DESIGN PRINCIPLES:
ANESTHESIA MACHINE

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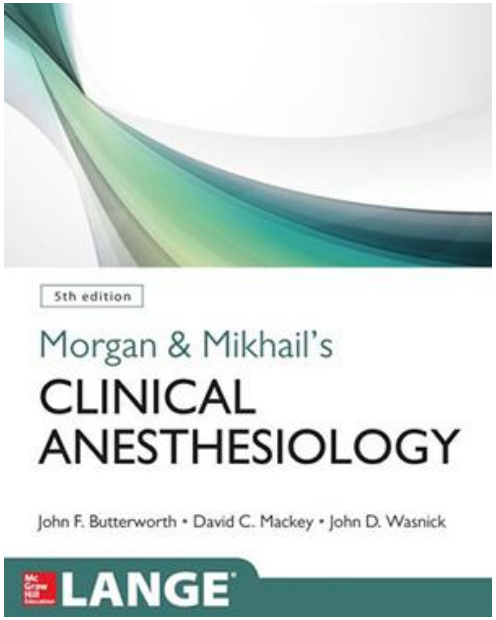
Recommended Textbook

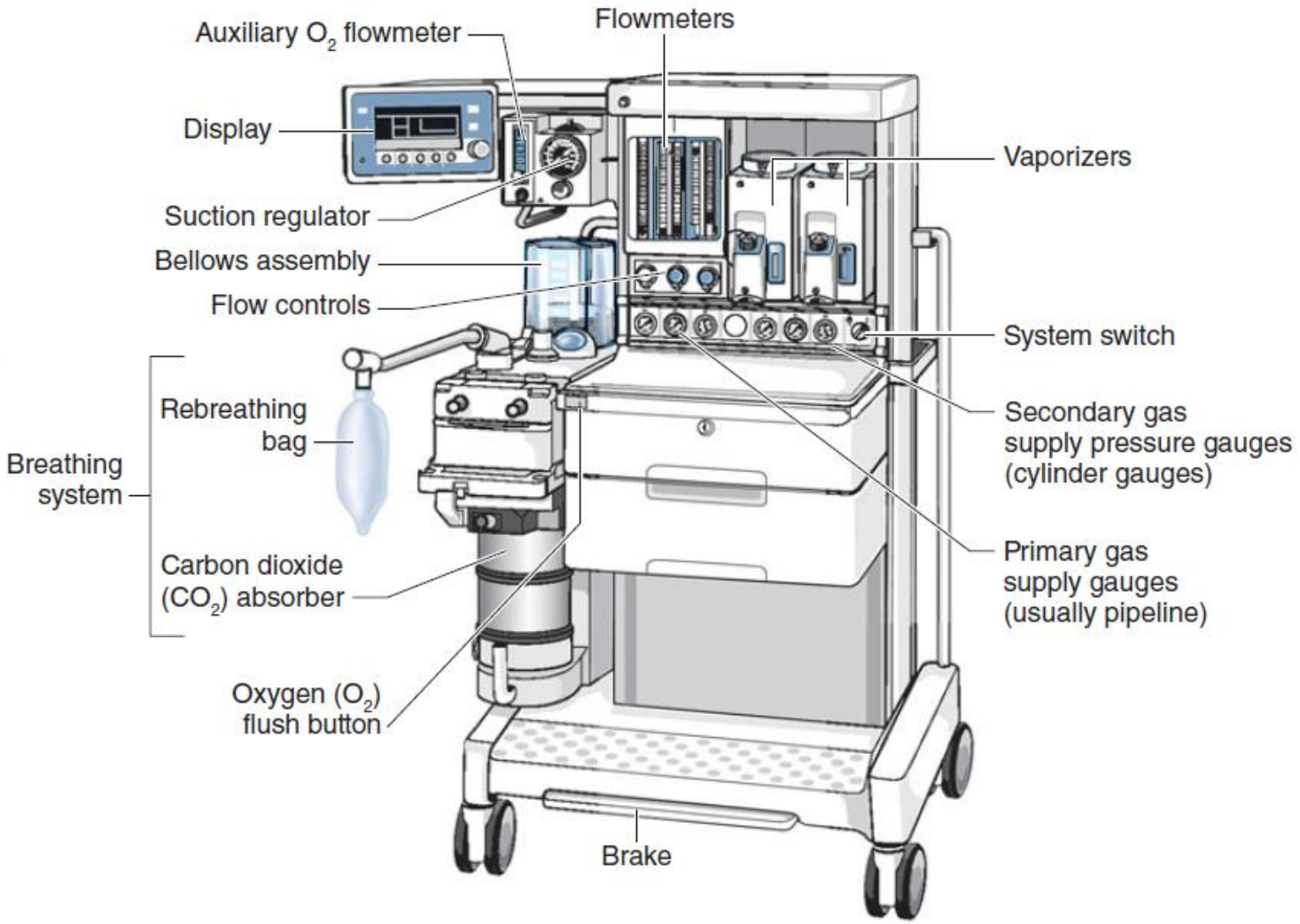
- John F. Butterworth IV, David C. Mackey and John D. Wasnick, *Morgan & Mikhail's Clinical Anesthesiology*, 5th Ed., McGraw-Hill Education, New York, 2013. (ISBN: 978-0-07-171405-1)
- Rüdiger Kramme, Klaus-Peter Hoffmann, Robert S. Pozos (Eds.), *Springer Handbook of Medical Technology*, Springer-Verlag, Berlin, 2011. (ISBN: 978-3-540-74657-7)



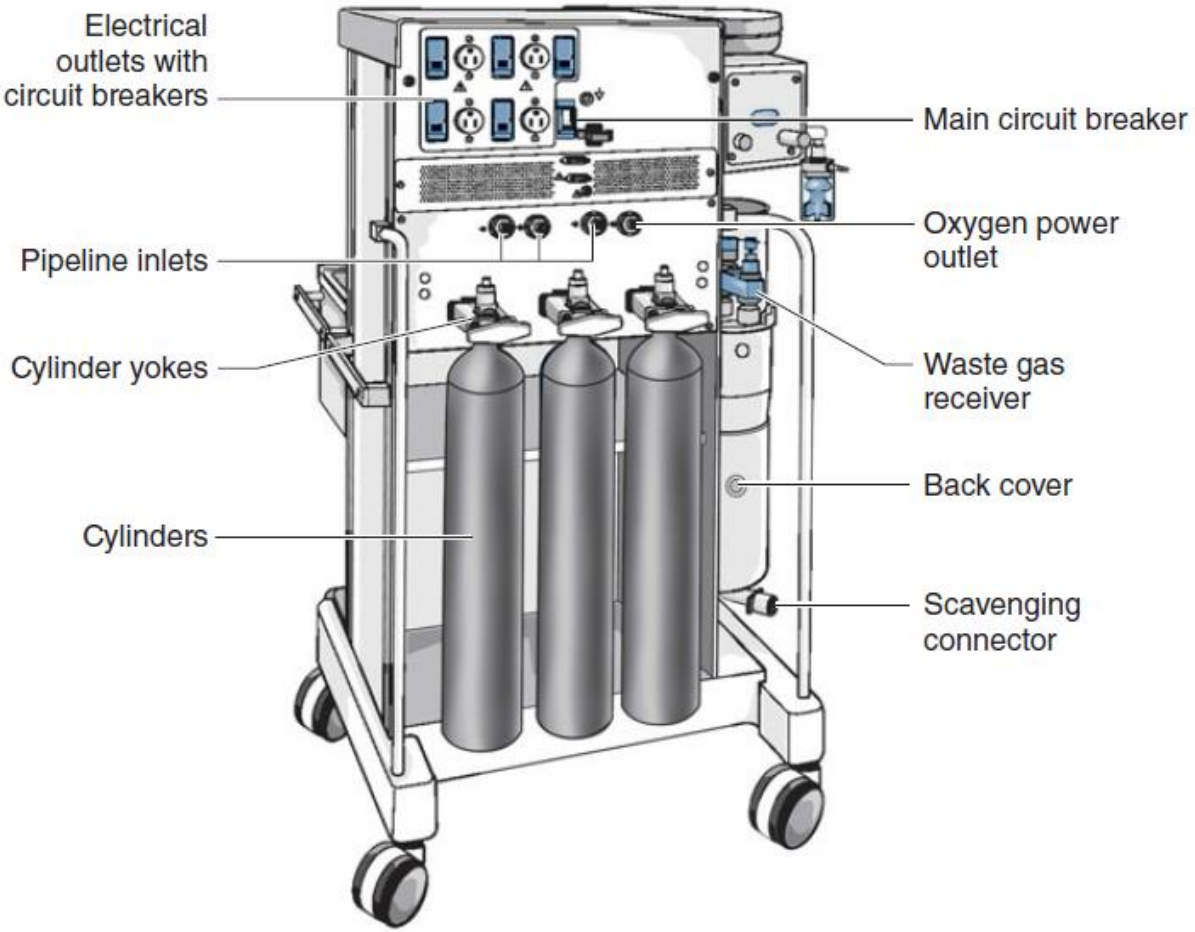
Definition

- Anesthesia devices are used in operating rooms in hospitals by medical staff to ensure that operative and diagnostic procedures can be performed on a patient without pain in an unconscious and relaxed state
- On the most basic level, anesthesiologist uses anesthesia machine to control patient's ventilation and oxygen delivery and to administer inhalation anesthetics

