Physics Applicable to Respiratory System

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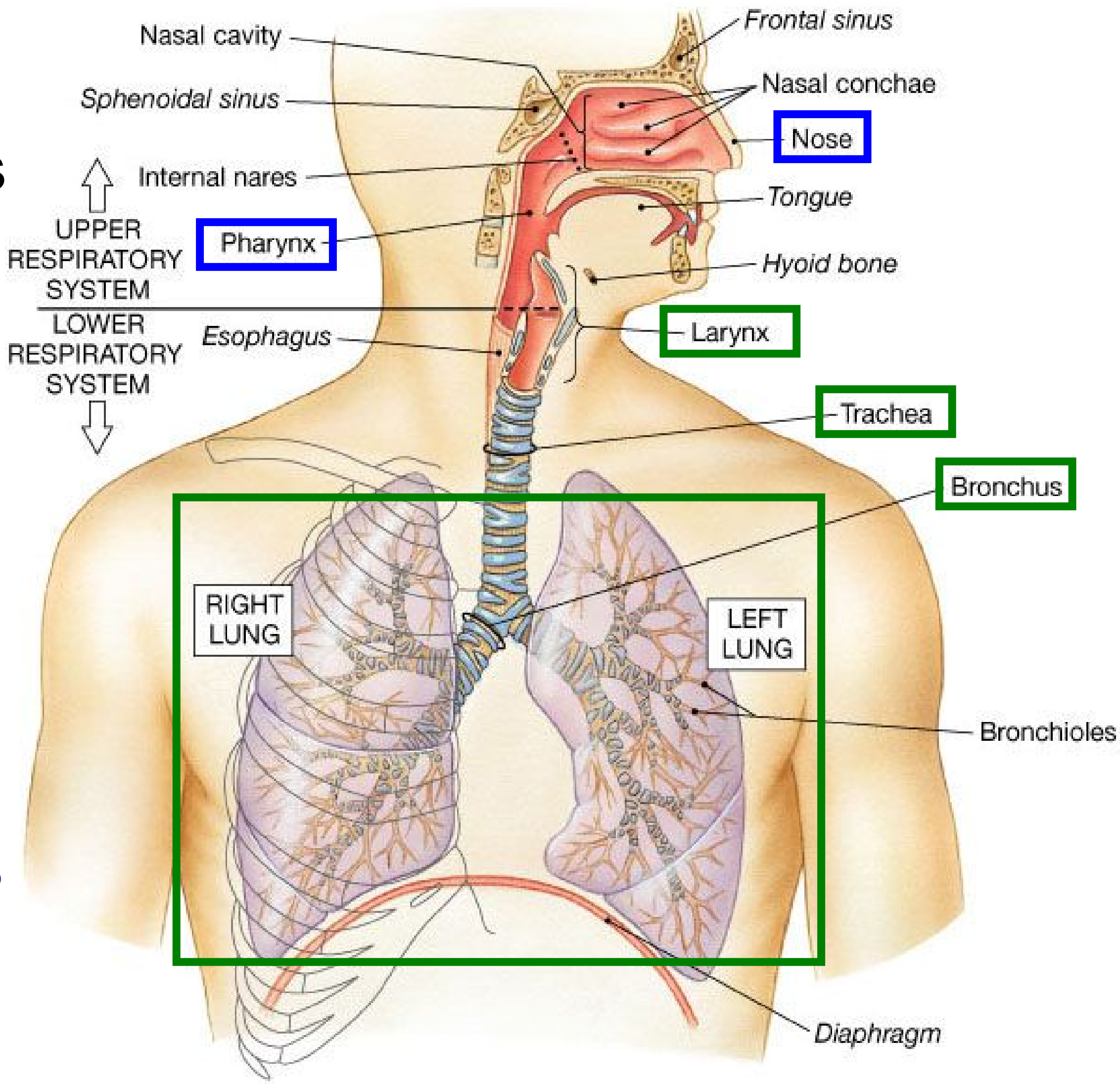
Respiratory System

Upper Tract

- Nose, pharynx & associated structures
- Filter & humidify incoming air

Lower Tract

- Larynx, trachea, bronchi & lungs
- Include delicate conduction passages & gas exchange surfaces (alveoli)

