressure. This 2:1 ratio is an important aspect of the gas proportion limiting system. The Link-25 system is designed to further adjust the 2:1 ratio to provide a flow ratio of up to 3:1 — three times as much nitrous oxide flow as oxygen flow. At the same time, the Link-25 system helps to prevent this ratio from exceeding 3:1 in order to maintain a minimum of 25% oxygen in the fresh gas mixture.

The Link-25 system affects gas flows only when the ratio of nitrous oxide to oxygen is 3:1. This is achieved through movement of a gear threaded on the body of the oxygen valve. When the ratio is less than 3:1, the flow of nitrous oxide can be increased without affecting the oxygen flow because the gear does not contact the O_2 flow control. When the ratio reaches 3:1, the gear moves toward the O_2 control knob, and the kick-in tab on the oxygen gear catches the stop screw on the collar of the oxygen flow control. Then, if the nitrous oxide flow is increased, the chain linking the two flow controls increases the oxygen flow to maintain the 3:1 ratio. This is done without the operator touching the oxygen flow control. If the ratio of nitrous oxide to oxygen is 3:1 and the oxygen flow is reduced the knob moves towards the gear, again engaging the kick-in tab so that the Link-25 system reduces the nitrous oxide flow to maintain the 3:1 ratio. This occurs without the operator touching the nitrous oxide flow control.

Because it would not cause the nitrous oxide to oxygen ratio to exceed 3:1, the oxygen flow can be increased without increasing the nitrous oxide flow, and the nitrous oxide flow can be decreased without affecting the oxygen flow.

Illustration 26

The Link-25 system



- O_2
- N_2O
- Air

Flowtube assembly

A flowtube assembly measures the flow of a gas supplied to the patient circuit. A flowtube assembly includes tapered glass flowtubes with filters at the entrance port (shown on the facing page). The floats in the flowtubes will rise and fall with an increase or decrease of gas flow in the flowtube. The float will line up with markings on the calibrated scale to indicate the rate of flow in the flowtube. Oxygen flowtubes contain an oxygen float that belongs only in the oxygen flowtube. This assembly will accurately measure the flow of oxygen. The nitrous oxide flowtube works in the same way as the oxygen flowtube and is labeled for nitrous oxide only. It contains a float that belongs only in this flowtube and is only accurate when used to measure nitrous oxide flow.

A flowtube assembly may contain both low and high flow tubes. When there are two flowtubes, the low flow tube has a scale that measures the gas flow in milliliters. The low flow tube is connected in series with a high flow tube that has a scale that measures the gas flow in liters per minute.

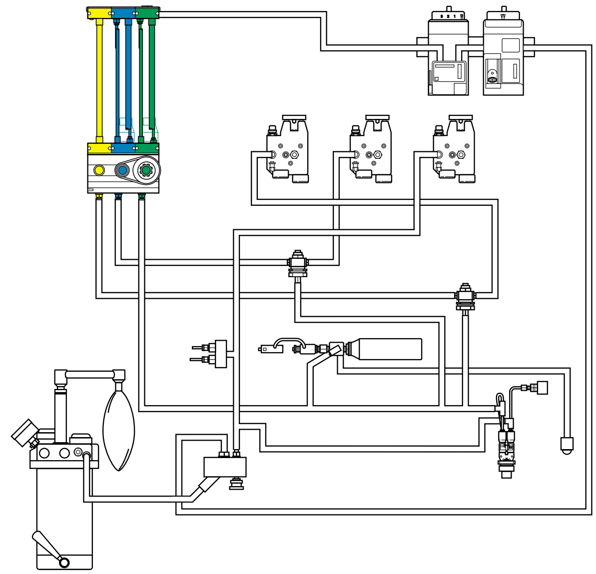
Current machine standards (ANSI) make it necessary for the oxygen flowtube to be connected closest to the vaporizer manifold inlet and placed to the right of all others as one faces the machine. This standard, for United States and Canadian machines, is intended to improve safety. With oxygen on the right, it is always downstream of all other gases that flow into the gas distribution manifold (see page 3-46).

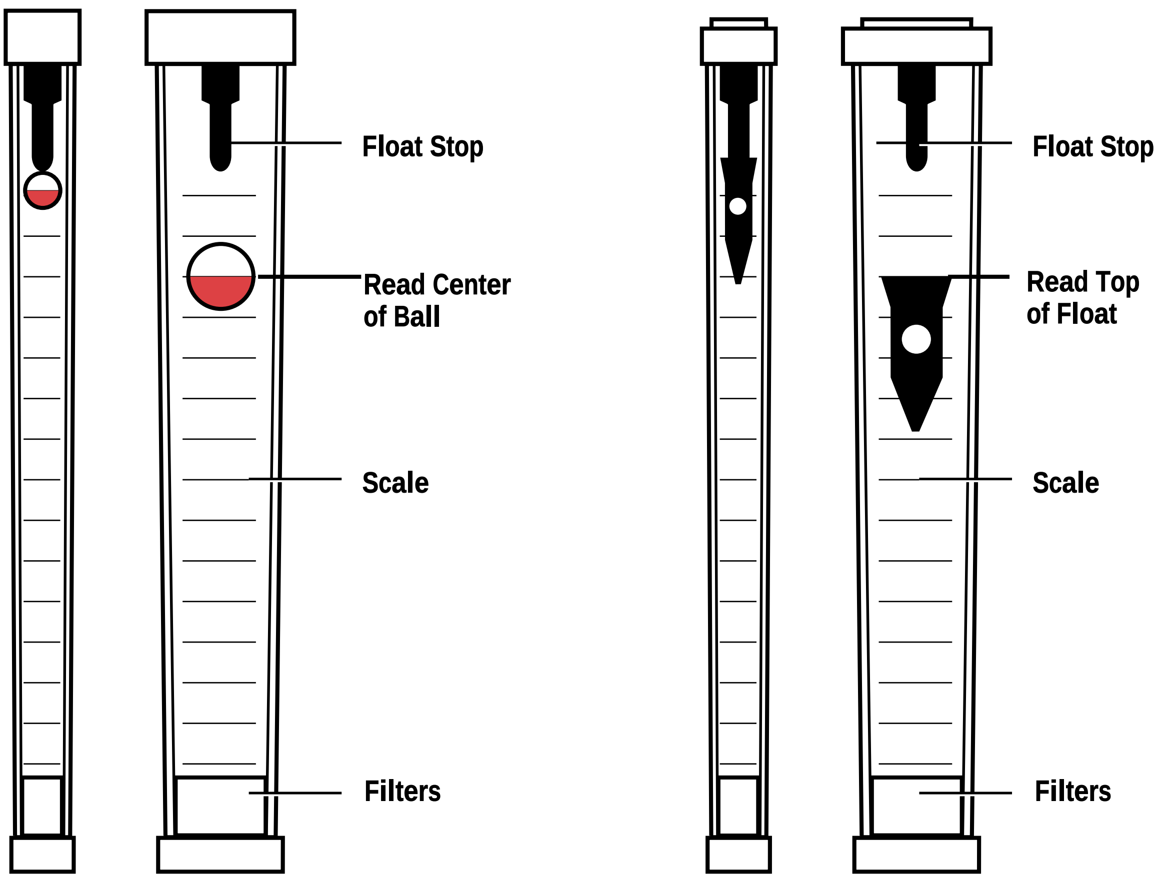
The top and bottom float stops ensure that the float is always in view of the operator. The top stop in the flowtube prevents the float from sticking to the top of the flow tube. The bottom stop gives the float a place to sit in the center of the flowtube when the gas flow is off. When the flow control valve is open, the float is kept in the center of the flowtube bore by the flow of the gas. Tapered floats are read at the top of the float. Ball type floats are read at the center of the ball.

When a flow control valve is ON (open), the gas flows through the flowtube into the gas distribution manifold.

Illustration 27

Different types of floats





Ball Float

Tapered Float

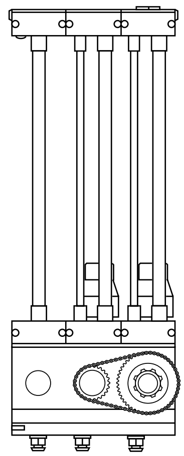
- O_2
- N_2O
- Air

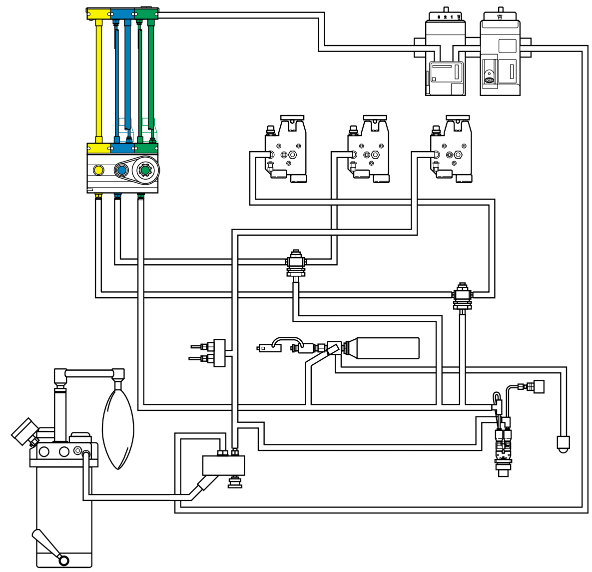
THE GAS DISTRIBUTION MANIFOLD

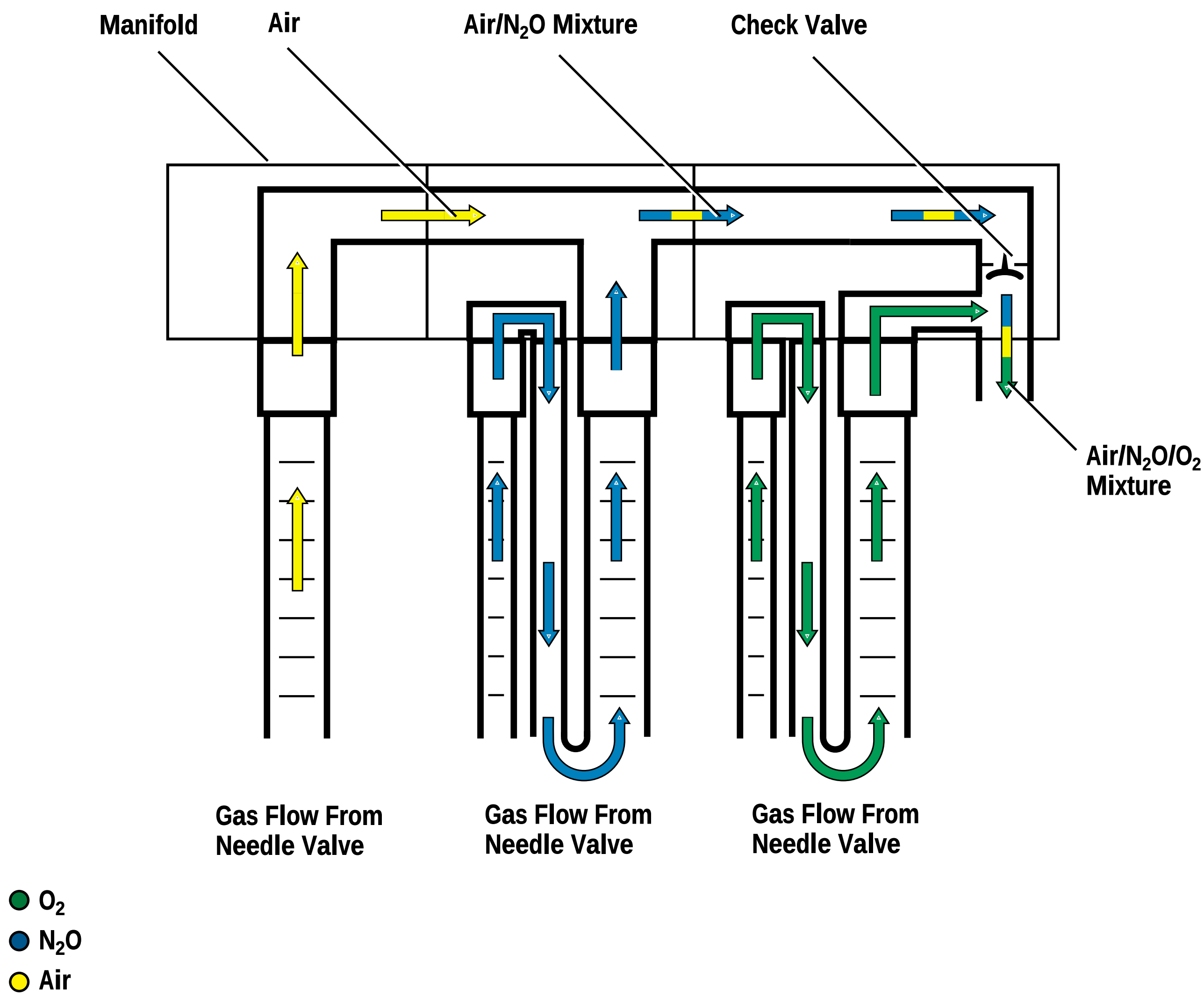
Output from the flowtubes mixes together at the top of the flowtubes in the gas distribution manifold. Because the oxygen flowtube is on the right side of the other flowtubes, it is always downstream of all other gases that flow into the gas distribution manifold. The illustration on the facing page shows the check valve located between the oxygen flowtube and the nitrous oxide flowtube. If a crack or leak develops in the nitrous oxide flowtube, for example, the check valve helps to prevent oxygen flow from flowing back to the nitrous oxide flowtube and leaking to atmosphere through the damaged flowtube.

Illustration 28

Flow into the gas distribution manifold







THE SELECTATEC VAPORIZER MANIFOLD

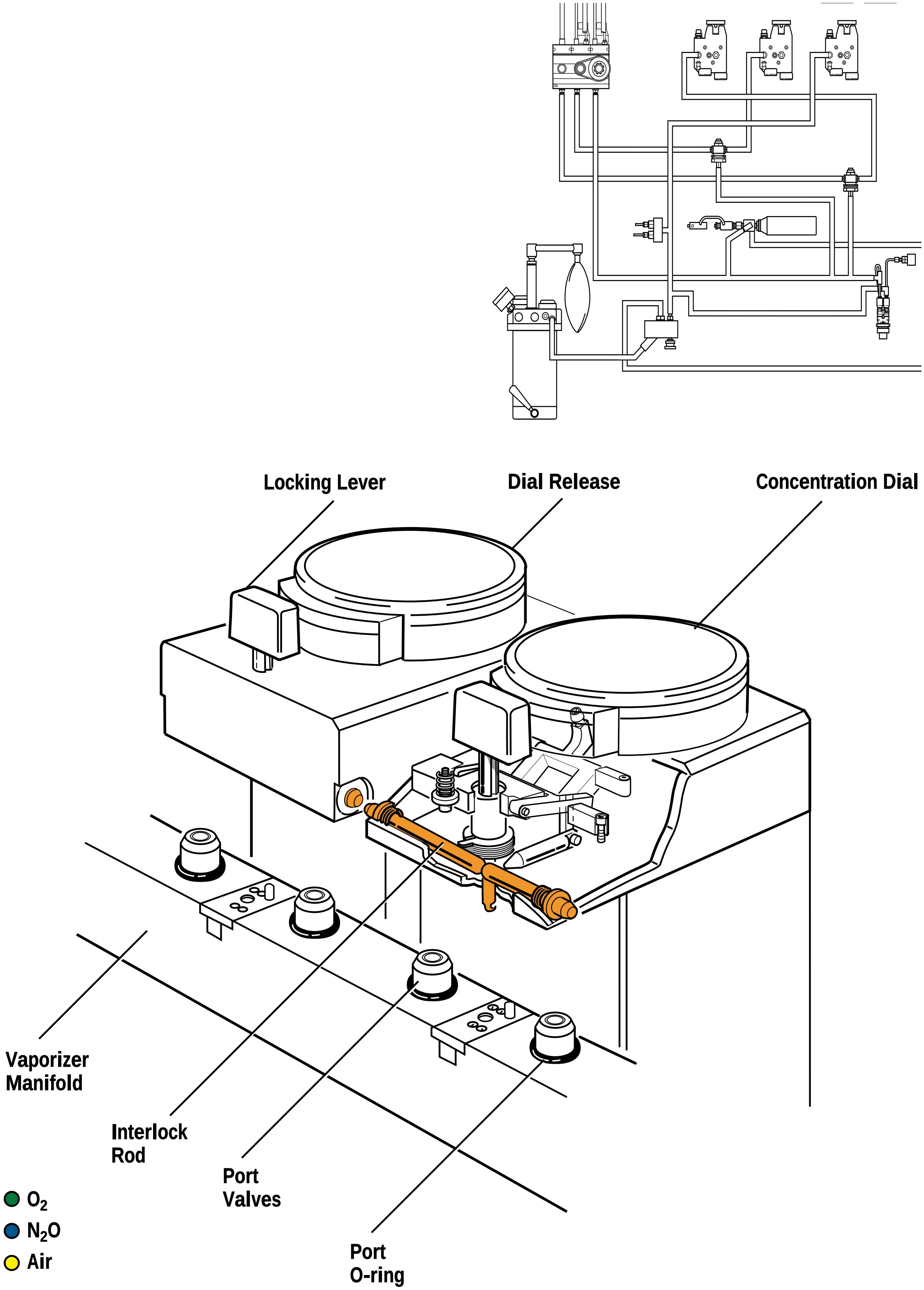
The gas mixture flows from the gas distribution manifold into the Selectatec Series vaporizer manifold located to the right of the flowmeter module.

The Selectatec vaporizer manifold and the vaporizer connection system form an interlock that allows only one vaporizer at a time to be ON. Only Selectatec Series compatible vaporizers can be installed on this manifold. Gases flowing through the vaporizer manifold bypass vaporizers that are turned OFF. When a vaporizer dial is turned ON, gases flow through the vaporizer, picking up vaporized liquid agent.

As shown in the illustration on the facing page, each vaporizer has a lever to lock it in place on the manifold. When vaporizers are correctly attached and are positioned next to each other on the manifold, interlock rods on the vaporizers will not permit more than one vaporizer to be turned on at the same time.

Illustration 29

The interlock rods

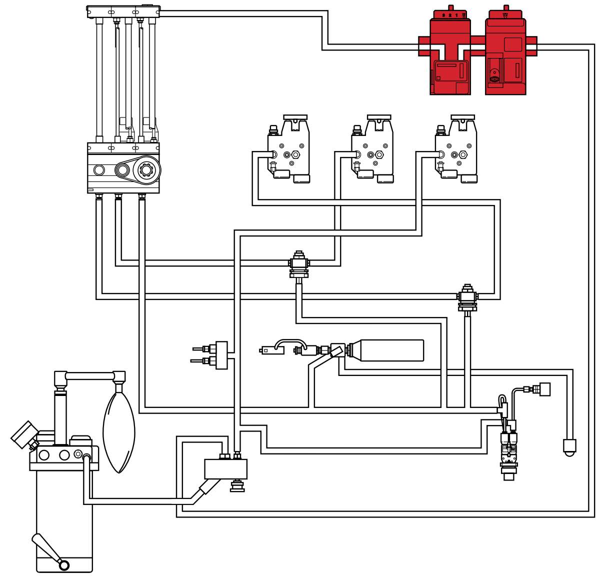


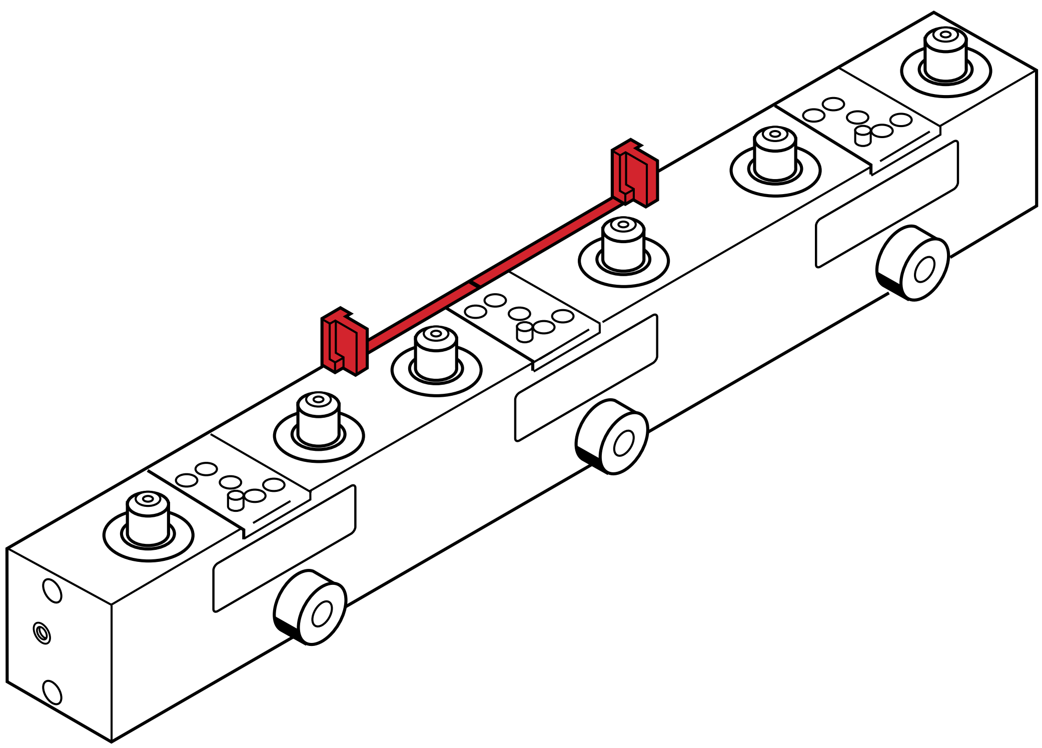
The vaporizer manifold can hold two to three vaporizers, depending on the machine model. On models that hold two vaporizers, the interlock rods in the vaporizers directly contact the other vaporizer to effect a lock out of the second vaporizer. On models that can hold three vaporizers, interlock slide bars (shown on the facing page) on the vaporizer manifold can be used with the interlock rods on the vaporizers to prevent more than one vaporizer being turned ON at the same time. This is important when the center position is vacant.

If a vaporizer on the right or left is turned ON, the bar will slide to the right or left to lock out the other vaporizers. If the vaporizer in the center position is turned ON, the interlock bar can split and both left and right halves of the bar lock out the left and right vaporizers.

Illustration 30

Interlock bar





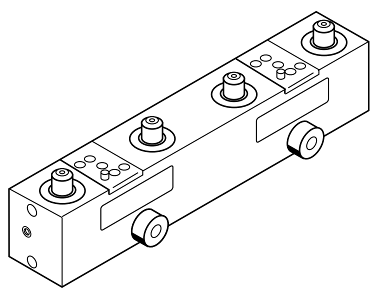
Three vaporizer position manifold

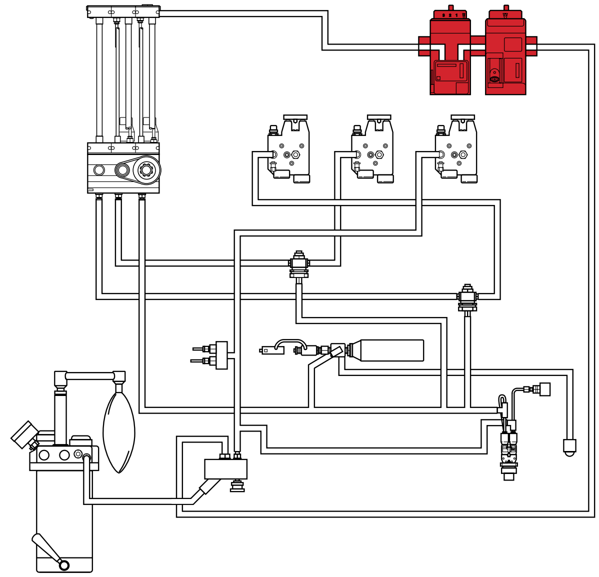
Vaporizers are installed on a pair of two-way port valves located in the vaporizer manifold. As shown in the illustration on the facing page, the port valves have a ball and spring inside. When a vaporizer is OFF, or if a vaporizer is not installed on the port valves, each port valve is closed. This seals the vaporizer from outside air and ensures that fresh gas bypasses the vaporizer through the vaporizer manifold bypass circuit. The ball stays pressed against its seat to prevent gas flow through the vaporizer until the vaporizer is turned ON.

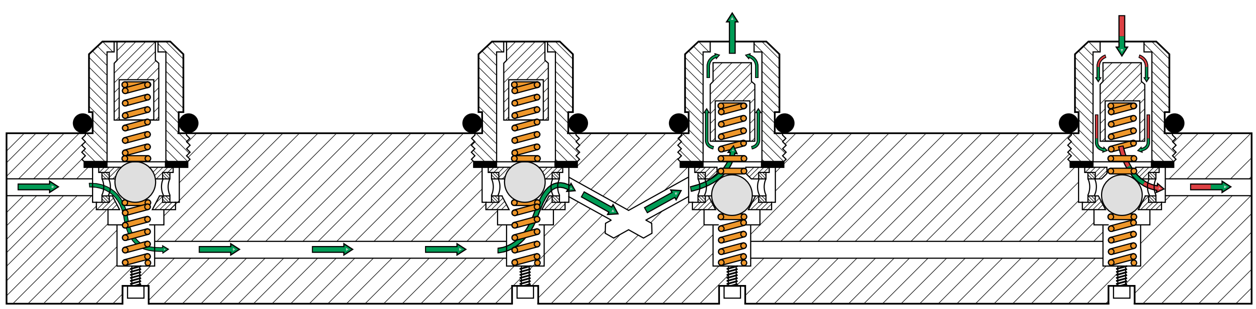
When a vaporizer is installed on a pair of port valves, locked in place, and the vaporizer control dial turned ON, the port valves are pressed open by pins on the vaporizer. An O-ring must be in place on each port valve to help prevent leaks when the vaporizer is turned ON. Fresh gas from the manifold flows into the vaporizer through the inlet port valve. Agent is added to the fresh gas mixture as it flows through the vaporizer (refer to the vaporizer section for a detailed explanation). The gas mixture flows from the vaporizer through the outlet port valve to the common gas outlet.

Illustration 31

How the port valves open







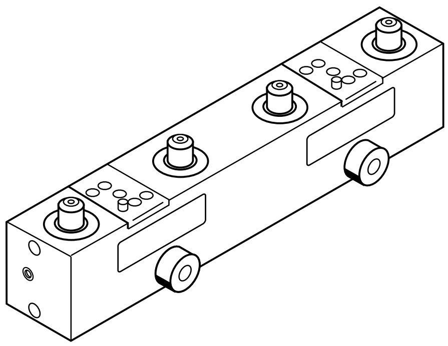
- O_2
- N_2O
- Agent
- Air

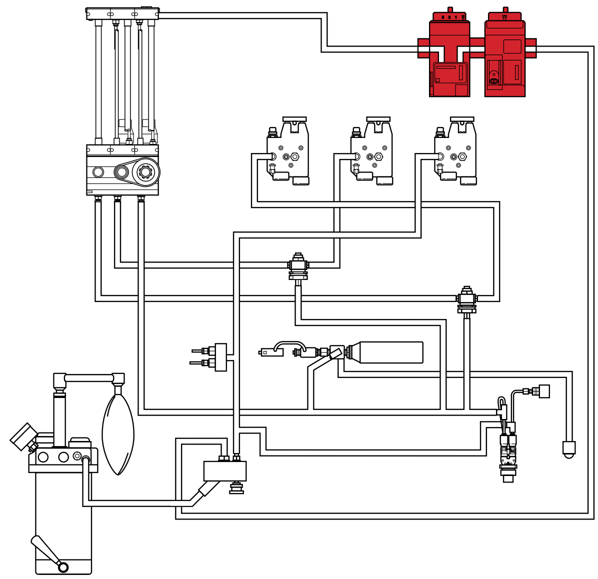
The illustration on the facing page shows how gas flows through the vaporizer manifold. When a vaporizer is ON, gas flows through the vaporizer. When a vaporizer is OFF, gas flows around the vaporizer.

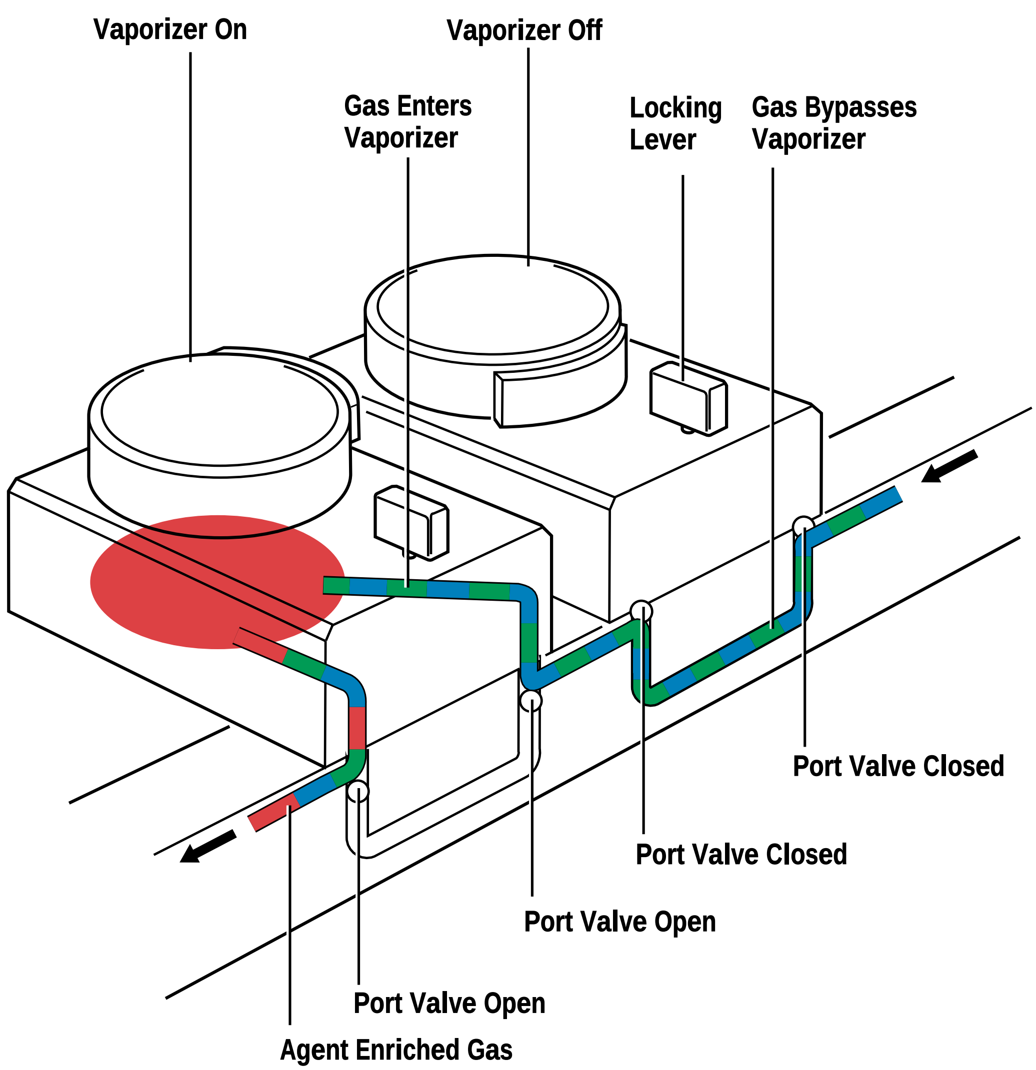
The vaporizer on the left in the illustration is ON. The mixed gas flows into this vaporizer. The vaporizer on the right is OFF. No gas flows through this vaporizer.

Illustration 32

Flow through the vaporizer manifold







- O_2
- N_2O
- Air

INTRODUCTION

Before modern vaporizers, the anesthesiologist put drops of anesthetic liquid on a mask over the patient's nose and mouth. The dosage was approximate.

Today's calibrated vaporizer holds the liquid anesthetic, and adds a set concentration to the mixed gas before it flows to the breathing circuit.

Because anesthetic agents have different physical and clinical properties, vaporizers are calibrated and identified with a label for use with one agent.

This section discusses anesthesia vaporizers. At the end of this section, the reader should know:

- Why each anesthetic agent has its own vaporizer.
- How liquid agent is changed to vapor and introduced into the gas flow.
- How pressure and temperature change the output of the vaporizer.

HOW A VAPORIZER OPERATES

THE VAPORIZER

Inhaled anesthetics agents are volatile liquids. They change easily from a liquid to a gas. During this process, they take some energy from their surroundings in the form of heat.

Vaporizers keep a portion of the mixed gas in contact with the anesthetic agent until the gas has absorbed all of the agent vapor it can hold at the current temperature and pressure. At this point, the gas is saturated.

The concentration control dial sets a valve that splits the gas flow as it enters the vaporizer. A thermostatically controlled valve changes how much of the gas flows through the vaporizer chamber to give the correct output concentration.

Temperature changes affect the output of the vaporizer. The fresh gas flow through the vaporizer also lowers the temperature inside the vaporizer. At higher flows, more agent changes to a vapor. This causes the vaporizer to become colder.

The vaporizer is constructed of materials that transfer heat quickly to keep all of the vaporizer parts at the same temperature. The materials used vary with the agent, and this why some vaporizers are heavier than others.

Fluctuations in barometric pressure, constant back pressure in the patient circuit, and short-term pressure variations during the breathing cycle may cause minor changes in vaporizer output. Selectatec® Series vaporizers compensate for normal breathing circuit pressure changes.

EXTERNAL COMPONENTS

The illustration on the facing page shows control locations on several types of vaporizers.

Control dial and release

The control dial sets the anesthetic dosage. The release must be pushed to turn the dial. The vaporizer must be filled with the agent for which it is labeled. If a vaporizer is used with an incorrect agent, the output of the vaporizer will probably not be the same as the control dial setting.

Safety lock lever

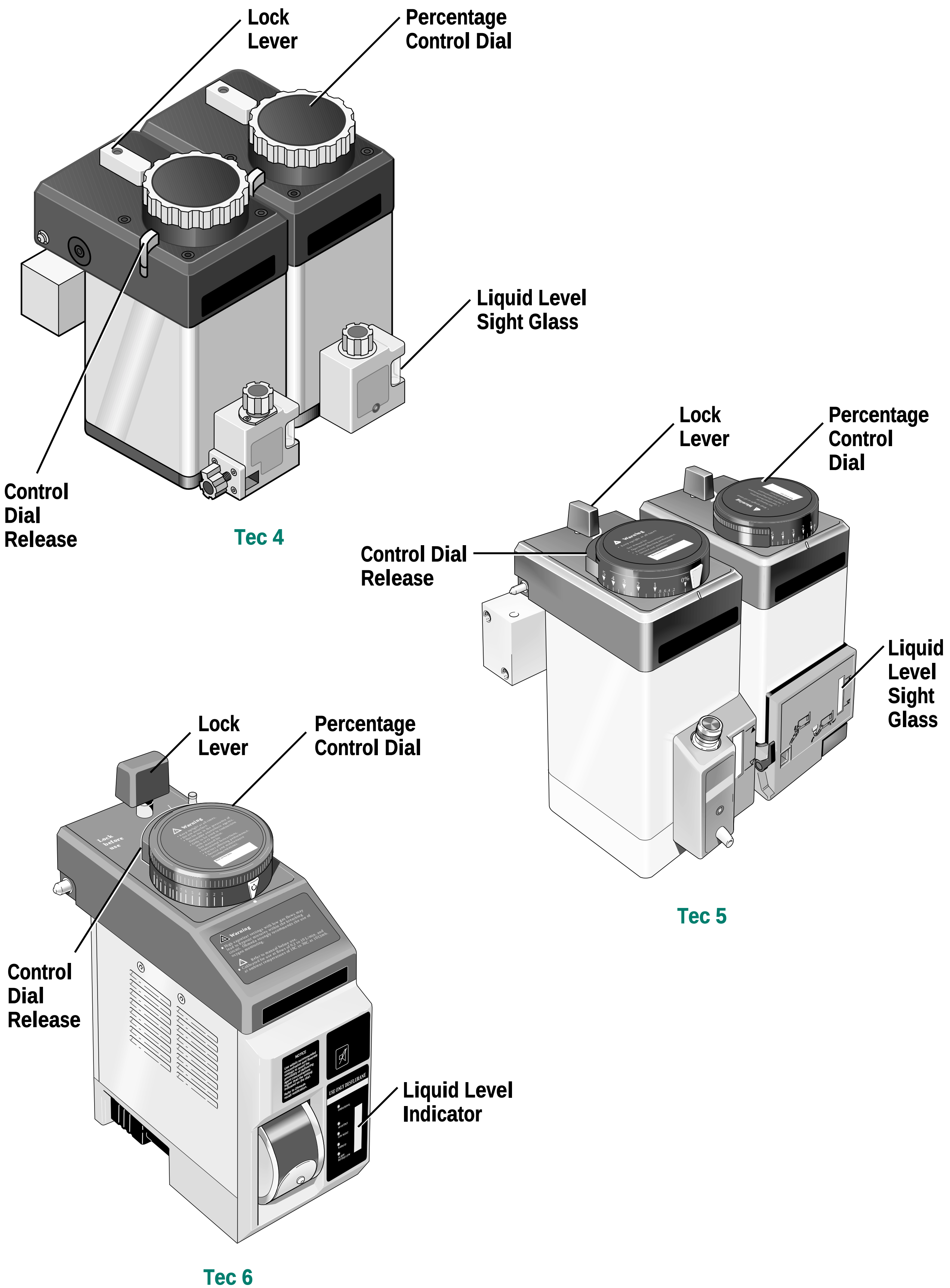
A safety lock connects to a lock lever and spindle on the vaporizer. This is a safety device to help prevent atmospheric pollution. The vaporizer cannot be turned ON unless it is locked on the manifold. Also, the vaporizer cannot be unlocked and removed unless it is first turned OFF. This ensures that the vaporizer stays OFF when it is not installed on the manifold.

Liquid level indicator

A window or electronic indicator on the front of the vaporizer shows the liquid level. With a glass window, the liquid agent can be seen directly.

Illustration 33

Tec 4, Tec 5, and Tec 6 vaporizers



TEC 4 VAPORIZER

A Tec 4 vaporizer holds approximately 125 mL of liquid and has a glass tube to show how much liquid agent is in the vaporizer. The control dial on the vaporizer can be adjusted from OFF to 5-7% depending on the agent. There are several models of the Tec 4, one for each agent. The labels use a color code to identify the agent.

The illustration on the facing page shows the flow of gas through the vaporizer. When the Tec 4 vaporizer is turned ON, the port valves are pushed open and gas flows into the vaporizer.