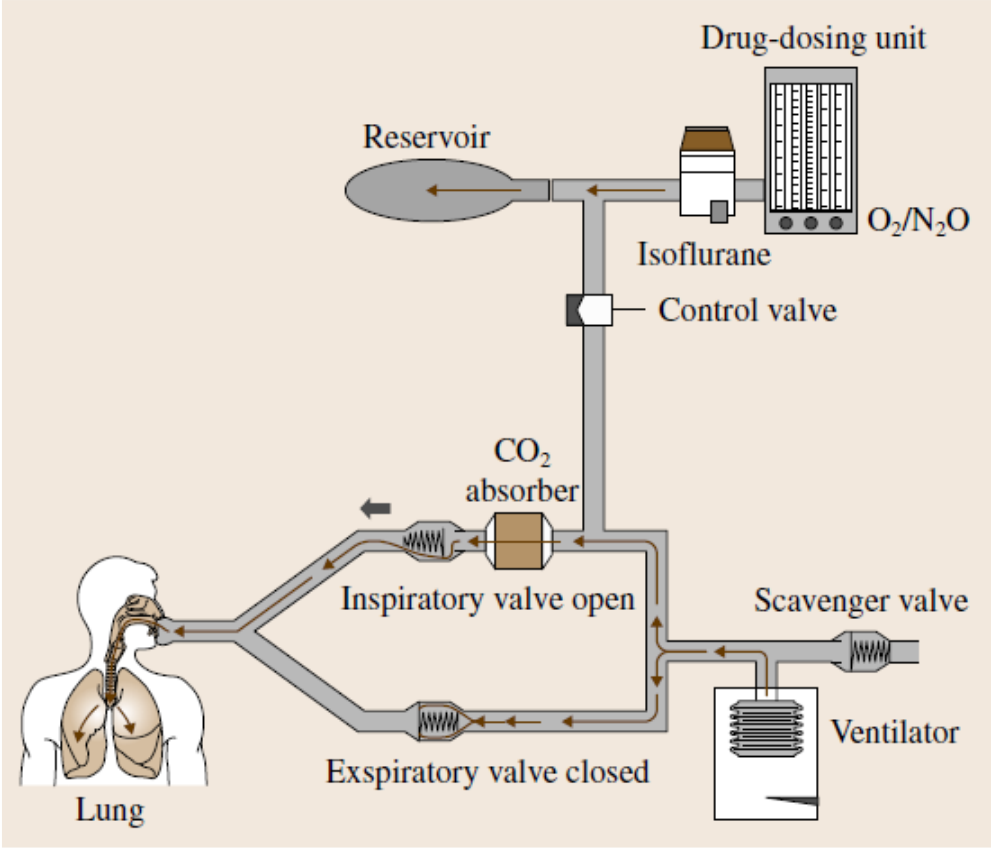
Modern Anesthesia Machine - Front

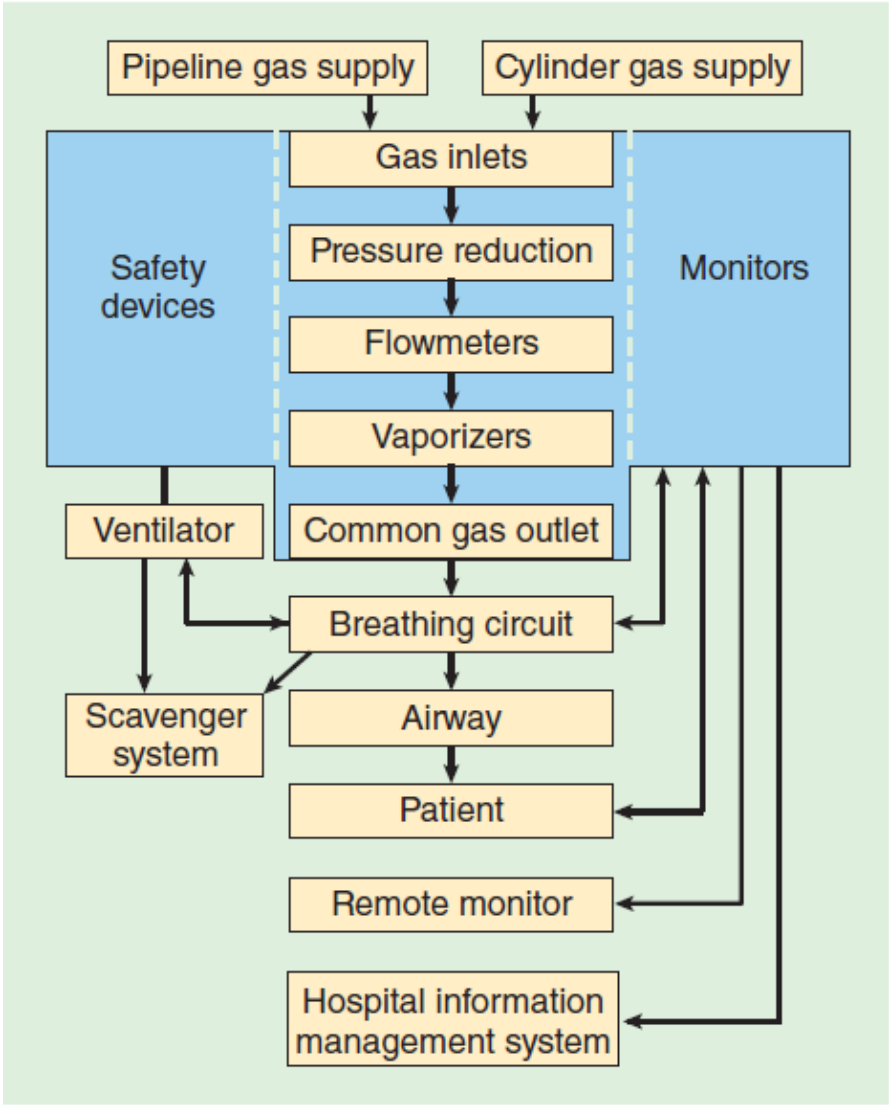


Modern Anesthesia Machine - Back

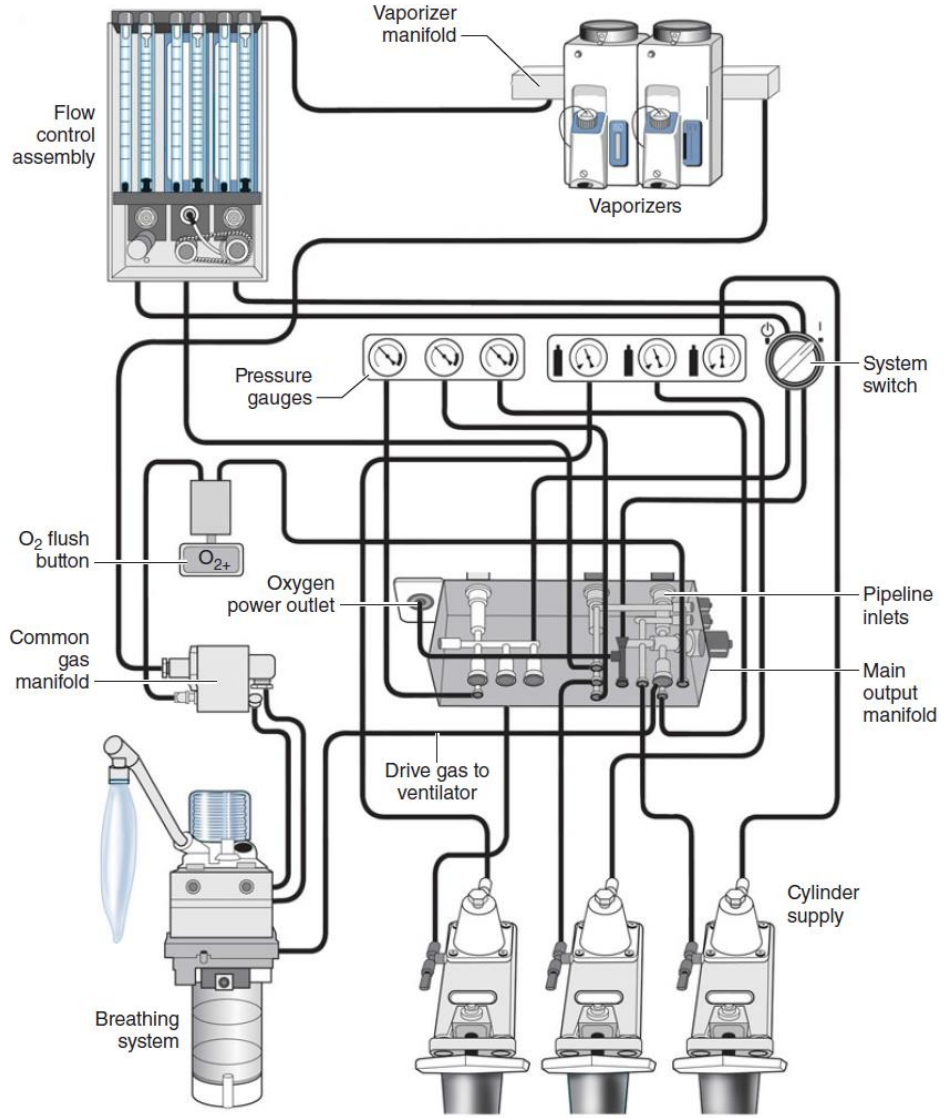


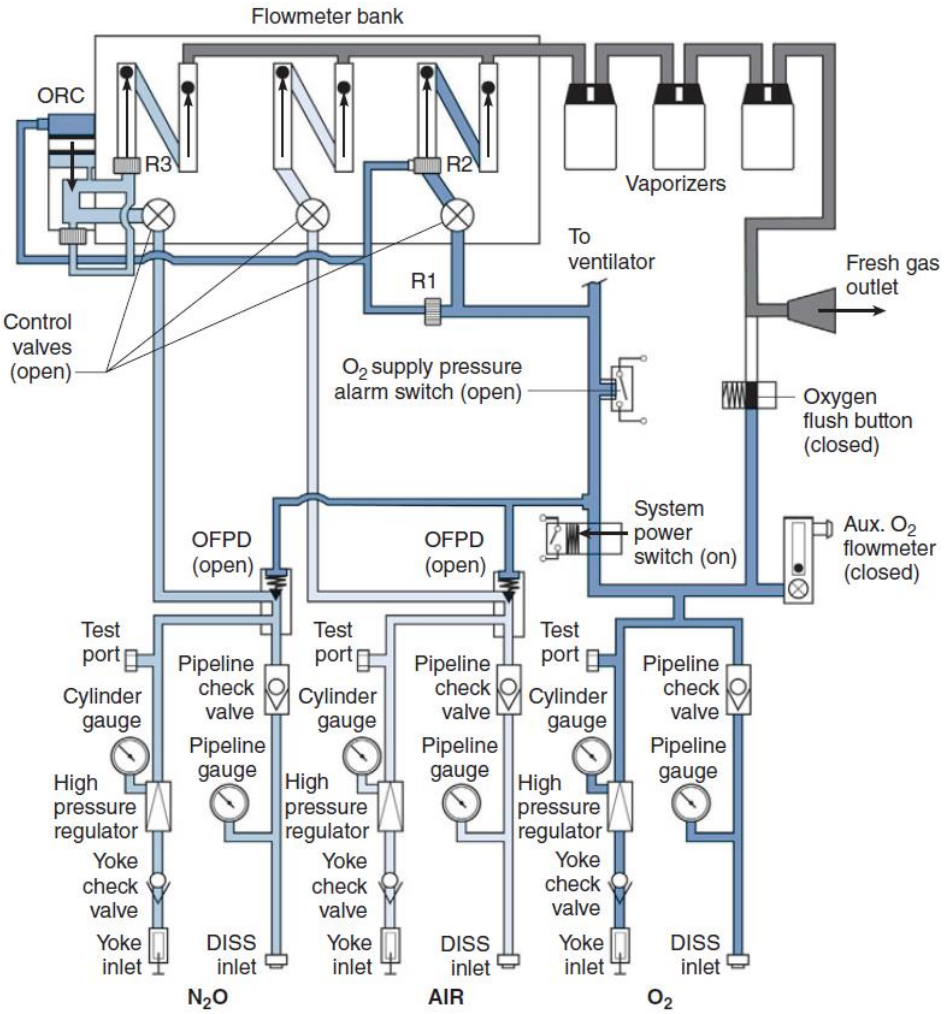
Functional Schematic





Internal Schematic Examples



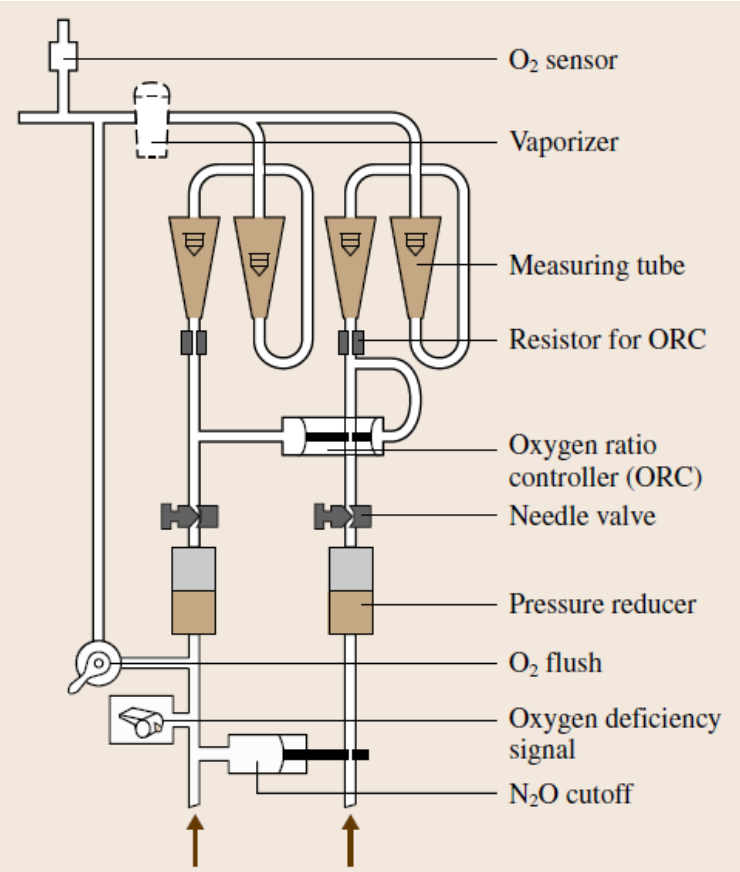


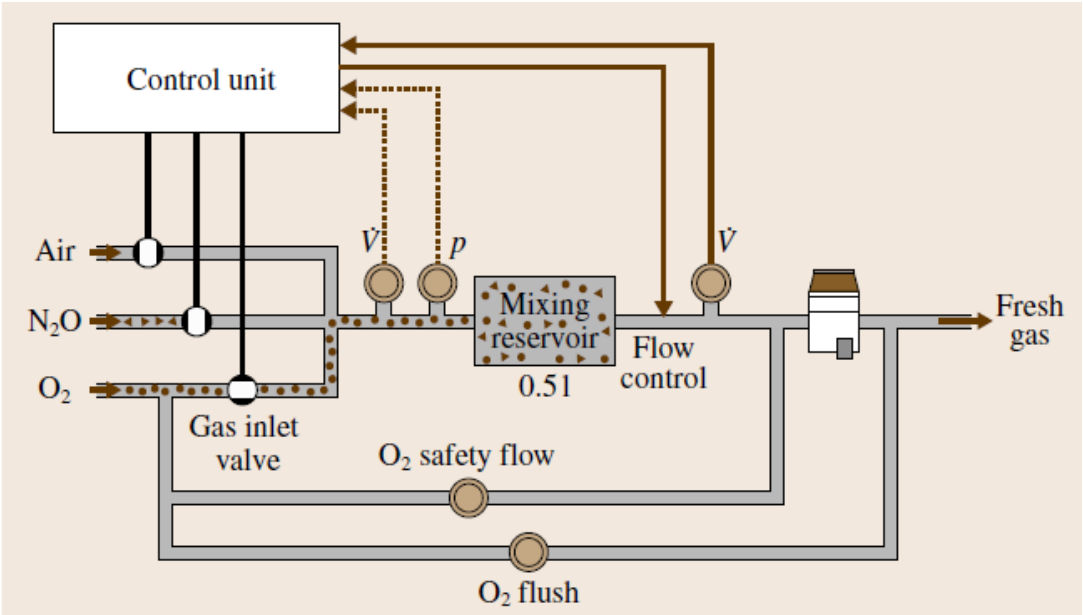
Components of Anesthesia Machine

- Anesthesia device consists of following components, according to its intended medical purpose:
  - Drug dosing unit
  - Ventilator with breathing system
  - Monitoring unit consisting of 3 subunits:
    - One monitors drug dosing and the ventilator called device monitoring
    - One monitors the patient called patient monitoring
    - One monitors the *depth of anesthesia* called anesthesia effect monitoring