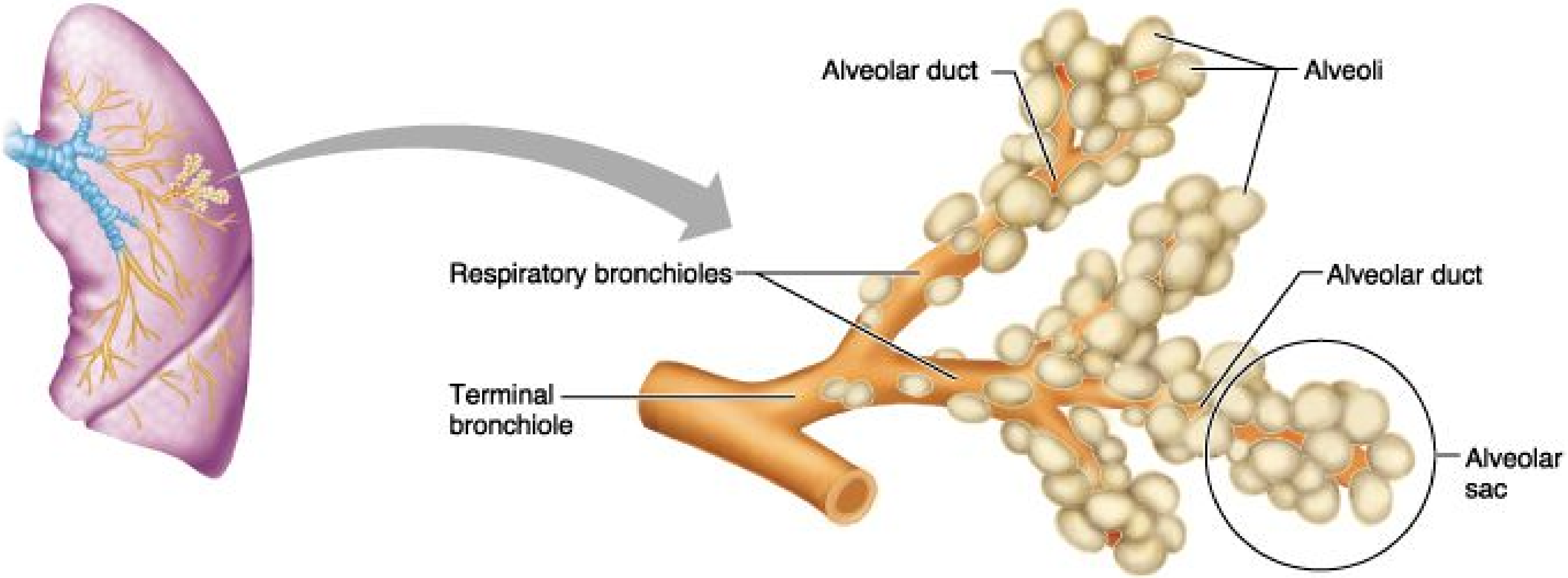


Respiratory System

Composed of respiratory & conducting zones

Respiratory zone

- Site of gas exchange
- Consists of bronchioles, alveolar ducts & alveoli



Respiratory System

Conducting zone

- Includes all other respiratory structures (e.g. nose, nasal cavity, pharynx, trachea)
- Provides rigid conduits for air to reach the sites of gas exchange

Respiratory muscles

- Diaphragm & other muscles that promote ventilation

Processes in Respiration

To supply the body with oxygen & dispose of carbon dioxide

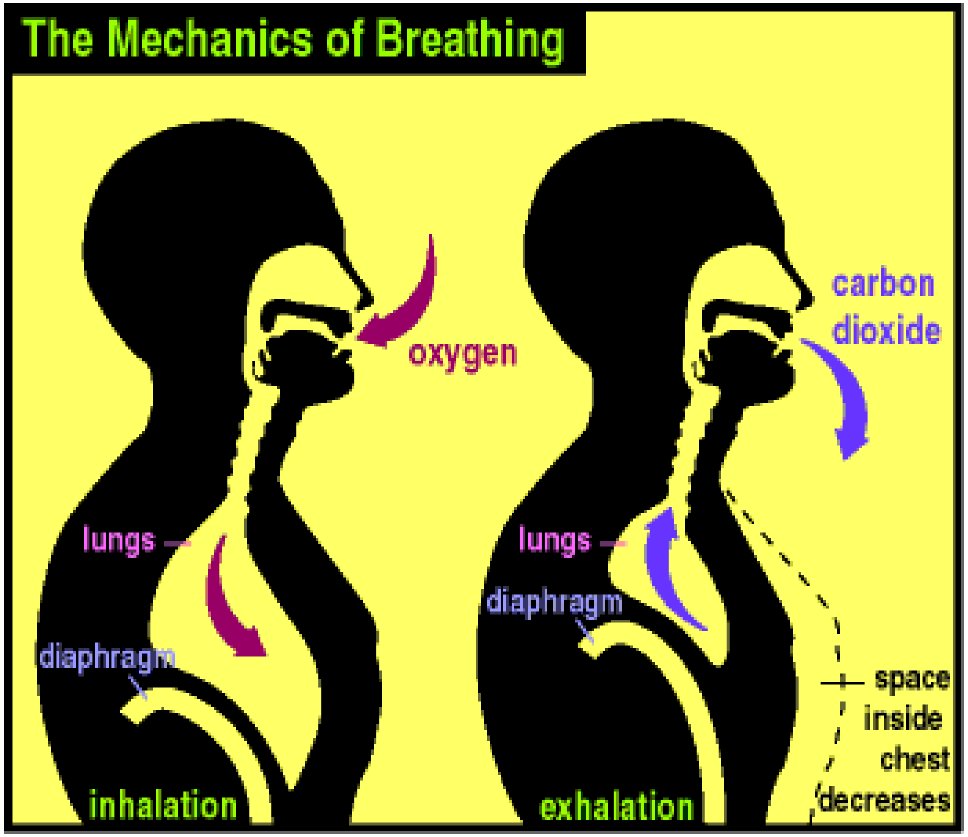
Respiration involves 4 distinct processes:

- **Pulmonary ventilation** – movement of air into & out of **lungs**
- **External respiration** – gas exchange between **lungs** & **blood**
- **Transport** – transport of O_2 & CO_2 between **lungs** & **tissues**
- **Internal respiration** – gas exchange between systemic **blood** vessels & **tissues**

Mechanics of Breathing

Pulmonary ventilation (breathing) consists of 2 phases:

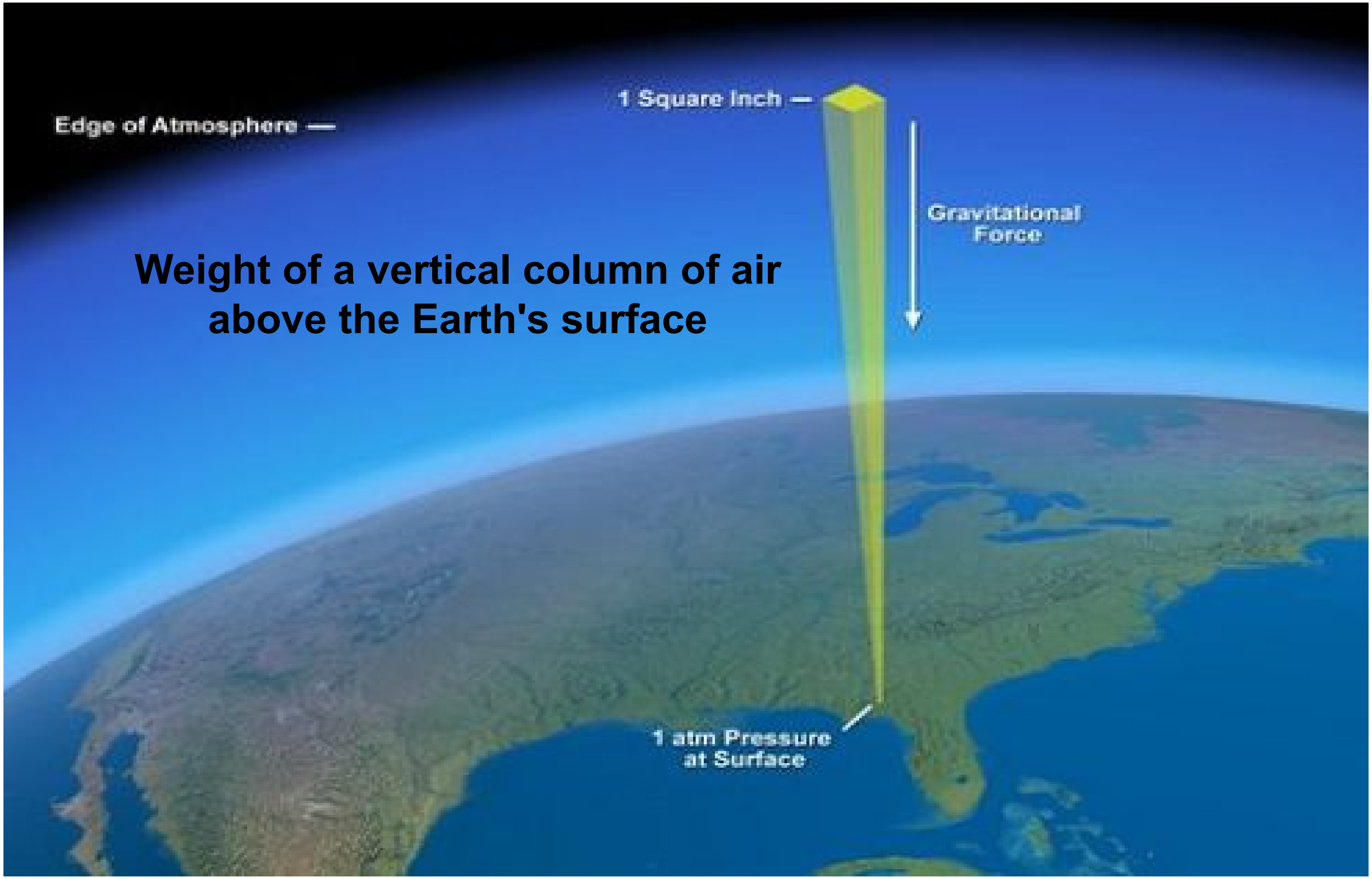
- Inspiration (inhalation) – air flows into the lungs
- Expiration (exhalation) – gases exit the lungs