The vaporizer control valve divides the gas into two flow streams. No agent is added to the first stream, which bypasses the vaporizing chamber and flows to the outlet of the vaporizer.

The second flow stream flows into the vaporizing chamber. The outlet of the vaporizing chamber is a spiral helix that buffers intermittent pressure changes in the breathing circuit. Two wicks line the outlet. The wicks keep the gas in contact with the liquid agent. This ensures that the gas is saturated when it flows out of the vaporizing chamber.

When the control dial is turned to set the concentration, the position of the control rotary valve is changed. This increases or decreases the resistance in the vaporizing flow stream to change the flow of gas through the vaporizing chamber.

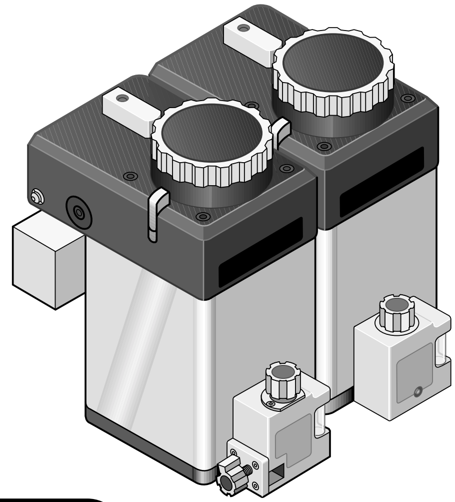
The amount of agent added to the gas in the vaporizing chamber changes with the temperature. At higher temperatures, the gas holds more vapor. The flow rate through the vaporizer also changes the temperature. At higher flows, more agent changes to a vapor. This cools the vaporizer.

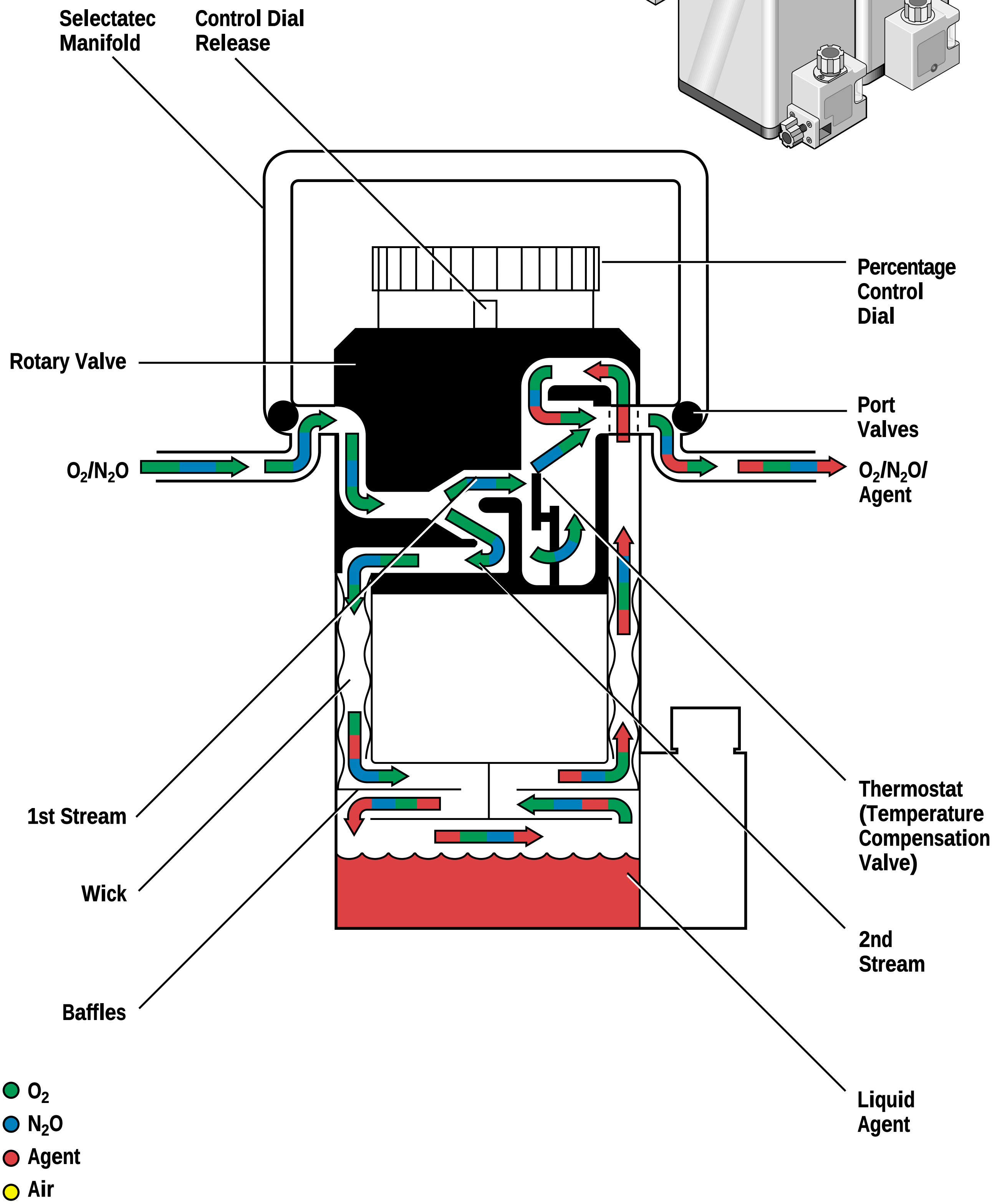
The Tec 4 vaporizer has a thermostat controlled valve to help keep the output constant when the temperature changes. The thermostat uses two strips of different metals bonded together. The metal strips contract or expand differently. This causes the thermostat to bend as the temperature changes and adjusts the flow through the vaporizing chamber. If the temperature decreases, the thermostat closes and more gas flows through the vaporizing chamber. If the temperature increases, the thermostat opens and less gas flows into the vaporizing chamber.

The vaporizer and the vaporizer manifold have a safety interlock system that prevents more than one vaporizer being turned on at the same time. This system includes a safety lock or release button adjacent to the control dial to help ensure that the vaporizer cannot be turned ON unless it is correctly installed. A system of baffles in the vaporizer decreases the risk that liquid agent will leak into the control rotary valve if the vaporizer is tipped more than 45°.

Illustration 34

Flow through a Tec 4 vaporizer





TEC 5 VAPORIZER

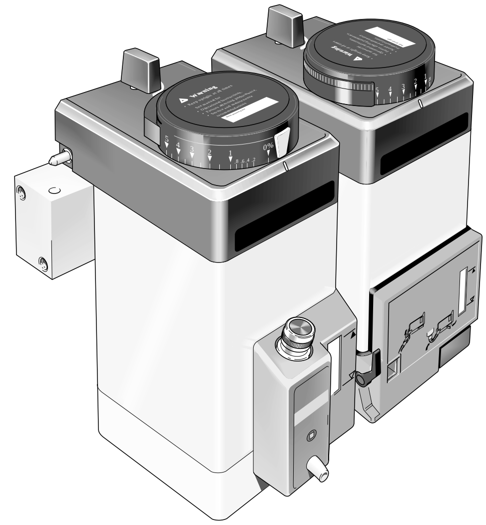
A Tec 5 vaporizer holds approximately 300 mL of liquid and has a glass prism to show how much liquid agent is in the vaporizer. The prism highlights a black background to show the liquid level. The result looks like a bar graph. The dial can be adjusted from OFF to 5-8%, depending on agent type, with an expanded scale below 1%.

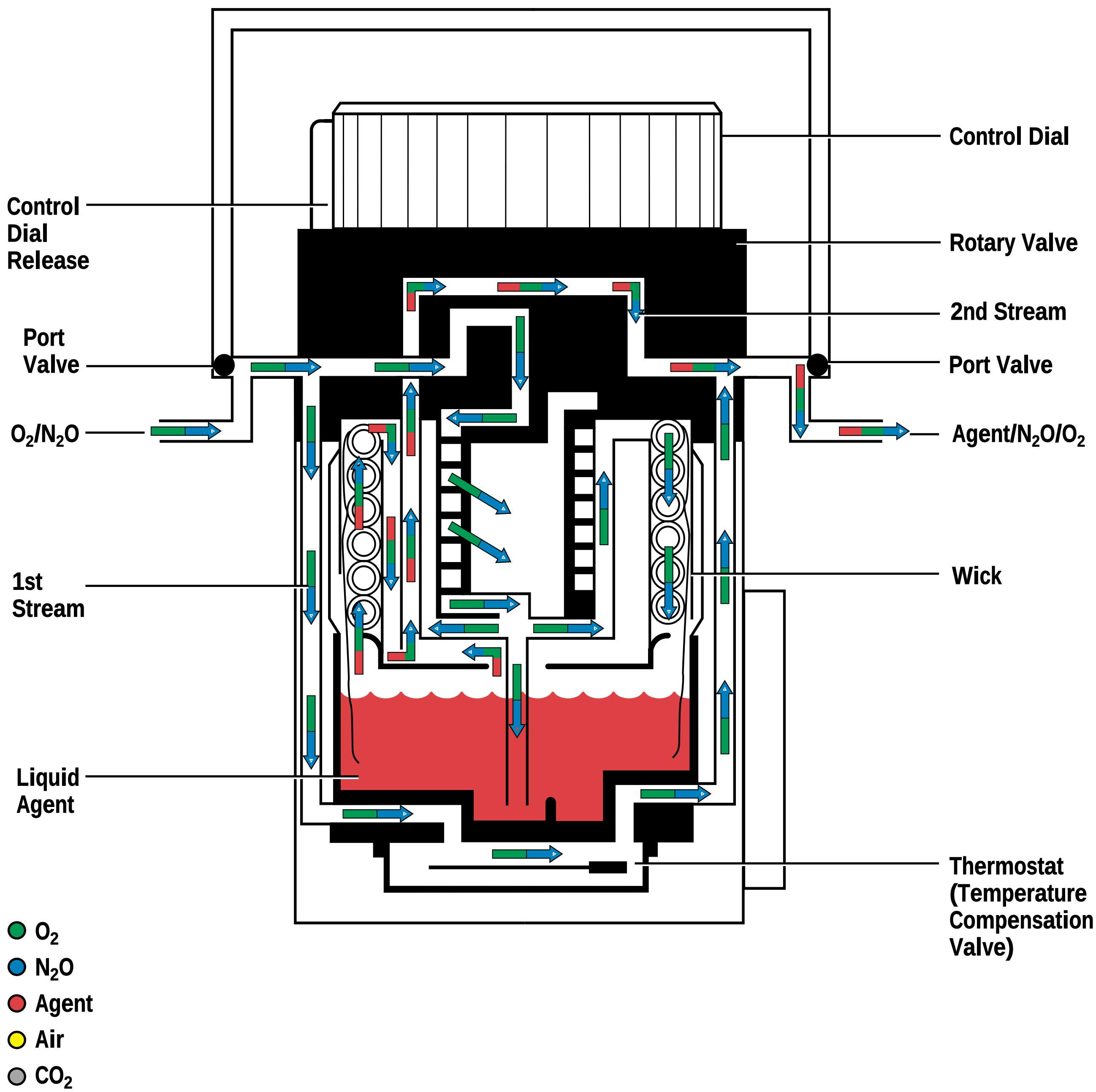
Labels on Tec 5 vaporizers employ a color code to identify the agent that can be used in a particular vaporizer.

The Tec 5 vaporizer operates very much like the Tec 4, with only minor changes to components and their locations within the vaporizer.

Illustration 35

Flow through a Tec 5 vaporizer





TEC 6 VAPORIZER

The Tec 6 vaporizer uses desflurane. Unlike the Tec 4 and 5, the Tec 6 heats the agent and keeps it pressurized. This is necessary because desflurane boils near room temperature (22.8°C or 73°F), and the higher temperature keeps desflurane in the vapor state during mixing within the vaporizer.

A Tec 6 vaporizer holds approximately 400 mL of liquid and has an electrical indicator to show how much liquid is in the vaporizer. The control dial on the vaporizer can be adjusted from OFF to 18%. The Tec 6 permits higher concentration settings because desflurane is not as potent as other anesthetic agents.

The Tec 6 adds agent vapor to the mixed gas from the anesthesia machine. The control dial adjusts the flow of agent vapor. Two heaters in the sump keep the agent at approximately 39°C (102°F). This supplies the operating vapor pressure. Two heaters at the top of the vaporizer help prevent condensation when the warm agent vapor meets the cooler gas from the anesthesia machine.

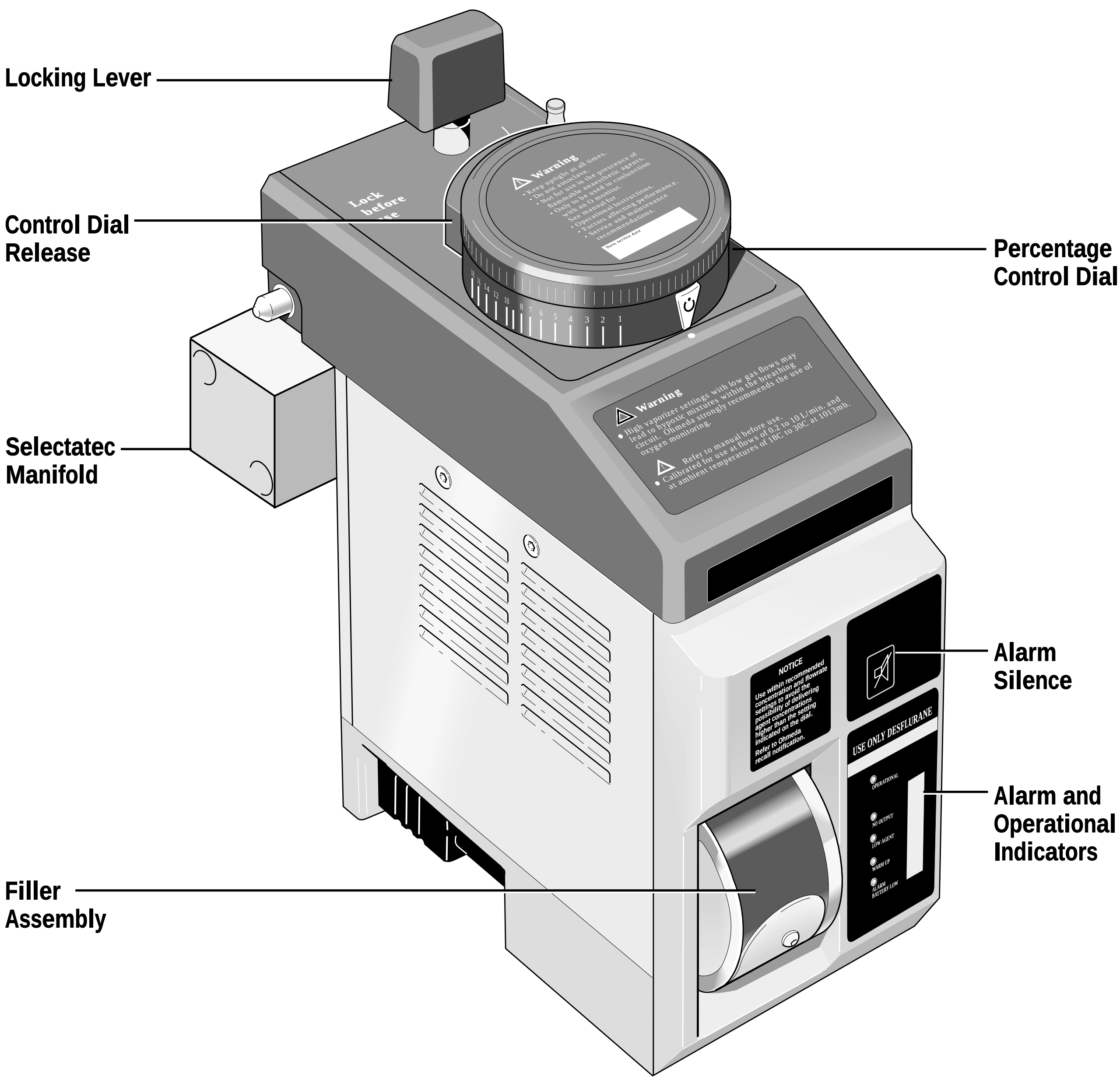
The Tec 6 operates by maintaining agent vapor from the control valve and fresh gas at the same pressure when they are mixed in the rotary control valve. The vaporizer uses transducers to measure the two pressures. Then it adjusts the control valve as necessary to regulate the pressure of the vapor downstream of the valve.

The Tec 6 has several safety devices:

- An interlock mechanism locks the control dial until the agent reaches the correct pressure and the warm-up indicator goes OFF.
- An electrical shutoff valve prevents vapor flow until the agent reaches the correct pressure.
- The tilt switch causes an alarm and stops vaporizer output if the vaporizer is tilted during operation.
- Indicators and/or an alarm speaker alert the operator if: the vaporizer is operational; there is a power failure; the alarm battery voltage is low; the agent level is low; vapor and gas pressures are out of tolerance; or an internal malfunction is preventing output.

Illustration 36

Tec 6 vaporizer



TEC 6 ALARM AND OPERATIONAL INDICATORS

The illustration on the facing page shows the visual indicators. The alarm silence switch is above the indicators.

The amber WARM-UP indicator comes on when the vaporizer is in its warm-up mode. The control dial cannot be turned when this indicator is ON.

The green OPERATIONAL indicator comes ON when the warm-up mode ends. The clinician can turn the vaporizer dial ON when this is green.

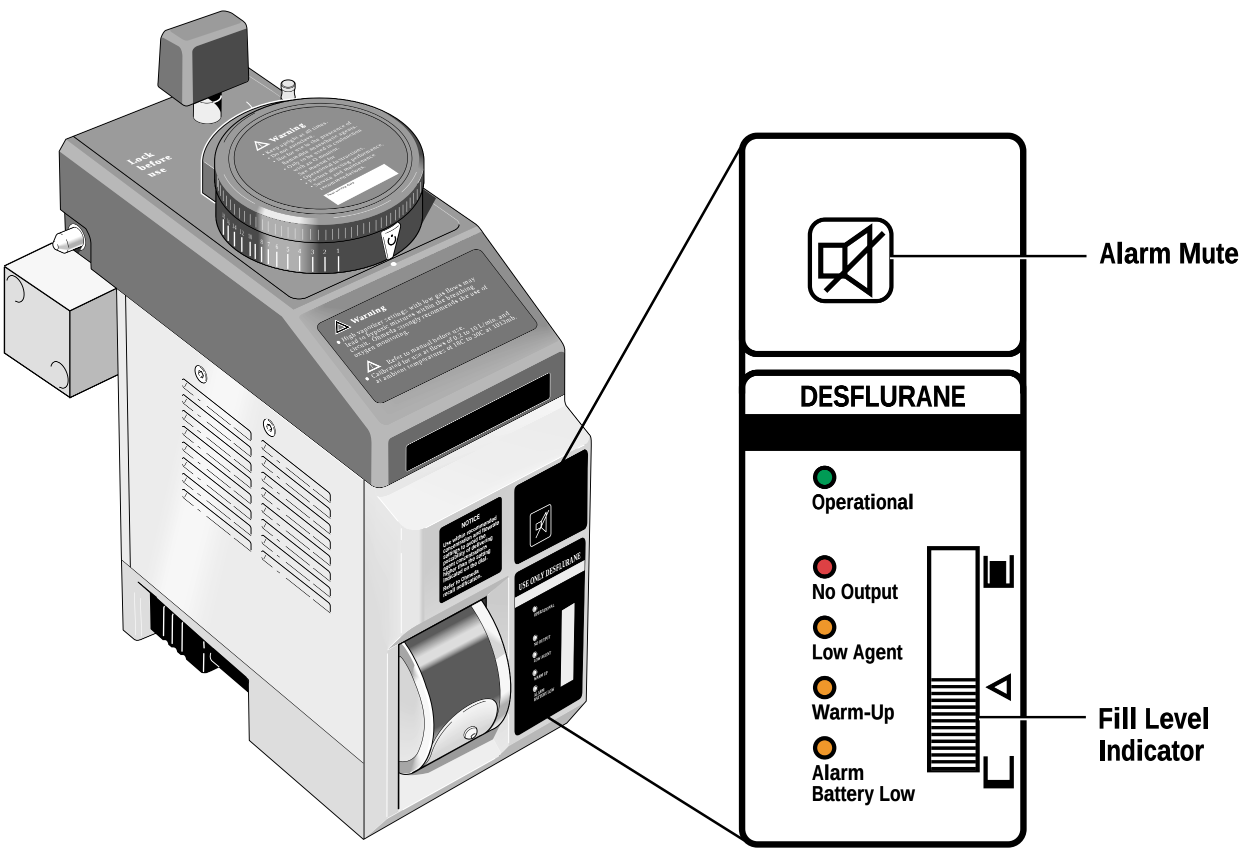
The red NO OUTPUT indicator comes on when the vaporizer cannot add agent vapor to the gas flow due to lack of agent, tilting, or a malfunction.

The LOW AGENT indicator comes on if the vaporizer has less than 250 mL of liquid agent in the sump.

The amber ALARM BATTERY LOW light comes on continuously when the alarm battery voltage is low. There is not an audible alarm during this alarm condition.

Illustration 37

The Tec 6 vaporizer alarms and operational indicators



TEC 6 SENSORS AND SWITCHES

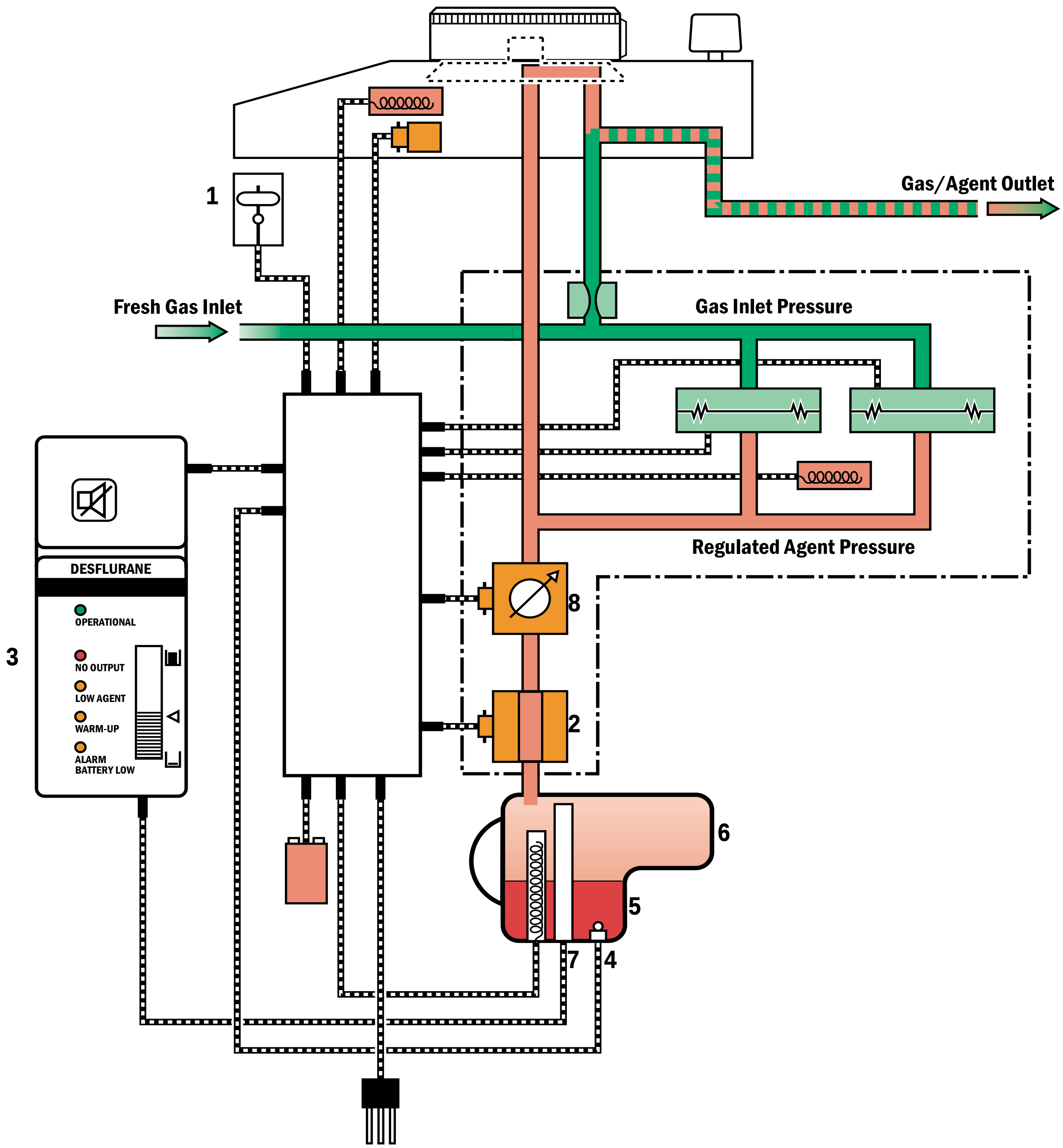
The tilt switch (1) senses if the vaporizer is tilted past 10° and sends a signal to the control electronics. The control electronics send signals to the shutoff valve (2) to shutoff flow, and to the front display panel to activate the no output alarm (3).

The level switch (4) senses the liquid agent level (5) in the sump (6). If the agent level is low, it sends a signal to the electronics to activate the low agent alarm indicator.

The level sensor (7) senses the level in the sump and sends a signal to the control electronics to turn on the LEDs in the bar indicator to indicate the liquid level.

Illustration 38

Tec 6 sensors and switches



Fresh Gas

Agent Vapor

Gas/Agent Vapor

Electrical Connections

1 Tilt Switch
2 Shutoff Valve
3 No Output Alarm
4 Level Switch
5 Liquid Agent
6 Sump Assembly
7 Level Sensor
8 Control Valve

TEC 6 POWER SUPPLY AND HEATERS

The Tec 6 vaporizer uses approximately 120 or 240 V and must be connected (1) to an approved hospital-grade outlet. The electrical connector to the vaporizer is on the bottom of the vaporizer.

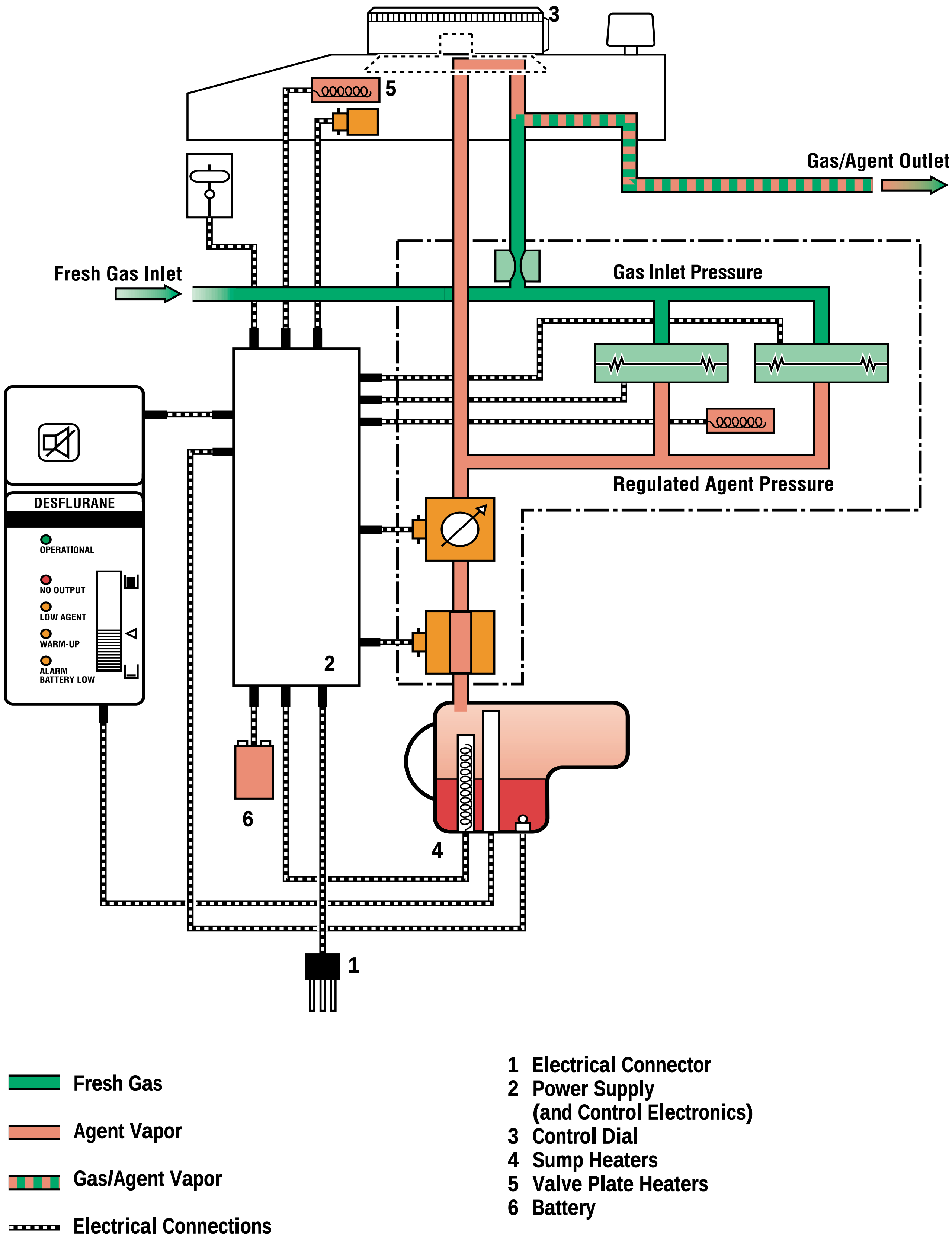
The internal power supply unit (2) supplies the 12 volts DC and 5 volts DC for the electrical system.

The Tec 6 vaporizer uses very little power when it is up to temperature and the control dial (3) is set to 0%. When the vaporizer is ON, the two sets of heaters in the sump (4) and the valve plate (5) cycle ON-and-OFF to use less current. If the vaporizer is always connected, no warm-up time is necessary. The vaporizer heaters may cause the vaporizer to feel warm when it is connected to the electrical supply.

The battery (6) powers only the alarms.

Illustration 39

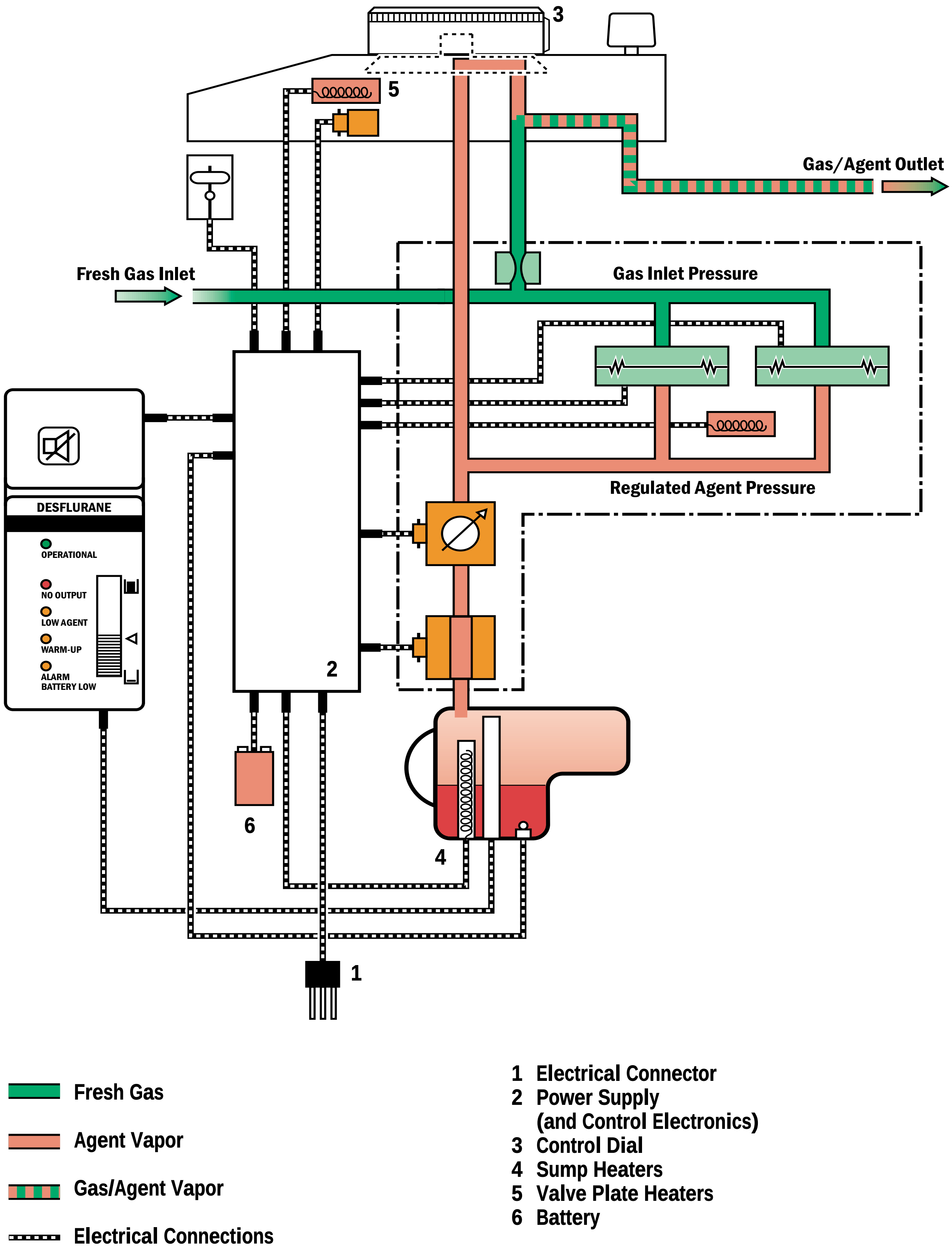
Tec 6 power supply heaters



1 Electrical Connector
2 Power Supply
(and Control Electronics)
3 Control Dial
4 Sump Heaters
5 Valve Plate Heaters
6 Battery

Illustration 39

Tec 6 power supply heaters



1 Electrical Connector
2 Power Supply (and Control Electronics)
3 Control Dial
4 Sump Heaters
5 Valve Plate Heaters
6 Battery

FLOW THROUGH THE TEC 6

The illustration on the facing page is a flow diagram of the Tec 6 vaporizer.

When the electrical supply is first connected, each light and each LCD agent level display bar on the front panel display flashes. The alarm sounds for a moment to show that the alarms are operational. After about one second, each light goes off, the LCD bars stop flashing, and the audible alarm stops.

The amber WARM-UP light (1) turns on to show that the vaporizer is in its warm-up cycle, and the LCD agent level display bars show the amount of agent in the vaporizer sump (2).

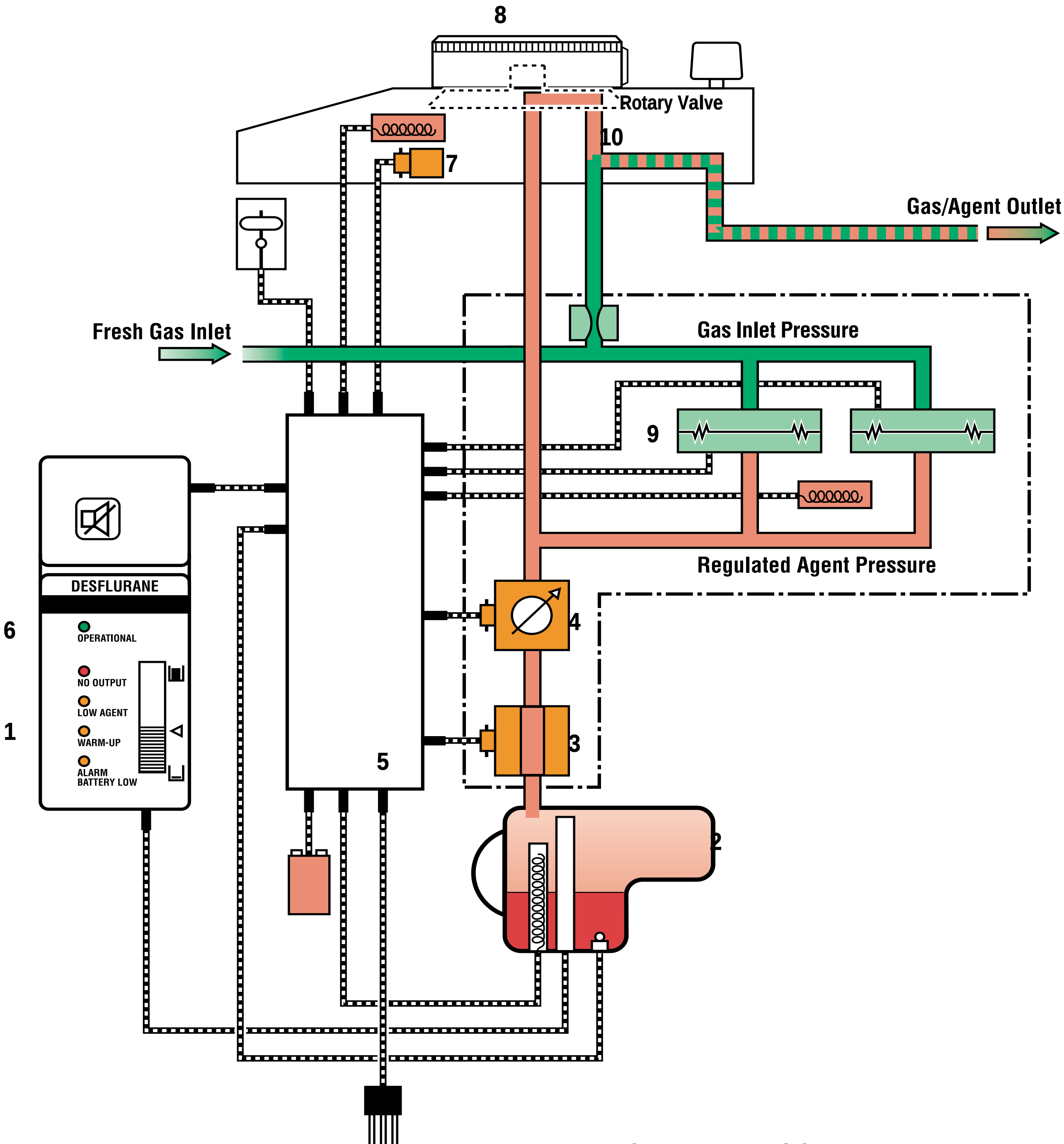
During the warm-up cycle, the shutoff valve (3) is closed to block the supply of vapor to the pressure regulating control valve (4). The electronics controlling the vaporizer (5) perform a “zero” check.

