How Ventilators Work

Chapter 3

To care for a ventilator patient, you need to know:

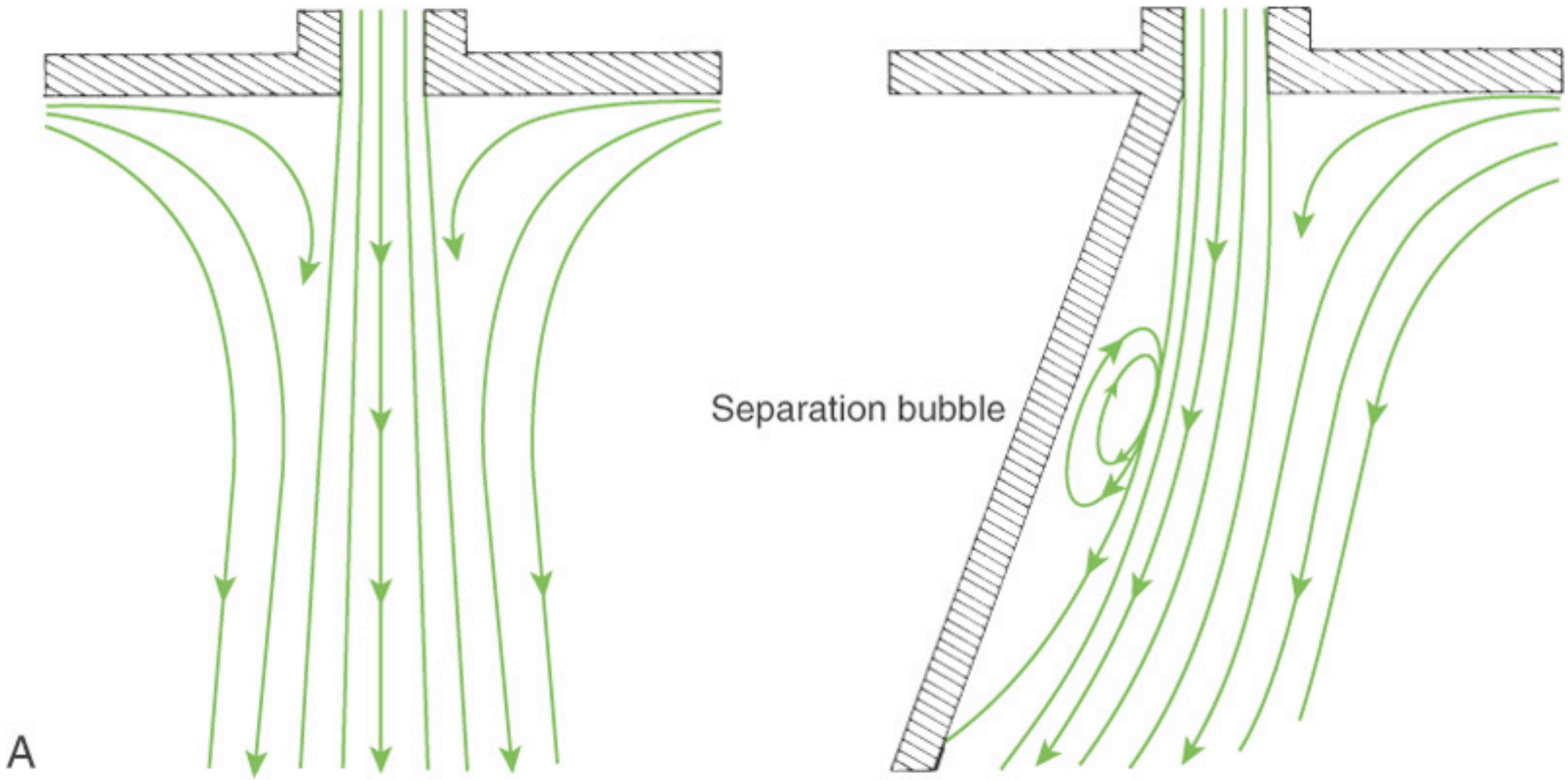
- The various functions of the ventilator used
- How the ventilator interacts with the patient
- How changes in lung condition can alter the ventilator's performance
- Ventilator Classification: The terminology employed by the different manufacturers is confusing!

Internal Ventilator Function

- “black box”
- Plugged into a power source
- User interface to set the controls
- Control system to interpret the operators settings to produce the desired output

Power Source : provides the energy to perform the work required to ventilate a patient

Electrically Powered	Pneumatically Powered
• Relies on electricity • Wall outlet (AC), battery (DC) • Powers internal motors which provide gas flow to the patient	• High pressure gas source • Usually 2 -50psi sources, air and oxygen • Built in reducing valves • Pneumatic • Fluidic



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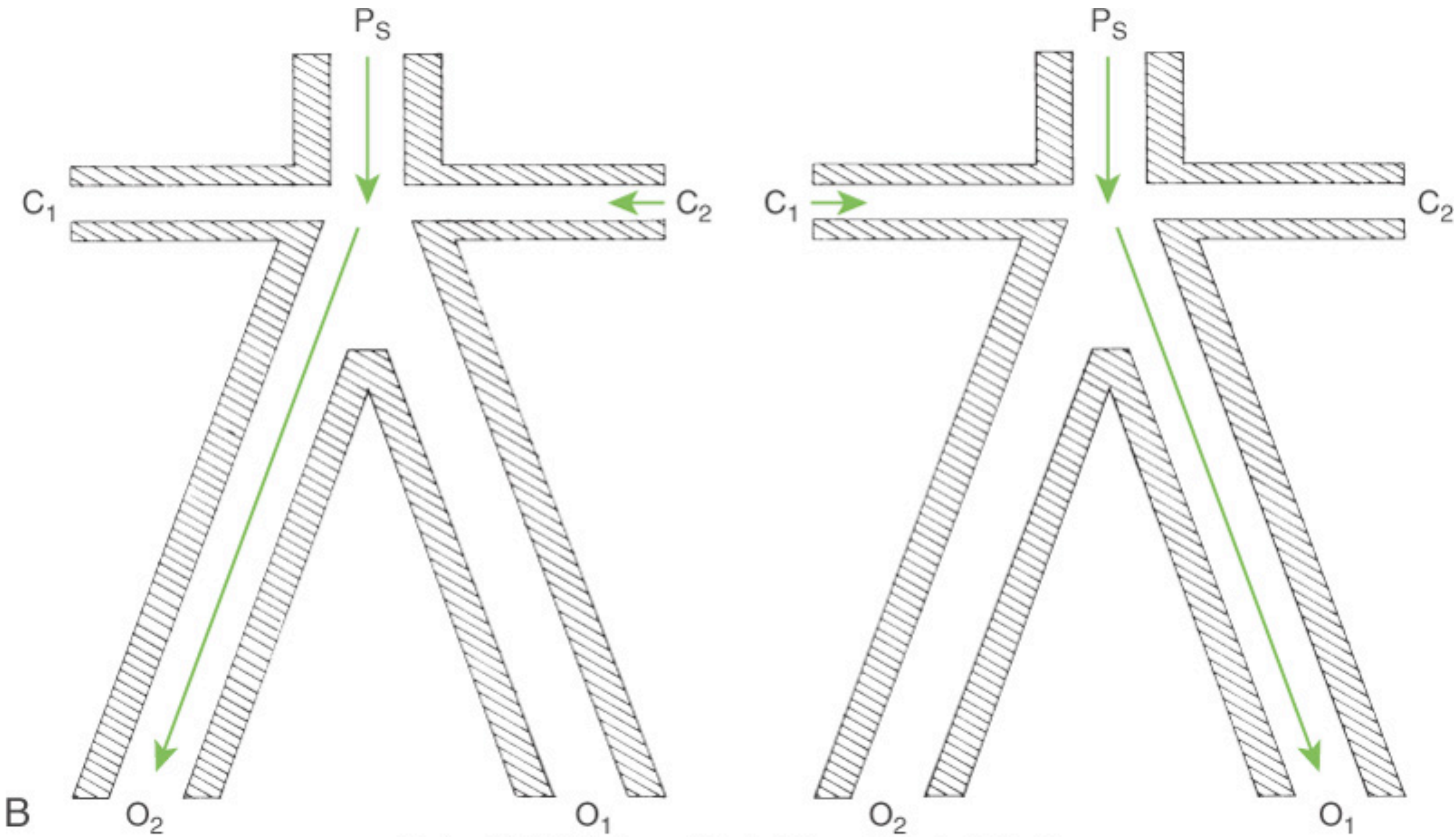

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Combined Power Ventilators

- Pneumatically powered – 50 psi gas sources
  - Mixture of air and oxygen allow variable FiO_2
  - Energy to deliver the breath
- Electrically powered
  - Controls the internal function
  - May be controlled by a microprocessor (1980's)

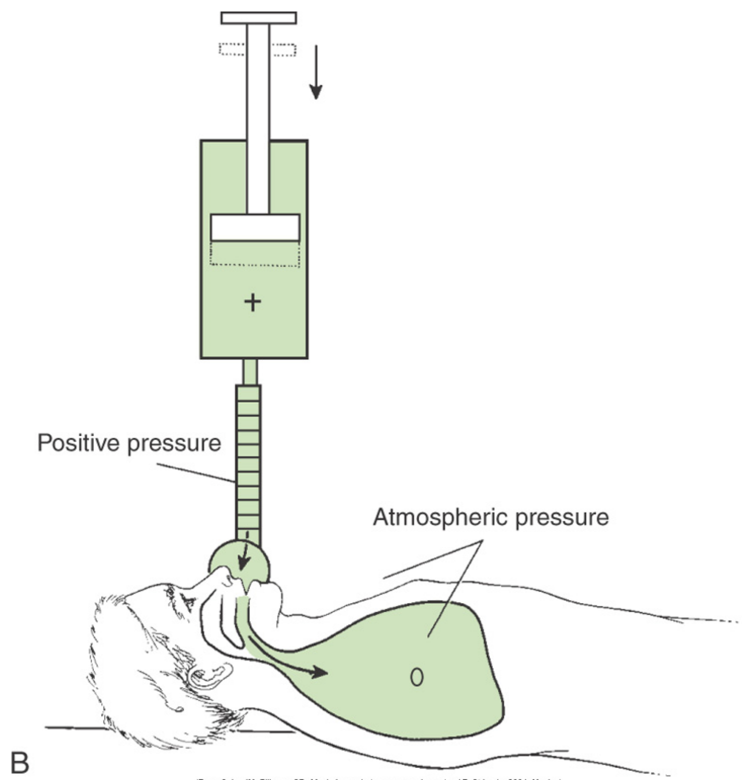
Clinical Rounds 3-1

A patient who requires continuous ventilatory support is being transferred from the ICU to a regular patient room. The regular hospital rooms are equipped with piped in oxygen but not piped in air. What type of ventilator would you select?

You would need an electrically powered ventilator with a built- in or external compressor. The availability of oxygen would allow you to provide oxygen as necessary for the patient.