Drug Dosing

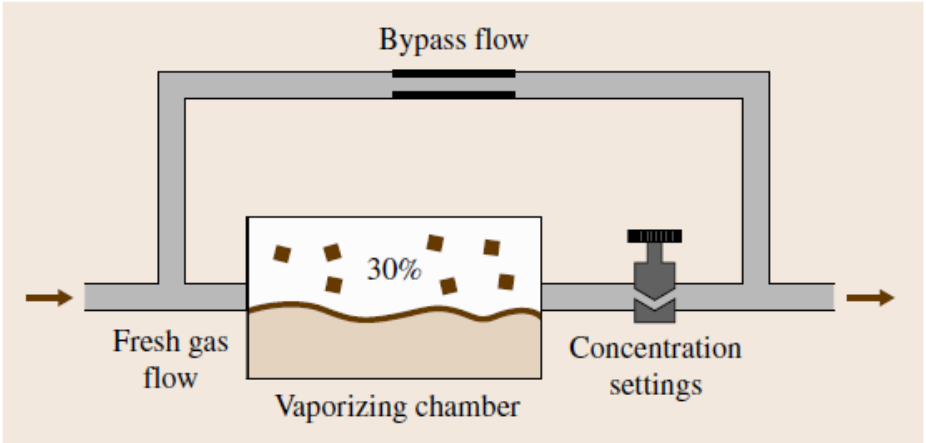
- Two principles are used for delivering O_2, air, and N_2O, namely mechanical metering valves and electronic mixers



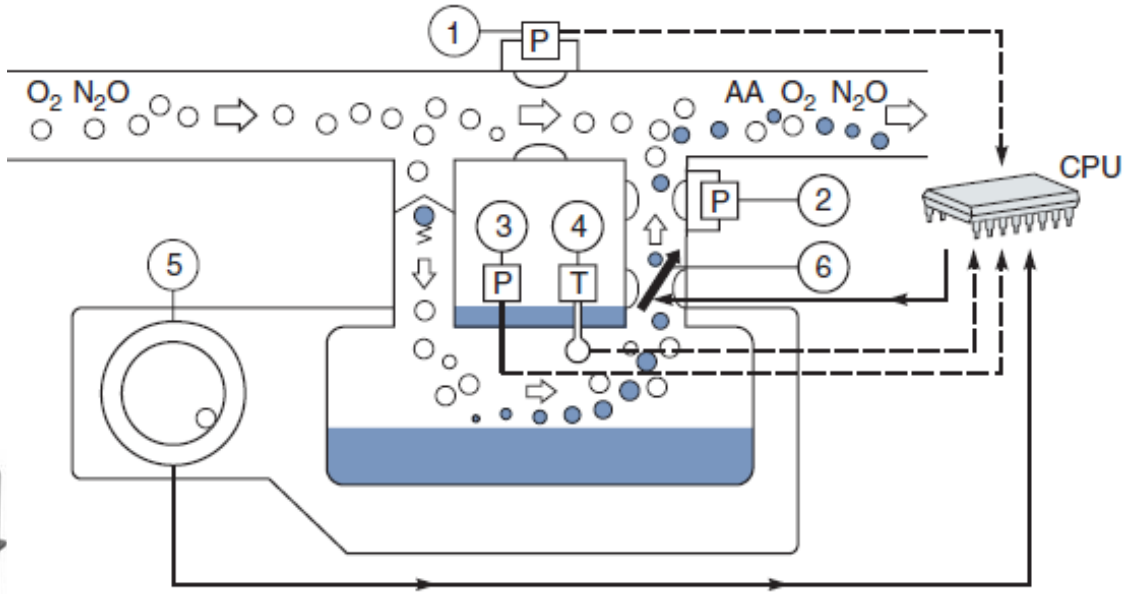


Anesthetic Agent Vaporizers

- Volatile anesthetic agents are used to achieve unconsciousness
  - Exhalable and evaporate quickly (e.g., isoflurane and sevoflurane)
- Anesthetic agent vaporizer converts anesthetic agent from liquid to vapor and mix it with fresh gas at preset concentration
- Concentration of saturated agent vapor is much higher (20 fold) than therapeutically necessary
  - Vaporizer is primarily designed to reduce high saturation concentration of, e.g., 30% to concentration required during anesthesia, e.g., 2%



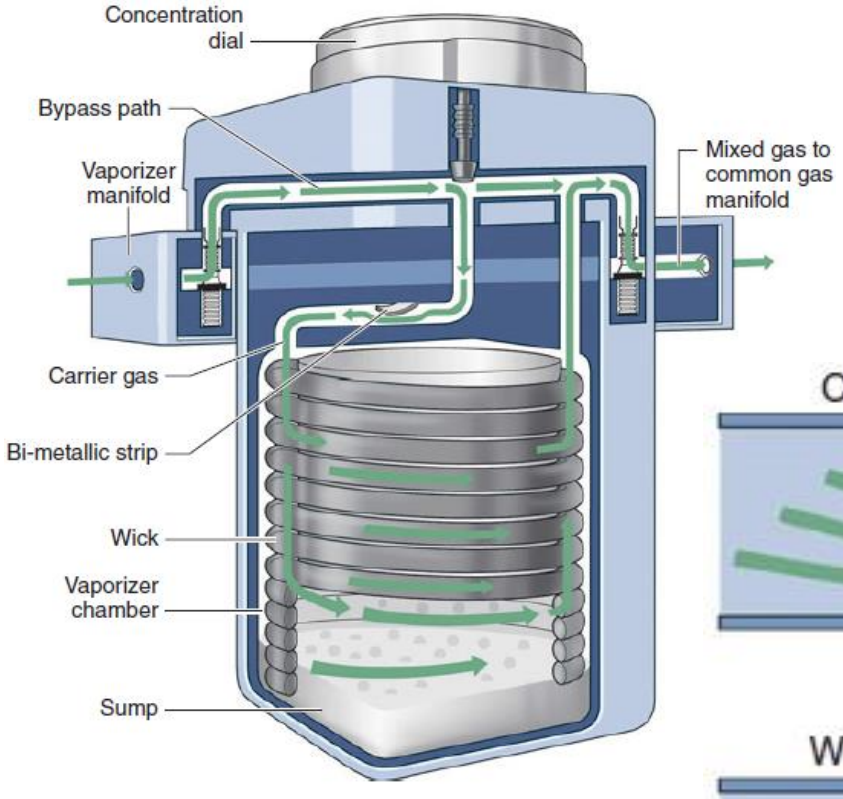
Electronic Vaporizer Example

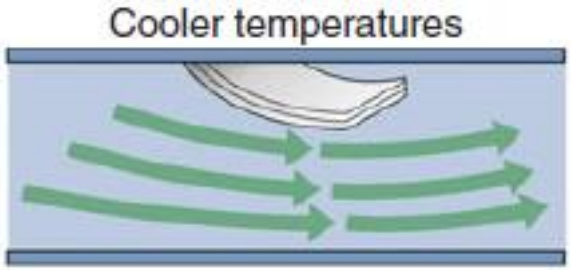


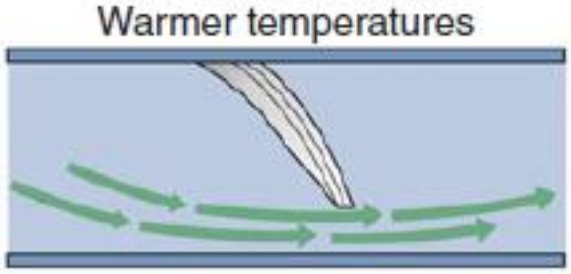
Measurement part
(1) Bypass flow
(2) Flow through the cassette
(3) Cassette pressure
(4) Cassette temperature