When the vaporizer reaches the correct operating temperature, the amber WARM-UP light goes off and the green OPERATIONAL light (6) turns on. This means that the vaporizer is ready for use.

- When the vaporizer is prepared for use, a signal from the control electronics (5) operates the solenoid (7) in the interlock mechanism, enabling the dial and rotary valve (8) to be turned.
- When the dial and rotary valve (8) are turned, a signal from the control electronics (5) opens the shutoff valve (3).
- The pressure transducer (9) sends a signal of the difference in the fresh gas inlet pressure and the regulated agent pressure to the control electronics (5). The control electronics maintains the required pressure differential between the fresh gas inlet pressure and the regulated agent pressure by opening or closing the pressure regulating control valve (4) to balance the pressures.
- The dial and rotary valve (8) in the illustration provides an adjustable pneumatic restriction that allows mixing of the agent vapor with the fresh gas mixture.
- Due to the electronics controlling the pressure differential across the rotary valve, the fresh gas and agent vapor (10) mixing is directly controlled by the position of the rotary valve. Therefore, the dial on the rotary valve can be marked with the percentage agent output corresponding to valve position.

Illustration 40

Tec 6



Fresh Gas

Agent Vapor

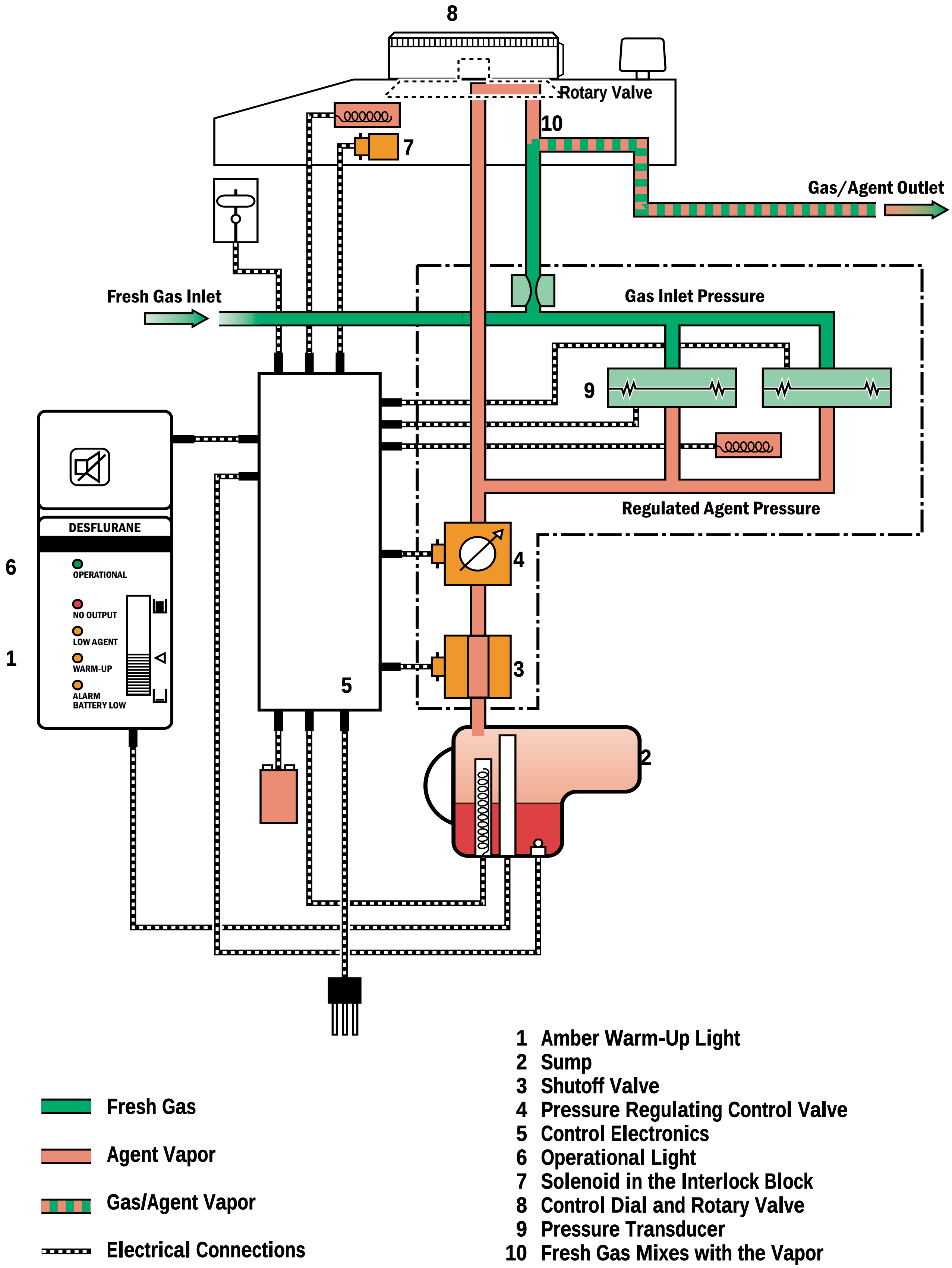
Gas/Agent Vapor

Electrical Connections

1 Amber Warm-Up Light
2 Sump
3 Shutoff Valve
4 Pressure Regulating Control Valve
5 Control Electronics
6 Operational Light
7 Solenoid in the Interlock Block
8 Control Dial and Rotary Valve
9 Pressure Transducer
10 Fresh Gas Mixes with the Vapor

Illustration 40

Tec 6



1 Amber Warm-Up Light
2 Sump
3 Shutoff Valve
4 Pressure Regulating Control Valve
5 Control Electronics
6 Operational Light
7 Solenoid in the Interlock Block
8 Control Dial and Rotary Valve
9 Pressure Transducer
10 Fresh Gas Mixes with the Vapor

DRAINING AND FILLING THE VAPORIZERS

Before filling a vaporizer, the operator should always make sure that the vaporizer label is the same color as the label on the bottle of agent. The vaporizer labels, the bottle labels, caps, and adapters use the color code to identify the agent.

Agent Color Codes

(as shown on vaporizers)

Halothane

Isoflurane

Enflurane

Desflurane

Sevoflurane

TEC 4 AND TEC 5 VAPORIZERS

Tec 4 and Tec 5 vaporizers use funnel-fill or key-fill ports.

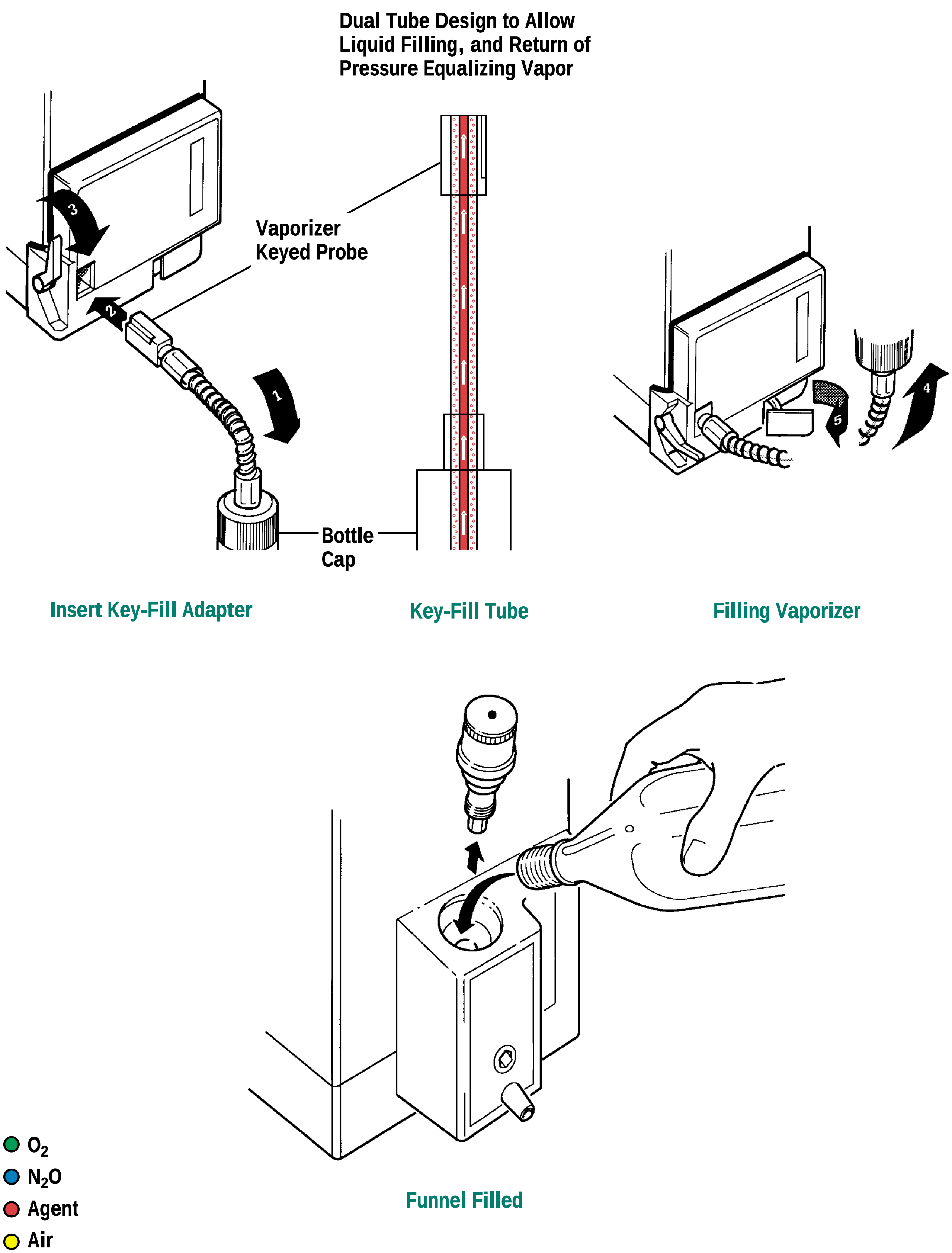
With a funnel-fill port, a port on the front of the vaporizer is opened and the agent is poured directly from the bottle into the vaporizer. The operator should read the labels to make sure that the vaporizer is being filled with the correct agent.

With a key-fill port, an adapter is used to connect the bottle to the fill port. One end of the adapter fits into the fill port and the other end fits into a keyed opening on the bottle. During filling, the filler tube assembly provides a tube for liquid to flow to the vaporizer, and a second tube to allow vapor return which equalizes pressure.

For draining a similar principal applies, with liquid returning to the bottle, and vapor entering the vaporizer to equalize pressure. To fill or drain a Tec 4 or Tec 5 vaporizer, the operator sets the control dial to OFF and follows the instructions in the Operation and Maintenance manual. Tec 4 and Tec 5 vaporizers with key-fill ports use different procedures. The Tec 4 requires extra steps to equalize the internal pressure.

Illustration 41

Tec 5 Filler ports



TEC 6 VAPORIZER

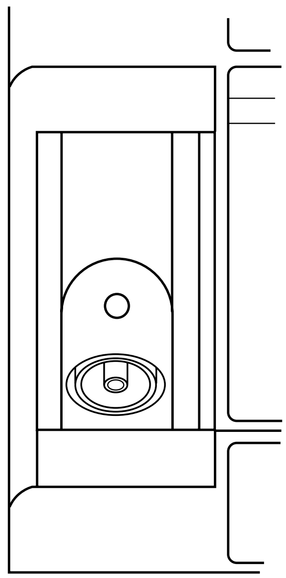
The Tec 6 vaporizer has a fill port that includes a keyed fitting. Only a desflurane bottle with a "Saf-T-Fill" valve can be used to fill the vaporizer. A Tec 6 vaporizer can be filled when it is "cold" (not connected or OFF), during warm-up, or when it is in use.

If a Tec 6 vaporizer is filled while it is warm, bubbles form in the agent bottle, the pressure of the agent in the bottle increases, and the vaporizer fills more slowly. This occurs because the vapor pressure and the temperature in the sump are higher than the pressure and the temperature in the bottle. Very little agent transfers from the bottle to the vaporizer during the first 30-40 seconds. After the temperature and the pressures are almost equal, the agent starts to flow. As the vaporizer fills, the agent in the bottle begins to bubble. The Tec 6 vaporizer takes longer to fill if the bottle of desflurane is cold. Desflurane bottles should be kept in a cool location, but not in a refrigerator.

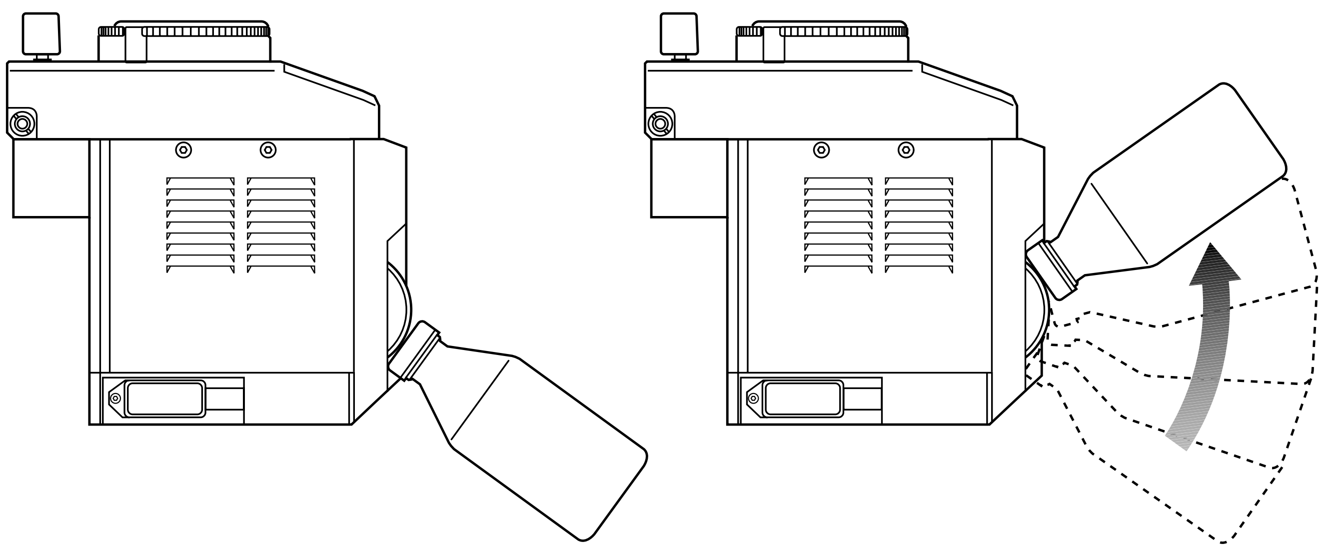
Complete filling instructions can be found in the Operation and Maintenance Manual.

Illustration 42

A fill port



Tec 6 Fill Port



Filling the Tec 6 Vaporizer

PREOPERATIVE CHECKOUT

Vaporizers should undergo leak tests. The Tec 4, 5 and 6 vaporizers can be checked with both negative and positive pressure leak tests. (The vaporizer leak check should be performed as described in the Operation and Maintenance manual for the related anesthesia system).

Note: Because Halothane contains the preservative Thymol, that can leave an unwanted residue, Halothane vaporizers should be drained at least every two weeks.

PROBLEM SOLVING

Incorrect Filling

If a vaporizer is filled (or charged) with an incorrect agent, some of the agent will be absorbed by the wick. The vaporizer must be removed from service. All liquid in the vaporizer must be drained and discarded. The vaporizer must be dried out by flowing 5 L/min of oxygen through it with the control dial turned to its maximum position. This procedure to dry the vaporizer must continue until agent can no longer be detected at the vaporizer outlet. The vaporizer temperature should then be allowed to stabilize at room temperature before the operator proceeds.

Note: Such a drying procedure will not remove thymol, the preservative in halothane, from a non-halothane vaporizer. In this situation, the vaporizer should be serviced in accordance with the manufacturer's instructions.

Agent Reuse

The practice of putting unused agent from the vaporizer back into a bottle to be used later could lead to errors and is not recommended. If an agent is put into an incorrect bottle, an incorrect agent could be put into the next vaporizer. Reusing agent bottles could also lead to incorrect information about the expiration date of the liquid in the reused bottle.

Tipping the Vaporizer

Different vaporizers have different limits to how far they can be tipped. This information is usually contained in the Operation and Maintenance Manual for the specific vaporizer. If a vaporizer is tipped too far, the liquid agent can leak into the central mechanism, where it will vaporize without control. This could result in a dangerously high output of agent to the patient. If the vaporizer is tipped further than the recommended specifications, the vaporizer must be purged. Flow 5 L/min of oxygen through the vaporizer, with the control dial turned to its maximum position, for 30 minutes. Following this procedure the vaporizer's output concentration must be verified before use.

INTRODUCTION

COMMON GAS BLOCK

The last component in the anesthesia machine that we will discuss is the common gas block. The mixture of gases from the flowtubes and anesthetic agent from a vaporizer that is ON flows from the vaporizer manifold to the common gas block. The mixture flows out of the anesthesia machine through the common gas outlet in the common gas block.

The common gas block is an assembly that includes four sub-assemblies:

- The oxygen flush button, discussed in an earlier chapter: provides a high flow of oxygen to the gas mixture supplied to the patient.
- The common gas outlet: fresh gas mixtures exit the anesthesia machine through it. When a common gas hose is connected to the outlet, the gas mixture flows through the hose to the absorber.
- The common gas outlet check valve: permits the gas mixture to flow in only one direction, from the flowtubes and vaporizer manifold to the common gas outlet.
- The pressure relief valve: opens to vent gas flow if pressure at the common gas outlet exceeds approximately 5.5 psig.

After reading this section, the reader should know:

- How to select the correct gas supply tubing to use at the common gas outlet.
- How the common gas outlet check valve works.
- Why the pressure relief valve is used in the anesthesia machine.
- How the pressure relief valve works.

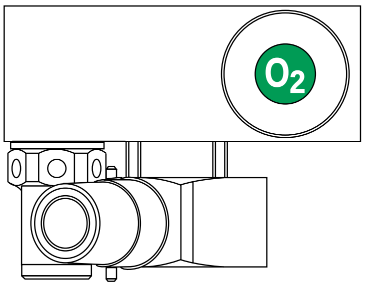
COMMON GAS OUTLET AND COMMON GAS SUPPLY HOSE

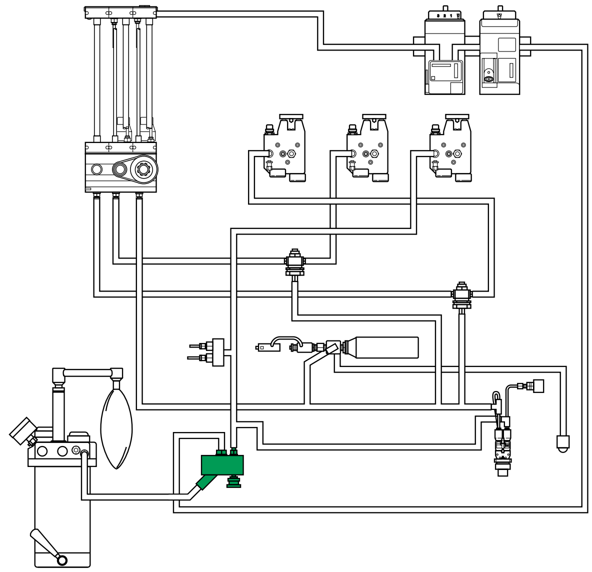
The common gas outlet is located on the front of the anesthesia machine near the oxygen flush button. A common gas hose is connected between the common gas outlet and the absorber. The gas mixture selected by the user flows from the anesthesia machine through the hose to the absorber.

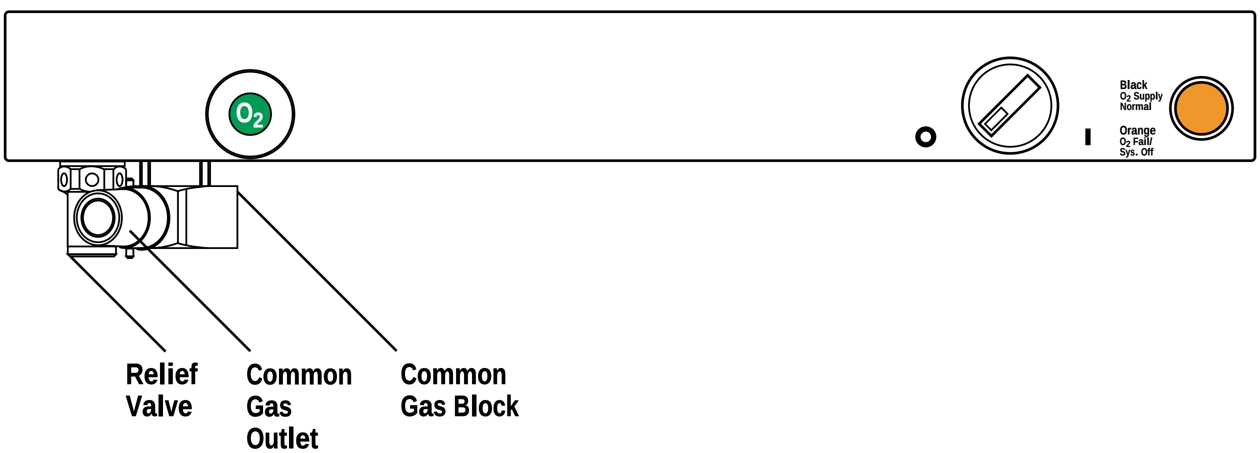
A bayonet-style adapter on the common gas hose connects to the outlet and helps prevent the hose from being accidentally disconnected. The illustration on the facing page shows the location of the common gas outlet and how the adapter on the hose connects to the outlet. Pins on the outlet match notches on the adapter. Tension from the spring inside the adapter holds the notches in place around the pins. The adapter is removed from the outlet by pressing the adapter toward the outlet and twisting the notches away from the pins.

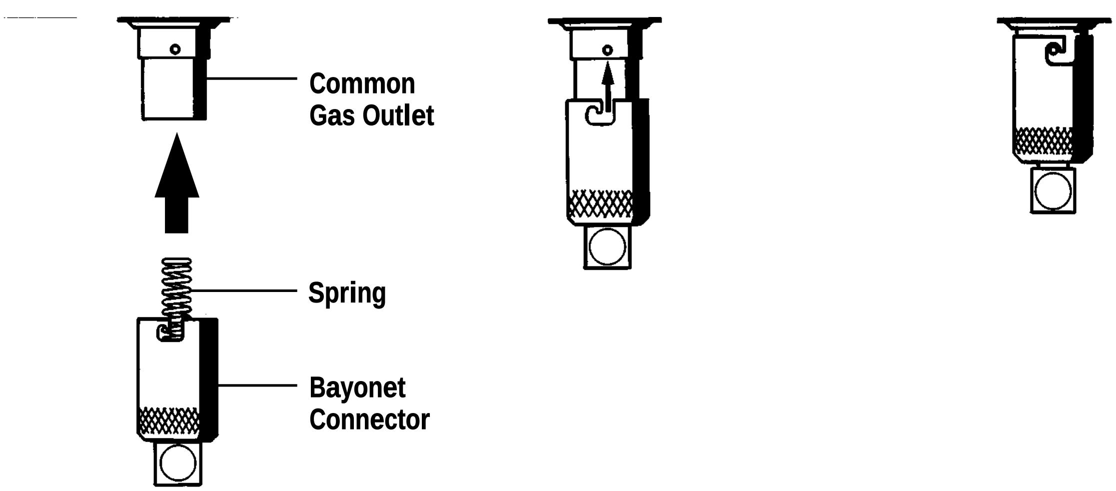
Illustration 43

Common gas outlet





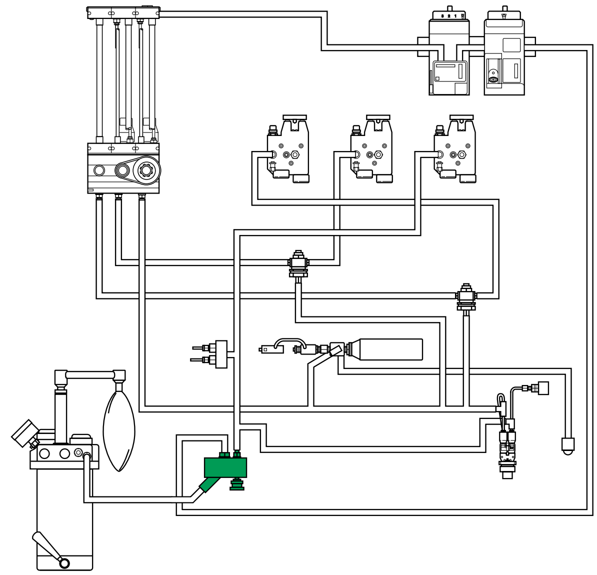


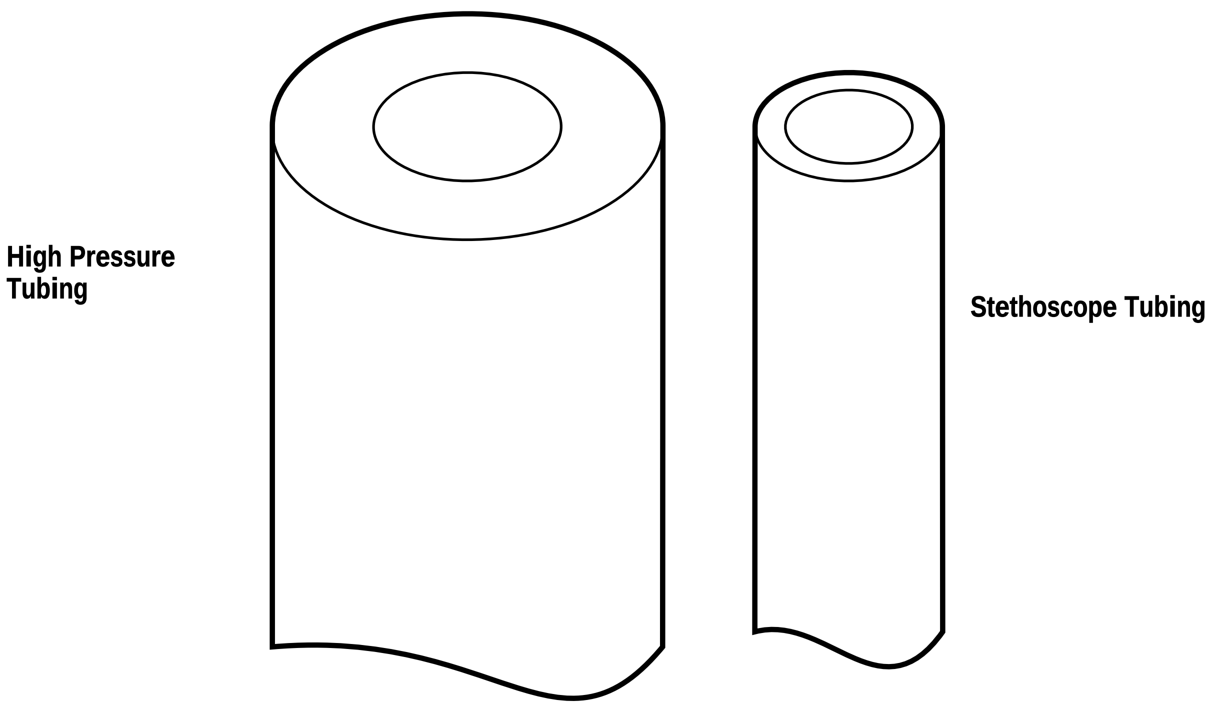


Two examples of tubing are shown in the illustration on the facing page. The tubing on the right is the kind used for stethoscopes. On the left is high pressure tubing used in gas supply systems. Only high pressure tubing should be used between the common gas outlet and the absorber. It has a larger internal diameter (1/4" I.D.) to reduce flow resistance and back-pressure. Because it has a thicker wall, it is not easily kinked and is less susceptible to splitting under high gas pressures. Lightweight, thin-walled tubing should not be substituted for gas delivery to any type of patient breathing system.

Illustration 44

Two different types of tubing





COMMON GAS OUTLET

When gas flow is in a reverse direction, toward the vaporizer manifold, pressure in a vaporizer or flowtube can increase. This is known as back-pressure. Pressures added to the breathing circuit by accessory equipment, such as ventilators, sometimes cause reverse flow and back-pressure. Pressure at the common gas outlet can increase, and cause back-pressure, if the flow of gas out of the common gas outlet is restricted.

Back-pressure added to the normal pressure in a flowtube can cause the float to drop to a lower position in the tube. If this happens, the float position provides a less accurate indication of gas flow. If high back-pressure is added to the pressure in a vaporizer, it can affect the output concentration of the vaporizer. The illustration on the facing page shows how the outlet check valve and the relief valve, both located in the common gas block, work together to help prevent gas flow toward the vaporizer manifold.

OUTLET CHECK VALVE

The outlet check valve is a flexible valve shaped like an umbrella. It opens to permit gas flow from the vaporizer manifold to the common gas outlet. When the direction of gas flow is from the manifold toward the common gas outlet, the pressure of the gas pushes the valve off the seat and the gas mixture flows past it to the outlet.

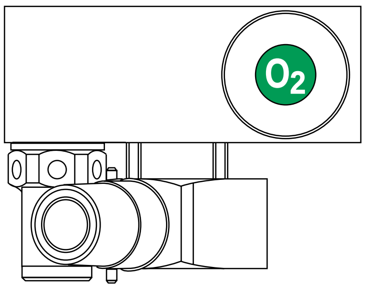
When the direction of gas flow is from the common gas outlet to the vaporizer manifold and flowmeter assemblies, the gas pressure pushes the valve against the seat and blocks the flow of gas to the vaporizers and flowmeters.

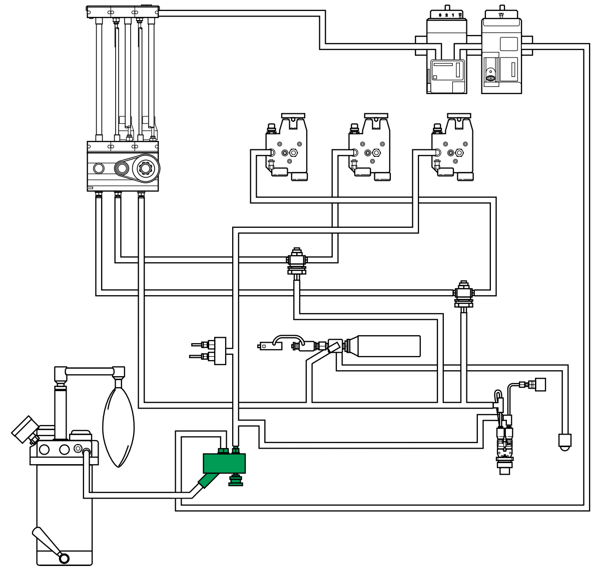
RELIEF VALVE

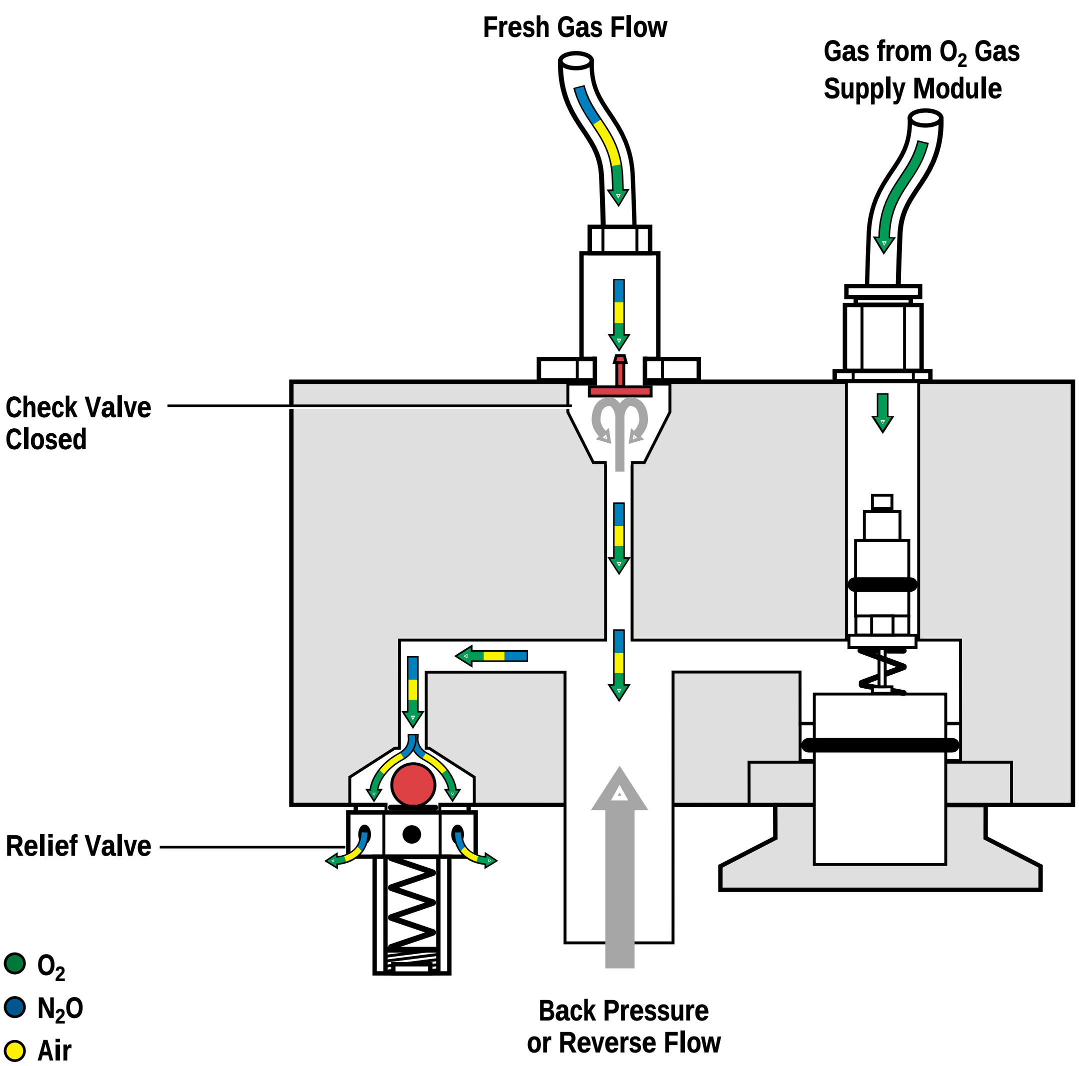
The purpose of the relief valve is to protect the internal components of the anesthesia machine. Inside the relief valve is a ball and spring. The force of the spring holds the ball against its seat and blocks the holes in the valve body. When pressure at the common gas outlet is approximately 5.5 psig, the spring force is overcome and the ball is lifted off the seat. This permits the gas to flow out the holes in the valve body and vents the excess gas pressure to atmosphere.

Illustration 45

How the check valve and relief valve operate







INTRODUCTION

VENTILATOR

During a surgical procedure, the patient is usually anesthetized and needs assistance to breathe. In most cases, a ventilator is used to control a breathing pattern for the patient.

An electronic ventilator:

- Recirculates exhaled patient gas through the absorber (where the carbon dioxide is removed and fresh gas is added to the mixture) with enough pressure to move the gas into the patient's lungs.
- Helps protect the patient from high airway pressure.
- Supplies rate, volume, oxygen, and pressure monitoring.
- Vents excess gas from the patient breathing circuit.

This section explains how the ventilator and its components operate, for the purpose of explanation it uses the 7800 ventilator. At the end of this section, the reader should know:

- How the controls on the ventilator can be set to change the breathing pattern.
- What the ventilator does during each phase of a breath.
- How safety devices help protect the patient from high pressures.
- How the monitors operate.

OVERVIEW OF MECHANICAL VENTILATION

The teaching model we are using, for the purposes of this book, is the Ohmeda 7800 series ventilator. Many anesthesia ventilators have a control module and a bellows assembly. The control module includes electronic circuits and pneumatic components. The bellows is part of the patient breathing circuit and can be mounted either directly to the control module, to the back of the absorber, or to a bracket on the anesthesia system. The illustration on the facing page shows the different ways the bellows assembly and control module can be installed on the anesthesia machine.

At the start of an inhalation, the bellows is inflated with fresh gas and recirculated exhaled gas from the patient breathing circuit. The ventilator control module meters gas from the pressured gas supply, called drive gas, to pressurize the bellows housing. The drive gas pressure pushes the bellows down and forces the gas mixture into the patient's lungs. This sequence is known as the inhalation phase of a breath.

At the end of the inhalation phase, the control module vents drive gas from the bellows housing out of the exhaust port, and allows gas to flow from the patient's lungs through the absorber and into the bellows. This sequence is known as the exhalation phase.

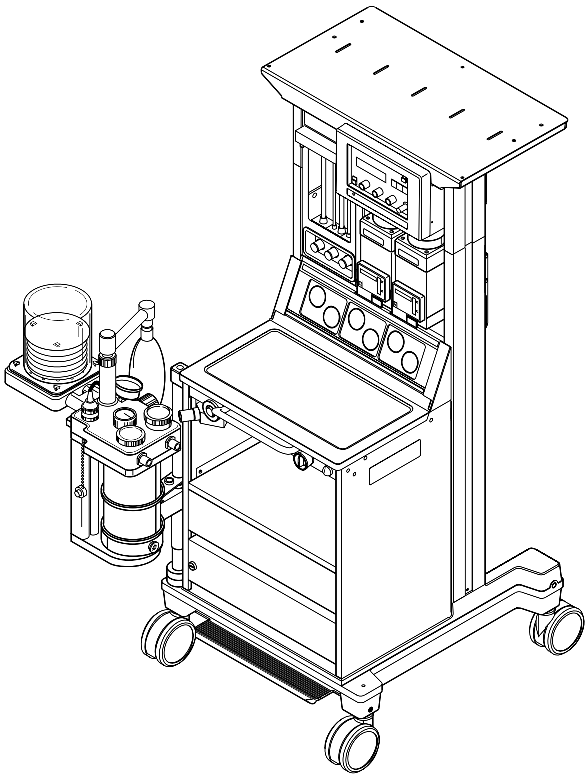
One property of a breathing pattern is the ratio of inhalation to exhalation time, or I:E ratio. Usually, the I:E ratio uses a "1" for the inhalation time and an appropriate number expressing the relative length for the exhalation time. If the inhalation time is greater than the exhalation time, the breath is said to have an inverse I:E ratio.