Pressure Delivery

Positive Pressure	Negative Pressure



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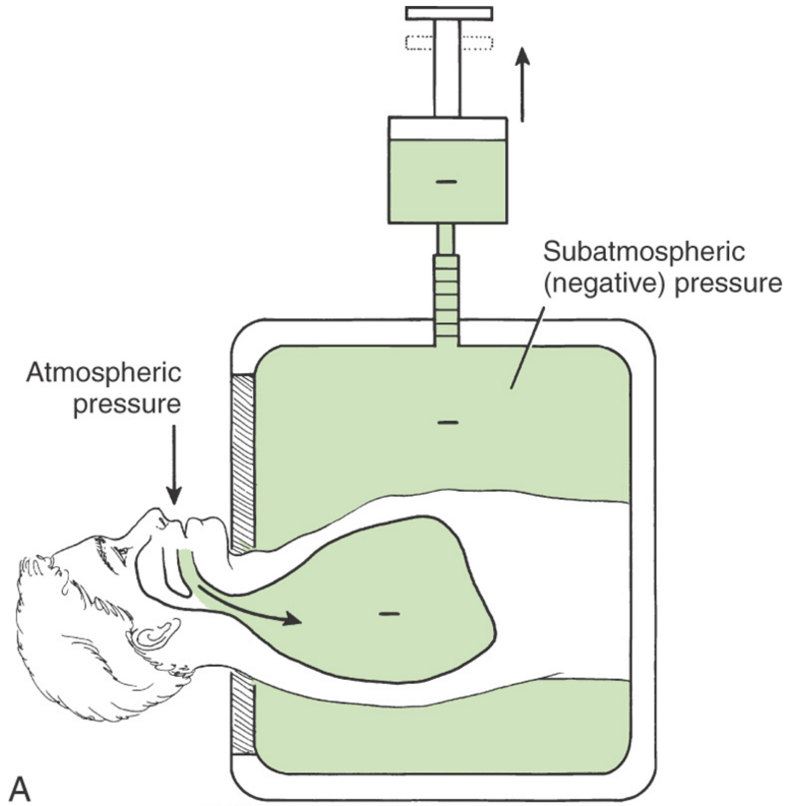

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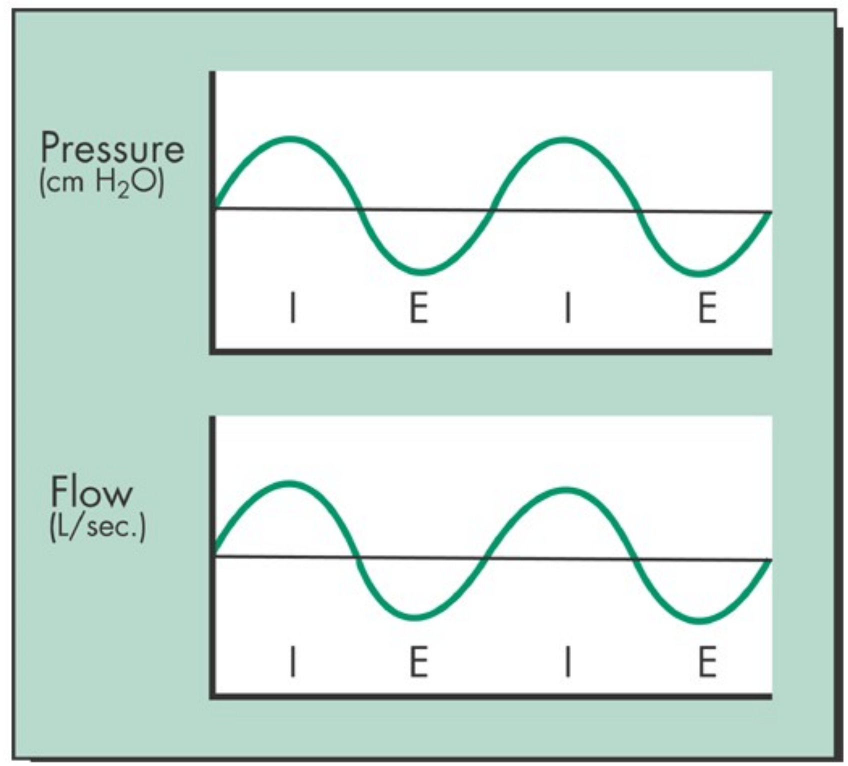
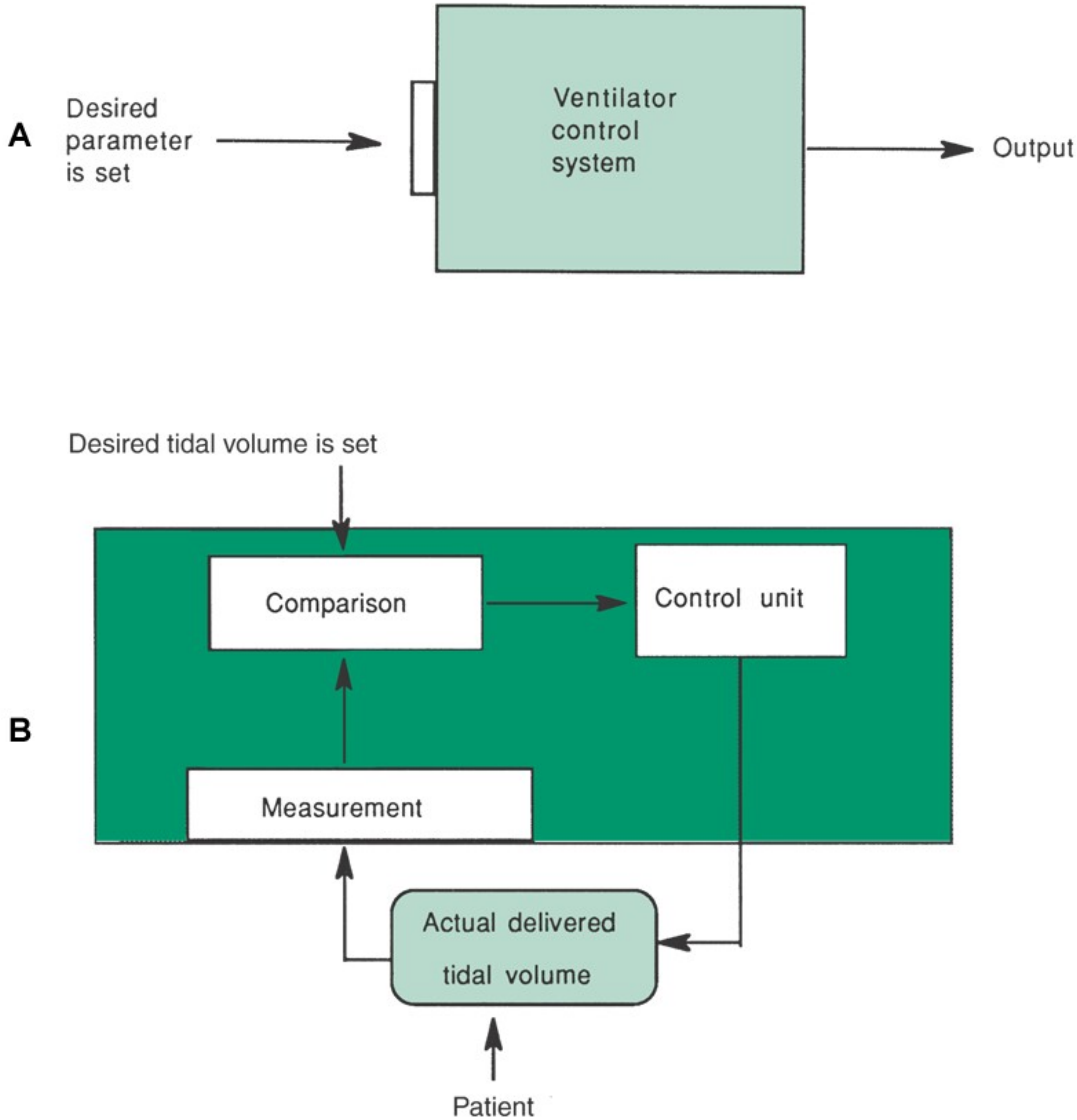
Pressure Delivery

- Combined pressure devices
- HFV
- Oscillating gas pressure waveforms, positive and negative pressure



Control Systems

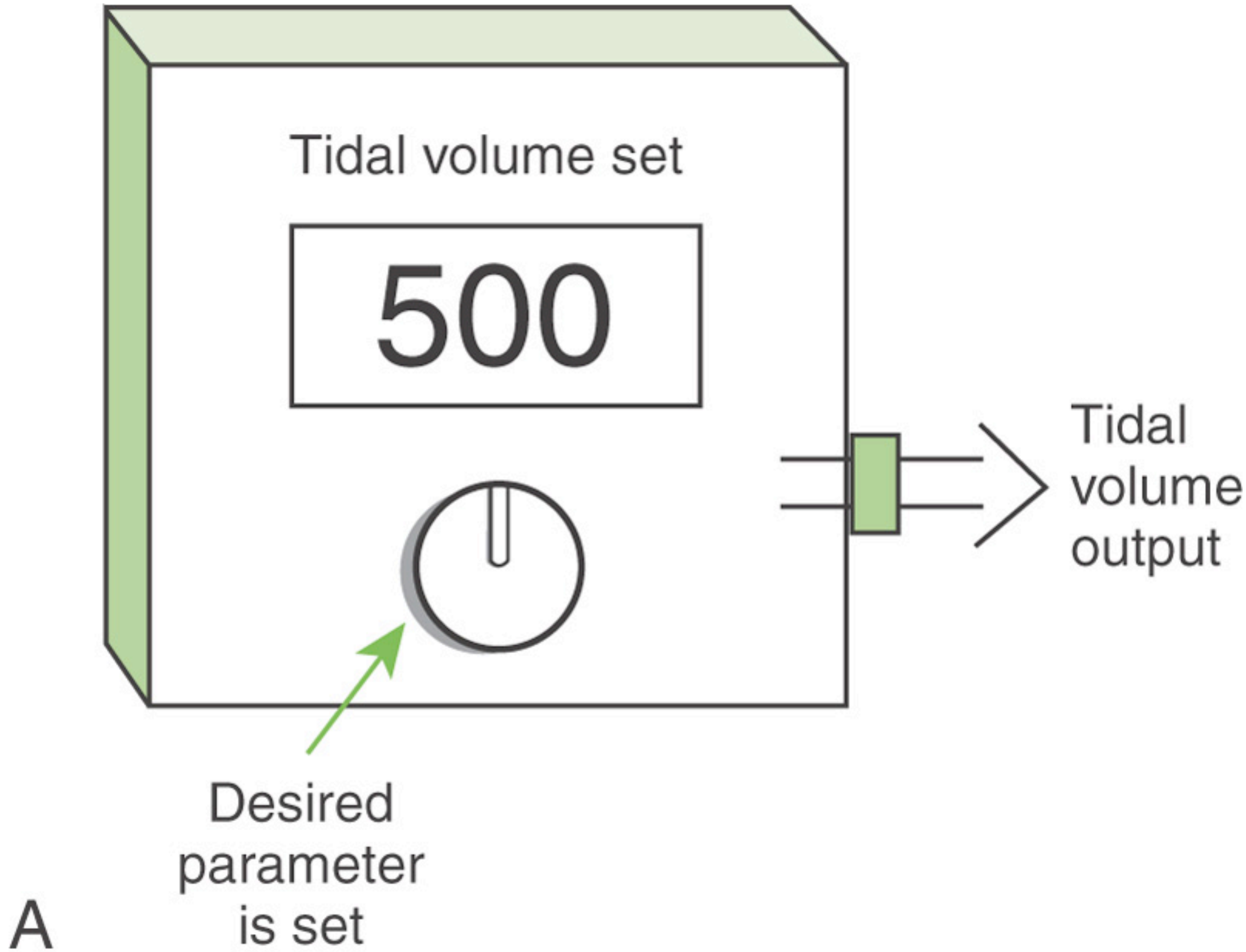
- Decision making systems
- Regulates ventilator function internally
- Open loop versus Closed loop