Agent control
(5) Agent setting
(6) Control valve

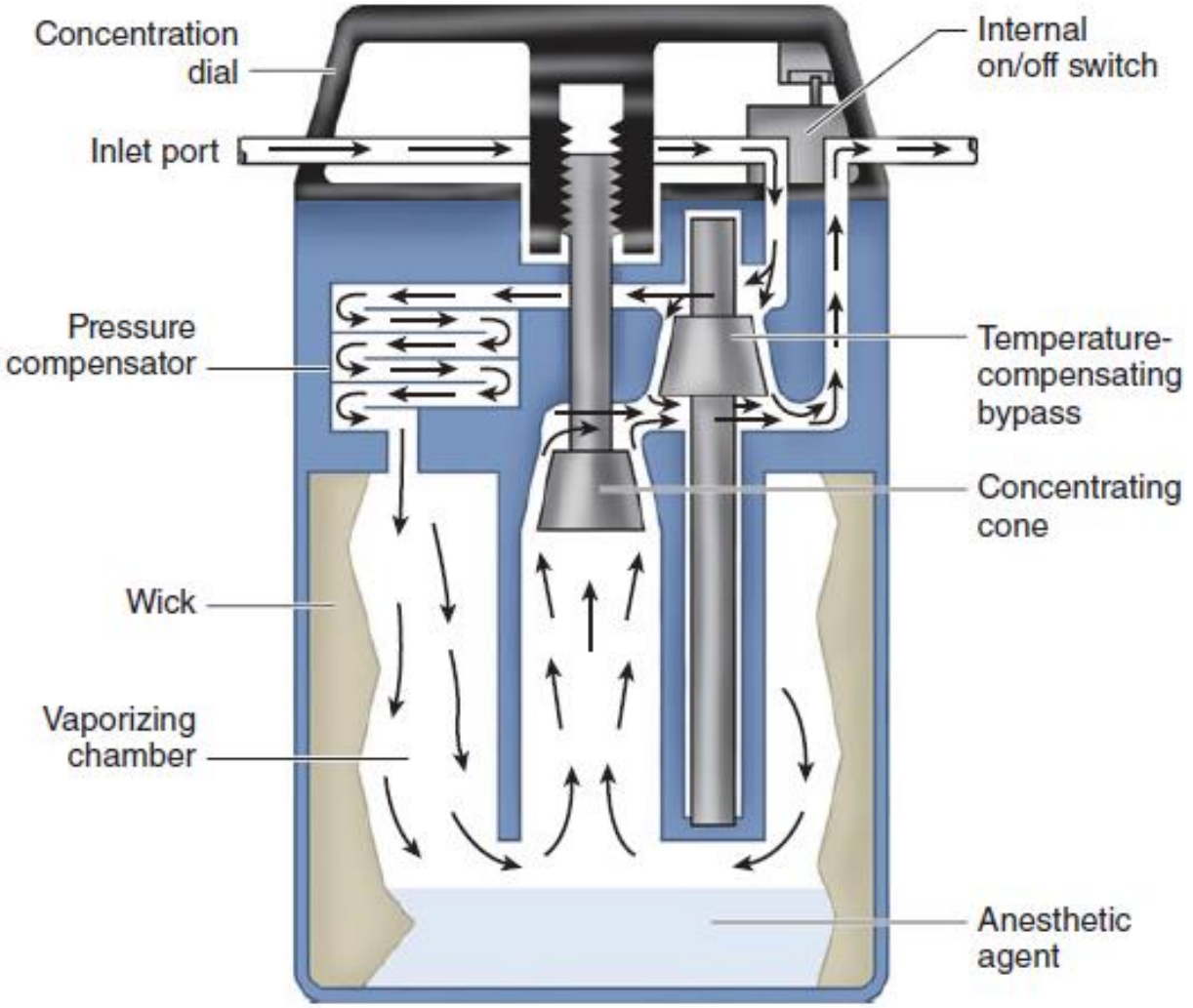
Mechanical Vaporizer Example







Mechanical Vaporizer Example

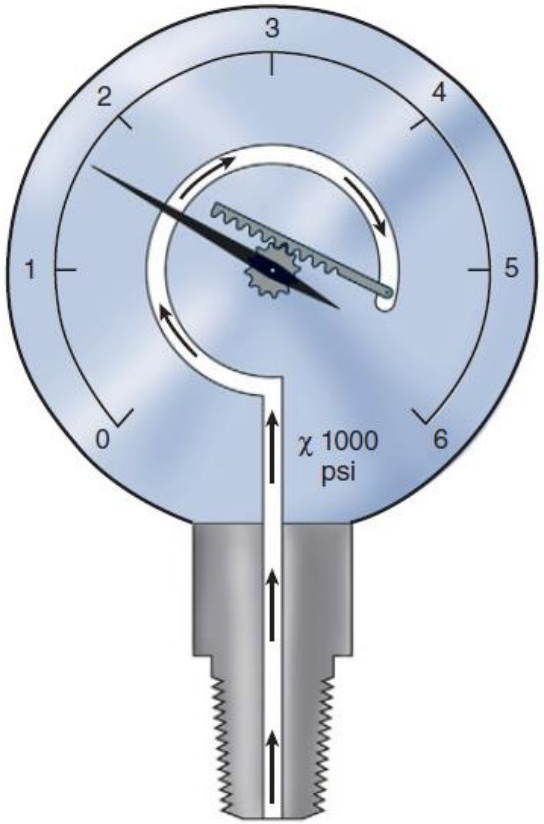


Monitoring in Anesthesia

- Generally, anesthesia devices are equipped with nine sensors
- Five device monitoring sensors for drug dosing and ventilation
  - Oxygen
  - Pressure
  - Volume
  - Carbon dioxide (CO2)
  - Anesthetic agent
- Four patient monitoring sensors for monitoring patient health during uncomplicated operations
  - Electrocardiogram (ECG)
  - Noninvasive blood pressure (NIBP)
  - Oxygen saturation (SpO2), and
  - Body temperature.

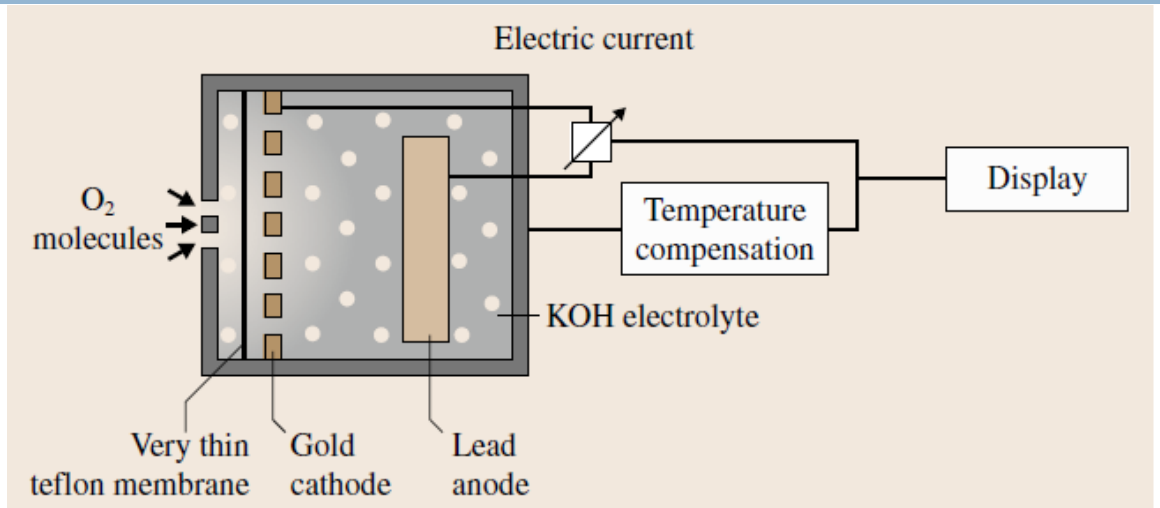
Bourdon Pressure Gauge

- Cylinder pressure is measured by Bourdon pressure gauge
  - A flexible tube within this gauge straightens when exposed to gas pressure, causing a gear mechanism to move a needle pointer