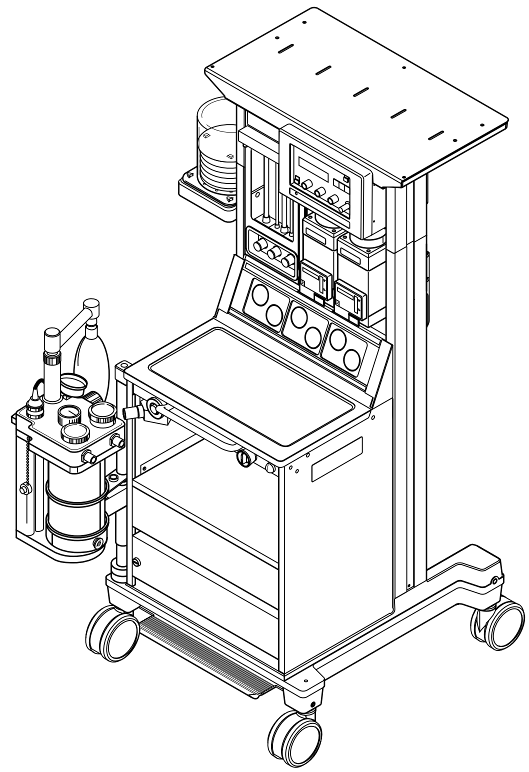
Controls on the front panel of the ventilator control module are used by the clinician to set how long the different phases of a breath last. When the clinician turns a control, the display window shows the control value or the I:E ratio. The display window alerts the operator if monitor alarm limits are exceeded, if gas supply pressure is too low, and if control settings are incorrect.

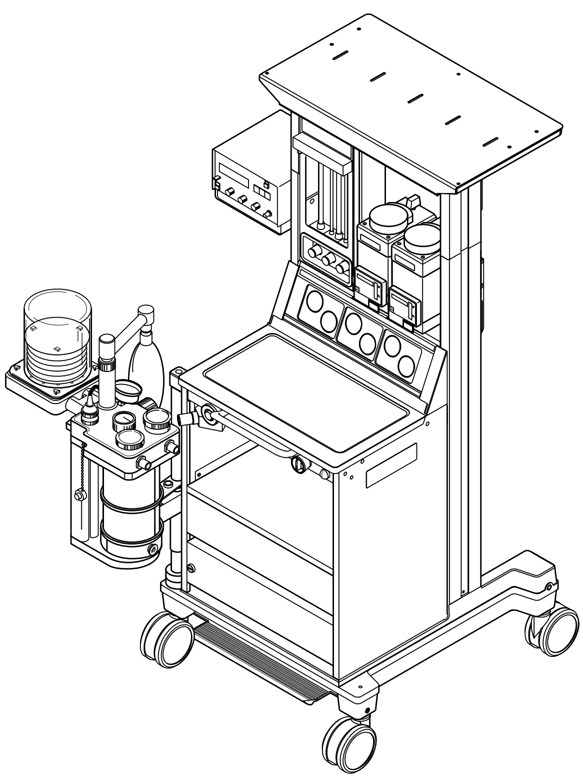
The ventilator contains a "set-up page" that permits the user to change the display contrast, the volume of alarms, and detection of reverse patient gas flow, as well as to turn the "sigh" function ON or OFF.

Illustration 46

Ventilator assembly mounting locations
on an Excel SE anesthesia machine







THE CONTROL MODULE

The control module of the ventilator is used to:

- Select the volume, rate, and limit the pressure of the gas to be delivered to the patient airway.
- Control components that allow inhalation or exhalation and to respond to high pressure in the patient airway.
- Display information about the percentage of oxygen in the gas supplied to the patient, and the volume of gas exhaled from the patient.
- Select alarm limits for oxygen percentage, airway pressure, and exhaled volume.
- Display and sound alarms when alarm limits are exceeded.

The control module includes:

- User controls and a display panel.
- A microprocessor and electronic circuits.
- Pressure regulators and transducers.
- Electronically controlled pneumatic valves that open and close to allow inhalation or exhalation.

CONTROL MODULE REAR PANEL

The illustration on the facing page shows the rear panel of the ventilator control module.

Electric Power Cable

The power cable attached to the back of the control module is used to connect the ventilator to an auxiliary electrical outlet on the anesthesia system.

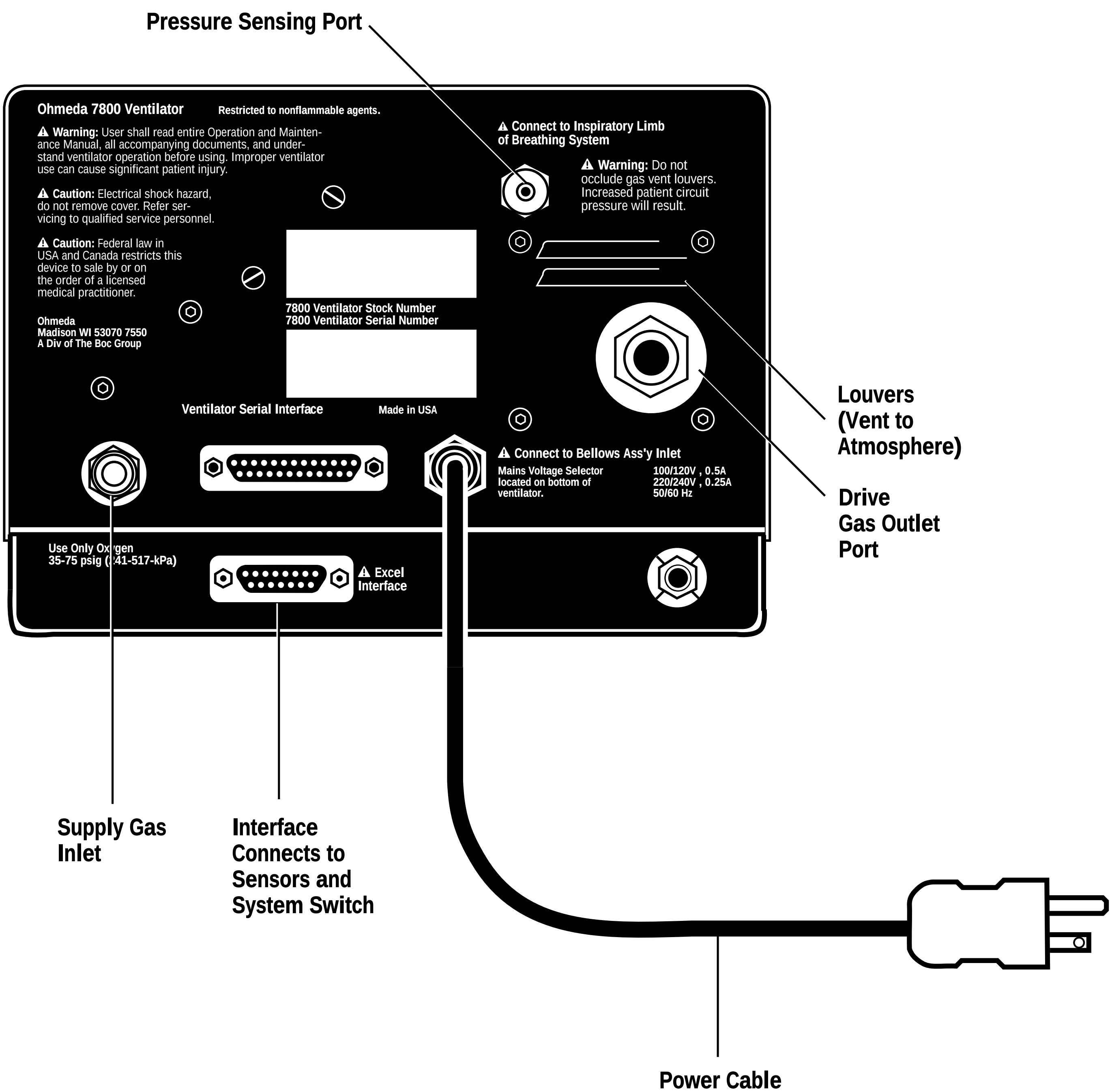
Supply Gas

Either clean oxygen or clean medical-grade air may be used to power the ventilator. Before changing from one supply gas to another, a qualified service person must set up the ventilator to operate correctly with the new supply gas because calibration settings are specific for each gas.

The supply gas hose connects to the control module connector labeled either *Use Only Oxygen,* or *Use Only Medical Grade Air.*

Illustration 47

Rear view, control module



Interface Cable

With an integrated ventilator mounting, sensors for monitoring oxygen and volume connect to the anesthesia machine sensor interface panel. Signals from the sensor interface panel and the system switch are routed to a connector at the rear of the anesthesia machine. This connector is labeled *Ventilator/Monitor Pod Interface.* An interface cable is used to connect this connector to the back of the ventilator at the connector labeled *Excel SE Interface*. The interface cable carries the information from the sensors to the electronic monitoring circuits of the ventilator.

Drive Gas

Drive gas flows through a hose, that connects from the ventilator control module to the bellows assembly, and is used to “drive” the bellows.

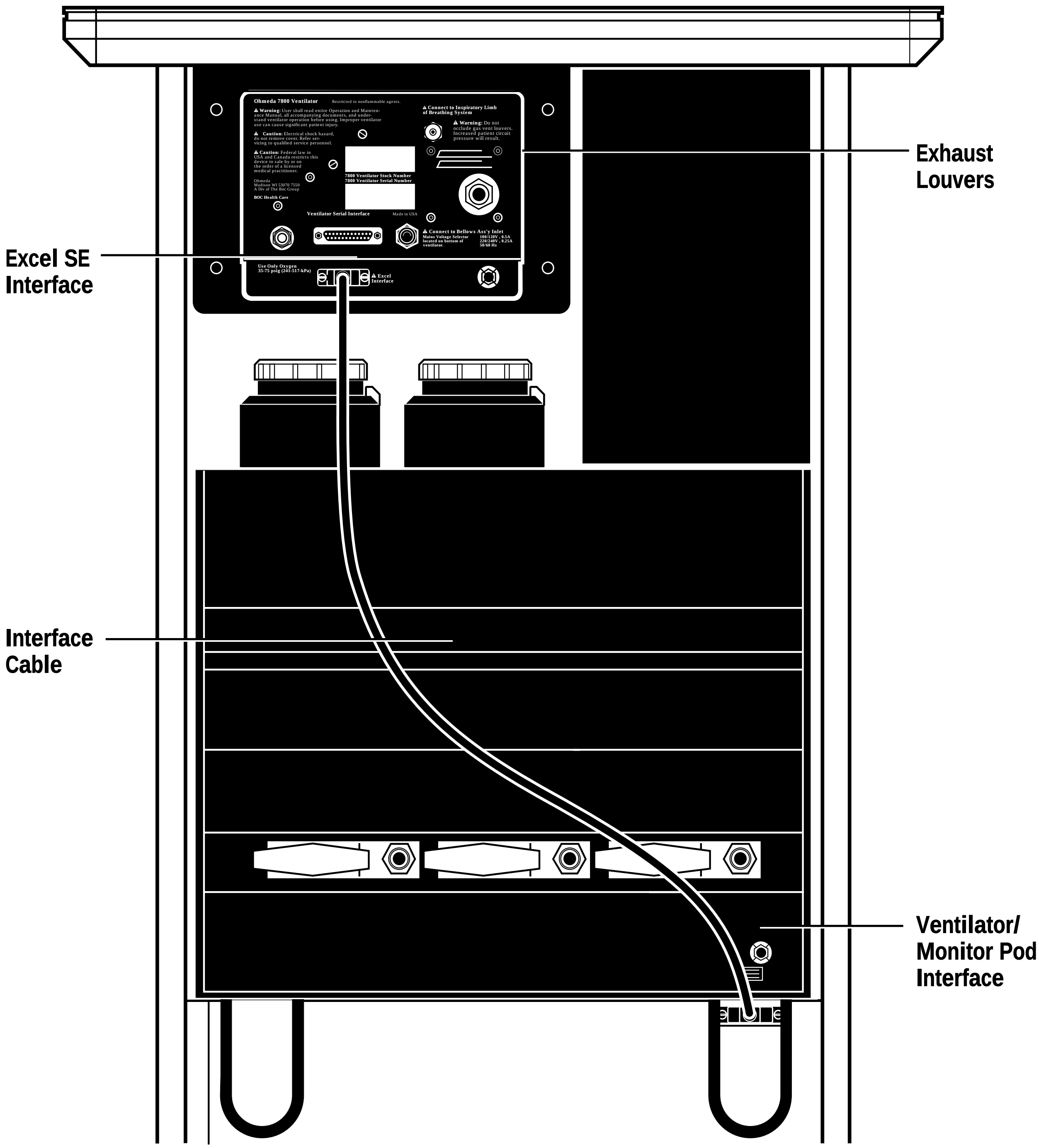
The drive gas hose is a 17 mm tube connected to a 90° fitting that connects to the drive gas outlet port. Drive gas flows through this hose from the control module to the bellows assembly. One end of this tube is attached to the connector labeled *Connect to Bellows Assembly Inlet* on the rear panel of the control module. The other end connects to the 17 mm inlet port at the bellows base. This tube has reinforcement to help prevent kinking and occlusion during use.

Pressure Sensor Tube

One end of a clear, 3 mm (1/8-inch) pressure sensor tube must connect to the barbed connector labeled *Connect to Inspiratory Limb of Breathing System* on the rear panel of the control module. The other end of the tube connects to the circuit pressure port, a barbed connector under the pressure gauge on the absorber. This tube must not be blocked or kinked. The pressure sensor tube is used by the ventilator to monitor pressure in the patient breathing circuit.

Illustration 48

Rear of view of ventilator control module and Excel SE anesthesia machine Interface cable connected to Excel SE Interface of the ventilator control module and the Ventilator/Monitor Pod Interface of the Excel SE anesthesia machine



CONTROL MODULE FRONT PANEL CONTROLS

This section describes the different controls for selecting the volume, rate, and limit pressure of a breath delivered to the patient.

Altitude Adjustment

Before the ventilator is used for the first time, the altitude of the ventilator location is entered into the ventilator. This helps ensure that an accurate tidal volume is delivered to the patient.

Mechanical Ventilation

When the mechanical ventilation switch is ON, drive gas from the control module drives the bellows assembly during inhalation. When the mechanical ventilation switch is OFF, drive gas to the bellows cannot flow and the bellows is stationary. When the switch is OFF, the patient can spontaneously draw a breath from the bellows (see section Free Breathing Valve, page 6-16).

The Set-Up Page

When the mechanical ventilation switch is OFF, the operator can access the set-up pages in the ventilator software. Page selections will appear on the display panel of the control module.

To access the set-up page, the anesthesia system switch must be ON, and the mechanical ventilation switch on the ventilator must be OFF. The alarm silence button is held down and the inspiratory pause button, is pressed; then both buttons are released. Pressing the alarm silence button allows the operator to cycle through the selection of set-up pages.

The set-up pages permit the operator to:

- Adjust the display contrast.
- Adjust the ventilator audible alarm volume.
- Turn the reverse flow alarm (tidal volume) ON and OFF.
- Turn the “sigh” function ON and OFF.

When sigh is ON, the volume of every 64th breath will be 150% of the set volume (subject to pressure limit).

Tidal Volume

The tidal volume control knob is used to set the volume of gas to be delivered by the ventilator to the patient circuit. This set tidal volume can be from 50 to 1500 milliliter per breath.

Rate

The rate control knob is used to set the breath rate. Breath rate is measured in breaths per minute. For instance if the rate knob is set to 10, an inhalation and exhalation cycle will be completed 10 times in one minute. Rate is adjustable from 2 to 100 breaths per minute.

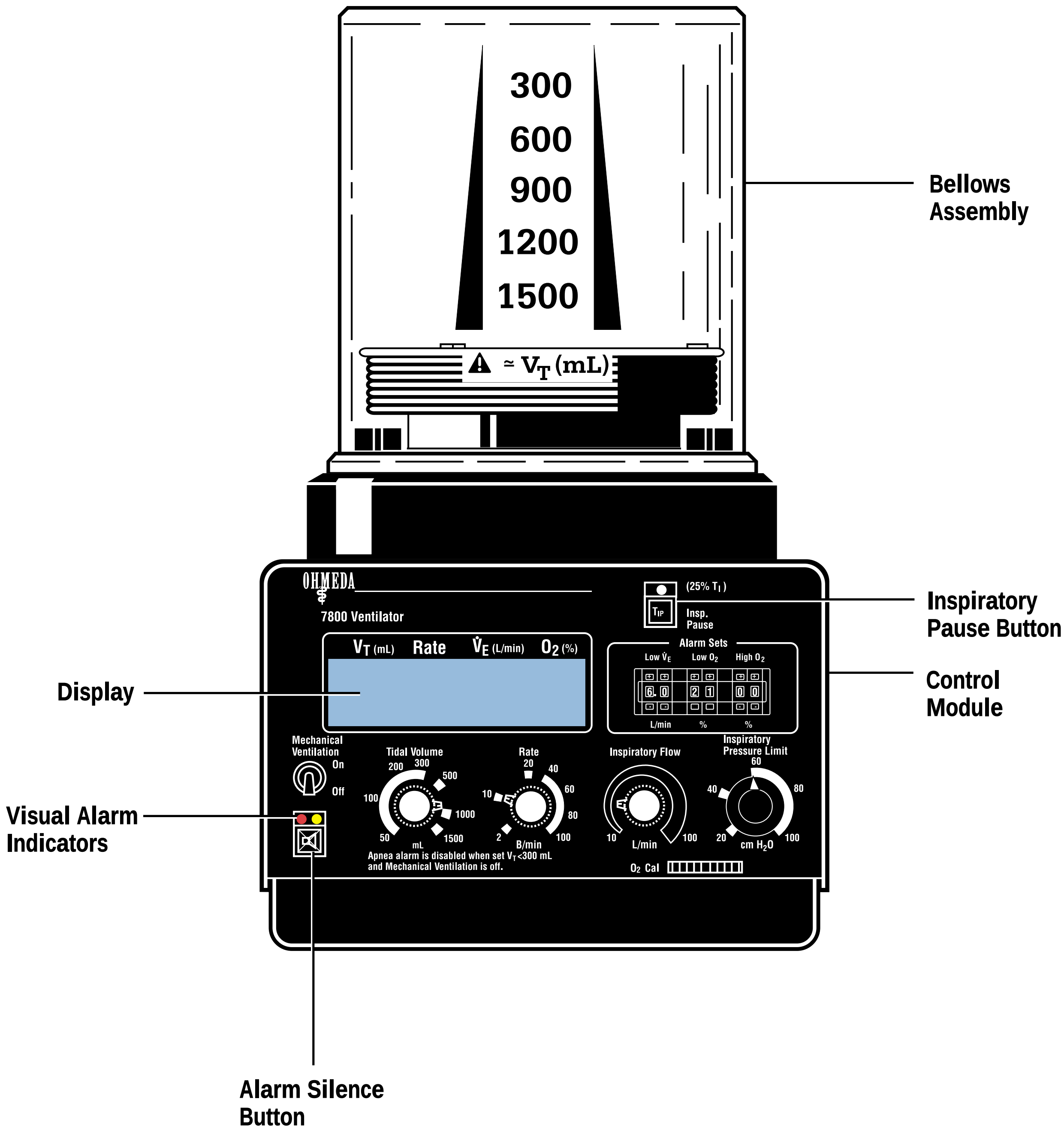
Flow

The flow control knob can be used to adjust the flow rate of drive gas during inhalation from 10 to 100 L/min.

When the inhalation flow rate is high, the drive gas quickly fills the bellows housing during the inhalation phase, more time then remains for the exhalation phase. If the tidal volume control is increased, it will take more time to deliver the extra gas volume to the patient. This increases the inhalation time. An increase in the (breath) rate will shorten the exhalation time. Whenever volume, rate, or flow settings are changed, the I:E ratio will change and the ventilator display will indicate the new I:E ratio.

Illustration 49

7800 ventilator assembly



Pressure Limit

The pressure limit control is used to limit the pressure in the patient circuit. If the set pressure limit is reached, the control module will switch to the exhalation phase, ending inhalation phase.

The pressure limit control also sets a sustained pressure alarm limit. Refer to the Safety section (page 6-22) for more information on these settings and alarms.

Inspiratory Pause

During inspiratory (inhalation) pause, the exhalation valve is held closed for a pause period to keep patient gas in the patient airway. If the inhalation pause function is ON, a green LED at the top of the button is ON and the inhalation time of the breath cycle is increased by 25%.

CONTROL MODULE DISPLAY

The ventilator's liquid crystal display serves three functions:

- On its top line, it provides numeric information about exhaled tidal volume, exhaled breath rate, exhaled minute volume, and inhaled oxygen concentration.
- On its bottom line, it displays messages such as alarms and control settings.
- For certain functions, such as the set-up page, the ventilator will display instructions on both lines of the screen.

INTERNAL CONTROL MODULE COMPONENTS

The control module uses air or oxygen from a central pipeline, or from one of the pneumatic outlets on the anesthesia machine, to operate the pneumatic components. This section describes what the different components in the control module do during a mechanical breath.

The illustration on the facing page shows the layout of the components. Some of the components are:

- Inlet solenoid and gas inlet valve.
- Primary and secondary regulators.
- Pneumatic manifold assembly.
- Airway pressure transducer.
- Regulated pressure transducer.
- Pressure limit switch.

Inlet Solenoid and Gas Inlet Valve

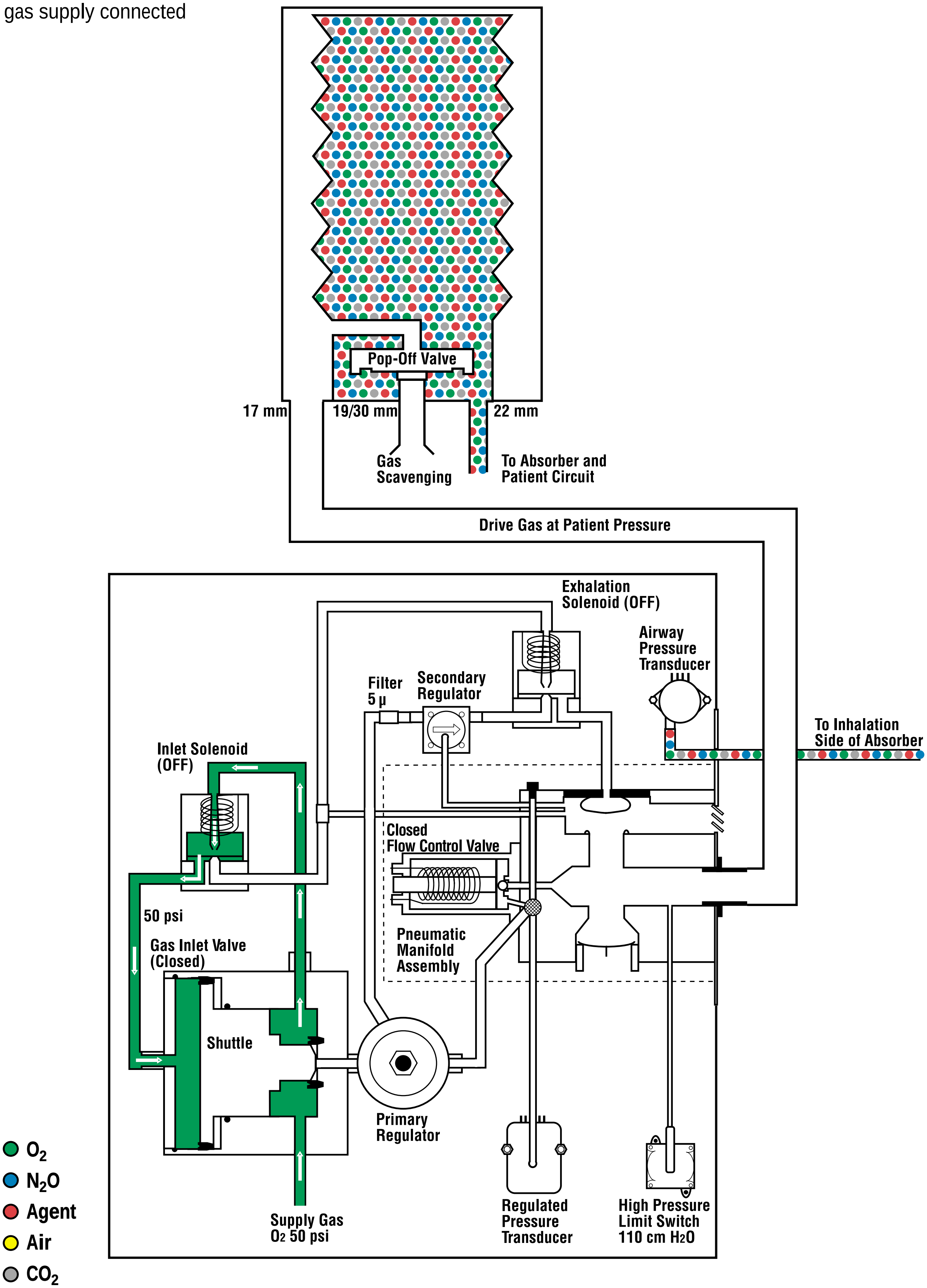
The gas inlet valve and inlet solenoid work together to control supply gas in the unit.

Inside the gas inlet valve is a shuttle, which has a small control stop on one end. When the mechanical ventilation switch is OFF, the inlet solenoid is OFF (closed), and a pressure differential holds the shuttle in the closed position. The control stop blocks the opening in the gas inlet valve and prevents the flow of supply gas through the opening to the primary regulator.

The gas inlet valve is normally closed and prevents gas pressure from entering the unit. When the inlet solenoid is energized by switching the ventilator (mechanical ventilation switch) to ON, the solenoid opens the gas inlet valve to allow supply gas to enter the ventilator.

Illustration 50

Electrical power OFF
gas supply connected



When the mechanical ventilation switch is ON, the inlet solenoid is turned ON (open), which shuts off the supply gas to the large side of the shuttle. Supply gas at the large end of the shuttle is vented through the inlet solenoid to the atmosphere. The pressure on the small side of the shuttle moves the shuttle away from the opening. This permits the supply gas to flow from the inlet valve to the primary regulator.

Primary and secondary regulators and the regulated pressure transducer

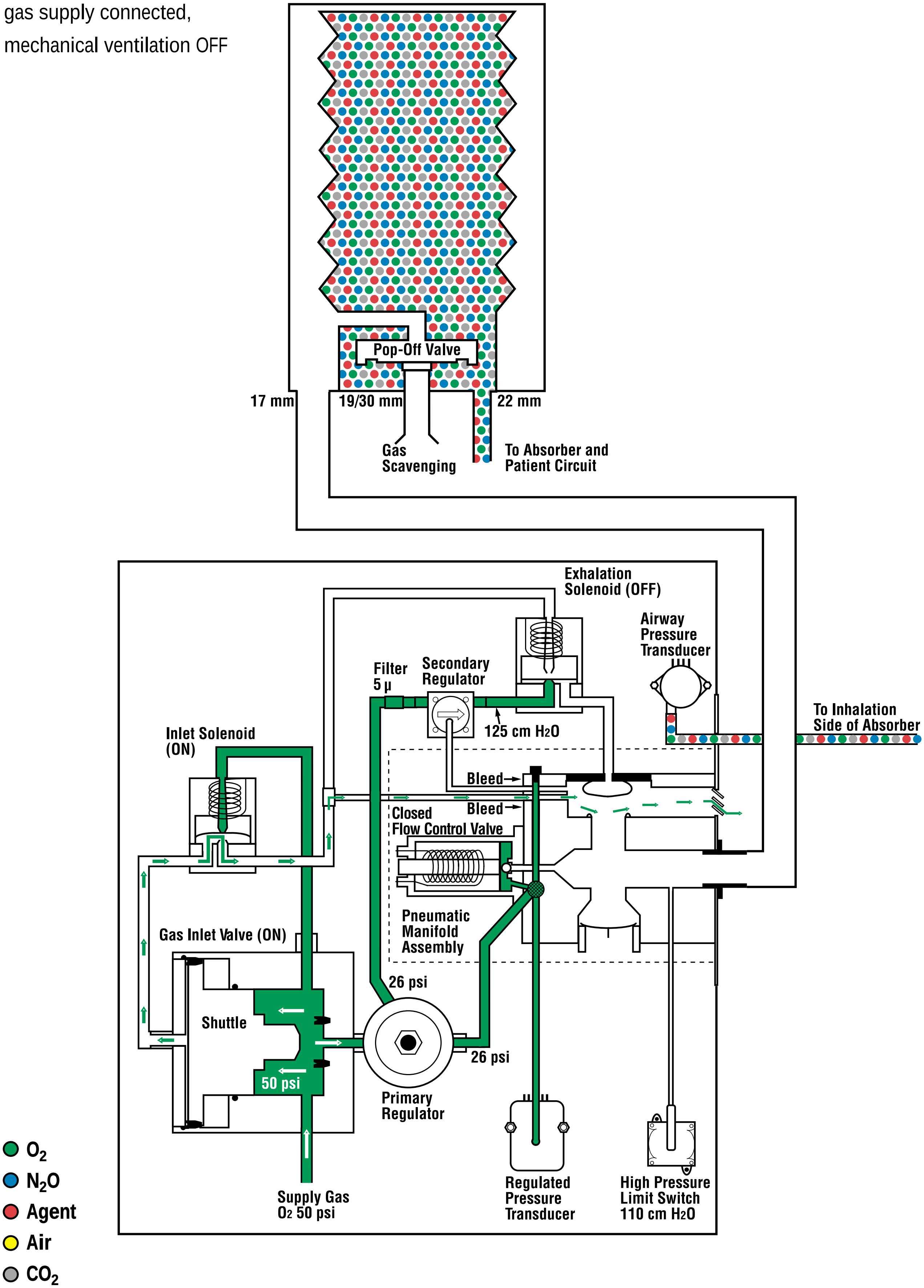
The primary and secondary regulators are used to decrease the supply gas pressure (50 psig), to functional pressures.

The primary regulator decreases the pressure of the gas from the inlet valve to 26 psig. The primary regulator has two output ports. One output connects to the pneumatic manifold assembly where it supplies the flow control valve and connects to the regulated pressure transducer. The other output port connects to the secondary regulator.

The secondary regulator reduces the pressure of the gas from the primary regulator (26 psig) to an output pressure of 125 cm H_2O. During inhalation and inspiratory (inhalation) pause, the output from the secondary regulator flows through an exhalation solenoid to inflate the exhalation valve.

Illustration 51

Electrical power ON
gas supply connected,
mechanical ventilation OFF



The Pneumatic Manifold Assembly

The pneumatic manifold assembly has two sections: a drive chamber and an exhaust chamber. It also includes:

- A flow control valve.
- An exhalation valve.
- A free-breathing valve.

The Flow Control Valve

Supply gas flows from the primary regulator to the flow control valve. The flow control valve precisely meters the gas flow to the bellows housing during the inspiratory cycle. This gas is known as drive gas because it is used to “drive” the bellows.

During inhalation, the control circuitry applies an electrical current to the flow control valve. When precise amounts of higher flows are selected, the current applied to the valve is increased, and gas flow through the valve increases. As flow increases, pressure in the patient circuit also increases.

At the end of inhalation, (or if electrical power is off), the flow control valve is turned OFF. The valve remains OFF through the inhalation pause and the exhalation phases.

The Exhalation Valve

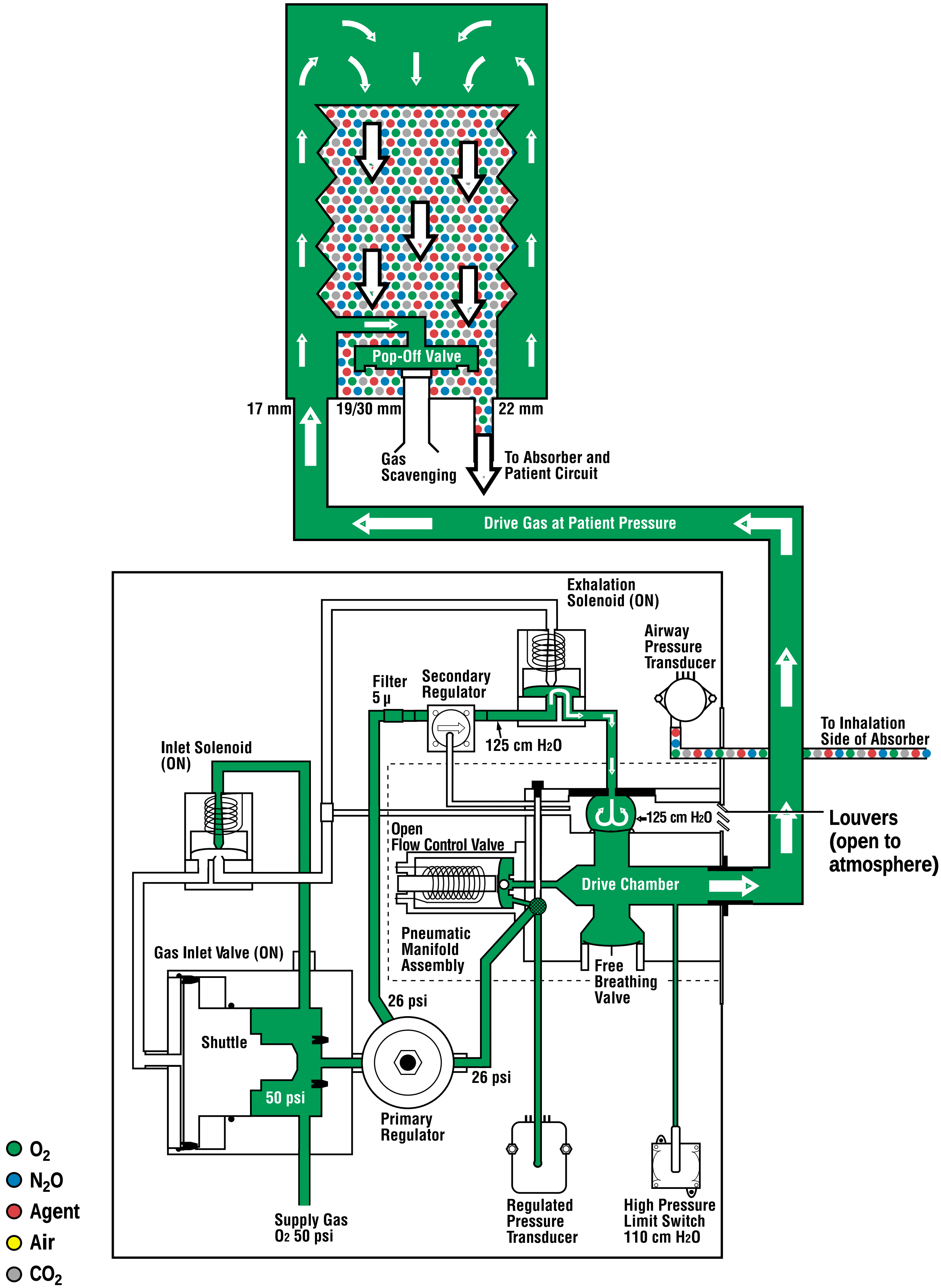
The exhaust chamber of the pneumatic manifold is open to atmosphere through the back of the control module. Note the louvers (see the illustration on the facing page) above the drive gas output on the rear panel of the ventilator control module. During inhalation, the exhalation valve is closed, preventing the exhaust of drive gas. During exhalation, the exhalation valve opens, allowing the exhaust gas from the exhaust chamber to vent to atmosphere through the louvers.

The exhalation valve is located in an opening between the drive chamber and exhaust chamber. During inhalation the exhalation solenoid is ON (open), and the output from the secondary regulator flows to the exhalation valve. The exhalation valve is inflated, like a balloon, to seal the opening between the drive chamber and the exhaust chamber.

When the exhaust chamber is blocked by the exhalation valve, drive gas cannot flow from the drive chamber to the exhaust port. It is directed through the drive gas hose to the bellows housing. The increased pressure in the housing presses the bellows down, and the set volume of gas in the bellows is supplied to the patient circuit.