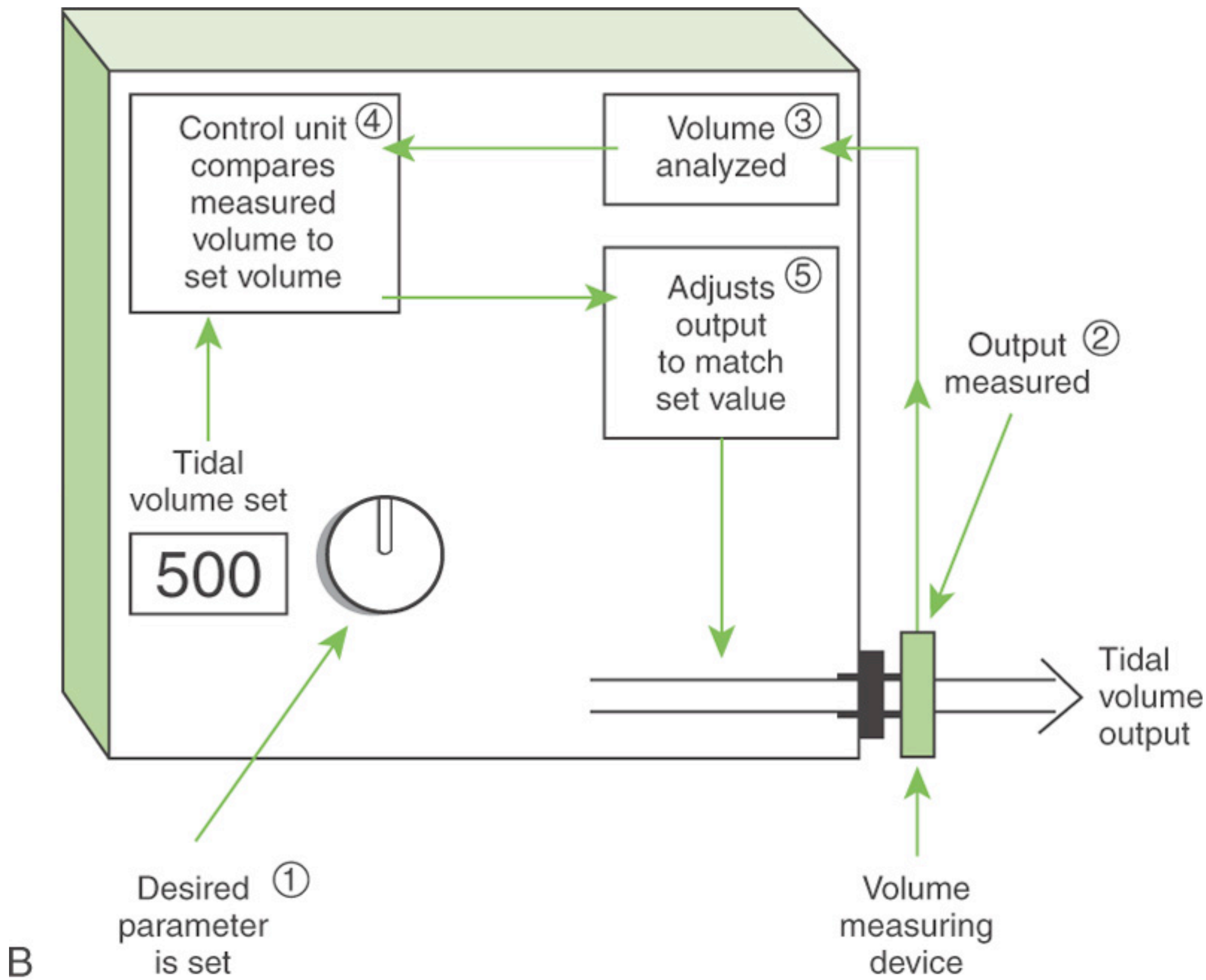


(From Pilbeam SP: *Mechanical ventilation: physiological and clinical applications,* ed 3, St Louis, 1998, Mosby.)

Control Systems

Open Loop	Closed Loop
• "unintelligent" systems • Does not respond to changes in patient condition • Does not measure variables or change them	• "intelligent" systems • Compares the set variable to the measured variable


Tidal volume set
500
Tidal
volume
output
Desired
parameter
is set
A


Control unit ④ compares measured volume to set volume
Volume ③ analyzed
Adjusts ⑤ output to match set value
Output ② measured
Tidal volume set
500
Tidal volume output
Desired ① parameter is set
Volume measuring device
B

Clinical Rounds 3-2

A ventilator is programmed to monitor SpO2. If the SpO2 drops below 90% for longer than 30 sec the ventilator is programmed to activate an audible alarm that cannot be silenced and a flashing red visual alarm. The ventilator also is programmed to increase the oxygen percentage too 100% until the alarms have been answered and deactivated. Is this a closed loop or an open loop system? Do you think it is a good idea for a ventilator to have such a system?

This is a closed loop system. The ventilator is providing a specific FiO2 and monitors SpO2. The ventilator can detect changes in SpO2 and change the FiO2 setting.

It can be argued that this would provide a safeguard for patient who suddenly became hypoxemic. It could also be argued that oxygen saturation monitors are not reliable enough and could result in erroneous readings resulting in an inappropriate ventilator response

Control Panel

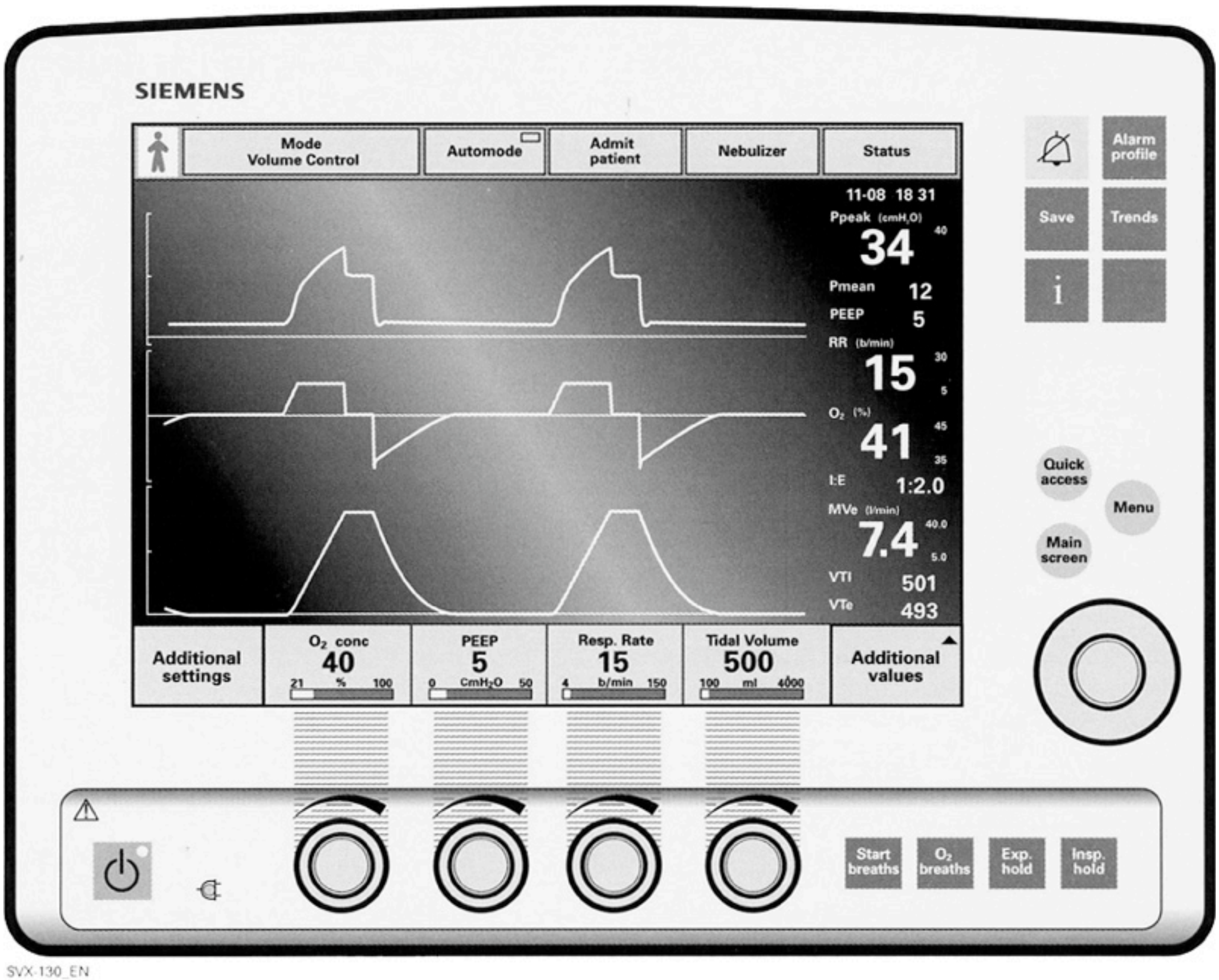
- User interface
- Monitored and set by the operator
- Knobs or touch pad/touch screen for setting ventilatory components and alarms
- Ultimately regulates the four ventilatory variables

Volume

Pressure

Flow

Time

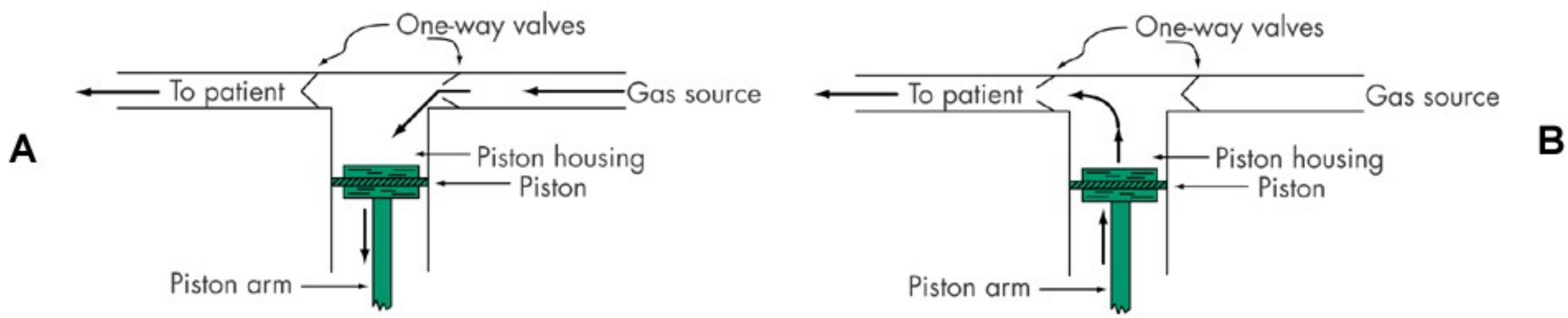


(Courtesy Maquet, Inc., Bridgewater, N.J.)