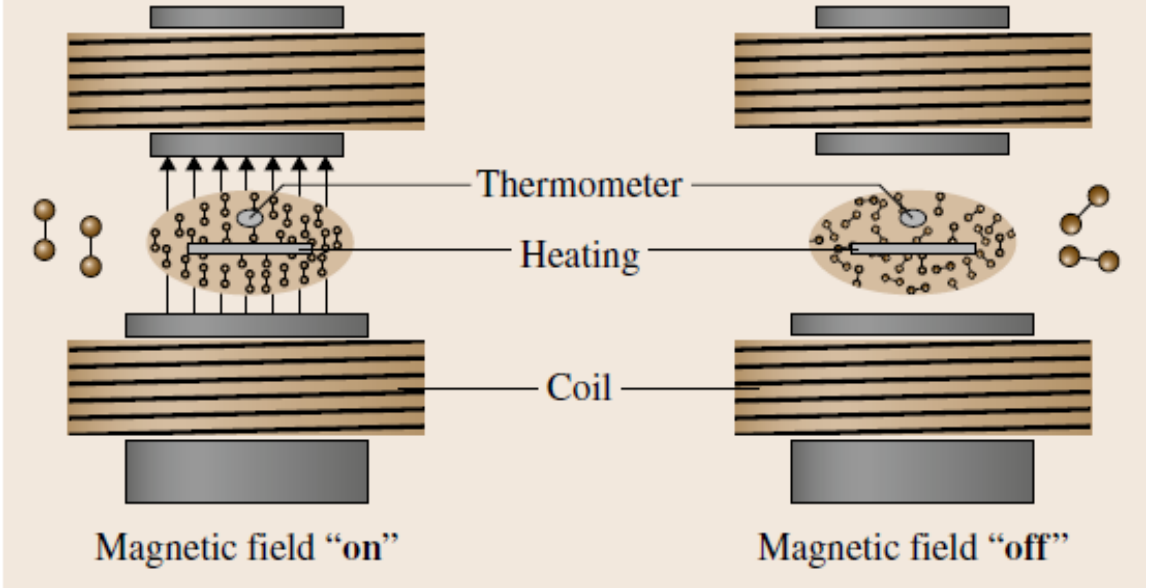


Oxygen Sensor

- Fuel Cell type

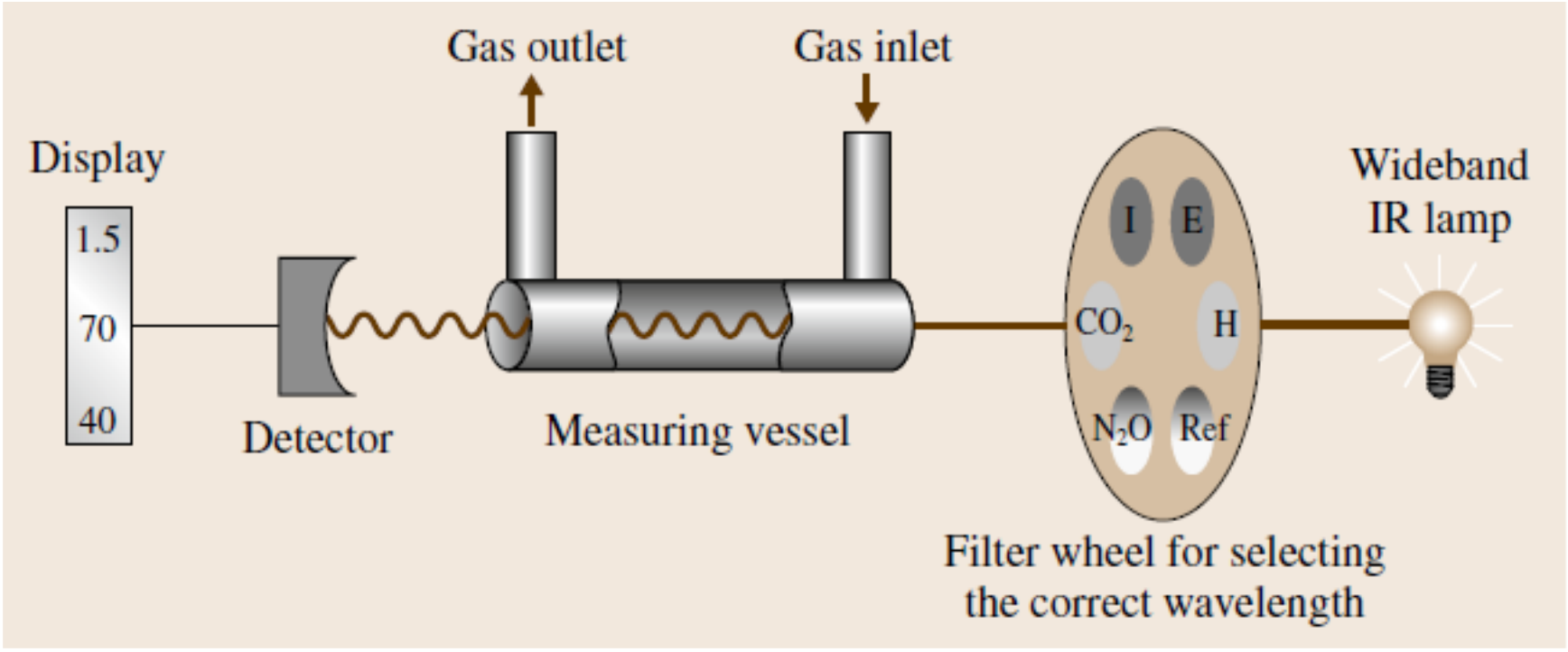


- Paramagnetic type



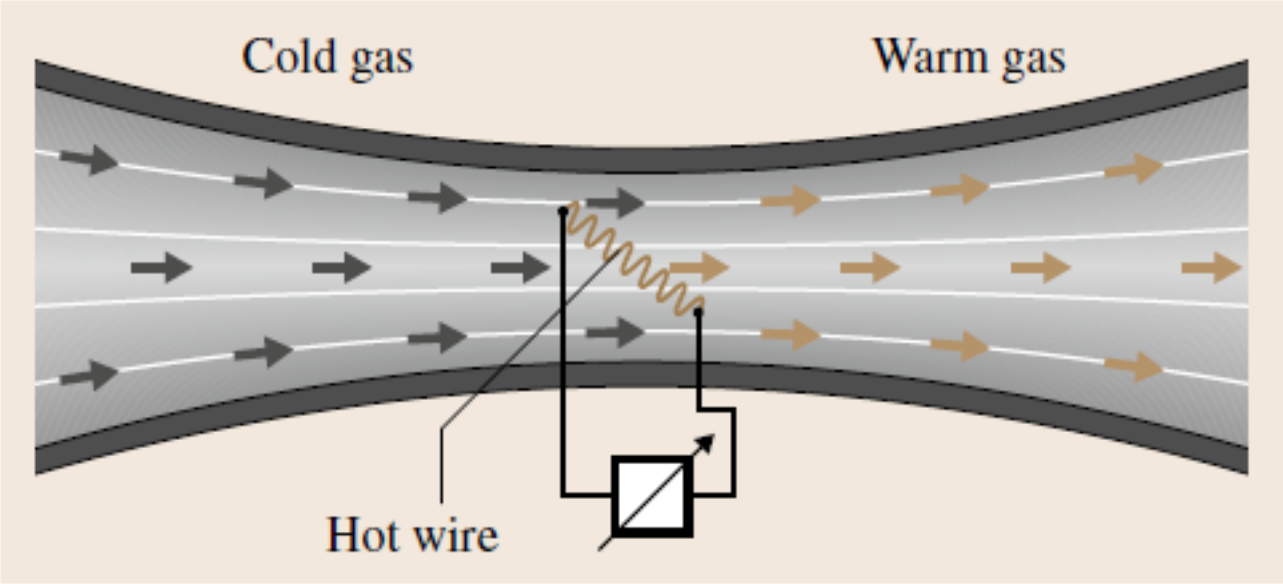
CO_2, N_2O, and Anesthetic Agent Sensors

- Infrared absorption spectroscopy
  - Based on physical principle that polyatomic gases absorb infrared radiation at characteristic frequencies
  - Level of absorption depends on concentration of molecules according to Lambert–Beer law: Concentration = Absorption constant × $\ln(I_0/I)$