Illustration 52

Inspiratory phase

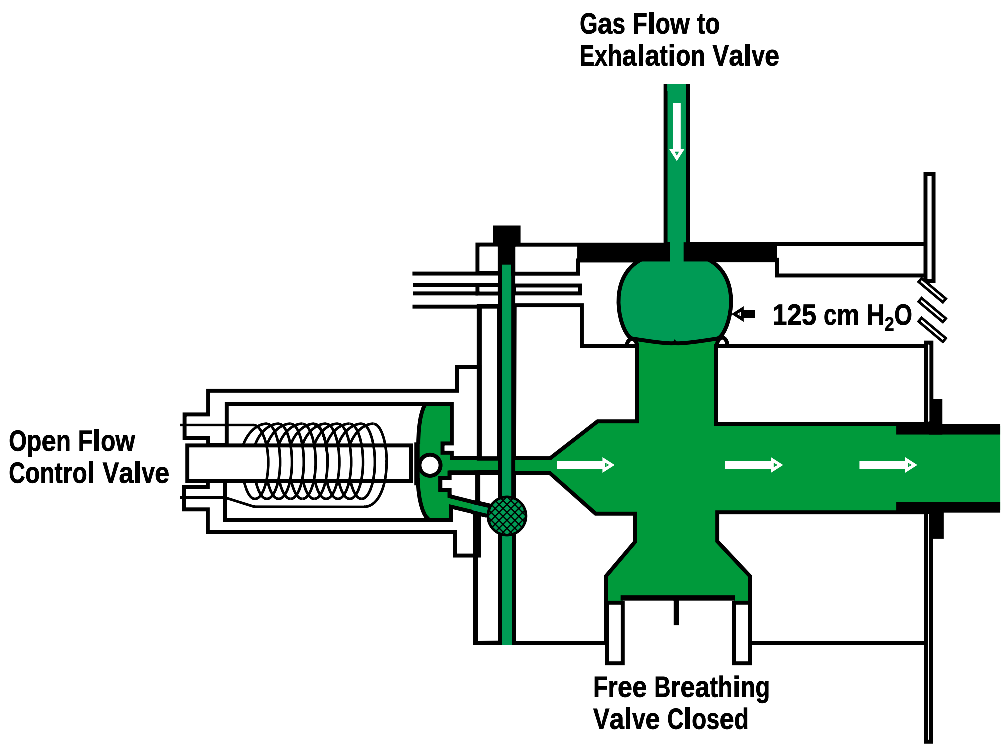


Free Breathing Valve

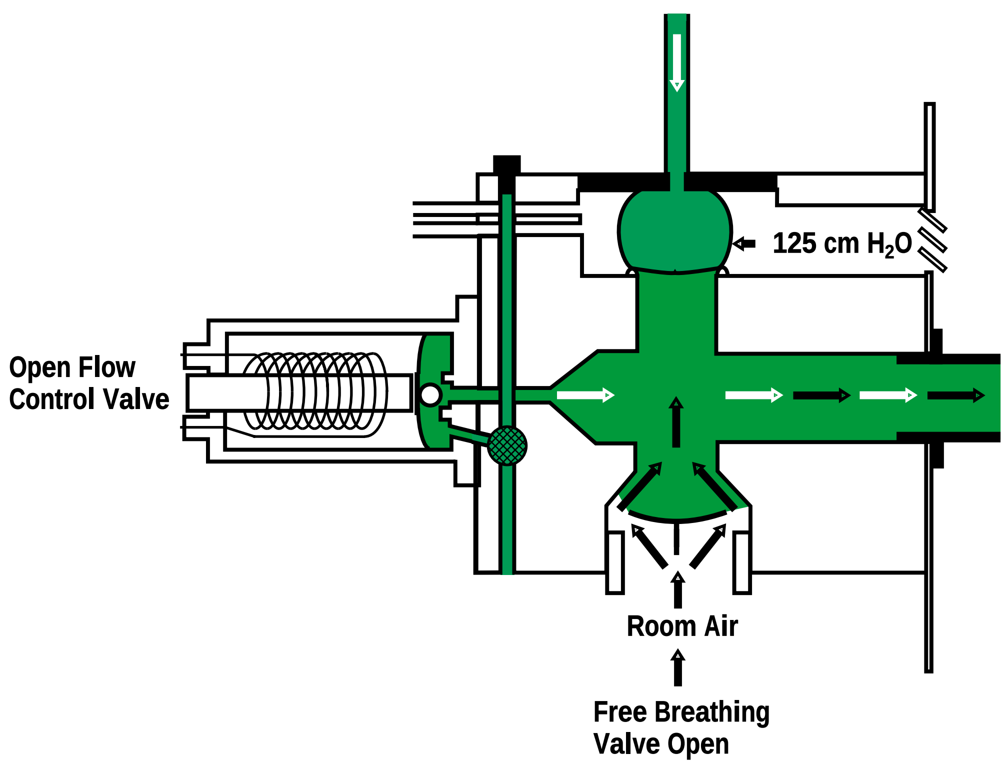
During normal operation (see Normal Operation Waveform on page 6-18), positive pressure inside the drive chamber keeps the free breathing valve closed. If the patient attempts to spontaneously inhale during mechanical ventilation, a negative pressure can be created in the bellows, lowering the bellows and decreasing the pressure in the drive chamber. If the pressure in the drive chamber decreases below atmosphere, the free breathing valve can open (see Normal with Inspiratory Pause Waveform on page 6-18) and allows outside air to enter the drive chamber. The outside air makes up the additional volume of drive gas necessary to allow the bellows to cycle and allows the patient to spontaneously draw a breath from the bellows.

Illustration 53

Pneumatic manifold assembly



Normal Operation

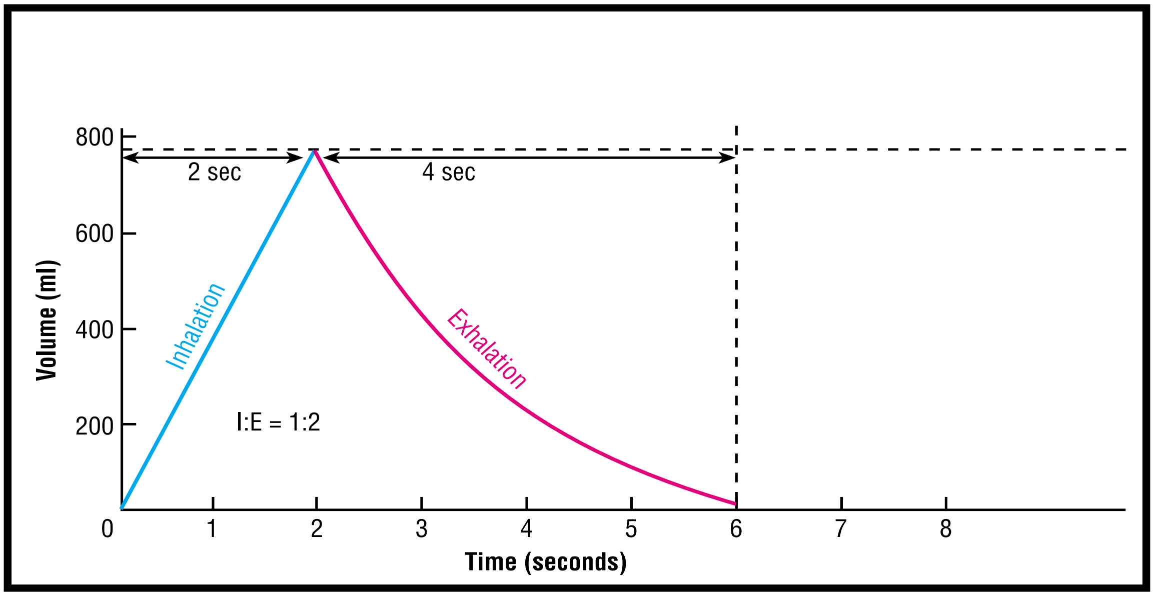


Spontaneous Breath During Inhalation

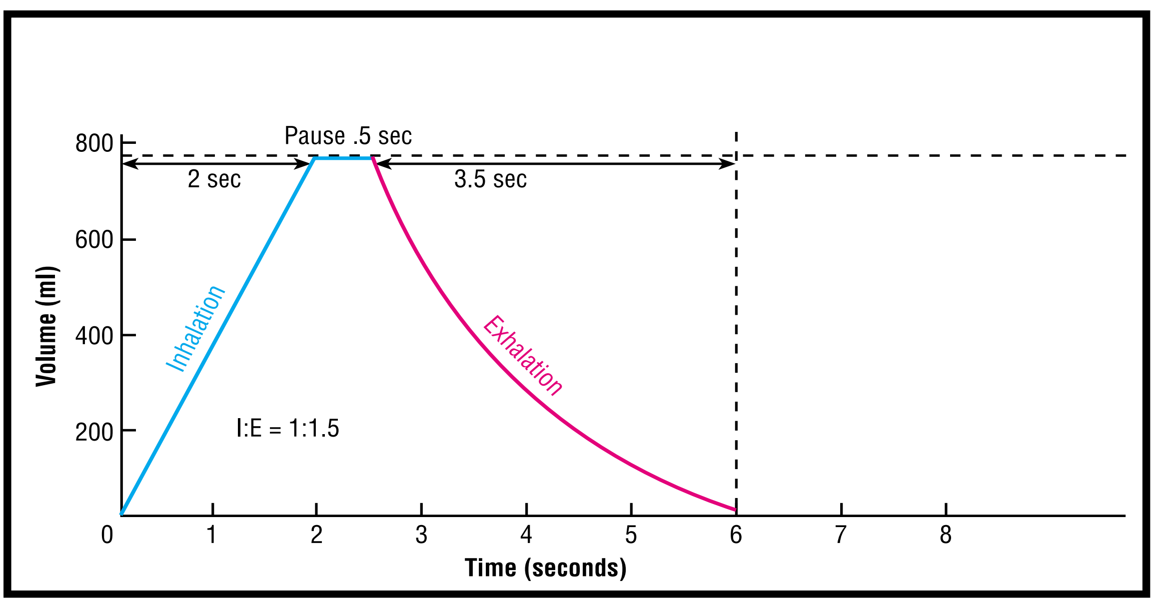
If inspiratory pause is ON, the exhalation valve stays inflated at the end of the inhalation phase for an additional 25% of the inhalation time. The flow control valve is OFF, the flow of drive gas stops, and drive gas pressure stays the same in the bellows housing. The volume of gas supplied to the patient is held in the patient's lungs until the exhalation phase begins.

A green LED is ON above the inspiratory pause button (control module) when inspiratory pause is ON.

Rate = 10 breaths per minute/60 sec = 6 seconds
Tidal volume = 750 ml



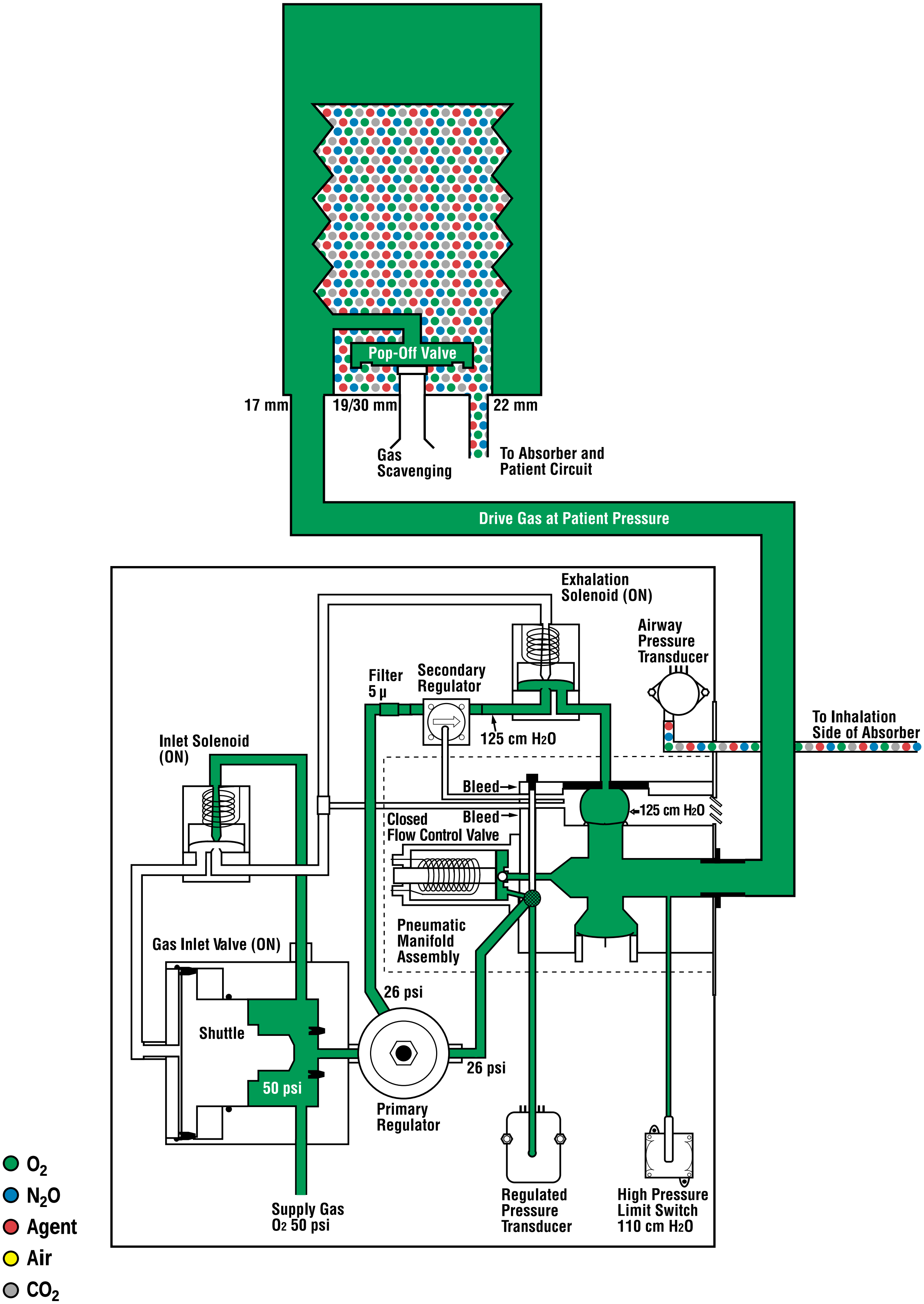
Normal operation



Normal with inspiratory pause

Illustration 54

Inspiratory (inhalation) pause

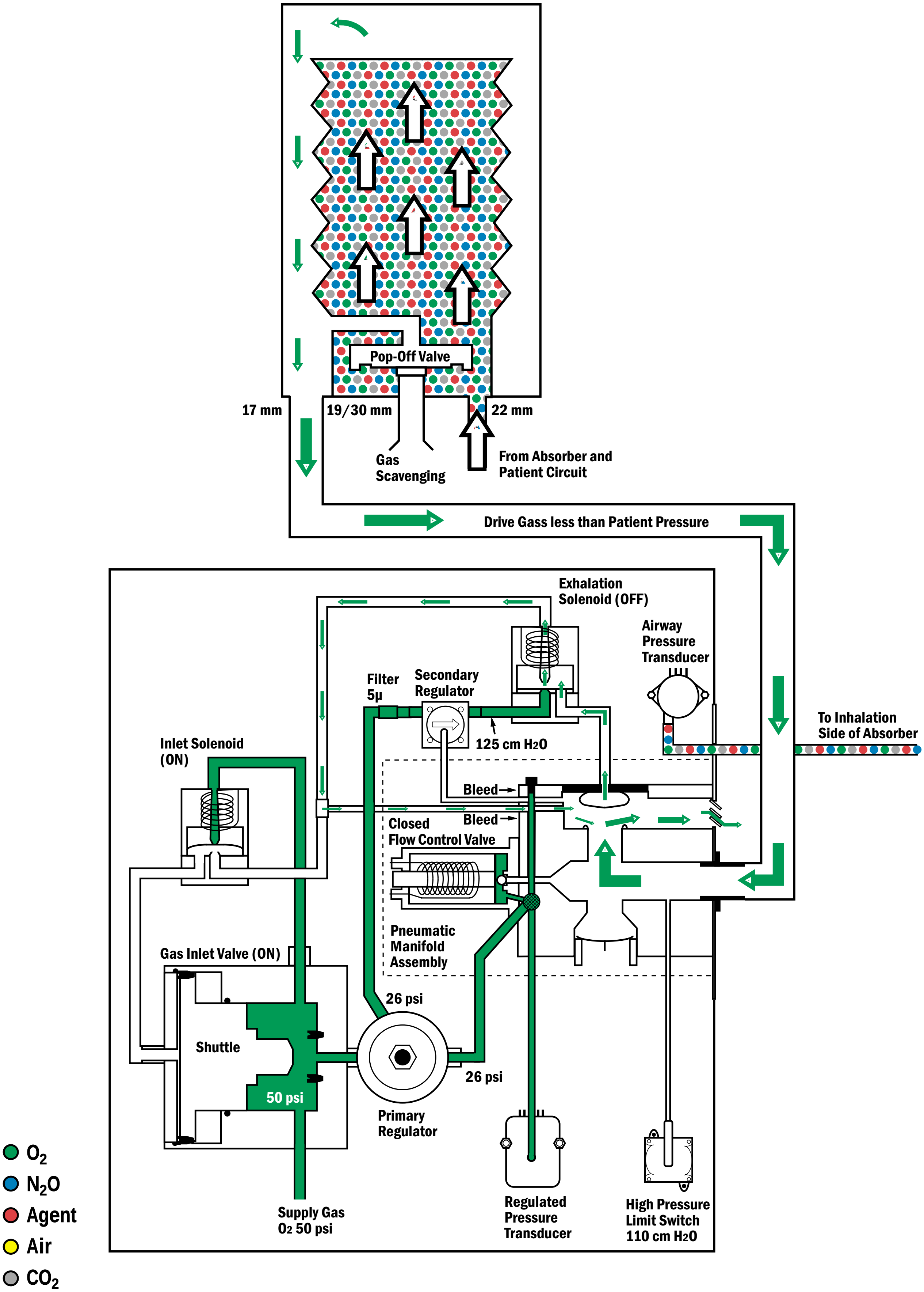


During exhalation, the exhalation solenoid is OFF and the flow of gas from the secondary regulator is OFF. The exhalation valve deflates and the port between the drive chamber and exhaust chamber is open. Drive gas vents from the bellows housing to the drive chamber through the exhalation chamber and out the back of the control module to the atmosphere. At the same time, the pressure outside the bellows decreases and permits exhaled gas from the patient circuit to enter the bellows.

If pressure in the patient airway rises to the set pressure limit during inhalation, the exhalation valve opens. The Safety section (page 6-22) explains how the ventilator detects and responds to high airway pressures.

Illustration 55

Exhalation phase



SAFETY

Ventilator safety features include:

- Airway pressure transducer.
- Regulated pressure transducer.
- High pressure limit switch.

Airway Pressure Transducer

Patient airway pressure is continuously monitored by the airway pressure transducer. This transducer helps prevent excess pressure in the patient circuit.

An airway pressure sensing line is located in the GMS absorber, it connects to the inhalation side of the absorber and a port located under the gauge. A clear tube is connected between the port under the gauge and the back of the control module. Patient airway pressure is measured by the airway pressure transducer in the control module.

The airway pressure monitor circuitry continuously compares the airway pressure, sensed by the airway pressure transducer, and the setting of the pressure limit control knob on the front panel. If the mechanical ventilation switch is ON and the airway pressure reaches the limit set on the pressure limit dial, the ventilator immediately stops the inhalation phase and enters the exhalation phase. An audible alarm will sound and a HIGH PRESSURE! message will be displayed on the control module screen.

Note: Patient circuit resistance to flow, patient airway resistance to flow, and elastic recoil of the lungs cause an increase in pressure readings during the inhalation phase.

The inhalation phase stops as the microprocessor in the control module turns OFF the electrical current to the flow control valve, and the flow of drive gas is switched OFF. The exhalation solenoid also closes removing pressure from the exhalation valve, the exhalation valve deflates and drive gas pressure vents through the exhalation chamber to atmosphere. This stops the flow of gas from the bellows to the patient, and allows gas to flow from the patient and reinflate the bellows.

If the mechanical ventilation switch is OFF and the maximum pressure limit is exceeded in the patient airway during manual ventilation, an audible alarm will sound and a HIGH PRESSURE! message will be displayed.

High Pressure Limit Switch

A high pressure limit switch operates independently of the microprocessor providing an independent high pressure limit. This switch monitors pressure inside the drive chamber. If the pressure reaches or exceeds approximately 110 cm H_2O, the switch closes. This causes the exhalation valve to deflate for the rest of that inspiratory phase. Drive gas vents from the bellows housing and relieves the pressure in the patient circuit.

Pressure is also limited by the setting of the secondary regulated pressure present in the exhalation valve. If pressure in the pneumatic manifold drive chamber reaches or exceeds 125 cm H_2O, the exhalation valve will lift from the seat to vent the excess drive gas pressure out the exhaust port to atmosphere.

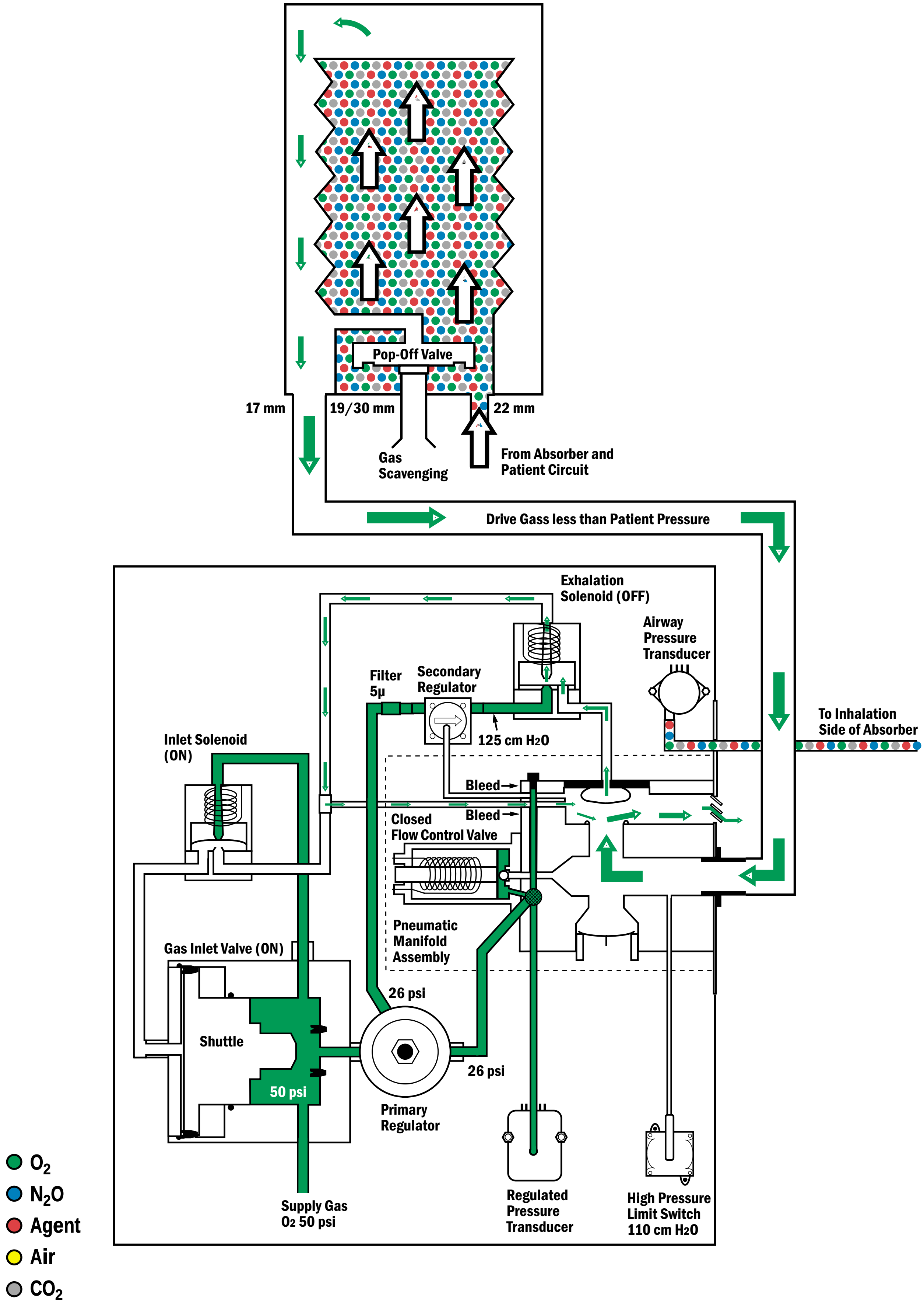
Regulated Pressure Transducer

The output of the primary regulator is monitored by a pressure transducer. If the pressure is greater than approximately 30 psig (207 kPa), a VENT FAIL 4! message is displayed. The microprocessor turns OFF the inlet solenoid, the gas inlet valve closes, and mechanical ventilation stops.

If the supply gas pressure drops below 22 psig, a LOW SUPPLY PRESS! message is displayed. This prompts the operator to check that the gas supply is connected.

Illustration 56

Exhalation phase



MONITOR ALARMS

Alarm pushwheel switches allow the user to change set points for detection of low expired minute volume and high or low percentages of inspired oxygen.

The operator can select peak inhalation and sustained pressure alarm set points by setting the inspiratory pressure limit (P_{limit}) dial.

Visual Alarms

When alarm limits are exceeded, the ventilator displays an alarm message. The message is updated every 1.5 seconds until the condition is corrected (apnea alarms are updated at one-second intervals).

Two LEDs, one red and one yellow, are located in the alarm silence button. They are used to indicate the status of alarms. When an alarm condition first occurs, a message appears on the screen, a tone sounds, and an LED flashes. The red LED is lighted during alarm conditions that require immediate operator response. These are high-priority alarms that warn of possible danger to the patient. The yellow LED indicates alarm conditions that require prompt operator response or operator awareness. These are caution alarms that can indicate incorrect settings, an indirect affect on the patient, or potential harm to equipment.

When more than one alarm is active, the ventilator displays the messages for all of the alarms by alternating the message, but sounds the audible alarm for only the highest priority alarm. If that condition is resolved, the ventilator then sounds the alarm for the next highest priority alarm condition. The priority of the audible alarms from high to low is:

- Warble.
- Continuous.
- Intermittent.
- Single beep.

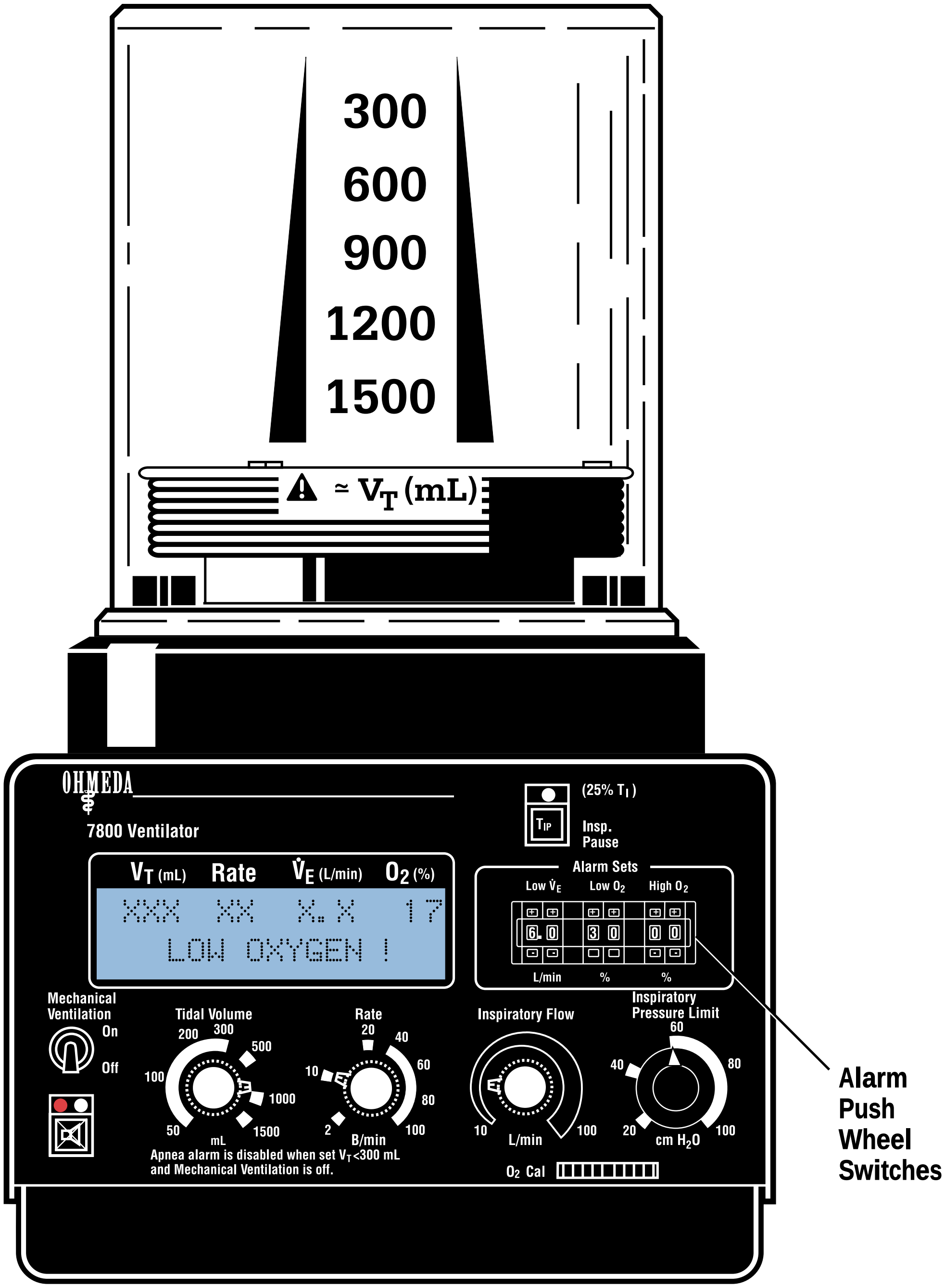
To silence an audible alarm, the operator presses the alarm silence button. Once the alarm silence button is pressed, the ventilator LED will stay ON as a reminder that the alarm condition still exists. If that alarm condition continues, the alarm will sound again in 30 seconds. If a new alarm condition occurs, its audible alarm sounds immediately.

Some audible alarms can be silenced permanently, even if the alarm condition continues. These permanently silenceable alarms include:

- Power failure.
- Low battery.
- Ventilator failure.
- Oxygen sensor failure.
- Oxygen calibration error.
- Volume sensor failure.

Illustration 57

7800 Ventilator alarm sets push wheel switches



ELECTRONIC MONITOR CIRCUITS

The ventilator control module contains electronic monitor circuits that provide information about the inhaled and exhaled patient gases. The integrated circuits monitor:

- The percentage of inspired oxygen.
- The volume of exhaled breaths.
- The number of breaths per minute.
- The pressure in the patient airway.

Monitor circuits are ON whenever power is applied to the control module.

When the mechanical ventilation switch is OFF, the microprocessor and the electronic monitoring circuits in the control module are ON. Information from the monitors is displayed on the screen even if the mechanical ventilation switch is not ON.

When the mechanical ventilation switch is ON, the monitor circuits are ON and work together with ventilator operation.

Oxygen monitor

Electronic oxygen monitor circuits in the control module provide information about the percentage of oxygen in the gas supplied to the patient circuit. Alarms are switched ON if the oxygen concentration of the gas is outside the limits that have been set using the pushwheel switches:

- The HIGH OXYGEN! message is displayed, the yellow LED flashes, and an intermittent beep alarm sounds if the ventilator senses an oxygen concentration equal to or higher than the one the operator set using the high O_2 pushwheel switch.
- The LOW OXYGEN! message is displayed, the red LED flashes, and a continuous warble alarm sounds if the ventilator senses an oxygen concentration equal to or lower than the one the operator set using the low O_2 pushwheel switch.
- The LIMIT SET ERROR! message is displayed, the yellow LED flashes, and a continuous alarm sounds if the operator attempts to set the high oxygen alarm limit to a level below or equal to the low oxygen limit. These alarms also occur if the operator attempts to set the low oxygen alarm limit to less than 18% .

Oxygen sensor assembly

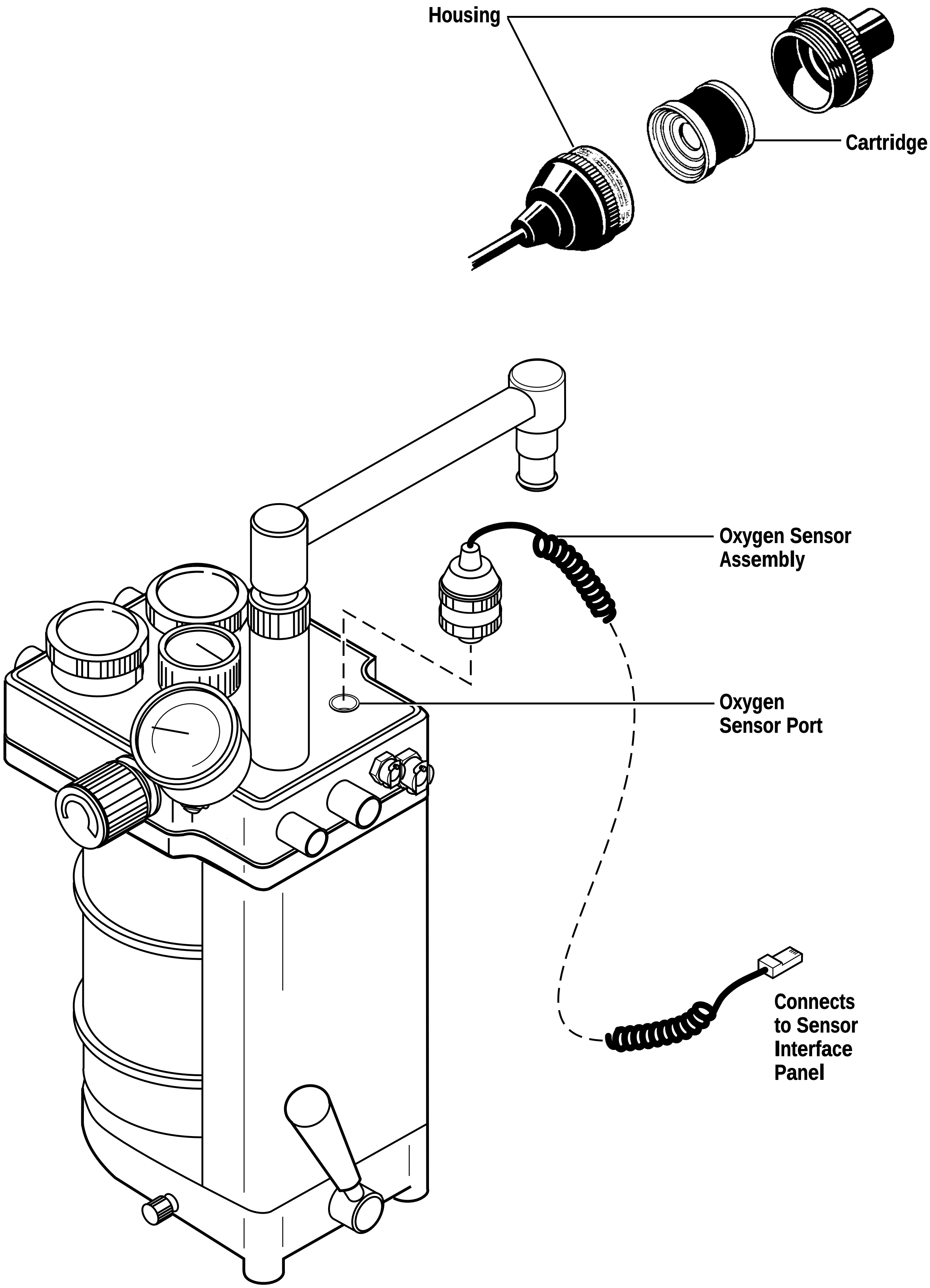
The oxygen monitor uses an oxygen sensor assembly to measure oxygen concentration in the gas supplied to the patient.

The assembly includes a housing that holds a sensor cartridge. An electrical current is transmitted from the cartridge to the electronic components in the housing, and through the cable to the ventilator control module.

The assembly is installed in the oxygen sensor port of the absorber. This port is open to the inhalation chamber of the absorber. When the sensor is installed in this port, gas supplied to the patient flows past the sensor.

Illustration 58

Oxygen sensor assembly



The sensor cartridge is an electrochemical device (galvanic cell). Oxygen diffuses through a membrane into the cell and oxidizes a base metal electrode. The resultant electrical current is proportional to the concentration of the oxygen.

The ventilator's monitor circuits processes the electrical current information from the sensor to produce a percent oxygen display on the ventilator control module. The displayed value is compared to the set alarm limits and, if necessary, appropriate alarms will occur.

The output voltage from the sensor cartridge is affected by the temperature of the monitored gas mixture. A thermistor in the sensor housing compensates for temperature changes.

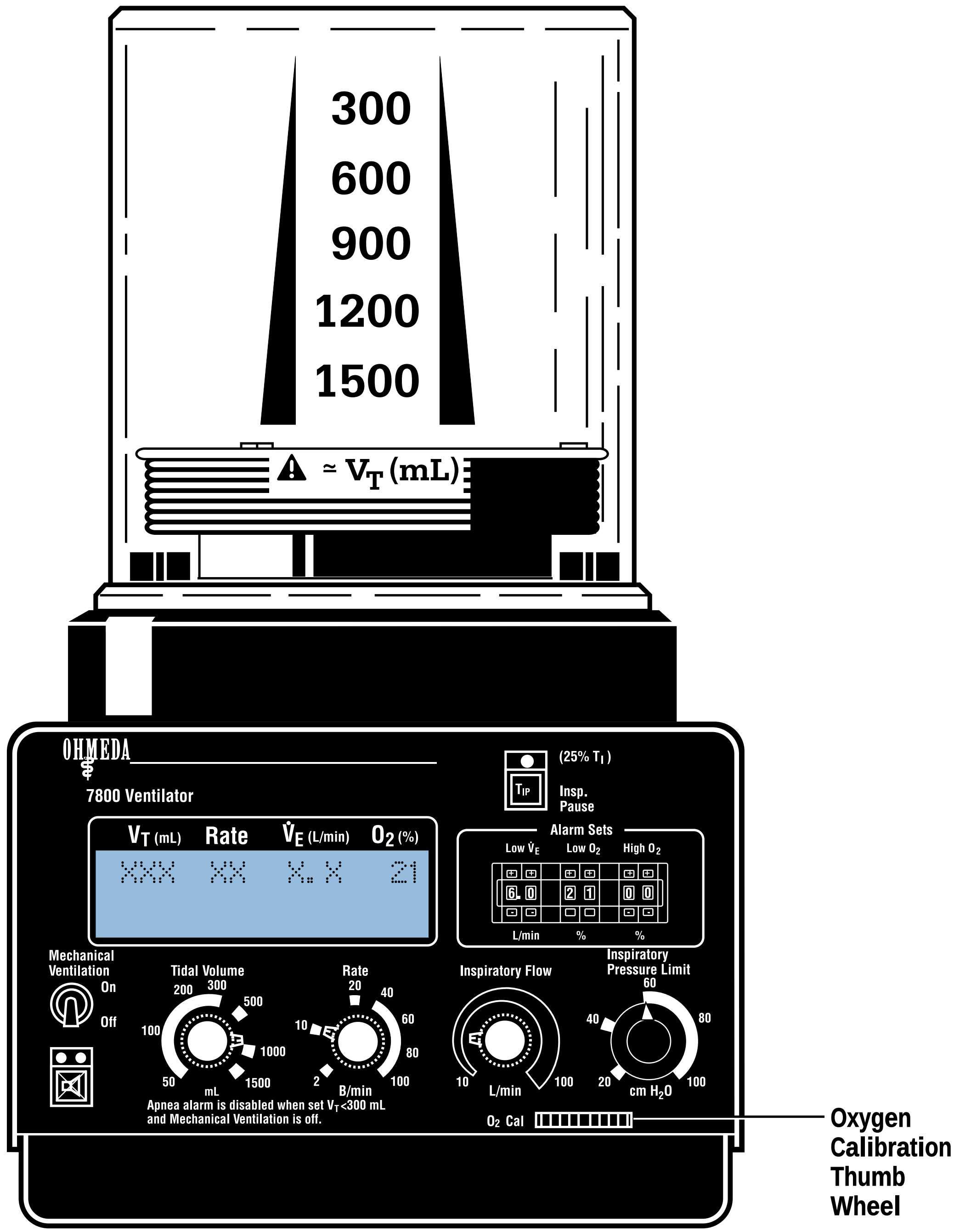
Calibration

The oxygen calibration thumbwheel on the front of the ventilator control module is used to calibrate the oxygen monitor sensor. This thumbwheel should be used only during the oxygen monitor calibration procedure. The oxygen sensor should be calibrated to 21% daily or as necessary, and to 100% at regular intervals (once each month or as necessary).