Pneumatic Circuit

- Pathway of gas flow
- Pressure gradients created by the ventilator's power source generates this flow
- Internal pneumatic circuit
  - From generating source through the inside of the ventilator
- External pneumatic circuit
  - Patient circuit
  - Flow between the ventilator and the patient

Single Circuit Design - Internal



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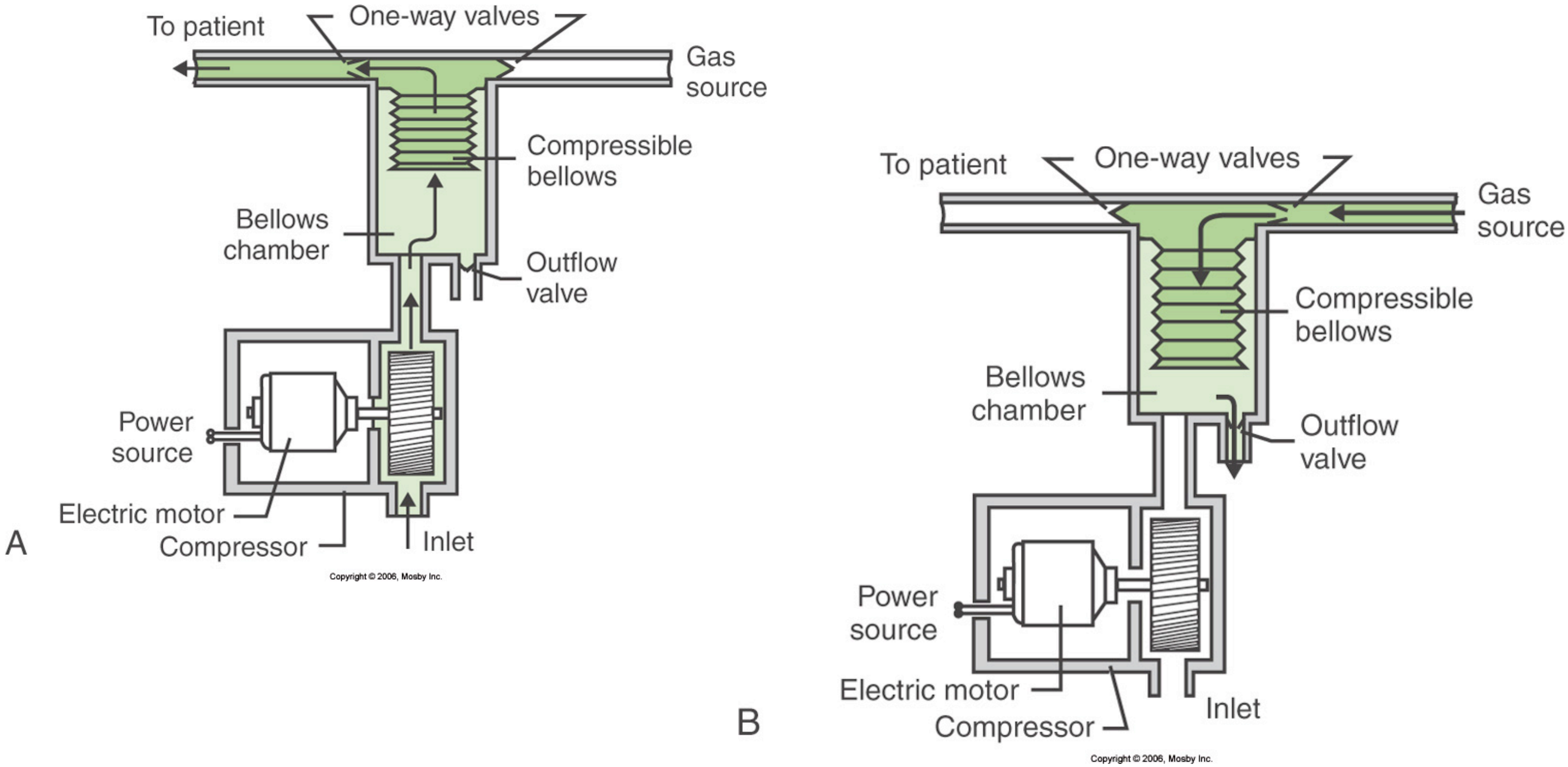
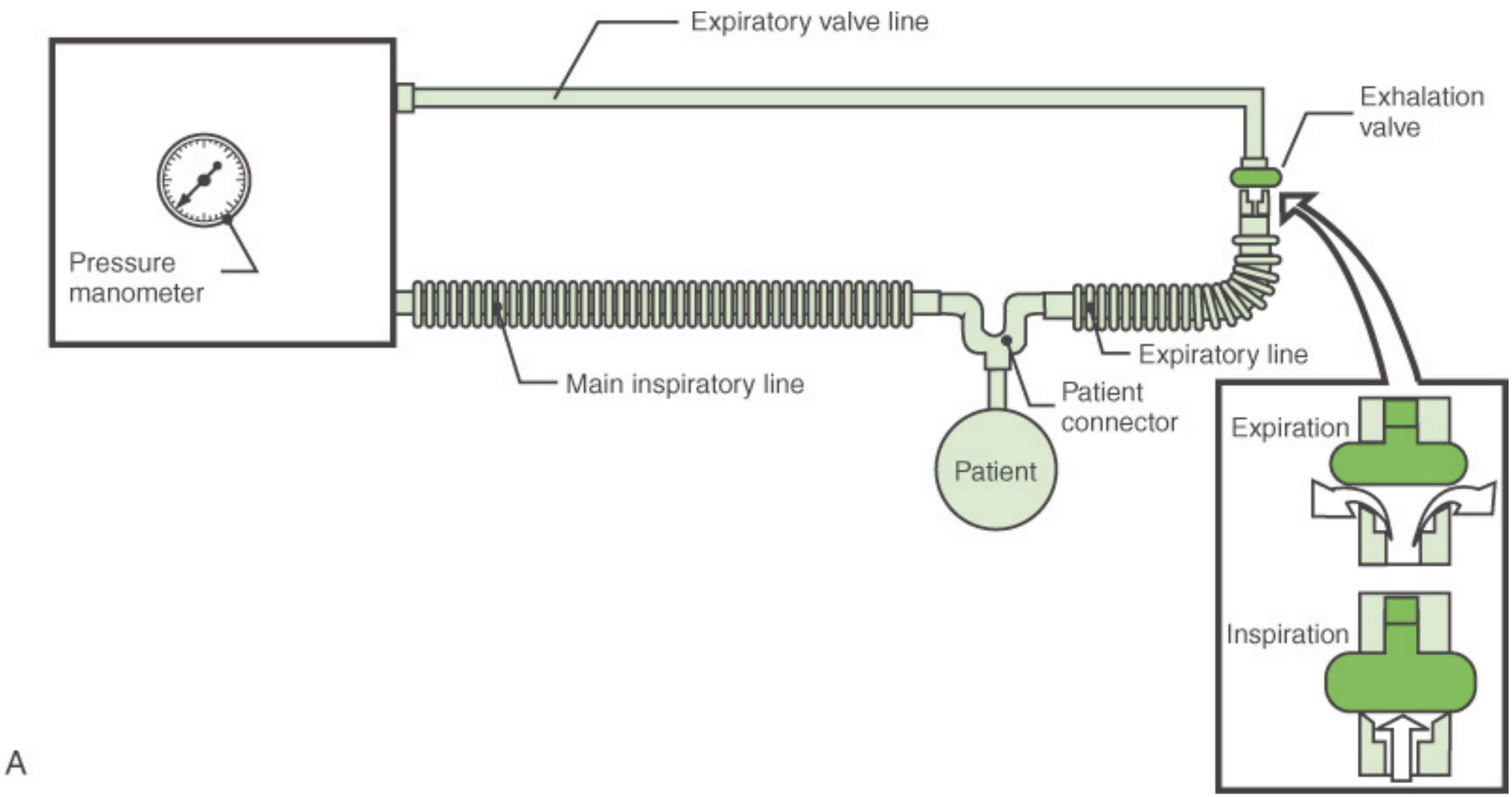
Double Circuit Design – Internal



Basic Elements of a Patient Circuit

- Main inspiratory line
- Adapter
- Expiratory line
- Expiratory valve
- Adjuncts
  - Device to warm/humidify air
  - Thermometer
  - Nebulizer
  - Bacteria filters



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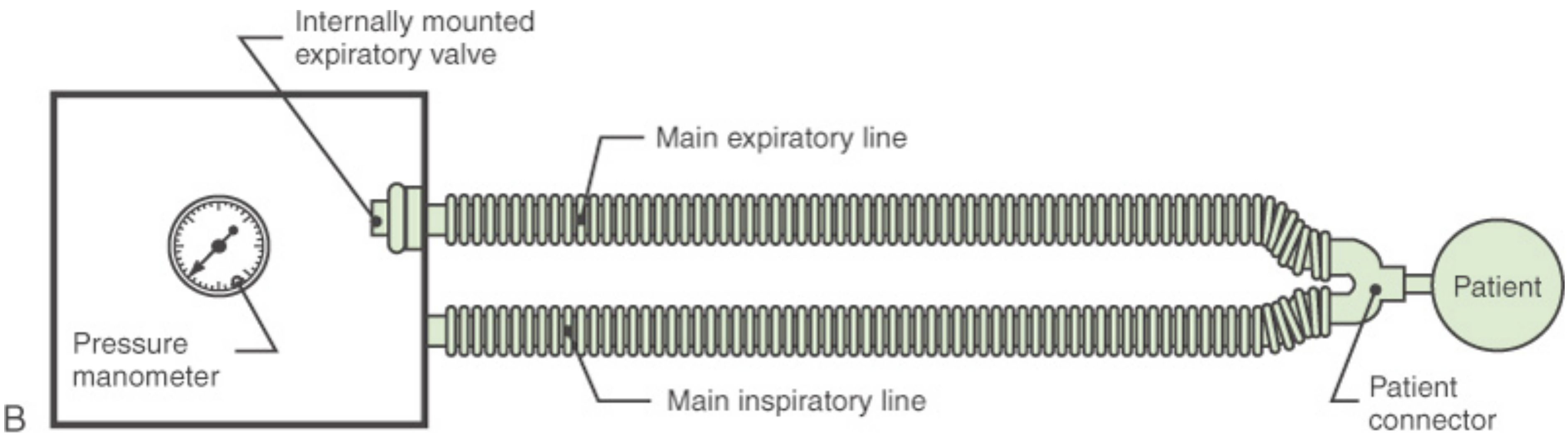