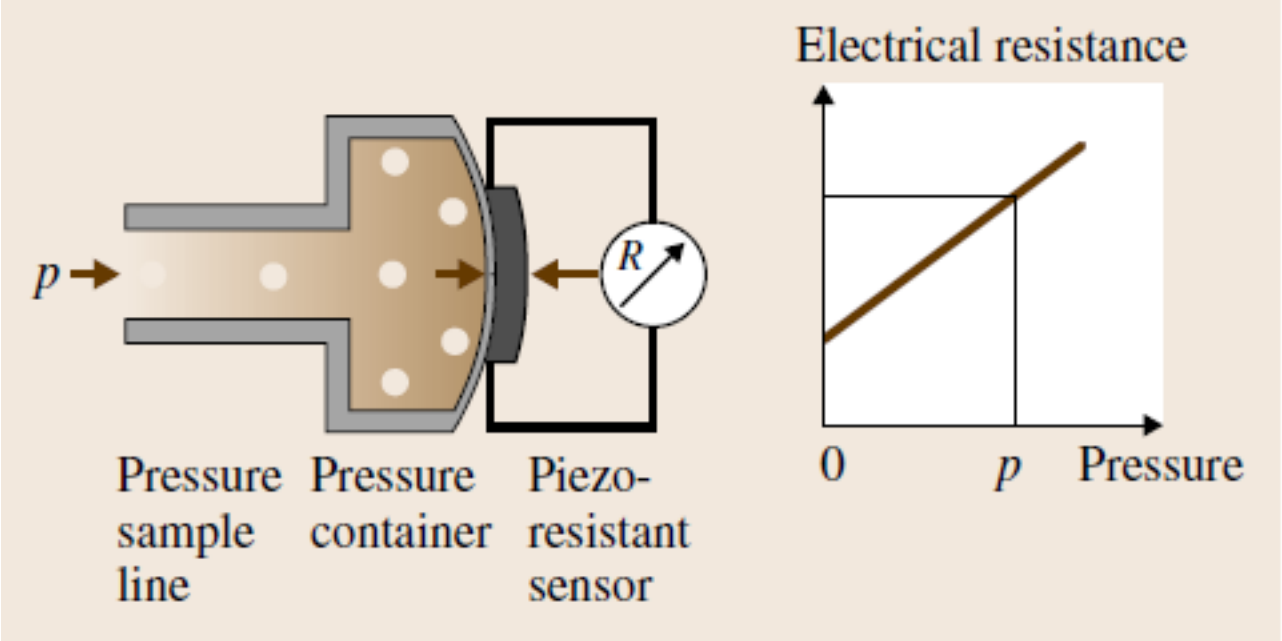
Volume and Flow Sensor

- Hot-Wire Anemometer method
  - Purely electrical method for volume measurement

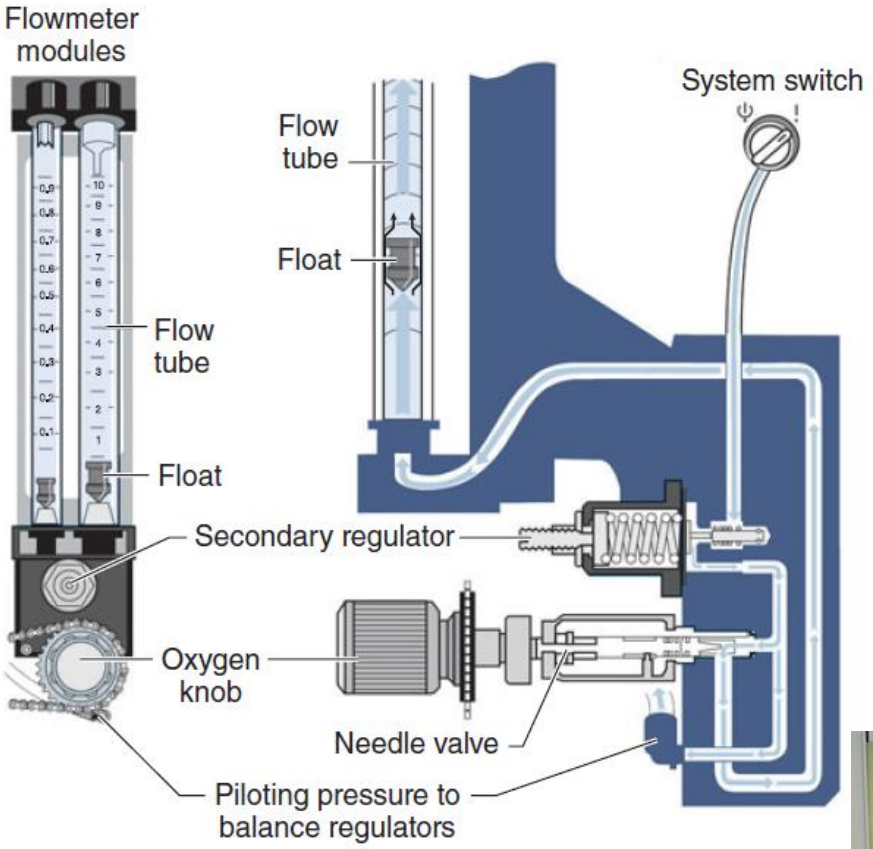


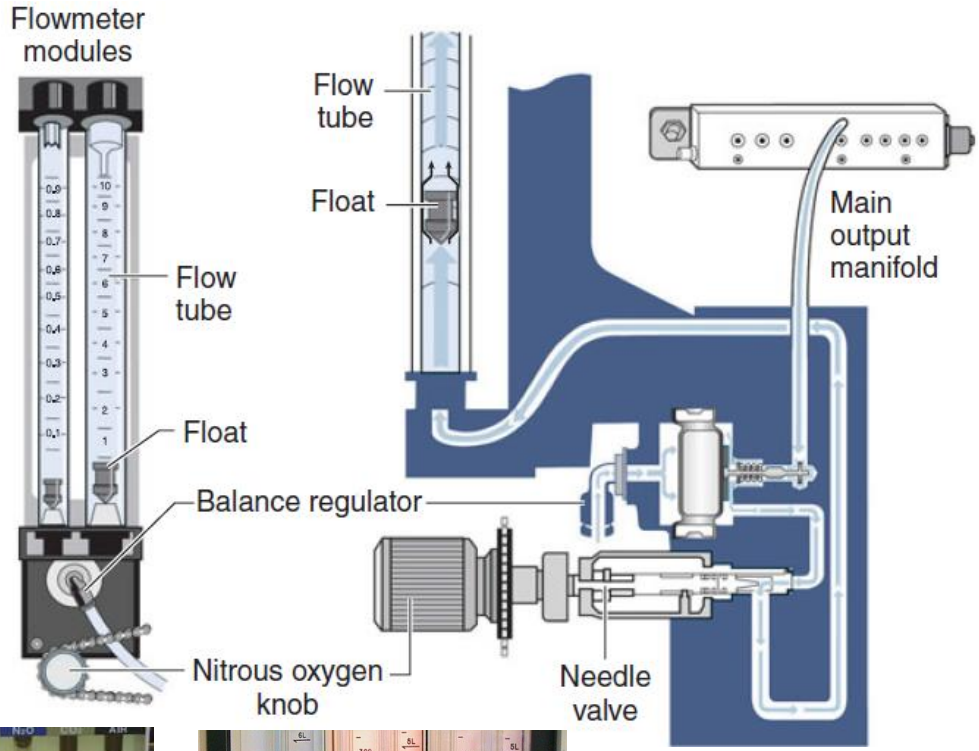
Pressure Sensor

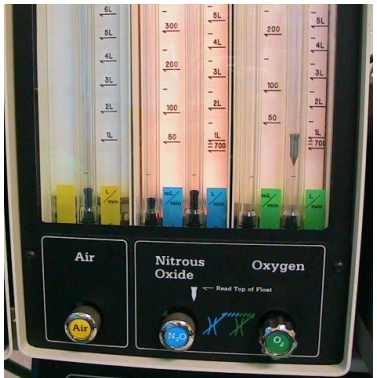
- Piezoresistive Sensor
  - Solid-state device whose electrical resistance depends on elongation of membrane (and hence, pressure)



Flowmeters

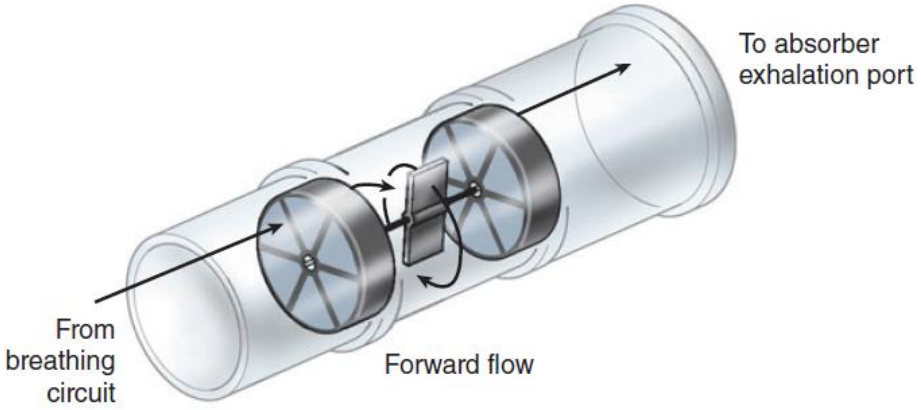

Flowmeter modules
Flow tube
Float
System switch
Flow tube
Float
Secondary regulator
Oxygen knob
Needle valve
Piloting pressure to balance regulators