If the sensor assembly has been disconnected for more than 5 minutes, or if the new sensor cartridge was previously removed from its protective packaging, allow the monitor to stabilize for as many hours as the sensor was disconnected (or for as long as it has been out of its packaging), up to a maximum of 24 hours. This time period is required to remove an oxide layer that builds up on the cell of the sensor (if disconnected and exposed to oxygen), which limits the output of the cell.

Illustration 59

7800 Ventilator oxygen calibration thumb wheel



Tidal volume monitor

The control module of the ventilator also includes electronic tidal volume monitor circuits. The ventilator uses a turbine vane transducer cartridge and a tidal volume sensor clip to convert gas flow into electrical pulses that are sent to the monitoring circuits in the ventilator control module.

The transducer cartridge is placed in the exhalation limb of the patient breathing circuit, and the sensor clip snaps onto the transducer cartridge.

Due to the effects of patient circuit fresh gas flow from the anesthesia machine adding delivered volume, and patient circuit compliance* decreasing delivered volume, the measured tidal volume can significantly differ from the set tidal volume.

To compensate for these effects, the user can slightly adjust the set tidal volume, anesthesia machine fresh gas flow, and the maximum inhalation pressure. Refer to the following summary for more details.

The exhaled tidal volume you would expect to measure (V_T) equals the tidal volume set on the ventilator (V_S) plus the tidal volume fresh gas flow adds (V_{fgf}) minus the tidal volume lost to breathing system compliance (V_C).

$$V_T = V_S + V_{fgf} - V_C$$

The equation above does not account for leakage or high airway resistance. You can compensate for high airway resistance by reducing inhalation flow or using the inspiratory (inhalation) pause function.

* Compliance (elasticity or elastic yield) can be caused by compressability of gases and the expansion of some breathing system components under pressure.

Step One, calculating V_{fgf}, the total of fresh gas delivered during inspiration.

FGF = total fresh gas flow from the anesthesia system, in ml per minute.

R = breathing rate from the ventilator, in breaths/minute.

$\frac{E}{I}$ = inverse I:E ratio from the ventilator.

$$V_{fgf} = \frac{FGF}{R\left(1 + \frac{E}{I}\right)}$$

Step Two, calculating V_C, the volume lost to breathing system compliance.

When the volume sensor is in the distal position, the compliance factor (C) for the Ohmeda GMS Absorber is about 8 ml/cm H_2O with adult bellows and about 6 ml/cm H_2O with pediatric bellows; because the volume sensor is located distally, however, actual patient volume will be somewhat less than the tidal volume the ventilator measures and displays. When the volume sensor is in the proximal position, the compliance factor is about 10 ml/cm H_2O for the Ohmeda GMS Absorber with adult bellows, 60" long, disposable, patient-circuit tubes, and no humidifier.

V_C = C x PIP.

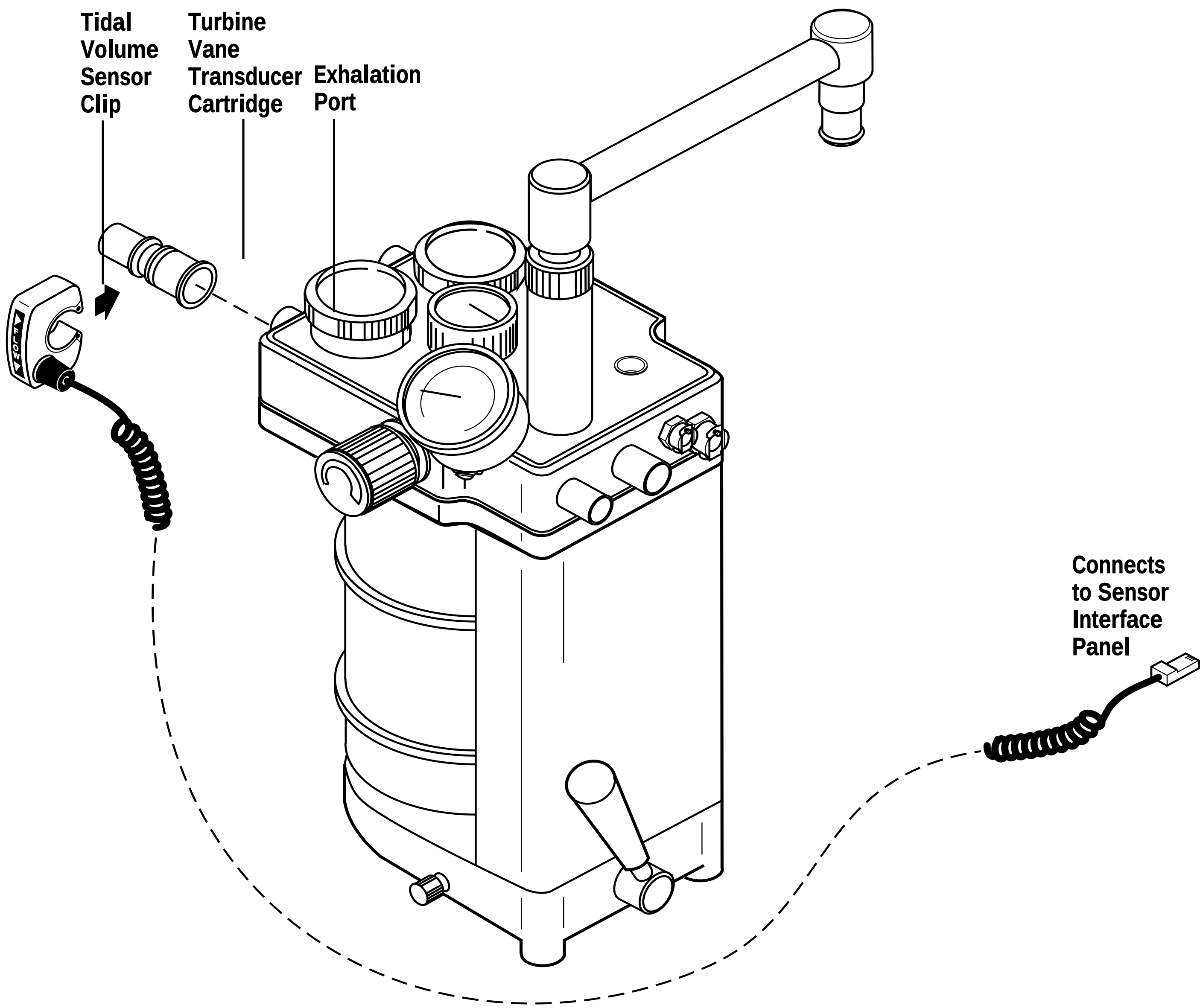
C = compliance factor in ml/cm H_2O.

PIP = peak inspiratory (inhalation) pressure, as shown on the breathing system pressure gauge, in cm H_2O.

$$V_C = C \times PIP$$

Illustration 60

Tidal volume sensor clip and turbine vane transducer cartridge placement



Volume transducer cartridge

The illustration on the facing page represents a side view of the transducer cartridge, showing the placement of three vane sets in the cartridge. The two outer vane sets are stationary and set at an angle. When gas flows through the cartridge, past the vanes, the vanes cause the gas to flow in a circular pattern. This spinning motion causes the center vane to rotate. The higher the gas flow rate, the faster the center vane rotates.

If the exhaled gas flow from the patient enters the cartridge inlet (normal flow), one outer vane will cause the center vane to rotate in a clockwise direction. If gas flow is in the opposite direction (reverse flow), the other outer vane causes the center vane to rotate in a counterclockwise direction.

Volume sensor clip

The sensor clip contains two identical types of light-detection circuit paths. Each circuit has an LED which beams infrared light to a light detector. The LEDs and detectors are placed across from each other in the sensor clip. When the clip is connected to the transducer cartridge, it is positioned so the center vane is between the LEDs and the light detectors. As the center vane spins, it momentarily interrupts the beams of light from the LEDs to the detectors. The detectors convert (transduce) these interruptions into electrical pulses which pass through the sensor cable to the ventilator monitoring circuits.

This pulse information is used by the ventilator to calculate the volume of the flow of exhaled gas from the patient. The number of pulses from the detectors is proportional to the gas flow volume through the transducer cartridge. The ventilator also determines the flow direction by monitoring the order in which the two beams of light are interrupted.

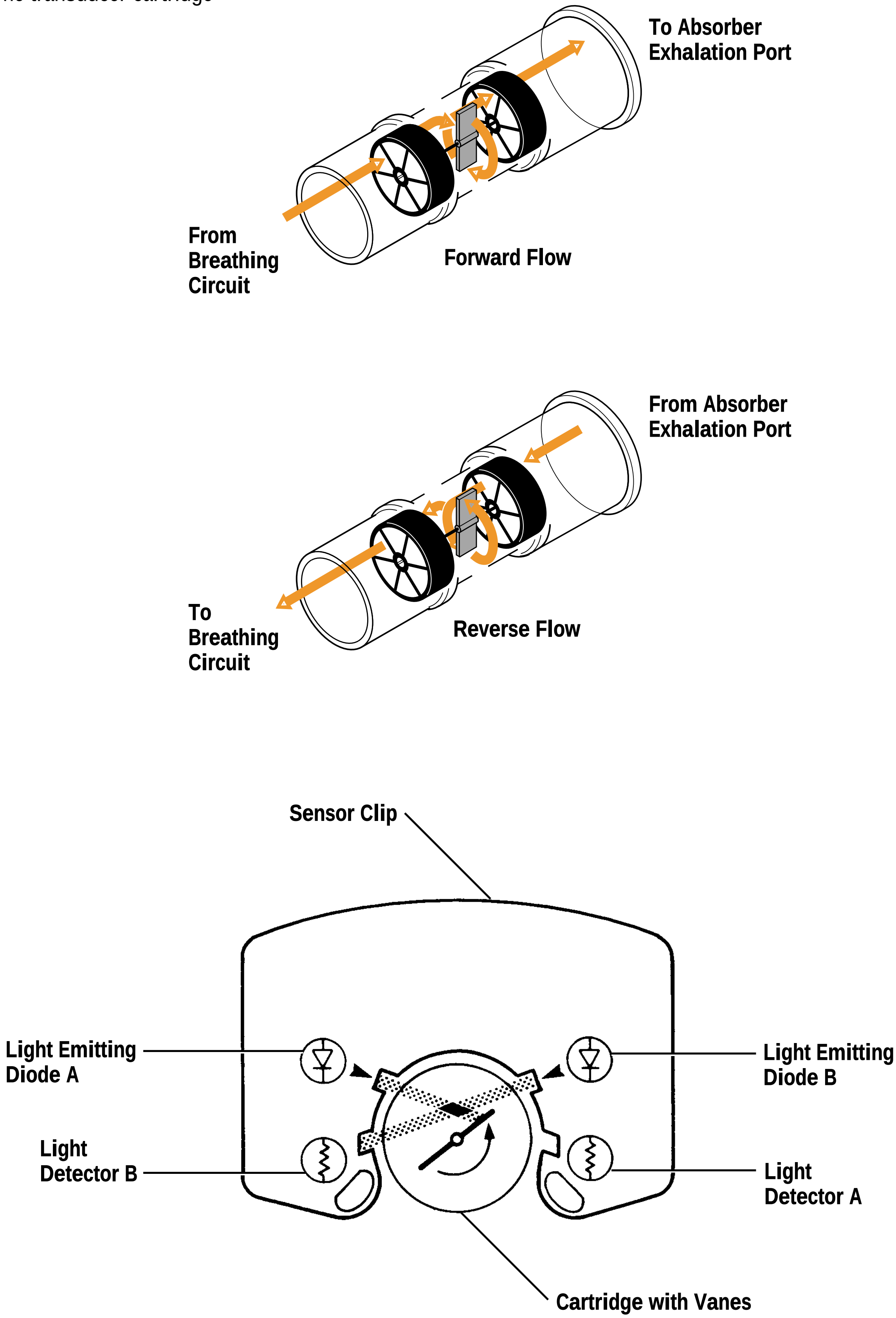
The volume sensor clip has a heater circuit in the area where it clips onto the transducer cartridge. Exhaled patient gas is warm and contains moisture. When the exhaled gas contacts the exhalation port of the absorber, which is usually at a lower temperature, moisture can condense and form water droplets in the transducer cartridge. The heater in the sensor clip keeps the cartridge warm and prevents moisture condensation from occluding the infrared light beams through the cartridge. To save energy, the heater is OFF when the ventilator is operating on battery power.

The ventilator calculates breath rate and volume at the end of each detected breath, or at 10-second intervals if no breath is detected, and are averaged over the last six calculations. On start-up, the monitor does not have information about previous breaths, so it does not display data until one breath is detected. After one breath, values for the first breath are calculated and shown on the display panel of the control module. At each breath that follows, or at each 10-second interval if no breath has occurred, new values are calculated and averaged with earlier breath information, and the results are displayed.

Only the results of the most recent calculations are averaged and displayed. Averaging information from six breaths helps to avoid interference from such factors as a patient’s cough. Alarm conditions are based on the calculations at the end of each breath, or at 10-second intervals if no breath has occurred.

Illustration 61

Volume transducer cartridge



Alarms

Tidal volume monitor circuits provide information about the patient's exhaled breath rate, exhaled tidal or minute volumes, and the direction of flow to the patient circuit. It will generate alarms if it senses volumes outside the levels set by the pushwheels.

- A LOW MINUTE VOLUME message is displayed, the yellow LED flashes, and an intermittent beep sounds if the ventilator senses that the minute volume is less than the level set using the low minute volume pushwheel.
- APNEA ALARMS are displayed by the ventilator if a sufficient breath, based on the setting of the tidal volume dial, is not detected within 30 seconds of the previous breath. If a breath is not detected in 30 seconds, an apnea alarm tone sounds at 30, 60, and 90 second intervals. A visual indication of the elapsed apnea time is also displayed. At 2 minutes apnea time, the alarm sounds continuously, the display changes to APNEA**, and a red LED is switched ON. The apnea alarm may be disabled by setting the mechanical ventilation switch to OFF (if in ventilation mode) or tidal volume knob to below 300 ml (if in non-ventilation mode).
- REVERSE FLOW! message is displayed, the yellow LED goes ON, and a continuous alarm sounds if reverse flow (toward the patient) is sensed by the ventilator.

Reverse flow detection by the volume transducer cartridge can be set ON or OFF by using the ventilator set-up page. When reverse flow is ON and the tidal volume control knob is set below 300 ml, as little as 20 ml/min of flow will activate the alarm. When the knob is set above 300 ml/min, reverse flow must be over 100 ml/min to sound the alarm. The monitor must sense two forward-directed breaths to silence and reset this alarm.

Note: Various circuit connections may create reverse flow past the tidal volume sensor and it is expected by the operator. In such cases, the reverse flow alarm can be turned off to avoid unnecessary alarms.

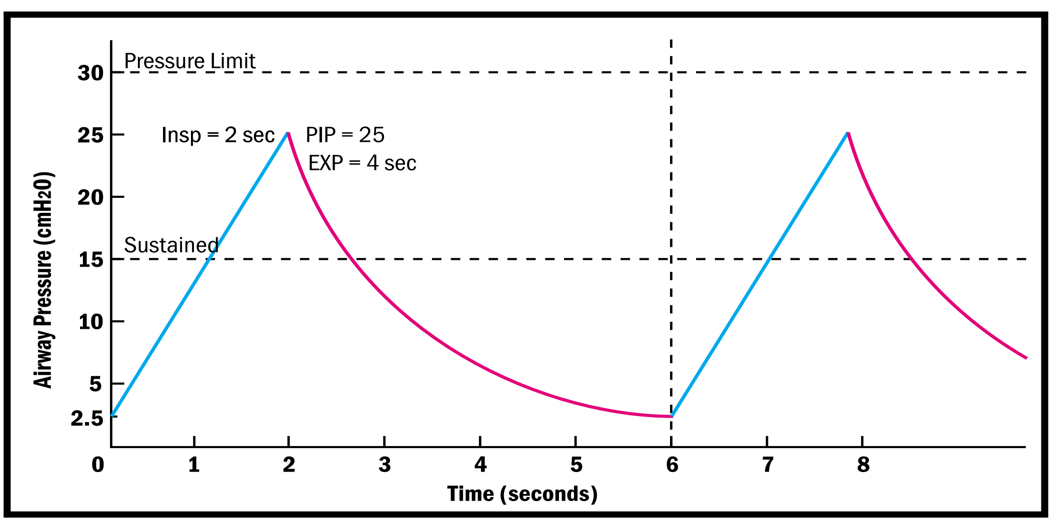
Airway pressure monitor

Electronic airway pressure monitor circuits in the ventilator are designed to give audible and visual warning signals if hazardous airway pressures occur in the breathing circuit.

The airway pressure transducer, located in the control module, senses the patient airway pressure through tubing connected to the breathing circuit. The transducer produces an electrical output signal that is proportional to the difference between the patient's airway pressure and atmospheric pressure. The airway pressure monitor circuits compare the airway pressure measurements with the set alarm limits and audible, and visual alarms are activated if the limits are exceeded.

Airway Pressure Waveform

Rate = 10 breaths per minute
InInhalation Pressure Limit set at 30 cm H_2O (sustained at 15 cm H_2O)
I:E - 1:2



Normal operation

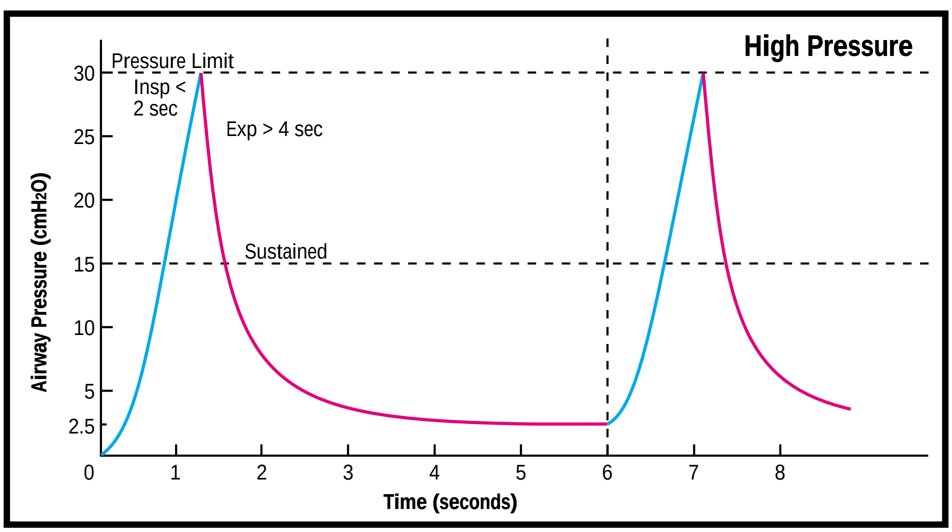
High Pressure

- In the monitor mode, a HIGH PRESSURE! message appears, the red LED flashes, and one warble tone per breath sounds if inspiratory pressure reaches or exceeds the set inspiratory pressure limit.

When the ventilator is in the mechanical ventilation mode, the same visual and audible alarms occur. In addition, the monitor circuits send a signal to the microprocessor, which turns OFF the flow control valve and exhalation solenoid and drive gas stops immediately. The exhalation valve opens to vent the drive gas from the bellows assembly. In this way, the ventilator stops the inhalation phase, allows the patient to exhale, and helps to prevent excess pressure in the patient airway.

Airway Pressure Waveform

Rate = 10 breaths per minute
Inhalation Pressure Limit set at 30 cm H_2O (sustained at 15 cm H_2O)
I:E - 1:2



Occluded airway, inspiratory pressure limit reached during inhalation

Sustained pressure

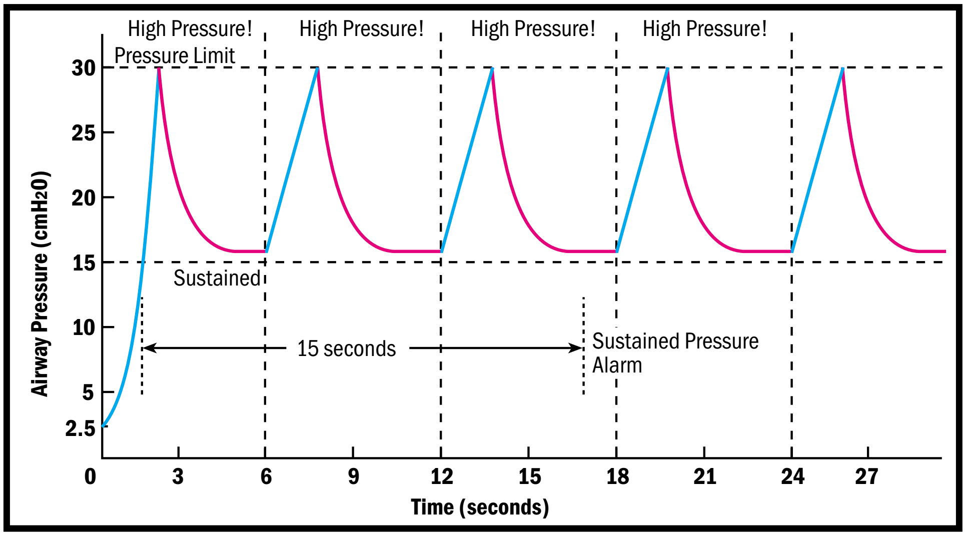
Sustained pressure limits are set when the clinician sets the inhalation pressure limit. As the inhalation pressure limit is varied in its range of 20 to 60 cm H_2O, the sustained pressure limit is one-half of the inhalation pressure limit. Any inhalation pressure limit setting of more than 60 cm H_2O maintains a set sustained pressure limit of 30 cm H_2O

For example, if the inhalation pressure limit is set at 42 cm H_2O, the sustained pressure limit is 21 cm H_2O, while inhalation pressure limits of 65 cm H_2O and 80 cm H_2O both result in a sustained pressure limit of 30 cm H_2O.

- A SUSTAINED PRES! message is displayed, the red LED flashes, and a continuous warble alarm sounds if airway pressures exceeds the set limit for 15 seconds or more.

Airway Pressure Waveform

Rate = 10 breaths per minute
Inhalation Pressure Limit set at 30 cm H_2O (sustained at 15 cm H_2O)
I:E - 1:2



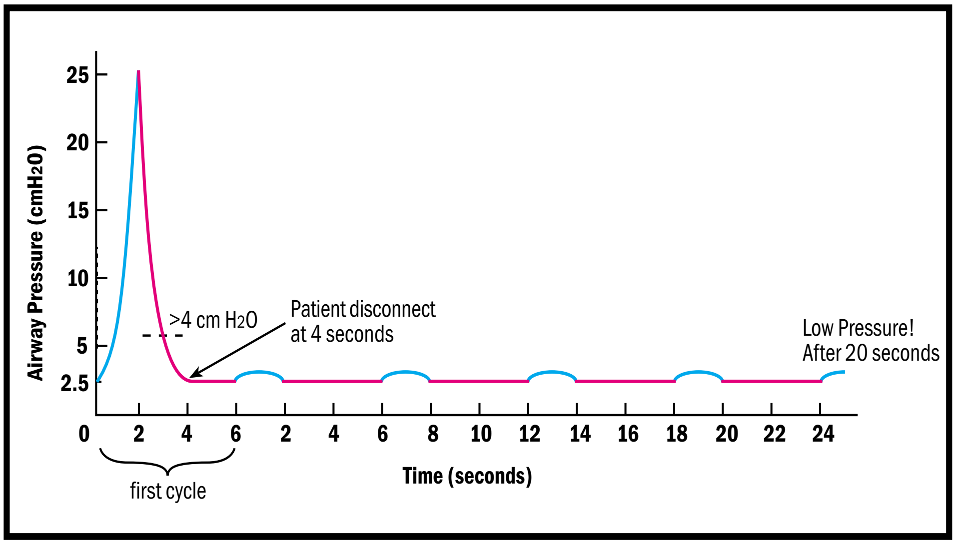
Sustained elevated pressure

Low and subatmospheric pressure

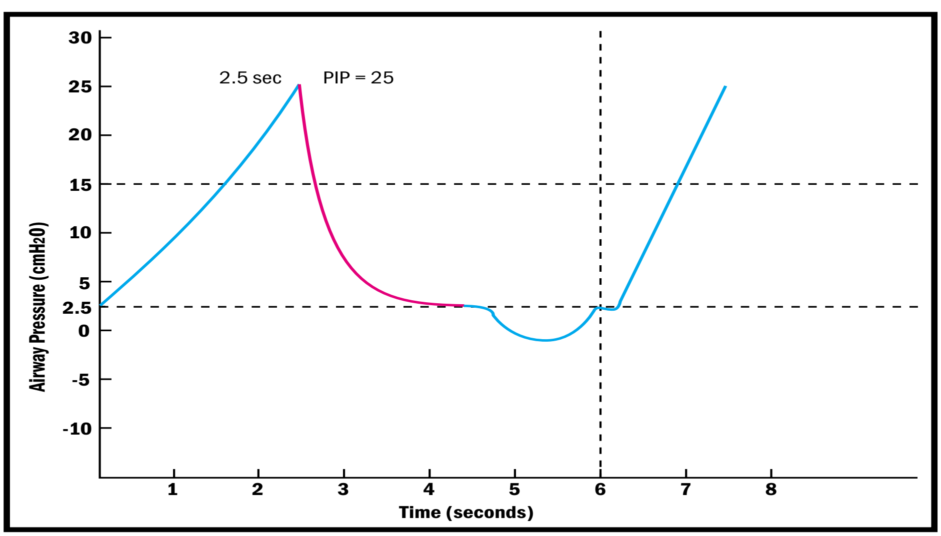
- A LOW PRESSURE! message appears, the red LED flashes, and one warble tone sounds if the ventilator does not detect a defined change of pressure within 20 seconds during each inspiratory cycle. The pressure change must be between 4 and 9 cm H_2O depending on inspiratory flow rate — the higher the flow, the greater must be the change in pressure.
- A SUB-ATMOS PRES! message appears, the red LED flashes, and a warble tone sounds continuously if the ventilator senses a pressure less than –10 cm H_2O.

Airway Pressure Waveforms

TV = 750 ml
Rate = 10 breaths per minute
I:E - 1:2 (inspiratory flow ≈ 23 L/min)



Low pressure alarm after first cycle



Sub-atmospheric pressure, patient taking a breath

The Bellows Assembly

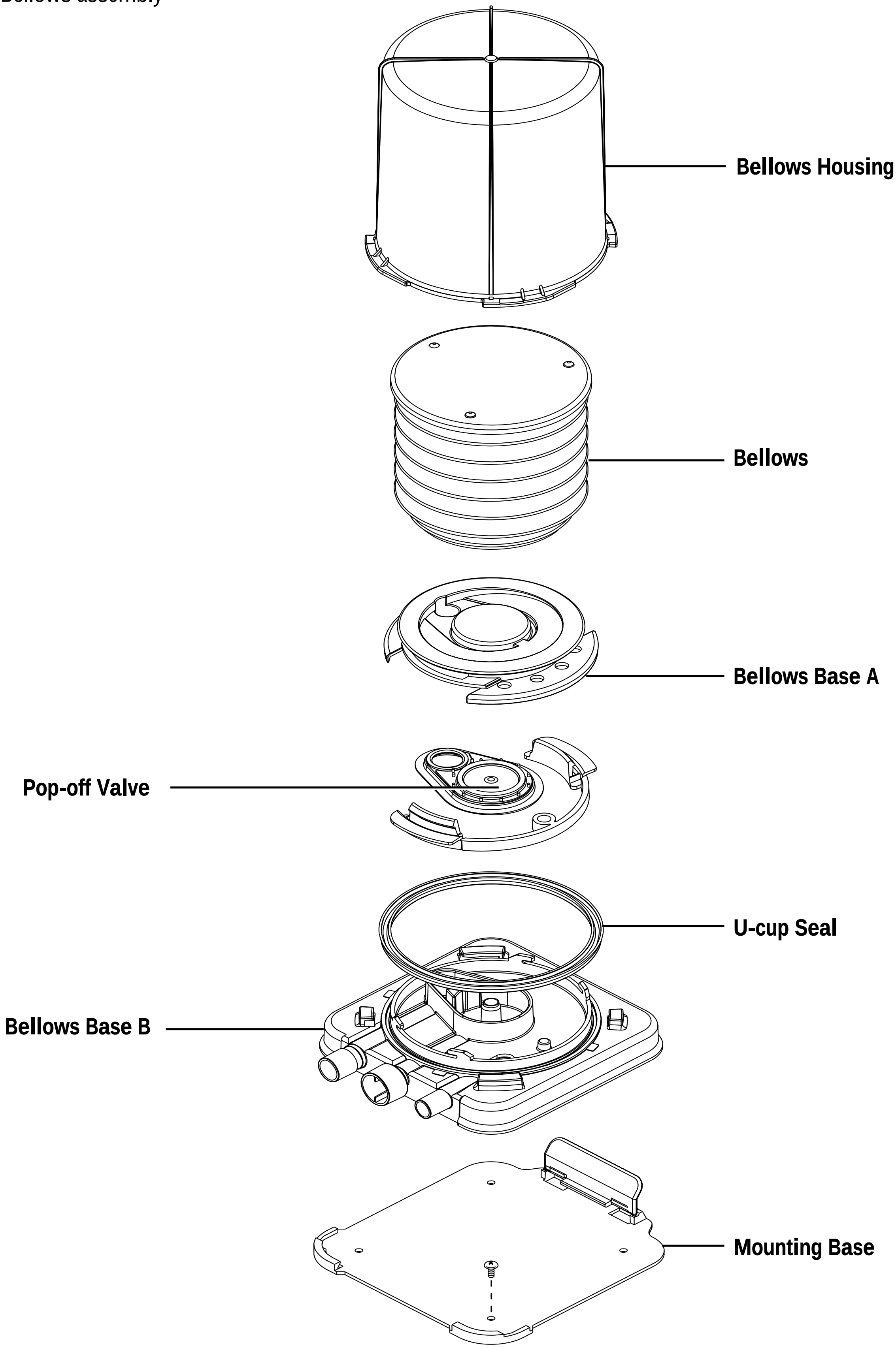
The autoclavable bellows assembly (ABA) is made of latex-free components that are intended for cleaning by autoclave. All autoclavable components are marked with 134°C markings.

The bellows assembly has five components:

- The bellows base.
- The bellows housing.
- The bellows housing gasket, also known as a U-cup seal.
- The bellows.
- The pop-off valve, sometimes known as the diaphragm and seat assembly.

Illustration 62

Bellows assembly



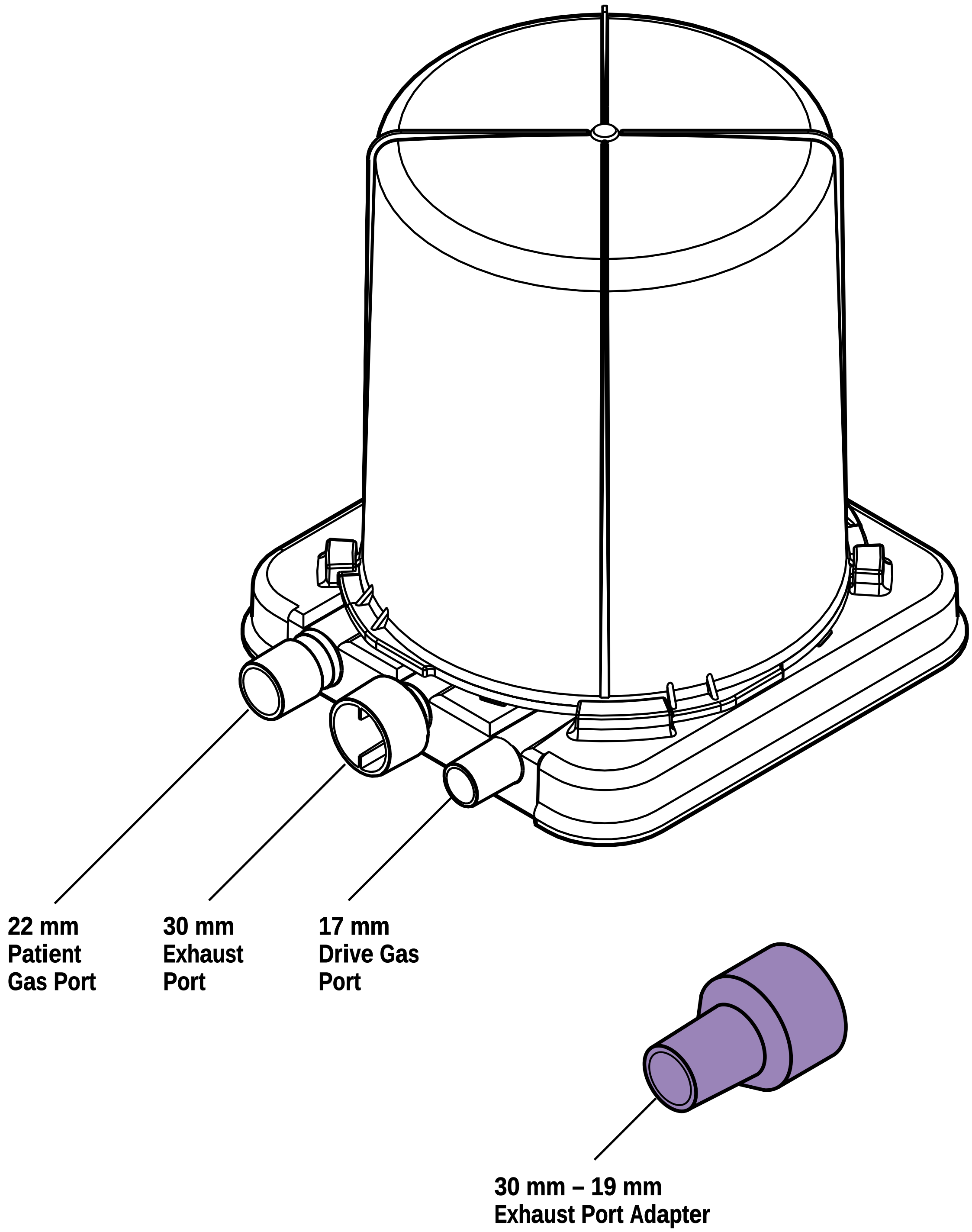
The Bellows Base

The illustration on the facing page shows the circuit connections to the bellows base:

- 22 mm opening. Anesthetic gas flows to and from the patient through this port.
- 17 mm opening. Drive gas from the control module flows through this port and holes in the base that surround the bellows. This drives the bellows down.
- 30 mm opening. Excess gas inside the bellows flows through this port to the waste gas scavenging manifold. A 30 mm to 19 mm adapter is used to attach to scavenging systems in several countries (including the United States and Canada).

Illustration 63

Bellows base with ports called out



The Bellows Housing

The bellows housing locks onto the bellows base by turning it clockwise.

During inhalation, drive gas enters the bellows housing, fills the area outside the bellows, and pushes the bellows down to deliver gas to the patient. Resistance and elasticity in the patient circuit and at the patient causes pressure inside the bellows housing to increase. During the exhalation phase, drive gas leaves the bellows housing, and pressure inside the bellows housing decreases to almost atmospheric pressure.

The Bellows Housing Gasket

A U-shaped gasket fits between the bellows base and bellows, acting as a seal.

The Bellows

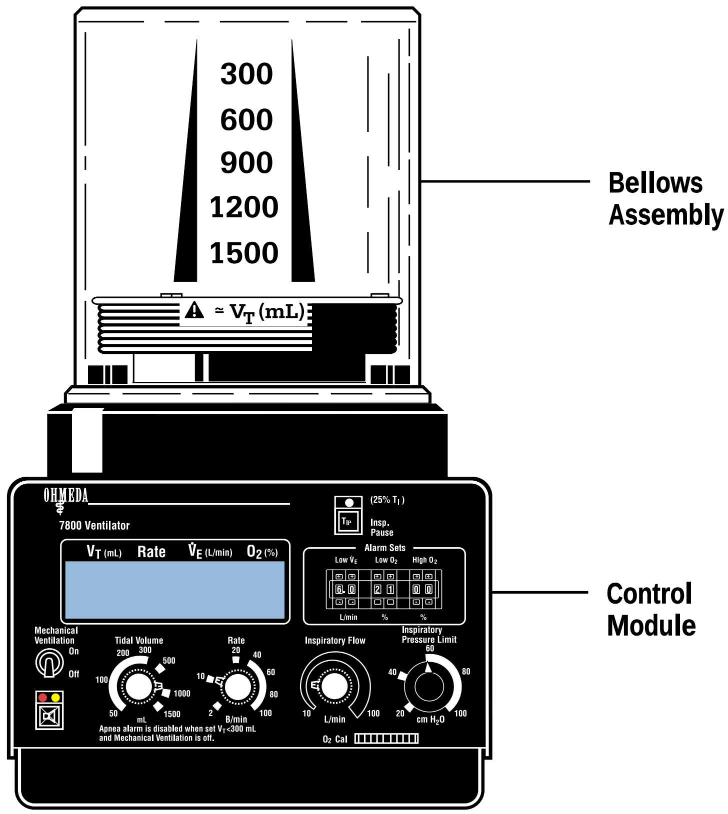
The bellows is attached to the bellows base. During the exhalation phase, exhaled patient gas enters the bellows through the 22 mm opening in the bellows base. The bellows expands and rises to the top of the housing. This action is called an “ascending” or “standing” bellows. The illustration on the facing page shows the direction of gas flow during the exhalation and inspiratory phases.

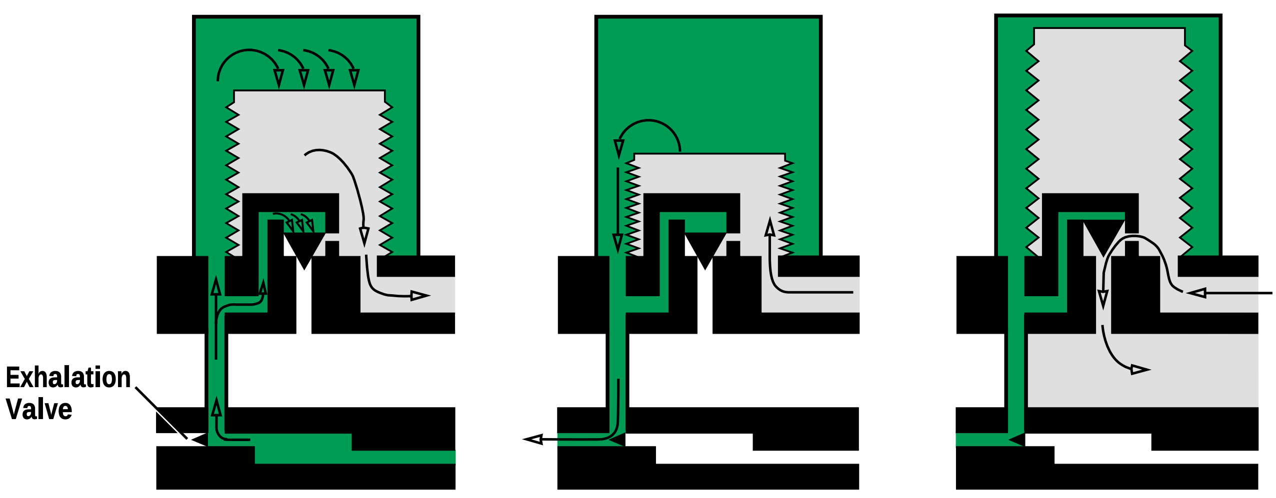
During the inhalation phase, drive gas from the control unit enters the bellows housing at a rate set by the flow control. Drive gas pressure in the bellows housing increases until a specific amount of drive gas volume, set by the tidal volume control, displaces an equal amount of gas from the bellows. The pressure of the drive gas pushes the bellows down and the gas in the bellows is forced out the 22 mm opening to the absorber, where CO_2 is removed, and fresh gas is added, and then to the patient circuit.