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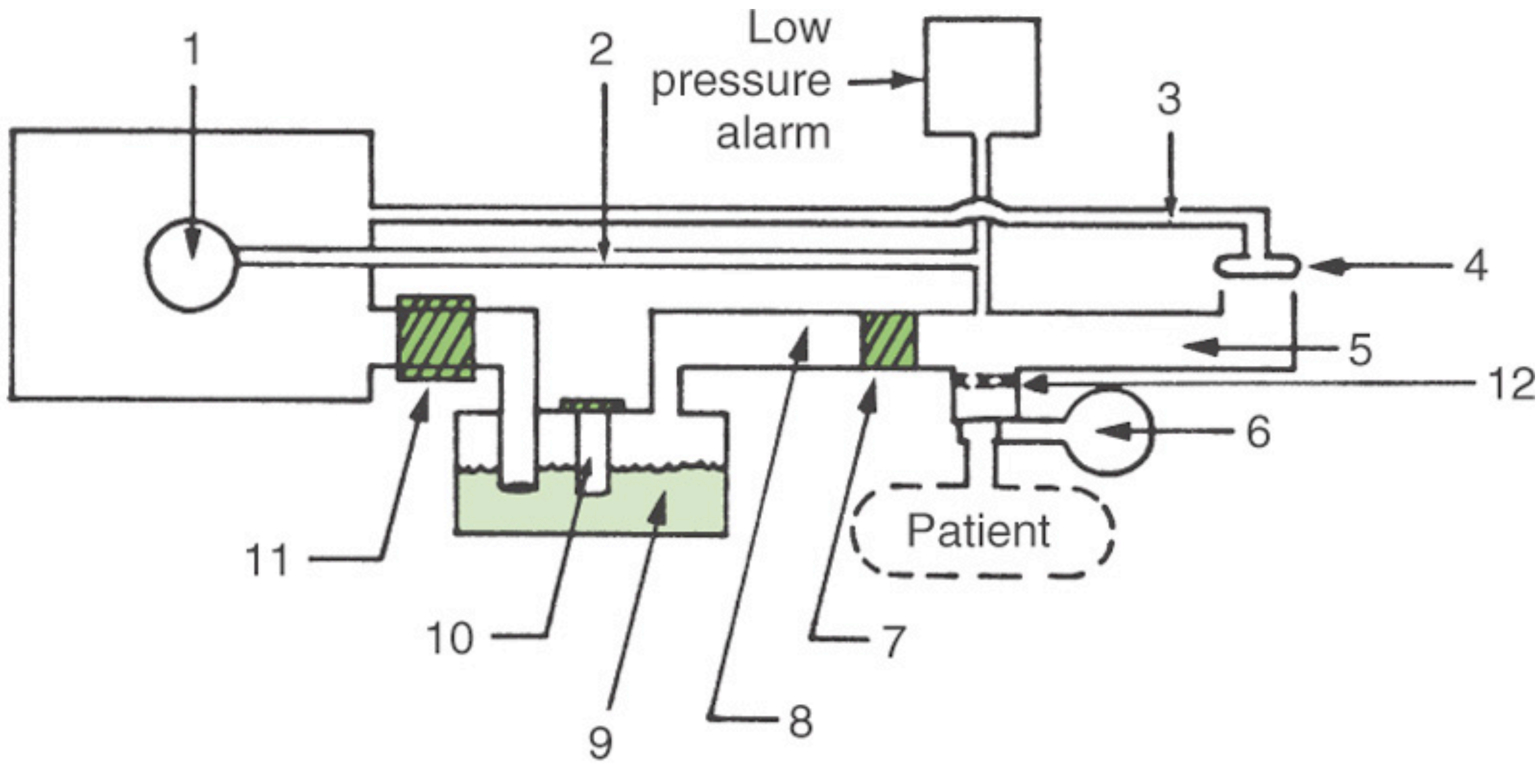


1 — Pressure manometer
2 — Upper airway pressure monitor line
3 — Expiratory valve line
4 — Expiratory valve
5 — Expiratory line
6 — Expired volume measuring device
7 — Temperature measuring or sensing device
8 — Main inspiratory line
9 — Humidifier
10 — Heater and thermostat
11 — Main flow bacterial filter
12 — Oxygen analyzer

Power transmission and conversion

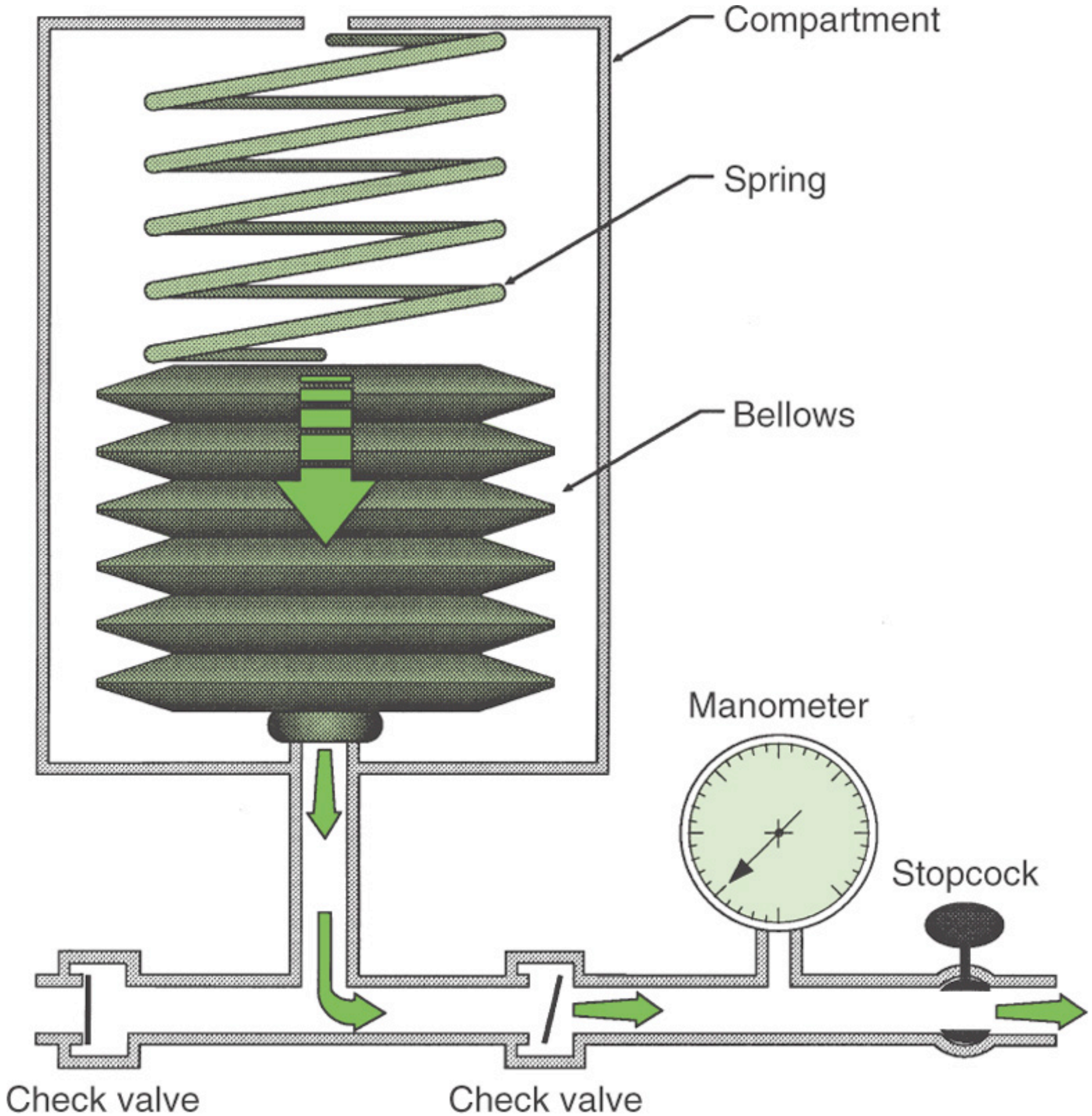
- Converts the electrical or pneumatic energy into a breath to the patient
- Consists of:
  - drive mechanism – mechanical device that produces gas flow to the patient
  - output control mechanism – one or more valves that determine the flow to the patient
- Categorized as volume controllers or flow controllers

Compressors

- Used as either a power source or to convert and transmit a power source
- Reduce internal volumes (compression) resulting in a change in pressure
- Piston driven, rotating vane (blades), moving diaphragms or bellows

Volume displacement designs

- Bellows
- Pistons
- Concertina bags
- “bag in a chamber”



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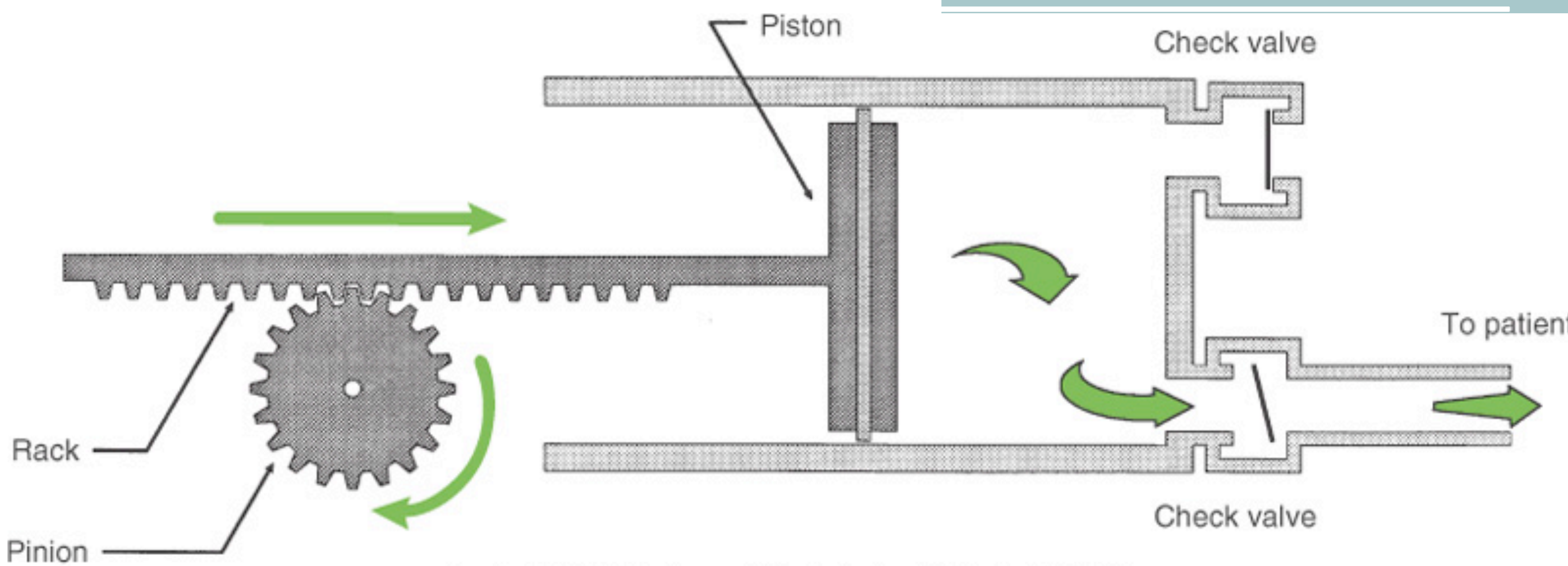