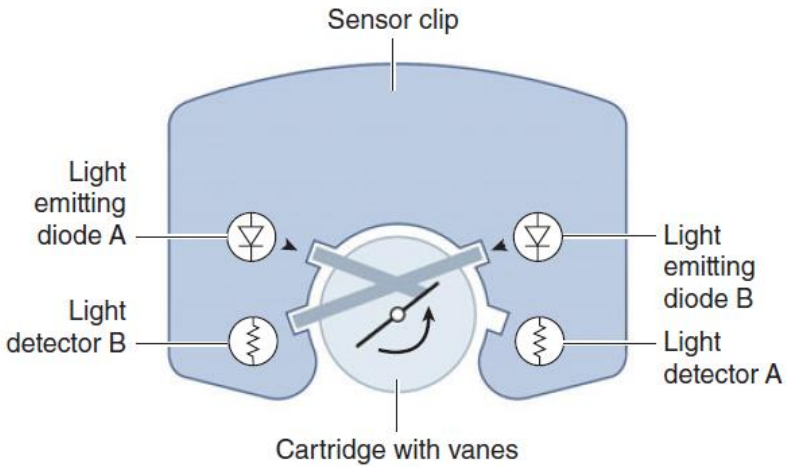

Flowmeter modules
Flow tube
Float
Balance regulator
Nitrous oxygen knob
Flow tube
Float
Main output manifold
Needle valve

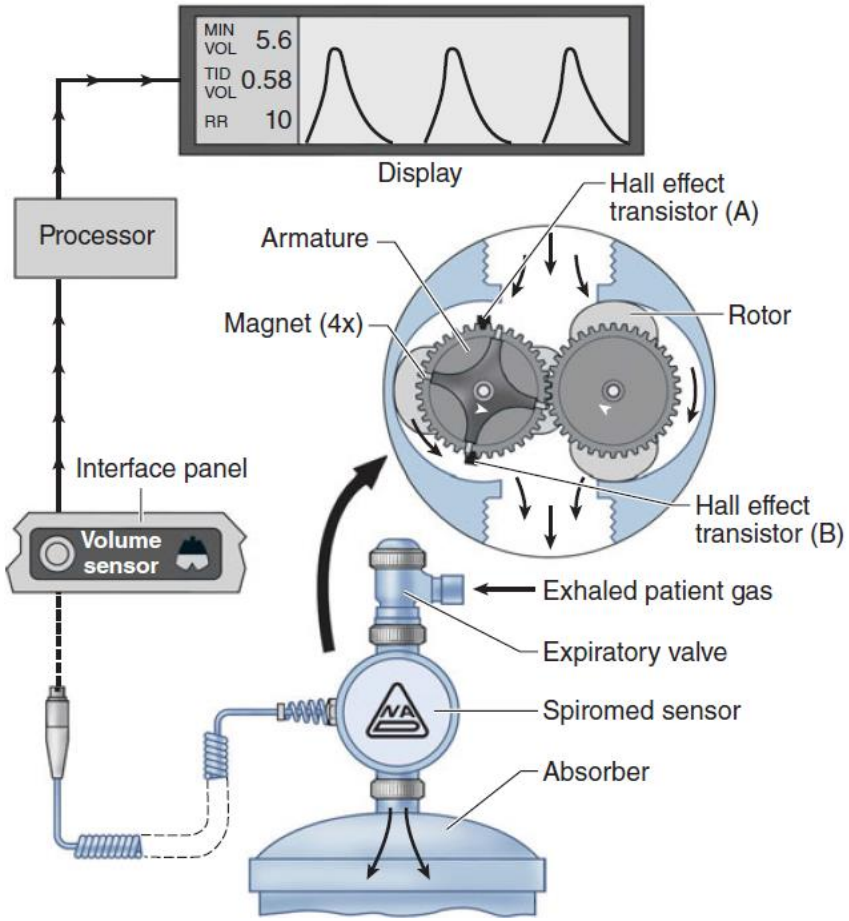

Air
Nitrous Oxide
Oxygen

Spirometers

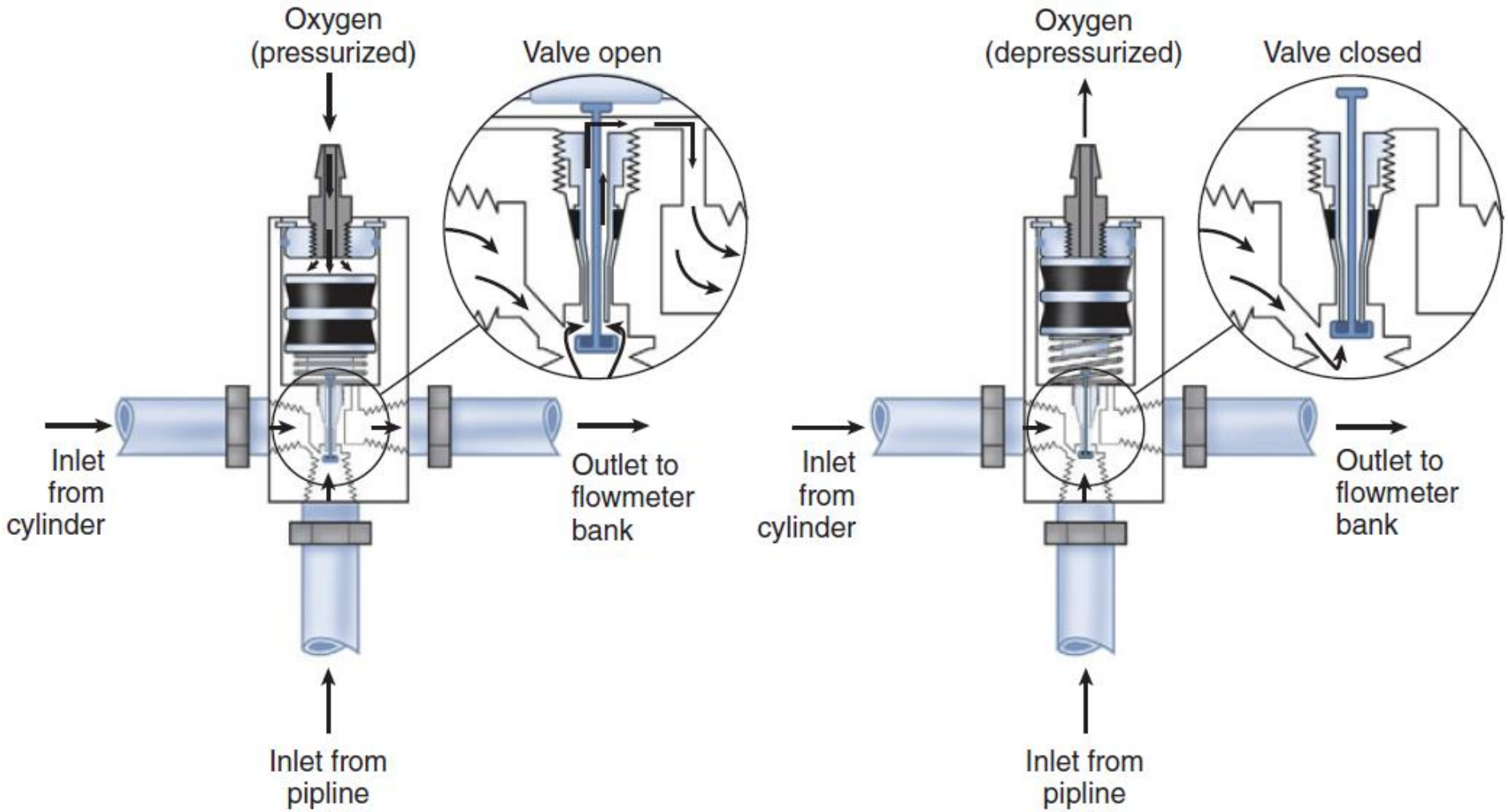
- Used to measure exhaled tidal volume in breathing circuit on all anesthesia machines, typically near exhalation valve







Oxygen Failure Protection



Suggested Readings and Assignments

- Chapter 4 of Recommended Reference #1
- Chapter 30 of Recommended Reference #2