Drive gas is released from the bellows housing during the next exhalation phase. The drive gas vents past the exhalation valve to atmosphere through louvers in the back panel of the control module. This decreases the pressure in the area outside the bellows and permits the exhaled patient gas to enter the bellows through the 22 mm port. This refills the bellows, and it rises to the top of the bellows housing until the start of the next inhalation cycle.

Illustration 64

How the bellows assembly operates
older bellows assembly illustrated





Inhalation

Airway and Drive Gas Pressure Increasing

Exhalation

Airway and Drive Gas Pressure Decreasing

End Exhalation

Airway Pressure Approximately 2.5 cm H_2O

Bellows at Top of Housing Pop-off Valve Open

- O_2
- N_2O
- Agent
- Air
- CO_2

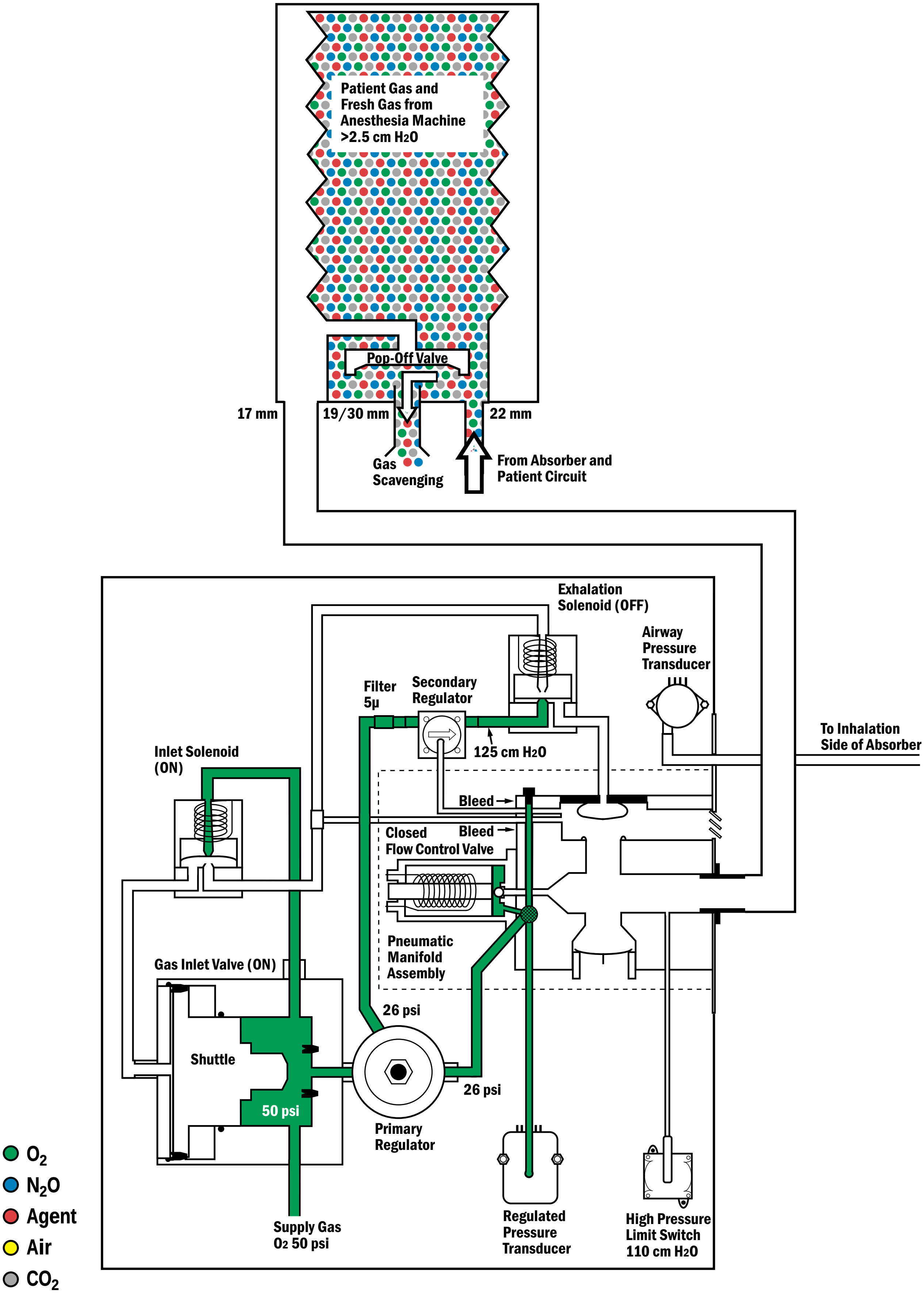
Bellows Assembly Pop-Off (diaphragm and seat assembly) Valve

The pop-off valve is a diaphragm and seat assembly. It is located under the bellows over the opening to the excess gas (30 mm) port. During inhalation, some of the drive gas is directed to the top of the pop-off valve. The drive gas pressure holds the pop-off closed, blocking patient gas (unless it exceeds drive gas pressure) from escaping to the scavenging system.

During exhalation, the patient's exhaled volume fills the bellows, and causes the bellows to rise to the top of the bellows housing (ascending bellows). Fresh gas from the anesthesia system is also filling the bellows. When the bellows reaches the top of the bellows housing, the pressure inside the bellows increases. When the pressure reaches approximately 2.5 cm H_2O, it lifts the pop-off valve off the excess gas port. This opens the port and permits excess gas (patient-exhaled anesthetic mixture) to vent out the 30 mm excess gas port. The excess gas port is usually connected to a waste gas interface manifold.

Illustration 65

End of exhalation phase



PEEP VALVE

At the end of the exhalation phase of a breath, patient airway pressure is approximately 2-3 cm H_2O (ventilator bellows pop-off valve setting). This pressure is called baseline or End Expiratory (Exhalation) Pressure. The End Exhalation Pressure can be increased to a positive pressure (typically between 3 to 30 cm H_2O) when a PEEP (Positive End Exhalation Pressure) Valve is added to the breathing circuit.

When the PEEP valve is adjusted, a set amount of pressure increase is seen at the end of the exhalation phase after the first breath. The breaths that follow show a pressure increase at the end of exhalation and at the end of inhalation.

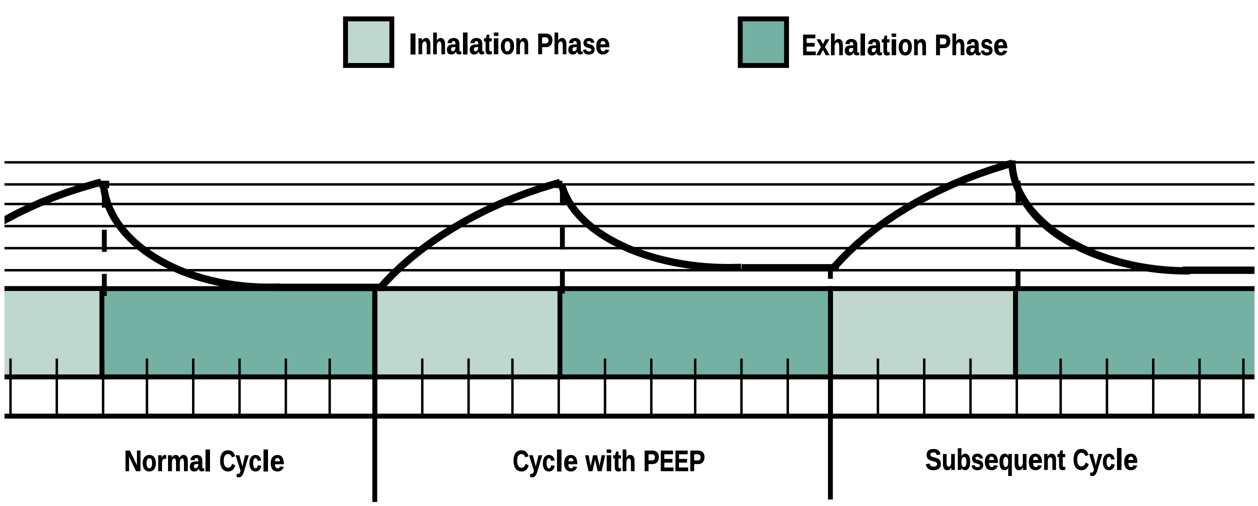
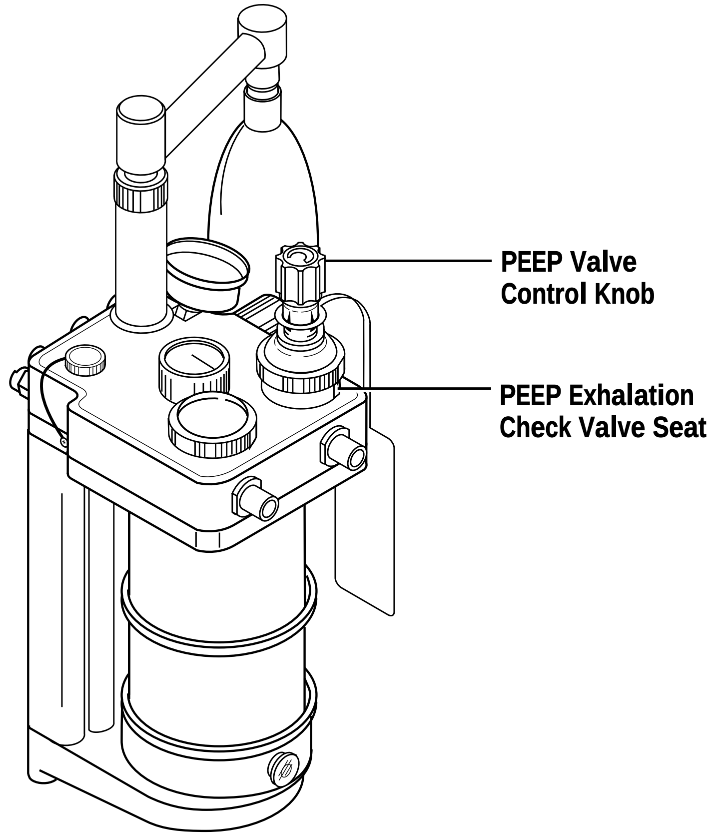
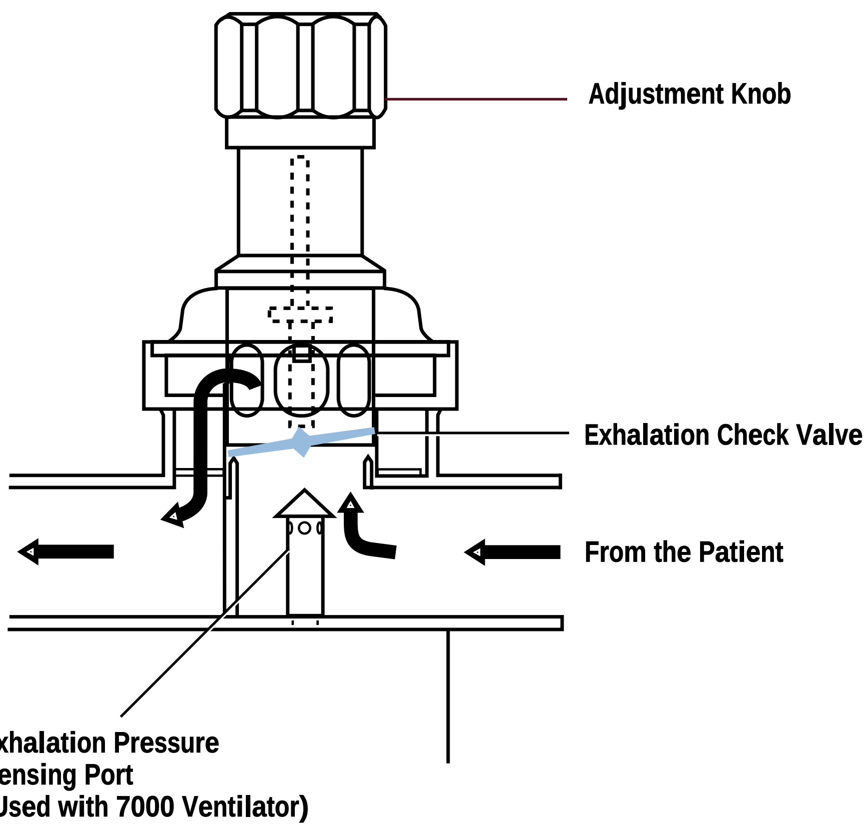


Illustration 66

Flow through the PEEP valve





INTRODUCTION

ABSORBER

The absorber removes carbon dioxide and excess moisture, and controls the path of the gas to the patient.

By the end of this section, the reader should know:

- How carbon dioxide is removed.
- How moisture is controlled.
- What safety devices are used.
- How gas flows are controlled.
- How to connect a breathing circuit.

HOW THE ABSORBER REMOVES CARBON DIOXIDE

During respiration, the blood in the lungs absorbs oxygen and releases carbon dioxide. Carbon dioxide is a waste gas from the respiratory process.

The parts of the absorber used to absorb carbon dioxide and manage moisture include:

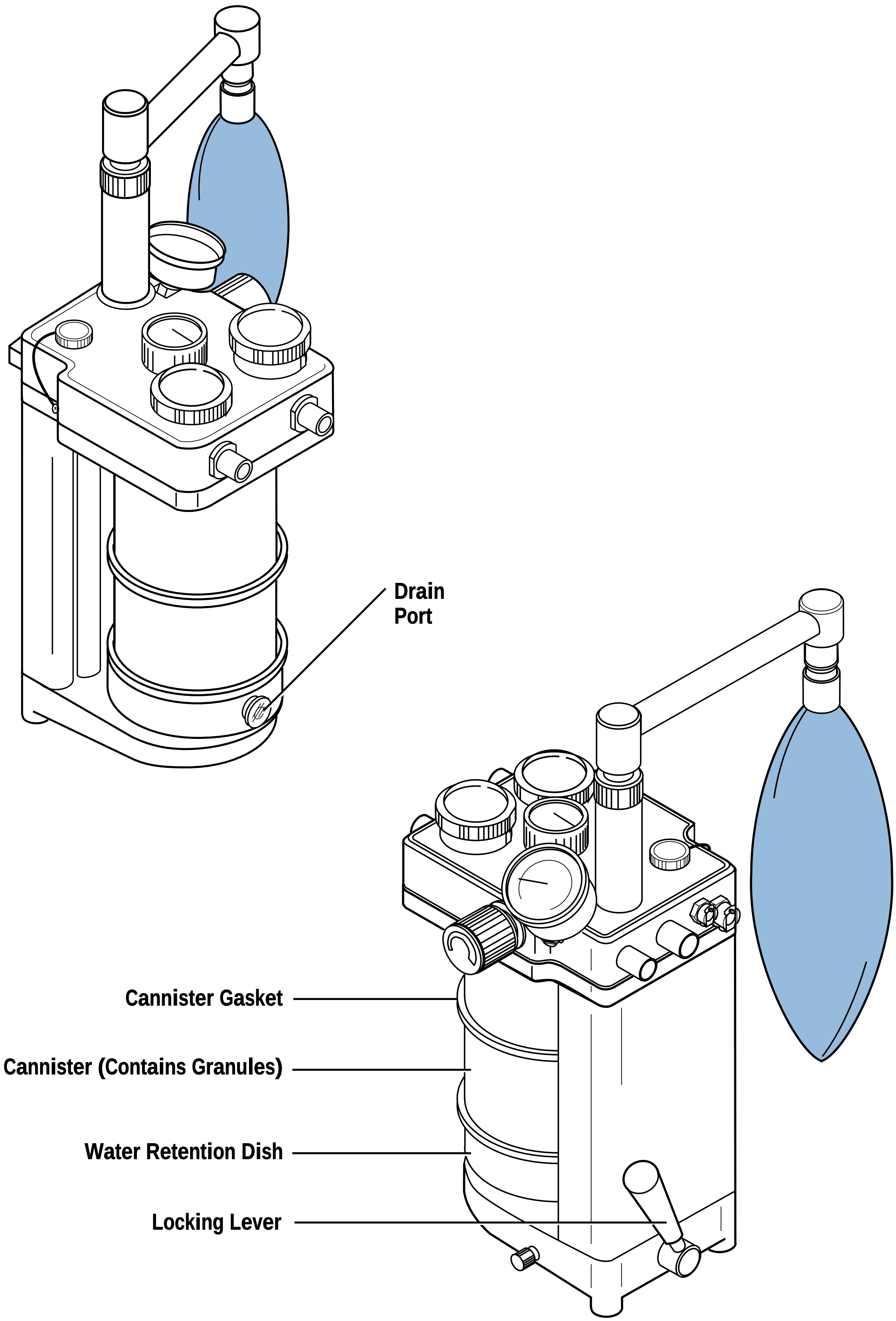
- Absorbent granules.
- Canisters.
- Gaskets.
- Dish with a drain port.
- Locking lever.

The absorber usually includes two canisters that sit one on top of the other over a dish. The canisters hold the granules that absorb carbon dioxide from the gas exhaled by the patient. The locking lever holds the dish and canisters on the absorber. Gaskets help prevent leaks between the dish, the two canisters, and the top of the absorber.

A chemical reaction with the absorbent granules removes carbon dioxide from the patient gases and produces water and during long cases supplies moisture to the patient circuit. Moisture is also added to the gases by the patient during exhalation. When the warm gas flows from the patient to the cooler absorber, drops of water form. The dish has a drain port and its plug can be opened to remove the water. To avoid leaks, the plug should not be opened while the absorber is in use.

Illustration 67

The GMS absorber



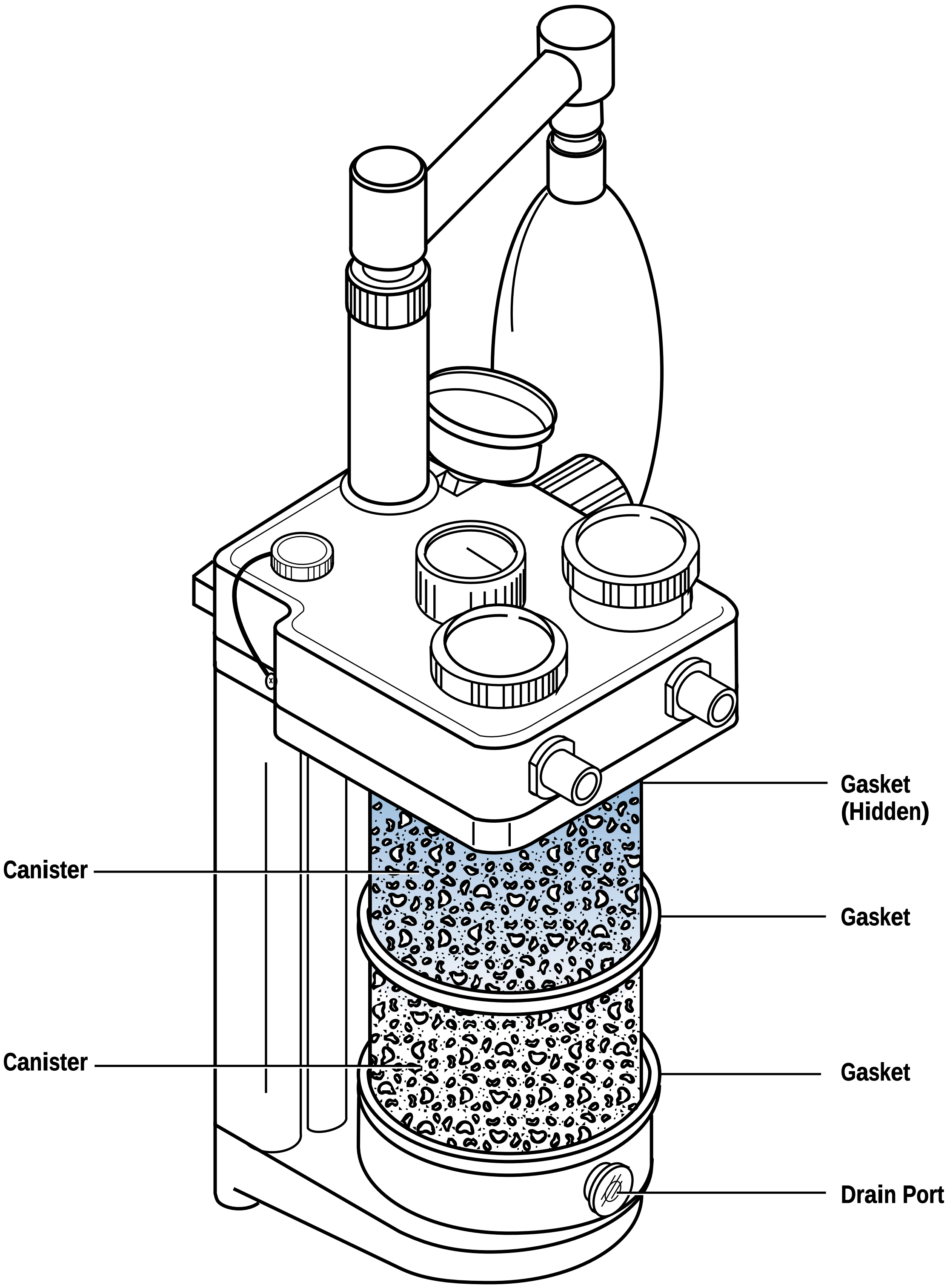
Most absorbent granules have color indicator chemicals added to indicate the condition of the granules. The color of the granules tells the operator when to replace them. When the granules can no longer absorb carbon dioxide, their color changes to pink, blue, or yellow. It is important for the operator to check the color of the granules during use and at the end of a procedure. Granules that are spent can change back to their initial color when they are not in use.

The granules in the canisters are depleted at different rates. The exhaled gases go through the top canister first, and the granules in this canister remove most of the carbon dioxide. When the granules in the top canister are used up, it should be filled with new granules and moved to the lower position. The lower canister should be installed in the top position. This rotation of absorbent is the most cost effective way of using absorbent.

The operator should make any necessary changes of absorbent granules before the anesthesia machine is used. Tests specified in the Operation and Maintenance manual should then be conducted to make sure that there are no leaks. Releasing a canister while the system is in use will cause a very large leak.

Illustration 68

Granule color changes



GAS FLOW THROUGH THE ABSORBER

The mixture of fresh gas and anesthetic agent flows to the absorber through the gas supply hose connected between the common gas outlet on the anesthesia machine and the common gas inlet port on the absorber. The gas mixture flows through the absorber to the patient through a breathing circuit. The breathing circuit is a set of tubes that connect to the inhalation and exhalation ports of the absorber on one end and to a connector at the patient's airway on the other end.

HOW THE ABSORBER CONTROLS THE FLOW OF THE GASES

The parts of the absorber used to control the flow of gas in the patient circuit include:

- The selector switch.
- The inhalation and exhalation check valves.
- Flow paths and chambers that are part of the absorber chassis.
- The adjustable pressure-limiting or APL valve.

The selector switch controls the path of the gas flow through the absorber. In the Bag-APL (manual) position, it routes the gas to the bag arm and the breathing bag connected to the bag arm. In the ventilator position, it routes gases to the bellows for mechanical ventilation.

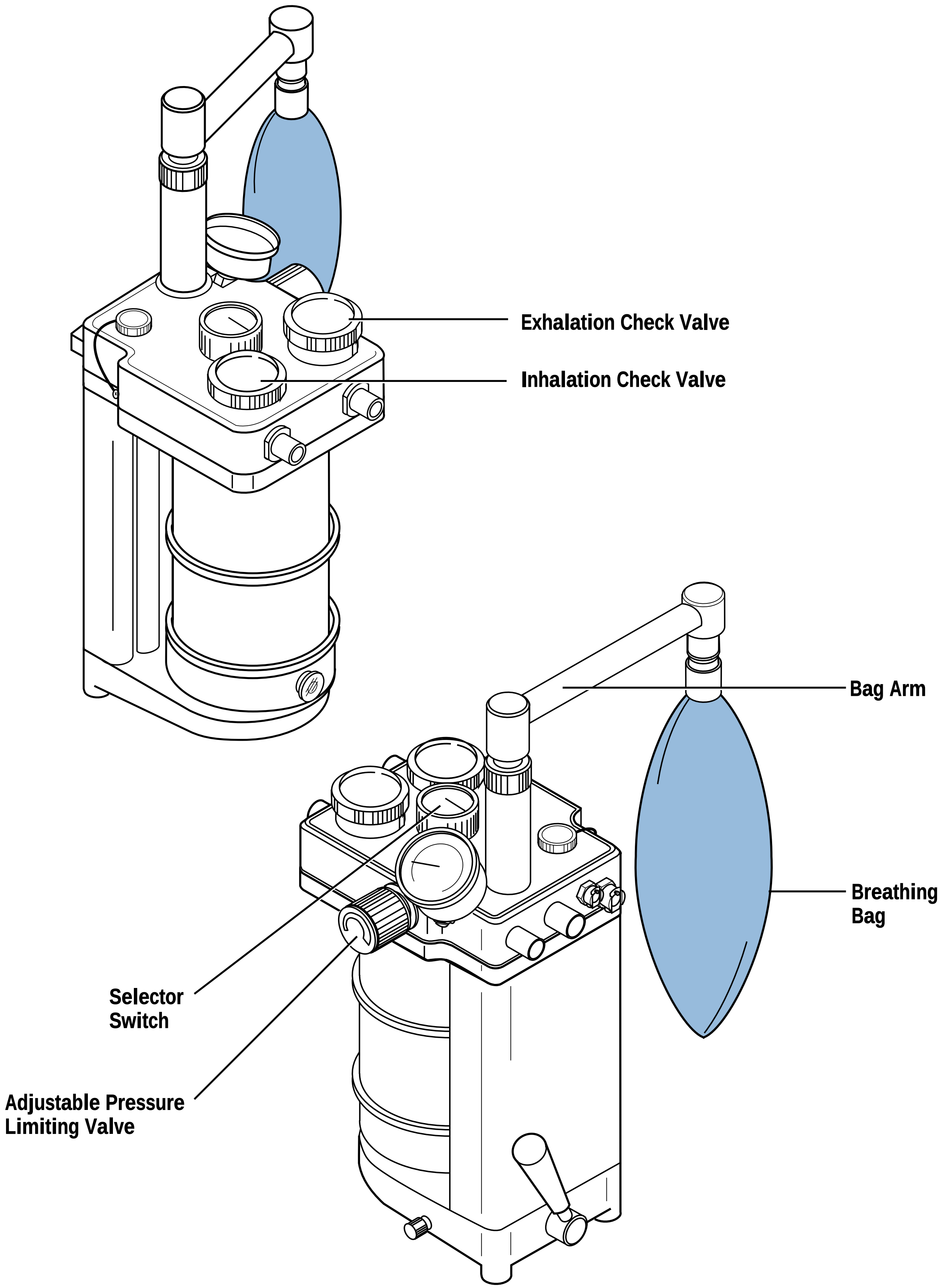
The operator can deliver a breath to the patient manually or use the ventilator to control the patient's breathing process mechanically. When the operator chooses to manually control the breathing process for the patient, the selector switch is set to the Bag-APL position. To supply gases to the patient for inhalation, the operator squeezes the breathing bag, that is connected to the bag arm. The operator squeezes the bag with enough pressure to push the gases through the patient circuit into the patient's lungs. The APL valve controls the amount of pressure in the patient circuit. The APL valve is part of the gas circuit only when the absorber is in the Bag-APL position. The check valves prevent reverse flow.

When the ventilator is used to deliver a breath to the patient, the respiratory rates and the volume of gas to be supplied to the patient are set using the controls on the ventilator. The absorber selector switch must be set to the Ventilator position. (A discussion of how the ventilator operates and the safety measures it provides can be found in the Ventilator section.) When the ventilator supplies a breath to the patient, the ventilator, not the APL valve, limits the amount of pressure allowed in the patient airway.

If the patient attempts to breathe independent of manual or mechanical assistance, this is called spontaneous breathing. If the patient attempts to breathe spontaneously, a breath can be drawn through the absorber to the breathing bag or bellows assembly.

Illustration 69

The GMS absorber



HOW THE INHALATION AND EXHALATION VALVES OPERATE

The inhalation and exhalation chambers of the absorber contain:

- A dome cover.
- A retainer.
- An O-ring.
- A valve seat.
- A check valve.

The dome is a clear plastic cover over the valve seat and is held in place by a retainer. The operator can look through it and see the check valve operate. An O-ring under the dome helps to prevent leaks between the dome, the retainer, and the valve seat. The dome, retainer, check valve, and O-ring are the same for both the inhalation and exhalation valve seats. But, the inhalation valve opens only during inspiration and the exhalation valve opens only during expiration. The valves are known as unidirectional valves because they each permit gas to flow in only one direction.

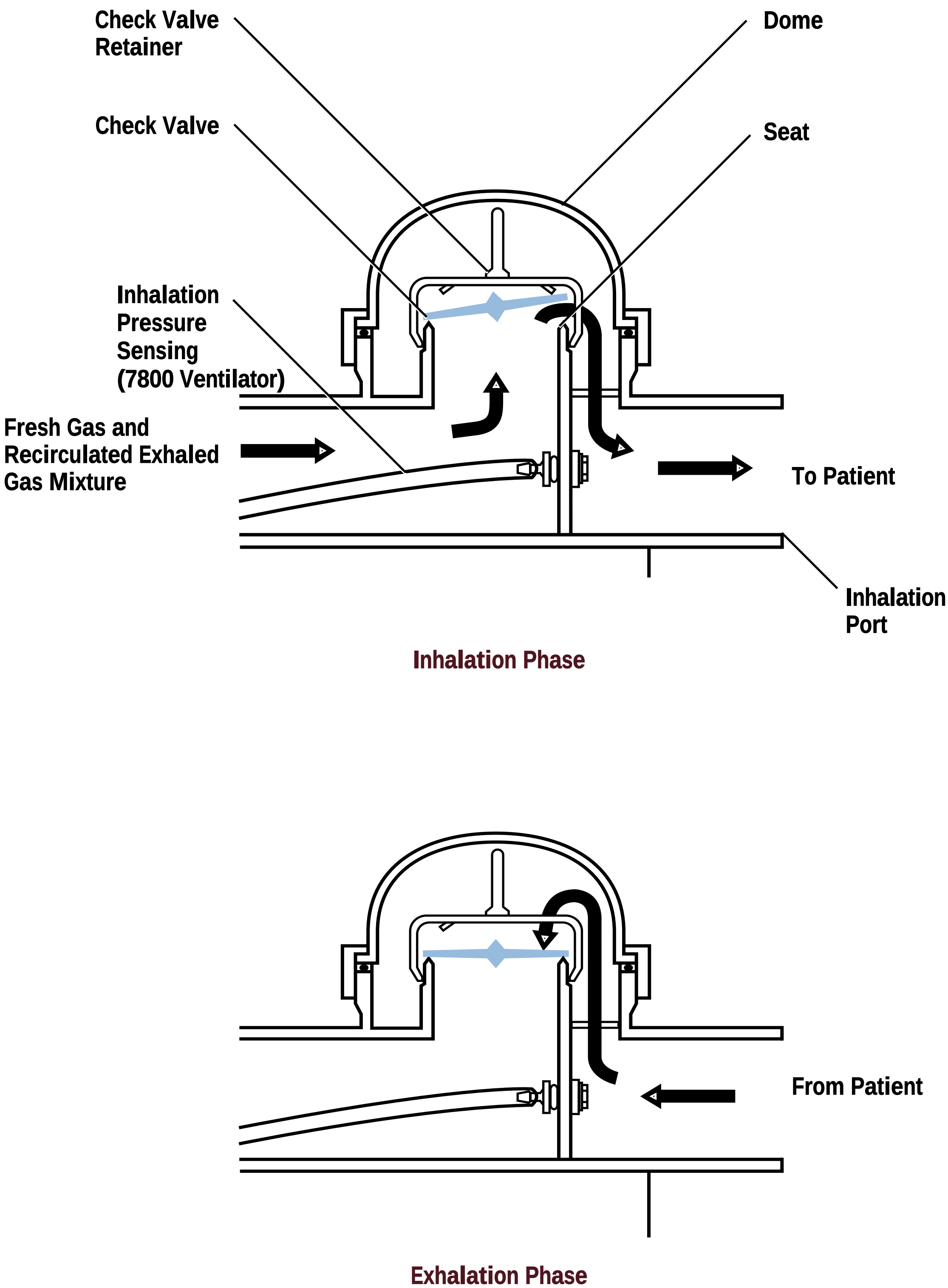
The exhalation valve seat is usually taller than the inhalation valve seat. This permits a PEEP valve (see the Ventilator section) to be connected to the exhalation seat. The illustration on the facing page shows how the valves work.

INHALATION

During inhalation, fresh gas flow is directed up through the center of the inhalation seat. The pressure of the gas lifts the check valve off the seat and the gas mixture flows past it to the patient airway. During exhalation, gas flow from the patient is directed up through holes outside of the inhalation seat. The gas pressure pushes the inhalation check valve against the seat. The inhalation check valve now prevents exhaled gas from flowing in a reverse pattern and entering the absorber through the inhalation chamber. If this were to happen, carbon dioxide concentration would increase in the patient circuit because exhaled patient gas would not flow through the absorbent granules for carbon dioxide removal.

Illustration 70

Flow through the inhalation check valve



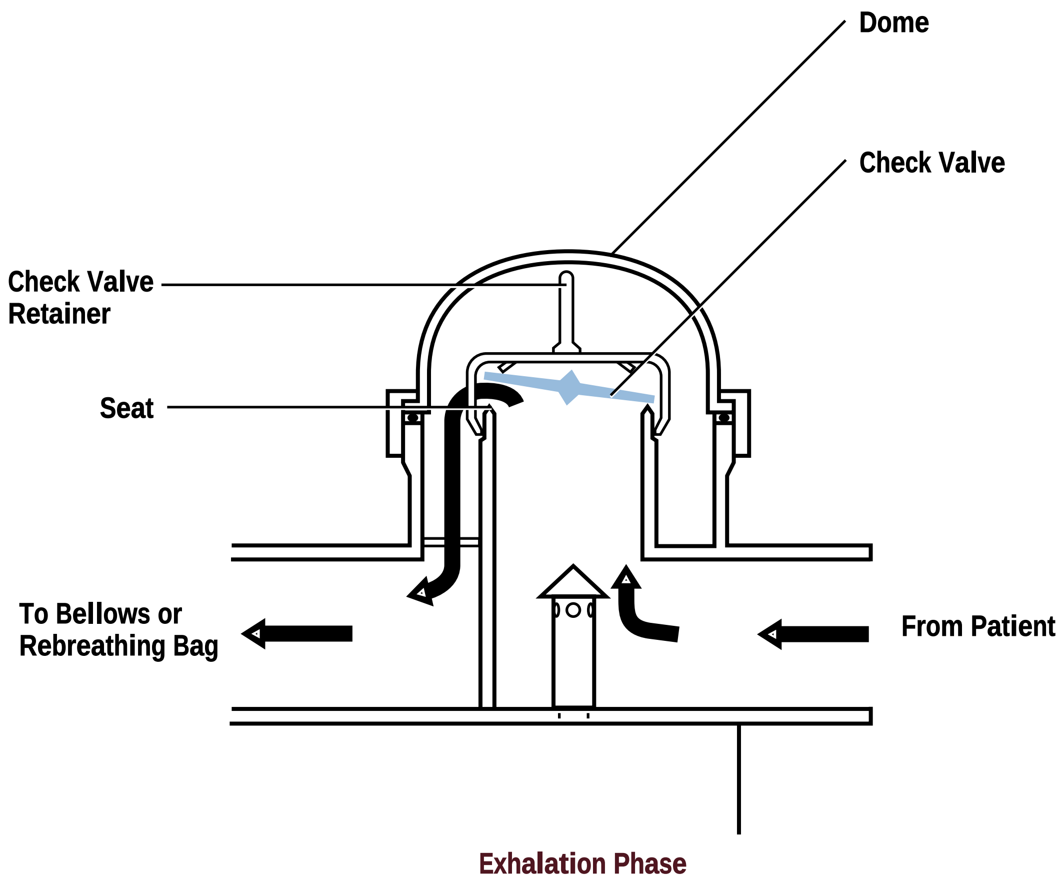
- O_2
- N_2O
- Agent
- Air
- CO_2

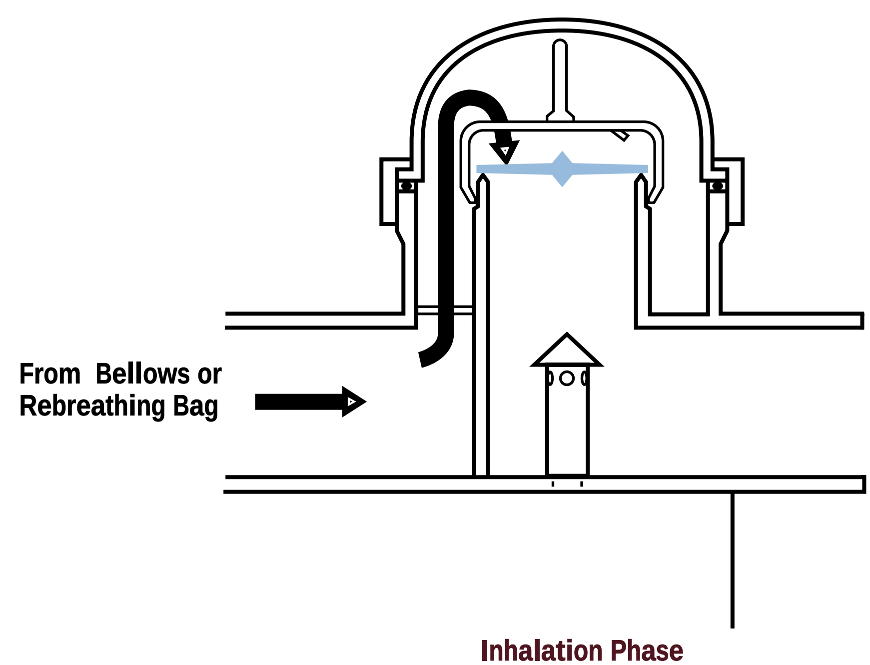
EXHALATION

During expiration, gas flows up through the center of the exhalation valve seat and lifts the check valve off the seat. During inhalation, gas flow is directed through small holes around the exhalation valve seat. The pressure of the gas pushes the exhalation check valve against the seat. This helps prevent the fresh gas mixture from entering the absorber and ensures that it is delivered to the patient.