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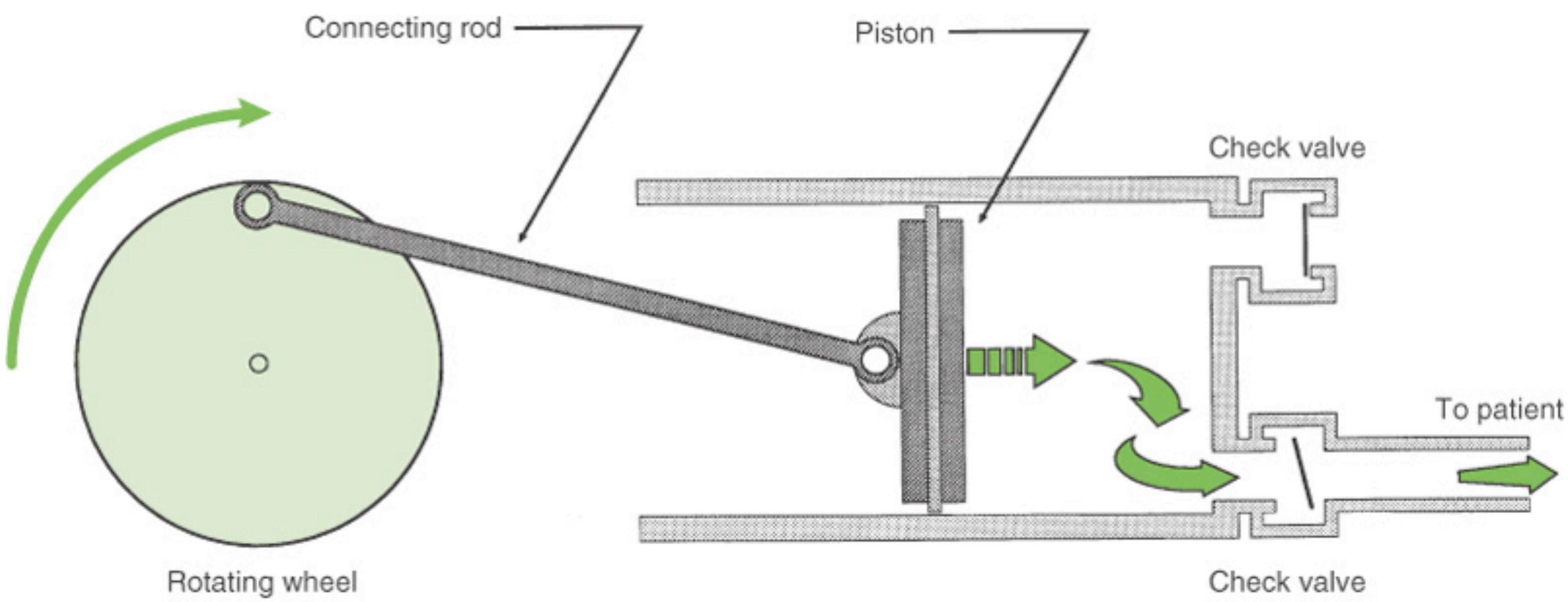

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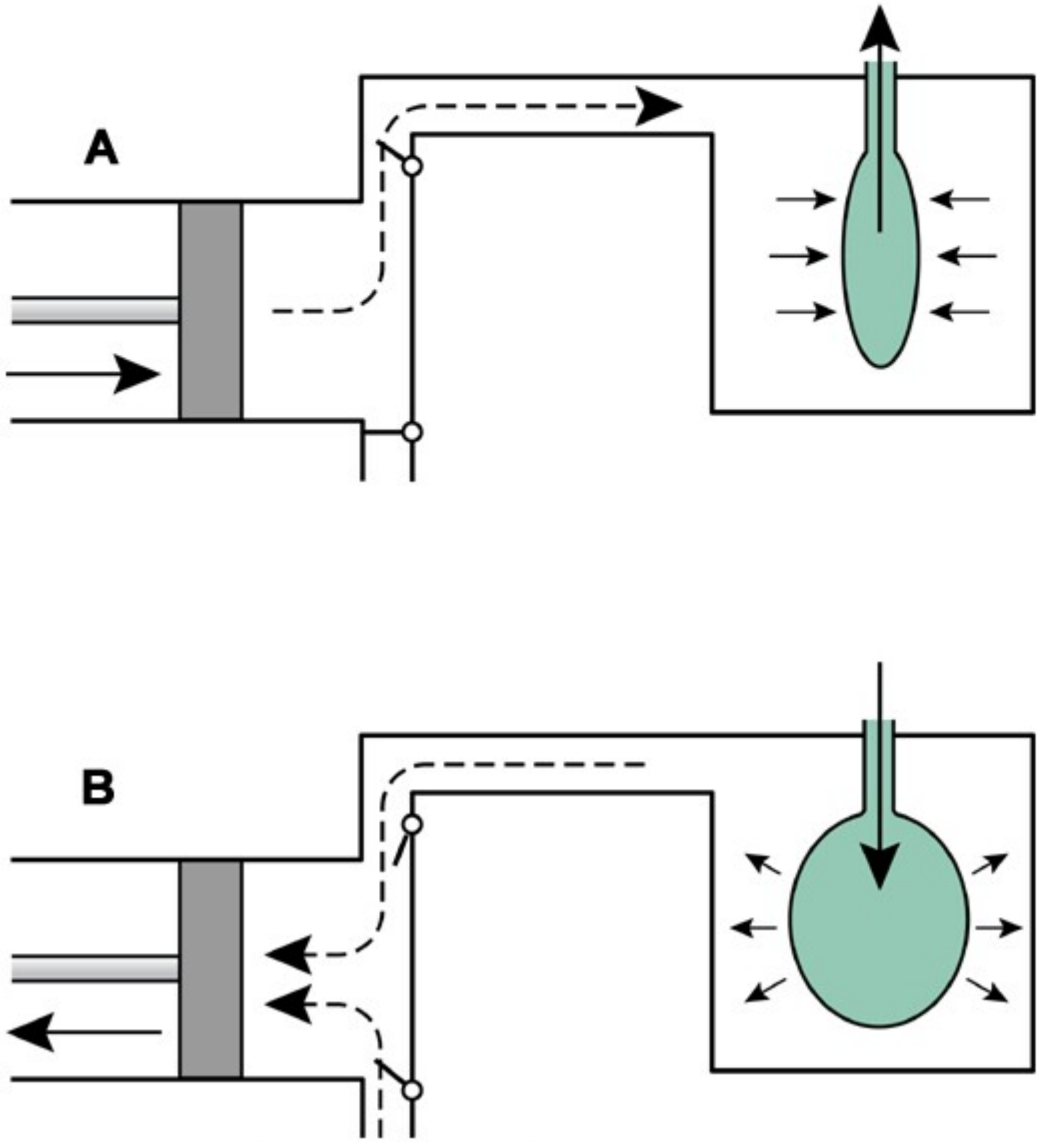
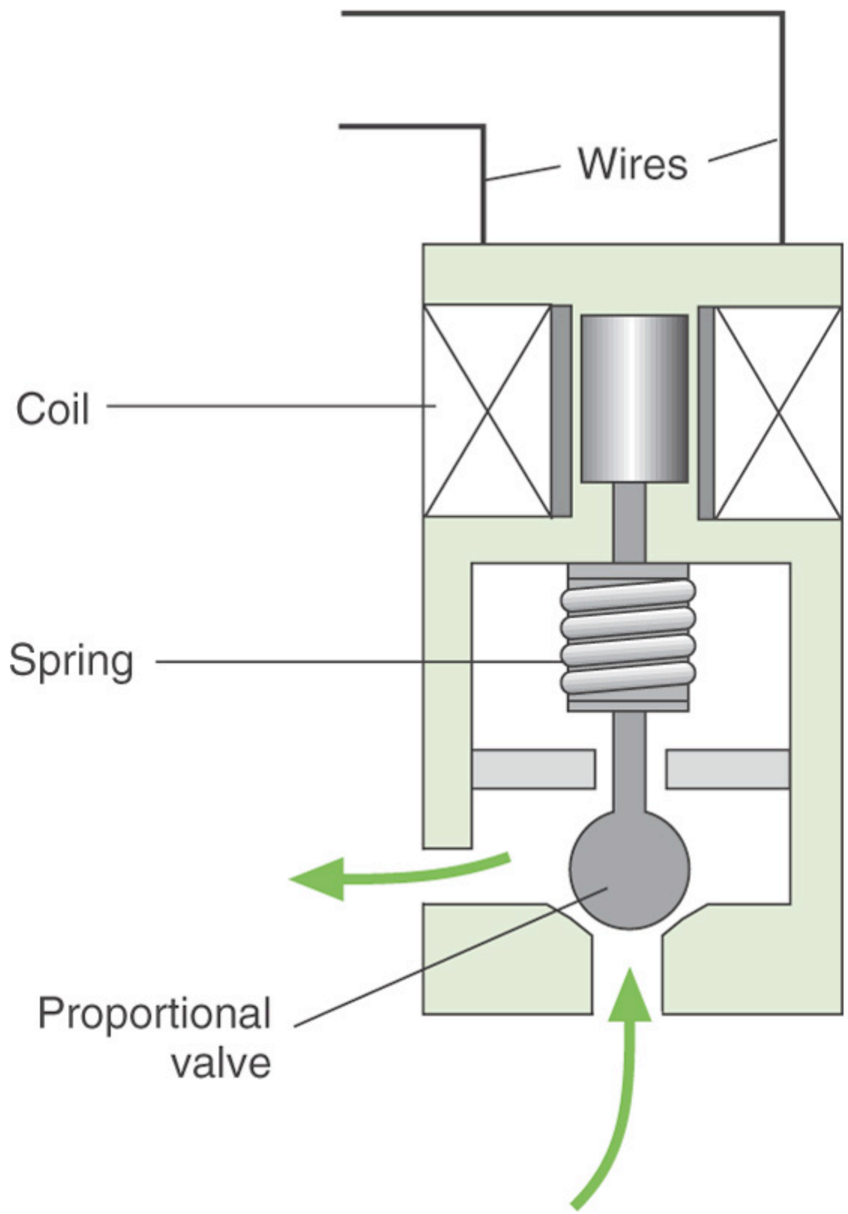
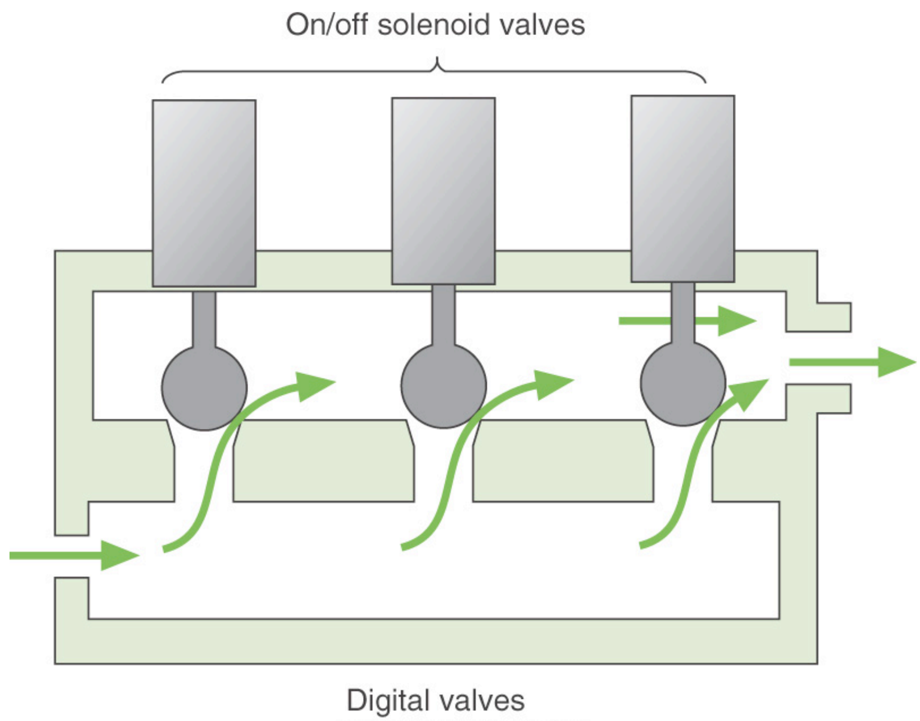

A
B

Flow control valves

- Control and direct flow by opening and closing
- Complete or incremental movement
- Rapid response time
- Great flexibility in flow control
- Proportional solenoid valve
- Stepper motor with valve
- Digital on/off valve configuration



(Redrawn from Sanborn WG: *Respir Care* 38:72, 1993.)



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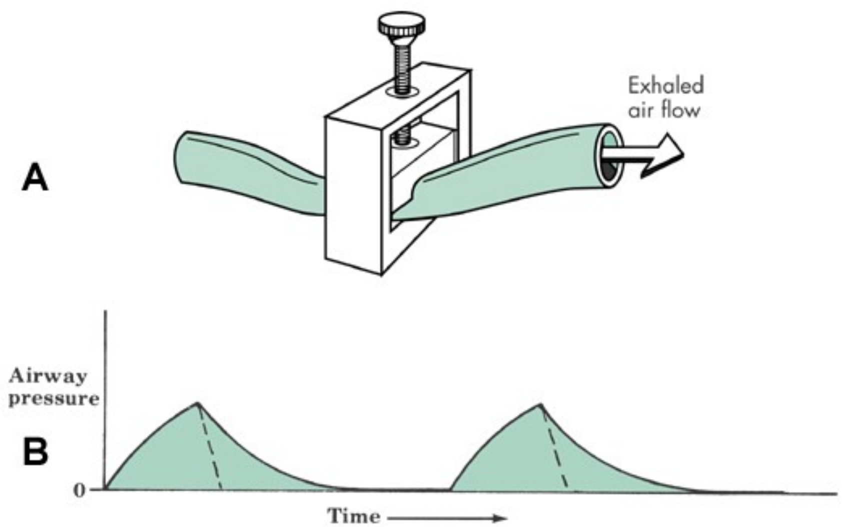
Expiratory Valves

- Allow exhalation to occur naturally
- Also applies positive pressure during exhalation to increase the FRC
- Flow resistance
- Threshold resistance



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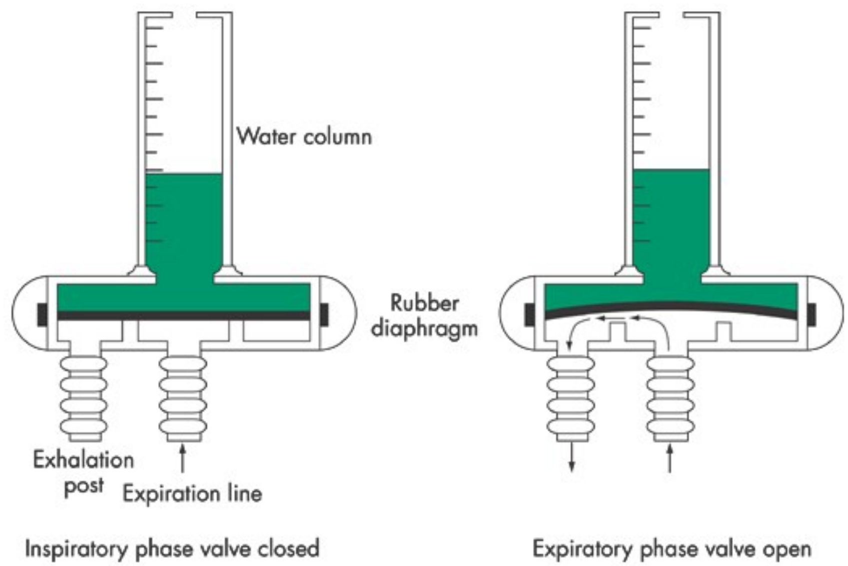

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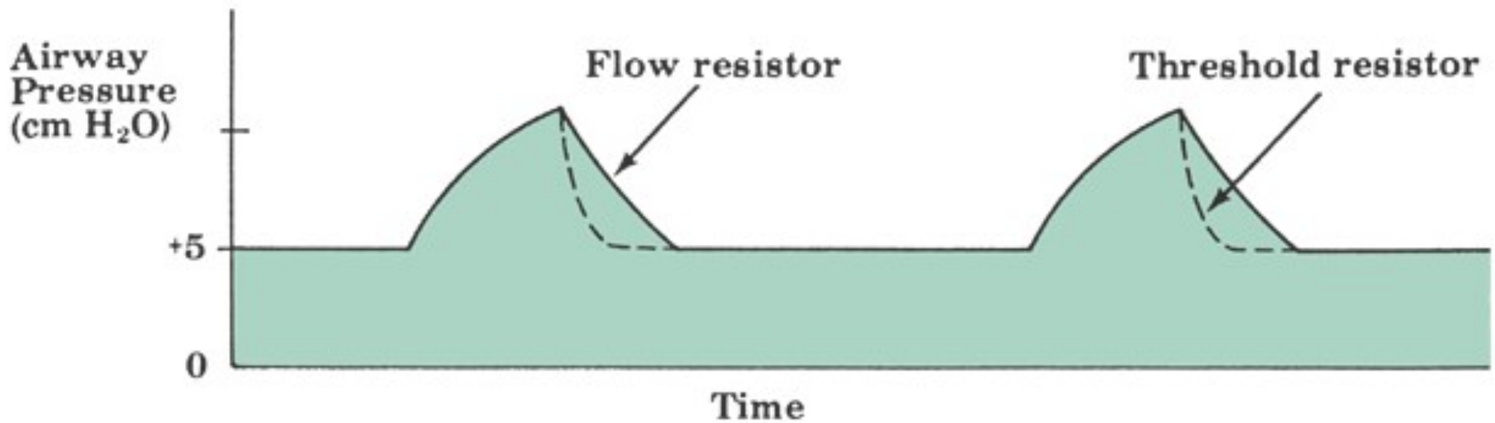

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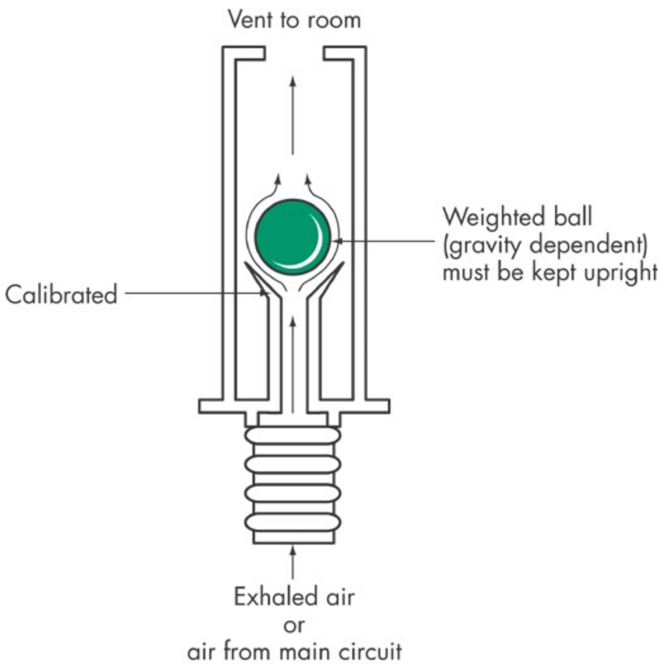

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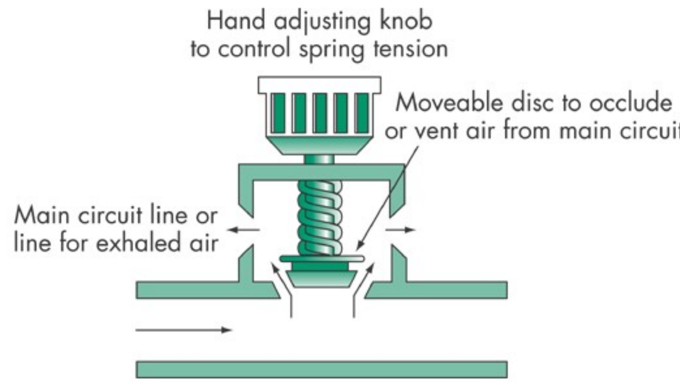