Illustration 71

Flow through the exhalation check valve





- O_2
- N_2O
- Agent
- Air
- CO_2

HOW THE SELECTOR SWITCH OPERATES

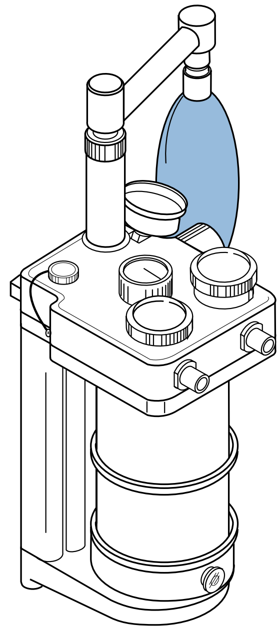
The selector switch includes a spring-loaded pivot bracket. The bracket holds two cup seals. The absorber manifold includes two ports. One port is open to the bag arm and the APL valve, and the other port is open to the ventilator bellows assembly. When the selector switch is used, the spring on the pivot bracket pushes one cup seal against one port at a time. The seal helps to prevent a leak through the port.

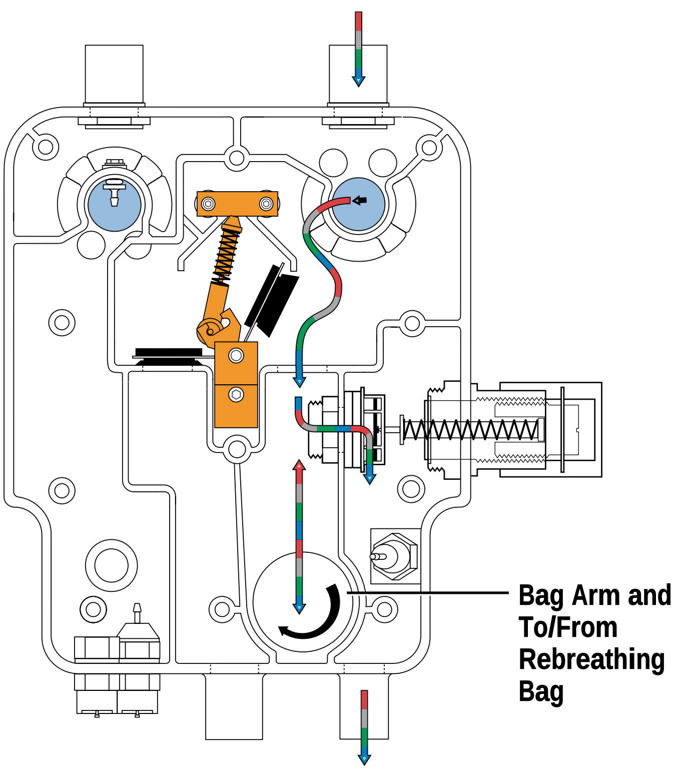
The switch can be turned to only two positions: Bag-APL or Ventilator (shown on the facing page). When it is in the BAG-APL position, a cup seal on the pivot bracket seals the port to the ventilator and helps to prevent flow to the bellows assembly. The other port is open to permit flow to the bag arm and the APL valve.

When the selector switch is in the Ventilator position, a cup seal on the pivot bracket seals the port to the bag arm and the APL valve. The other cup seal is open to permit flow to the ventilator. It is a switch that will be either in one position or the other, there is no midway position.

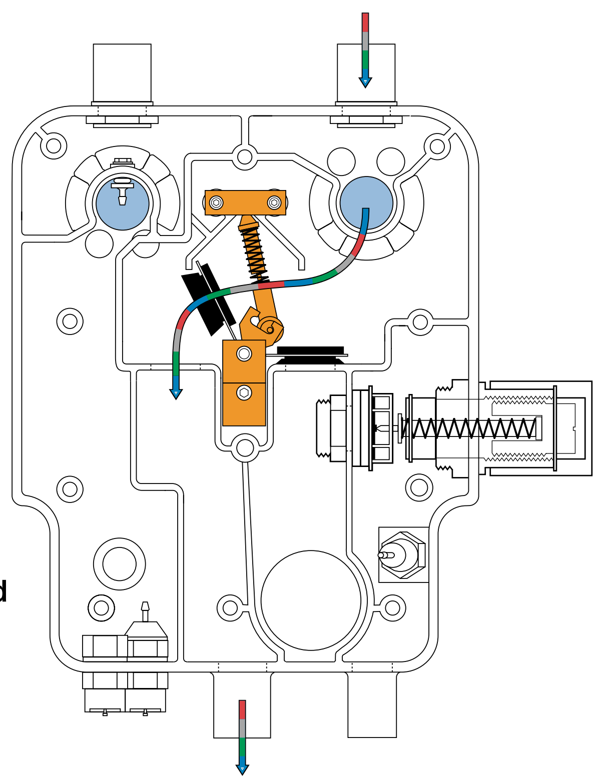
Illustration 72

The selector switch (underside view)





Switch In Bag/APL Position



Switch In Ventilator Position

- O_2
- N_2O
- Agent
- Air
- CO_2

HOW THE APL VALVE FUNCTIONS

The APL valve is an adjustable pressure limiting valve designed to limit pressure in the exhalation chamber of the absorber (patient circuit pressure) to an operator adjusted set point. Pressure in the breathing circuit is controlled by the APL valve when the absorber selector switch is in the Bag-APL position.

It is an assembly that includes:

- A control knob and screw.
- A seat.
- A valve disc.
- A retainer that holds the valve disc in place.
- A valve stem and spring.

The APL valve is adjustable from a minimum of 1 cm H_2O to approximately 75 cm H_2O pressure in the patient circuit. The APL valve knob sits on tapered grooves and a screw in the knob rides along the grooves. When the APL valve is adjusted to allow approximately 30 cm H_2O (and above) pressure in the patient circuit, the user can feel the resistance of the screw against the grooves — a tactile indication of pressure in the patient circuit.

The valve disc sits on the seat located between the exhalation chamber and the excess gas chamber and is held in place on the seat by the retainer. The valve stem and spring apply pressure to the valve disc and presses it against the seat.

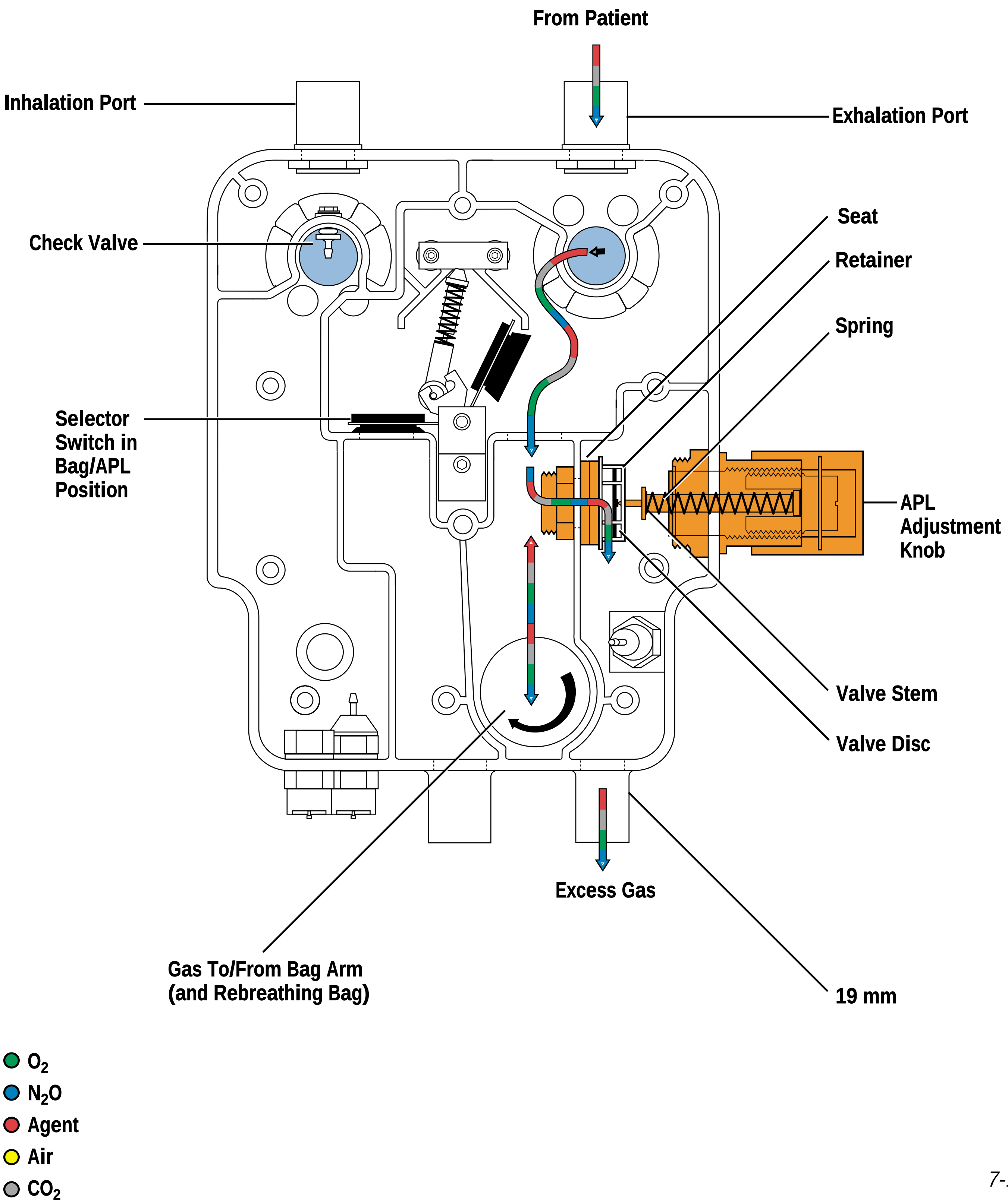
If the user adjusts the APL control knob fully counter clockwise to the minimum, only 1 cm H_2O pressure in the exhaust chamber is needed to lift the valve disc off the seat. This permits the excess gas to flow from the exhaust chamber into the excess gas chamber and out the excess gas outlet.

If the user adjusts the APL control knob clockwise, the spring compression increases and the pressure of the valve stem and spring against the valve disc increases. This closes the exhaust port and keeps the patient gas in the absorber. If the pressure of gas from a compressed breathing bag exceeds the pressure of the valve stem and spring, the valve disc lifts off the seat. The maximum pressure that can be applied by the APL valve to the valve disc is 75 cm H_2O, any pressure above that set limit will lift the valve disc off the seat and permit the excess gas to vent from the absorber.

Pressure in the breathing circuit is indicated on the absorber pressure gauge. When excess gas is vented from the absorber, the pressure should not decrease below 0 cm H_2O.

Illustration 73

The APL valve (underside view)



GAS FLOW THROUGH THE ABSORBER WITH THE SELECTOR SWITCH SET TO BAG-APL

During inhalation, fresh gas enters the absorber through the common gas inlet. The gas flows past the oxygen sensor port to the inhalation valve. The pressure of the gas lifts the check valve off the seat and the gas mixture flows out the inhalation valve to the patient airway.

During exhalation, gas returns from the patient to the exhalation valve seat and lifts the valve disc off the seat. This permits the gas to flow to the bag arm and the rebreathing bag.

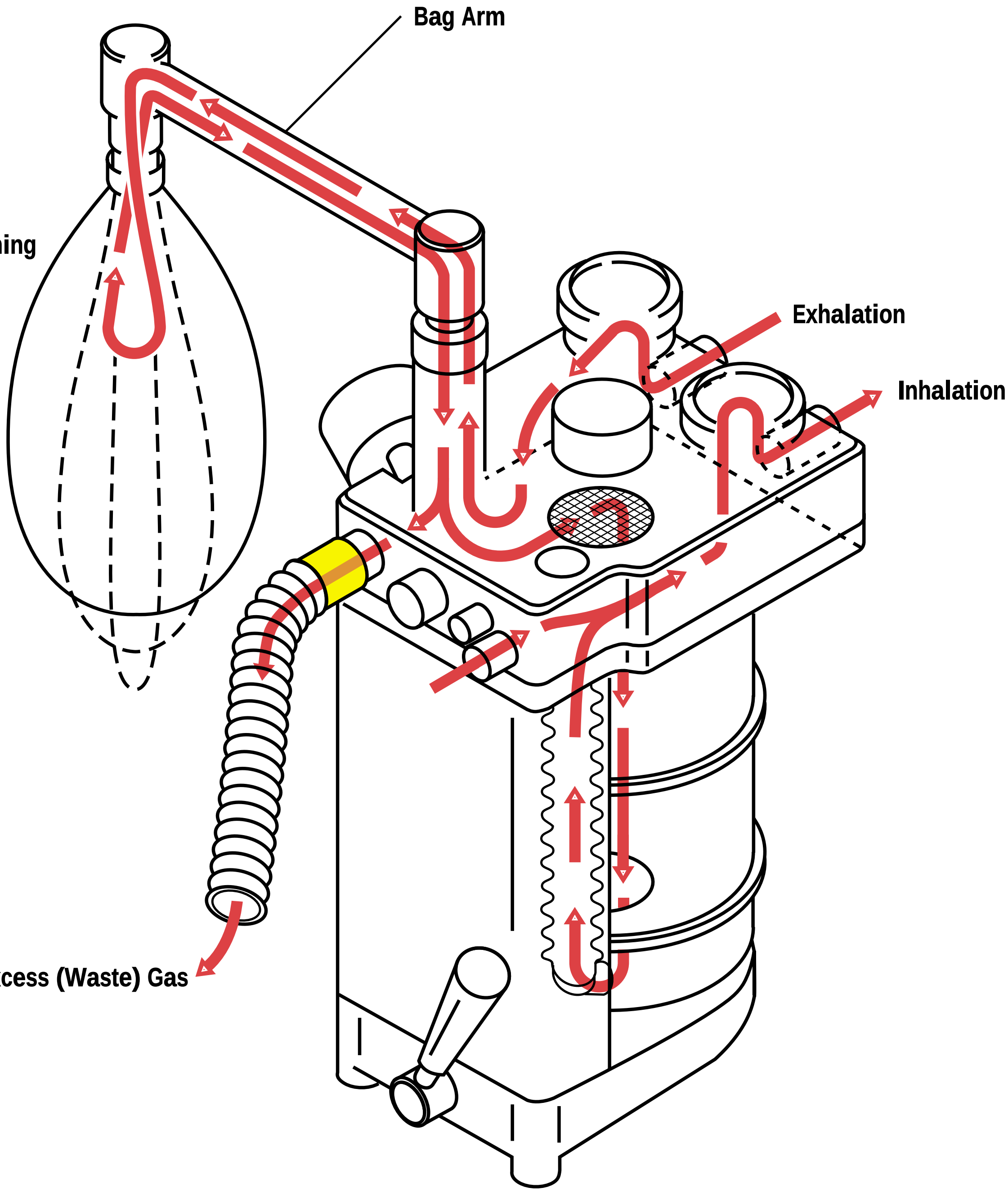
When the user squeezes the rebreathing bag, gas is pushed from the bag into the top of the absorber. It flows down through a screen, through the absorbent granules in the canister, and into the dish.

Gas returns from the dish through the return tube and mixes with fresh gas entering the absorber at the common gas inlet. The mixture of fresh gas and recirculating gas (with the carbon dioxide removed) flows toward the inhalation port — and the process begins again.

Excess gas vents through the APL valve and out the excess gas port to the waste gas interface manifold.

Illustration 74

Gas flow through the absorber with the selector switch set to Bag-APL.



GAS FLOW THROUGH THE ABSORBER WITH THE SELECTOR SWITCH SET TO VENTILATOR

When the selector switch is turned from the APL position to the Ventilator position, the absorber is connected to ventilator bellows assembly. During inhalation, fresh gas enters the absorber through the common gas inlet. The gas flows past the oxygen sensor port to the inhalation valve. The pressure of the gas lifts the check valve off the seat and permits the gas to flow through the valve to the patient airway.

During exhalation, gas flows from the patient to the exhalation valve seat and lifts the check valve off the seat. This permits the gases to flow through the seat, out the ventilator port, and into the ventilator bellows.

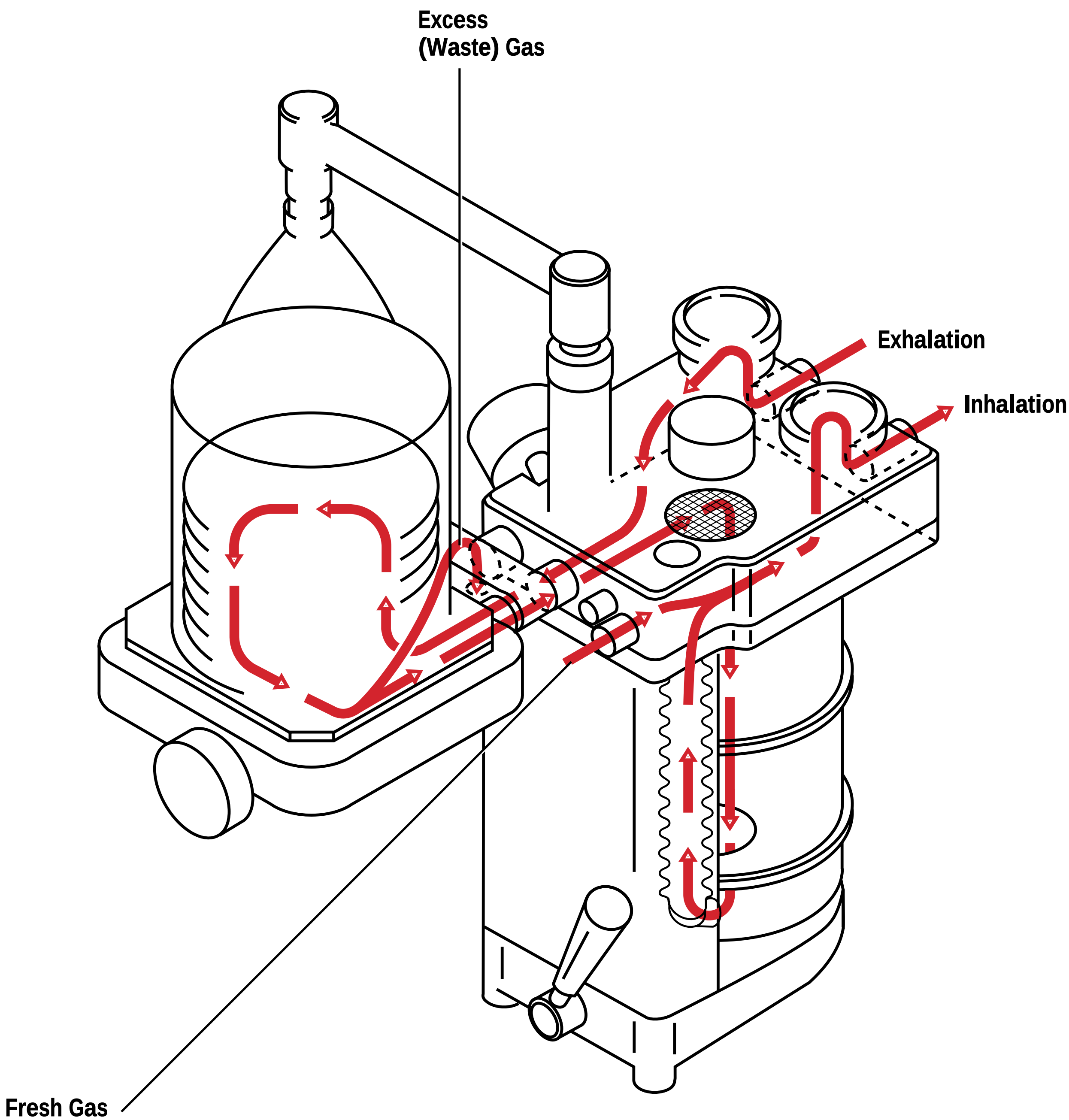
The ventilator controls the timing of the compression of the bellows which delivers the gases into the absorber manifold. The APL valve is not in the circuit and the ventilator electronically limits the maximum pressure allowed in the patient circuit. Excess gas is vented through the relief valve (pop-off valve), located in the ventilator bellows assembly, to the waste gas scavenging system.

The rest of the gas reenters the absorber through the ventilator port, (See the Ventilator section for an explanation of how the pop-off valve operates.)

Next, the gas flows down through the screen, through the absorbent granules, and into the dish. Then it flows up through the return tube and mixes with fresh gas entering the absorber at the common gas inlet. The mixture flows to the inhalation port — and the process begins again.

Illustration 75

Gas flow through the absorber with the selector switch set to ventilator.



SAFETY DEVICES

The breathing system also includes four safety devices. Most are part of the absorber. We have already discussed:

- Color indicators for carbon dioxide absorbent.
- Adjustable pressure limiting valve.

Other safety devices include:

- Diameter indexed ports on the absorber.
- Airway pressure gauge to monitor airway pressure.
- Ports that are used to monitor the airway pressure and the concentration of oxygen in the inspired gases.

PORT DIAMETERS

Excess (waste) gas ports can be connected to a scavenger system and are 19 mm in diameter. The inhalation and exhalation ports of the absorber connect directly to the patient breathing circuit and are 22 mm in diameter. The diameters of the patient circuit connections are different from waste gas connections to help make sure the patient breathing circuit (positive pressure) is not accidentally connected to the scavenger exhaust system.

PORTS USED TO MONITOR PATIENT GASES

An oxygen sensor probe assembly is used by an oxygen monitor or a ventilator to sense the percentage of oxygen concentration in the gas pplied to the patient. The probe housing portion of e sensor assembly can be installed in the oxygen nsor port located in the inhalation chamber of the absorber.

It is important to remember that if an oxygen monitor sensor is not installed in this port, it must be sealed with the oxygen sensor port plug. If the plug is not installed, the gas mixture intended for the patient will escape to the atmosphere. A port plug is attached to the top of the absorber to assure that it will not be lost.

The sensor should be positioned vertically to prevent moisture from accumulating on the sensor.

PORTS USED TO MONITOR PATIENT AIRWAY PRESSURE

An airway pressure gauge is installed in the circuit pressure port in the top of the absorber manifold. It is used to monitor patient airway pressure during manual or mechanical ventilation. The gauge connects to the inhalation side of the absorber and indicates pressure in centimeters of H_2O.

One end of the distal pressure sensing line of the 7800 series ventilator connects to the hose barb on the back of the ventilator. The other end of the pressure sensing line connects to a hose barb under the gauge. The hose barb is open to the inhalation chamber and is used by the ventilator to sense patient circuit pressure.

The port labeled circuit pressure connects to the exhalation side of the absorber. This port is provided to connect to the distal pressure sensing line of the 7000 series ventilator and is used to sense patient circuit pressure.

INTRODUCTION

WASTE GAS SCAVENGING

The waste gas scavenging system removes gas vented from the breathing system. This helps minimize venting of waste gas into the operating room.

There are two types of scavenging systems, active and passive. This section describes each system. At the end of this section, the reader should know:

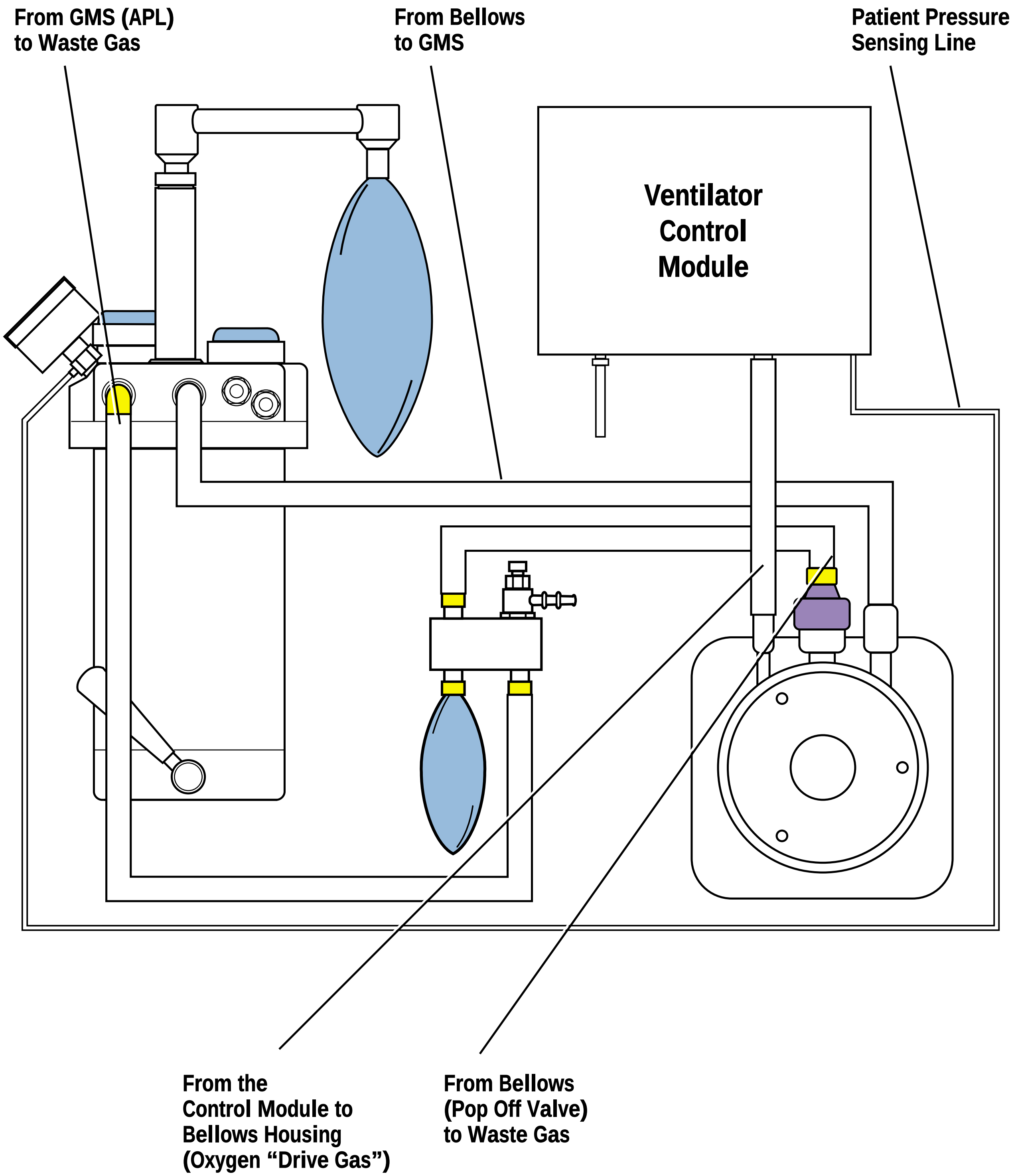
- How the waste gas flows out of the breathing system.
- How passive and active systems operate.
- What general precautions are necessary for each system.

SCAVENGING CONNECTIONS

Excess gas, or waste gas, from the breathing circuit is vented through the APL valve when the absorber selector switch is in the Bag-APL position (manual ventilation). It is vented through the pop-off valve in the bellows assembly when the absorber selector switch is in the Ventilator position (mechanical ventilation). The gas flows through hoses connected to 19 or 30 mm (on newer systems) intake ports of the waste gas manifold. The illustration on the facing page shows the exhaust connections. Waste gases from additional monitors connected to the breathing circuit can also be vented to the 19/30 mm intake ports. Hoses that connect to the intake ports are identified by 19 mm yellow or 30 mm magenta collars on the hoses.

Figure 76

Waste gas connections



ACTIVE SYSTEMS

An active system connects to the hospital's vacuum system and uses the needle valve to adjust flow through the manifold. Positive and negative pressure relief valves help protect the patient from pressure fluctuations.

The illustration on the facing page shows the flow of waste gas from the breathing circuit into the waste gas scavenging manifold. As gas is drawn into the hospital vacuum system, it flows through the manifold, between the two relief valves, and to the hose barb opening. Waste gases flow through a vacuum hose connected between the hose barb and the pipeline vacuum outlet. A 3 L reservoir bag connected to a manifold port holds the waste gas until the vacuum can remove it. The needle valve changes the flow of waste gases out of the manifold and reservoir bag into the vacuum source during normal operation the bag will expand and collapse as patient ventilation cycle increases and decreases waste gas flow. Ideally, the needle valve should be adjusted so that the flow out of the manifold keeps the reservoir bag expanding and collapsing slightly and less than half full.

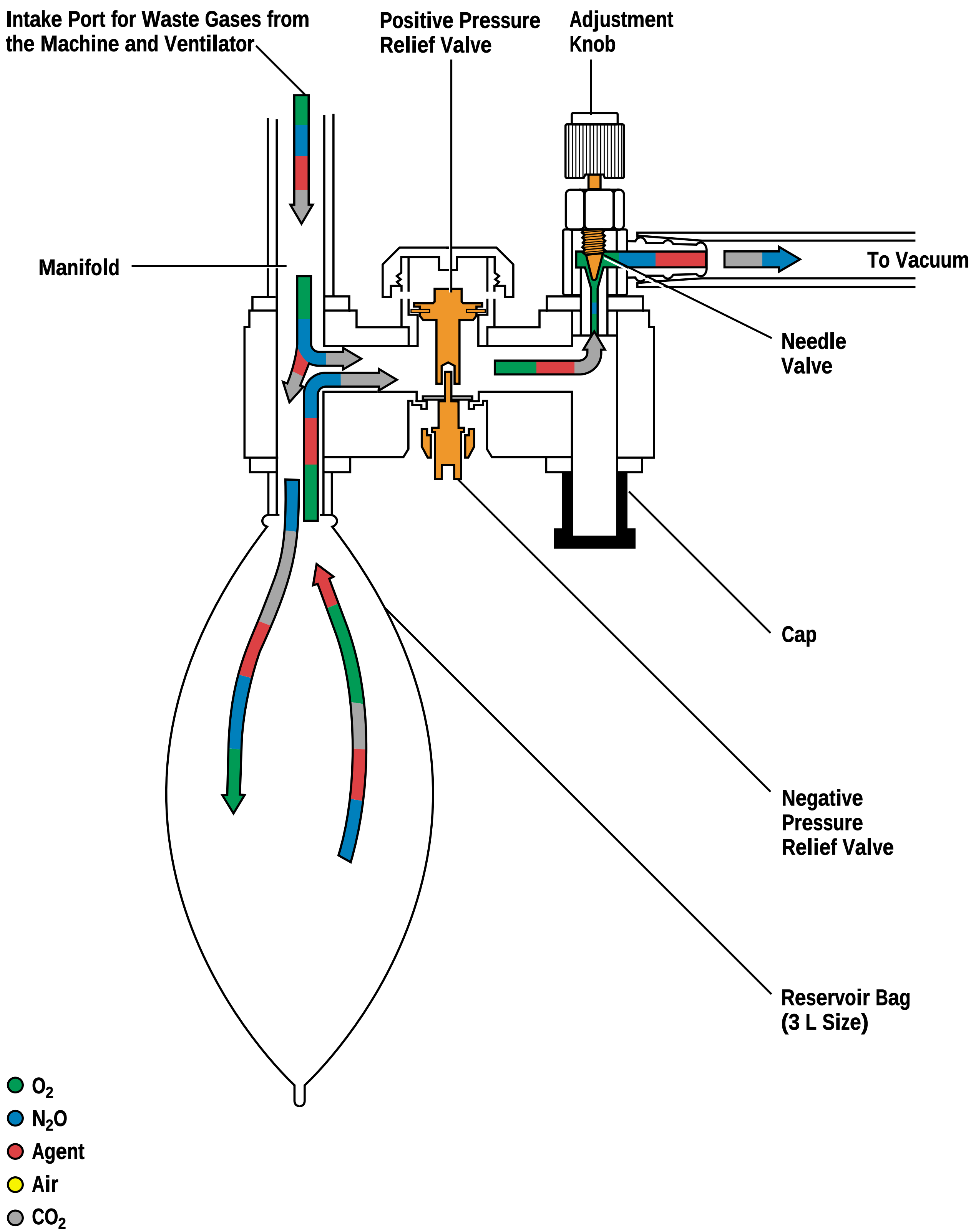
The positive pressure relief valve includes a gasket to seal small openings above the gasket. If the flow out of the manifold is set too low, the reservoir bag fills up with waste gases and pressure in the manifold increases. At approximately 5 cm H_2O (this depends on the rate of flow into the manifold), the positive pressure relief valve lifts up. This moves the gasket above the openings and permits some of the waste gases to flow past the gasket, through the openings. This vents waste gases into the room and helps prevent a pressure increase in the patient circuit.

The negative pressure relief valve includes a gasket to seal an opening under the gasket. If the flow of waste gases out of the manifold is set too high, the bag deflates. At approximately –0.25 cm H_2O, the negative pressure relief valve lifts up. This moves the gasket away from the opening and permits room air to enter the opening and flow past the gasket into the manifold. This adds room air into the flow of waste gas to the vacuum source and helps prevent a negative pressure in the patient circuit.

Open intake ports permit waste gas to flow into the atmosphere or cause a leak in the vacuum system. To help protect operating room personnel from exposure to waste gases, the needle valve must be properly adjusted and all intake ports that are not connected must be capped.

Illustration 77

The waste gas scavenging valve active system



PASSIVE SYSTEMS

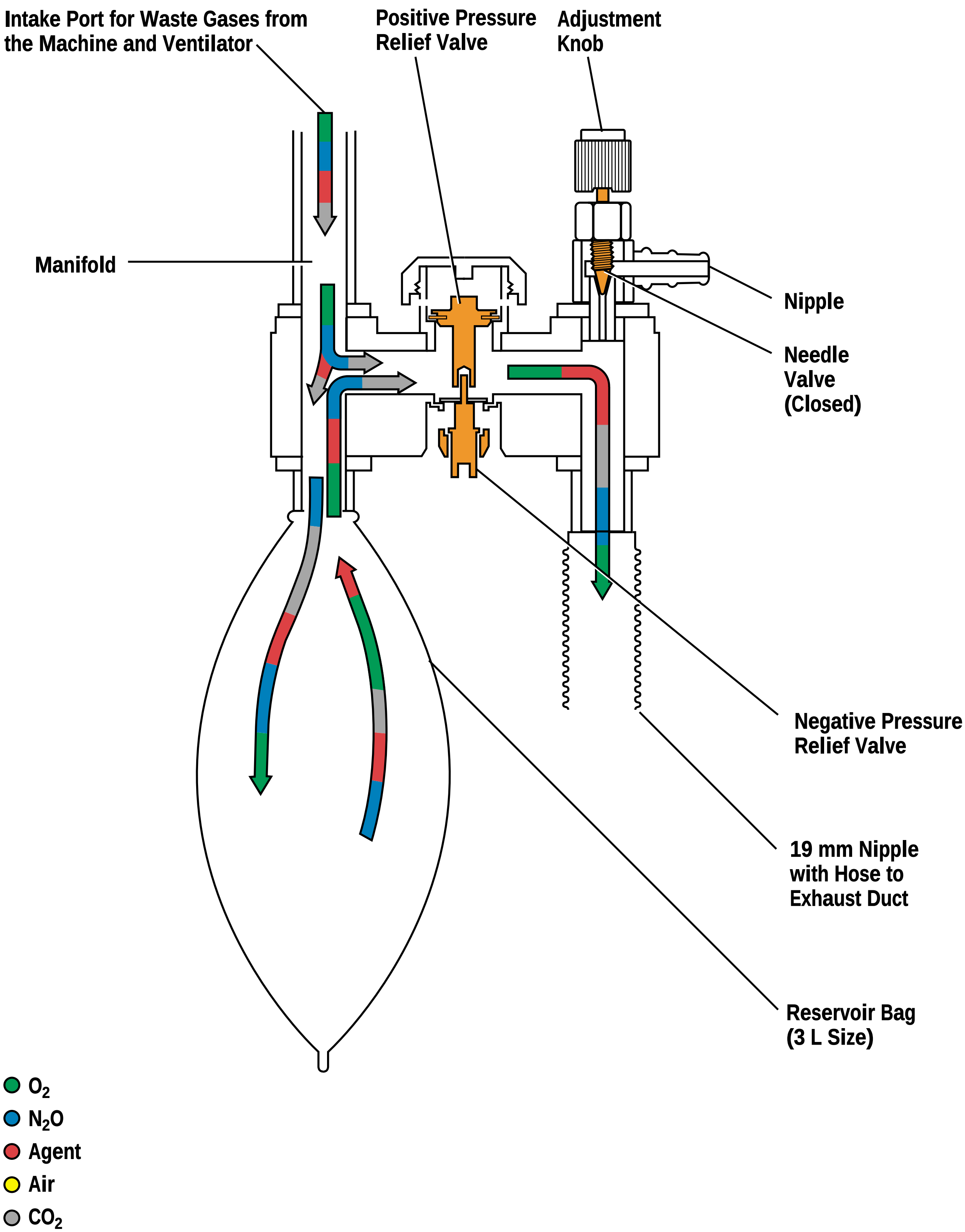
A passive system connects the waste gas interface manifold to a hospital's ventilation duct. Usually, a reservoir bag is also used to hold the waste gas from patient ventilation until it flows out of the valve.

The illustration on the facing page shows the waste gas scavenging valve connected to a passive system. Waste gases enter the manifold intake ports in the same way, and the relief valves operate the same way, as in an active system, but the needle valve is closed. A 19 mm hose is connected between an intake port (now an "out" port) of the manifold and the exhaust duct in the room.

Sometimes both active and passive systems are used in the same surgical area. To understand fully how each waste gas removal system functions and how to adjust it properly, consult the manufacturer's Operation and Maintenance manual.

Figure 78

Waste gas interface valve passive system



Datex·Ohmeda

Datex-Ohmeda Division • Instrumentarium Corp.
P.O. Box 900, FIN-00031 Datex-Ohmeda, Finland
Tel. +358 10 394 11 • Fax +358 9 146 3310

www.datex-ohmeda.com

Datex-Ohmeda, Inc.
P.O. Box 7550, Madison, WI 53707-7550, USA
Tel. 800 345 2700 • Fax 608 221 4384

In the USA: www.us.datex-ohmeda.com