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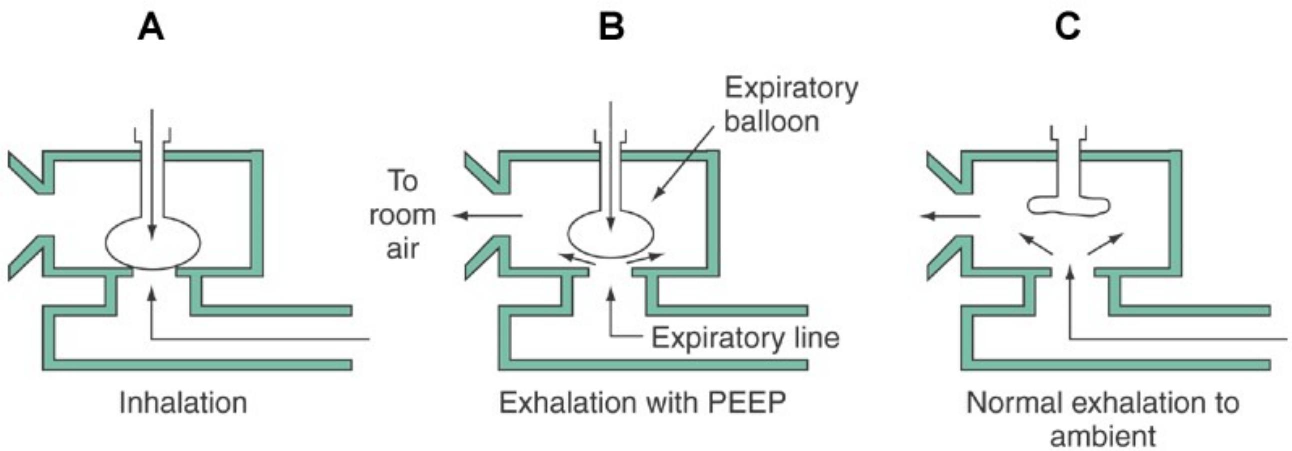

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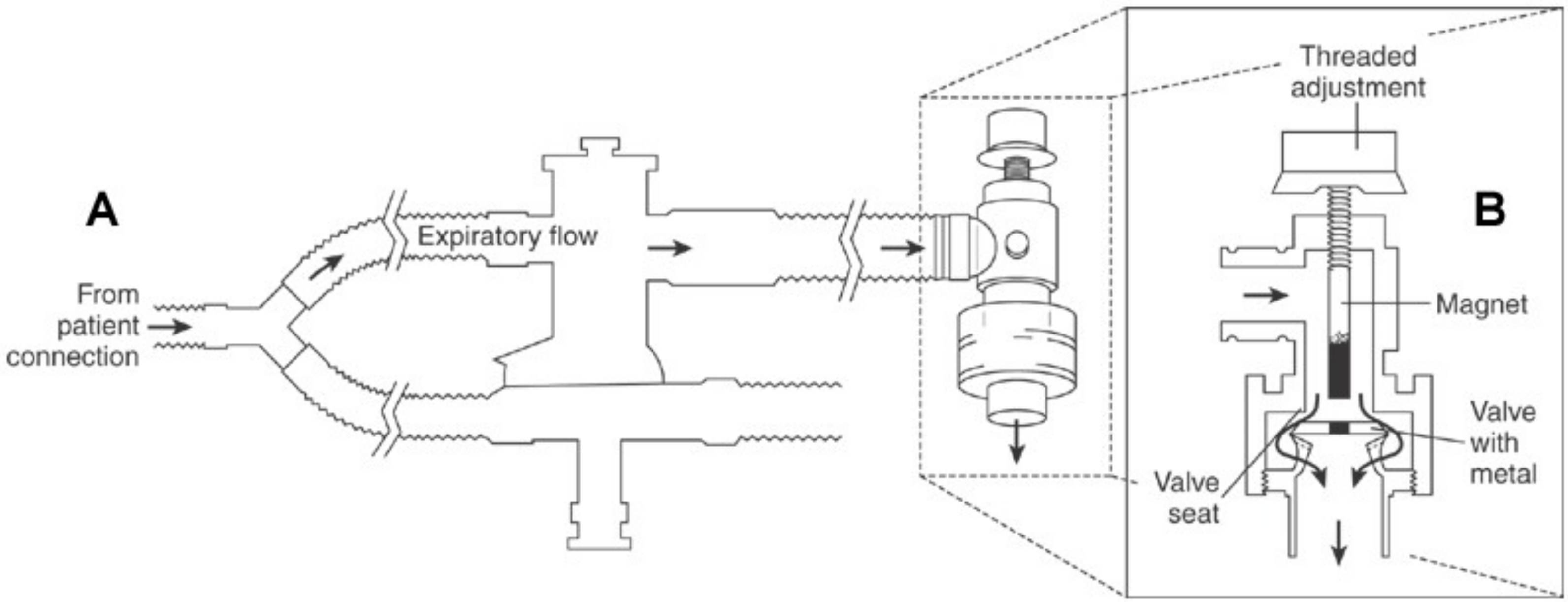
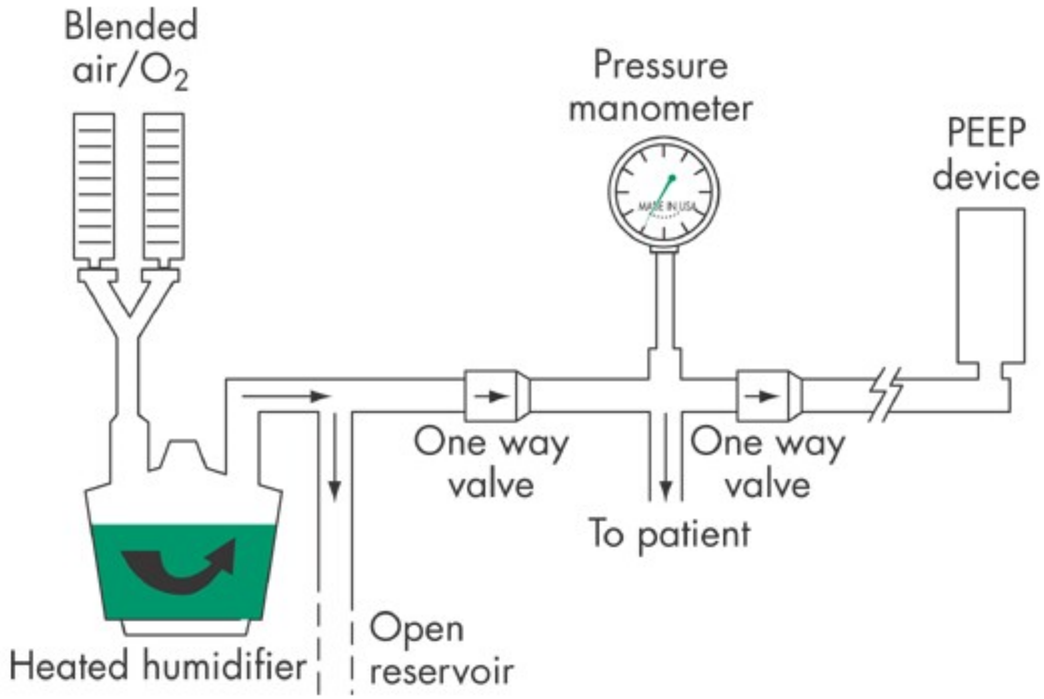

A
Expiratory flow
From
patient
connection
Threaded
adjustment
B
Magnet
Valve
with
metal
Valve
seat

CPAP Devices

- Spontaneously breathing patients
- Often provided through ventilators
- Originally and still may use free standing systems



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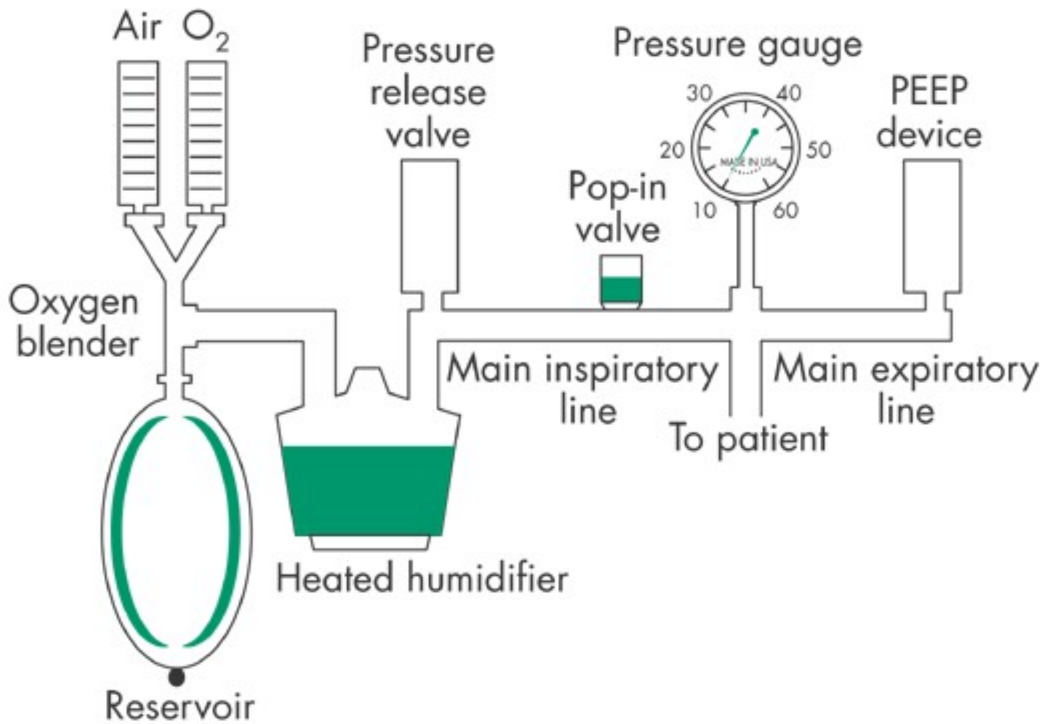

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Common features of Ventilators

- Rapidly changing environment
- Important to distinguish between different models/versions from the same manufacturer
- Common internal mechanisms
- Patient monitoring
- Parameters and displays
- Alarms

Infant Ventilators

- Different approaches to ventilation – regardless:
  - must monitor parameters closely
  - provide the appropriate level of support
  - respond to physiologic changes quickly
- Two different choices for ventilators
  - Ventilators designed exclusively for infants and small children
  - Single ventilator for all ages

Transport Ventilators

- Requires great care and skill; same level of care and monitoring throughout the transfer
- Gray area of risk versus benefit
- Physiologic changes due to gravity of condition not the transport itself
- Requires preparation and communication
- Ventilator should be compact, lightweight, reliable power source (internal battery or gas source)
- Able to function in extreme conditions

Home Care Ventilators

- One of the fastest growing areas of healthcare, home care is a viable alternative to hospital or extended care facilities
- Increased ability to support diseases once thought incurable
- Ventilators must be simple, operator friendly with clear alarms
- Main caregivers are family!

Noninvasive Ventilators

- Increased usage in the last 15 years
- Portable, safe, user-friendly interfaces
- Requires properly fitting interface

Negative Pressure Ventilators

- Attempts to mimic normal respiration
- Applies negative pressure to the outside of the chest
- The greater the pressure applied the greater the gradient, the greater the volume delivered
- 3 basic modes: inspiratory negative pressure only, inspiratory negative pressure/positive expiratory pressure, continuous negative pressure