Basic Atmospheric Conditions

Atmospheric pressure:

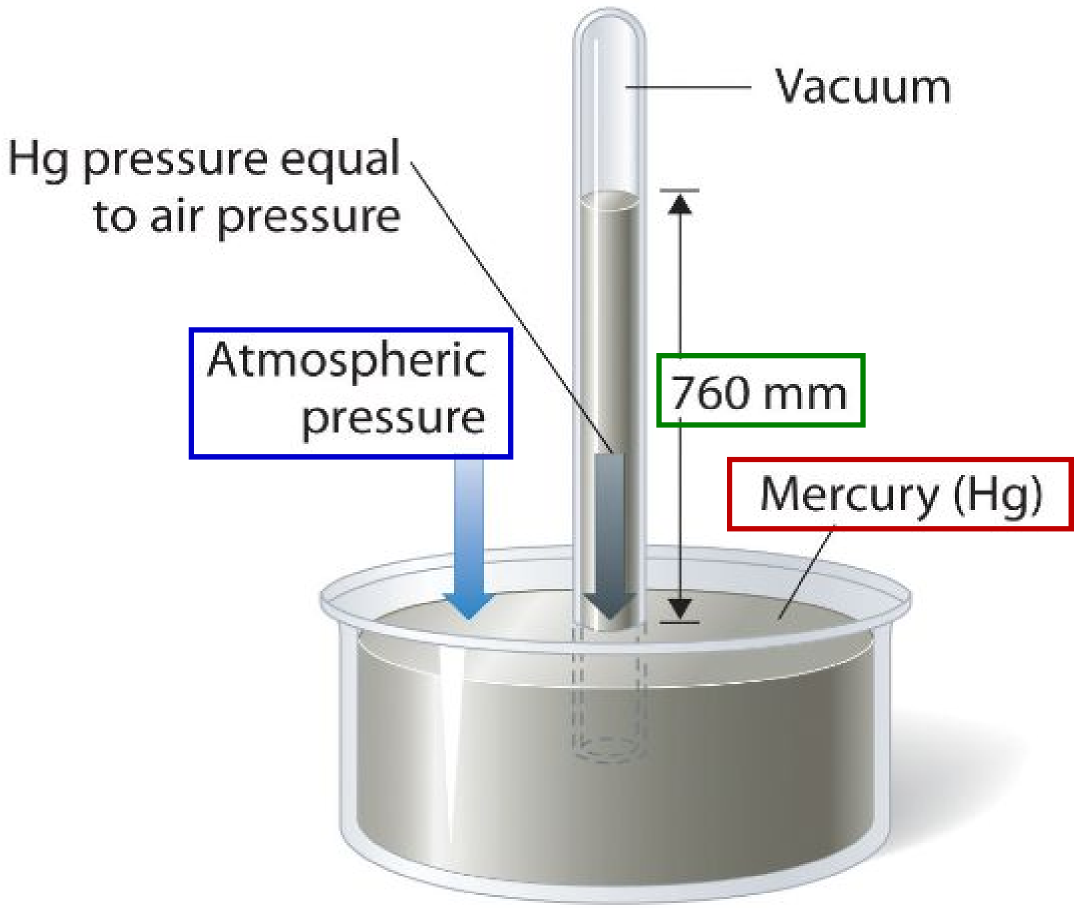
Pressure exerted by the weight of air in the atmosphere of Earth



Basic Atmospheric Conditions

Atmospheric pressure: 760 mmHg

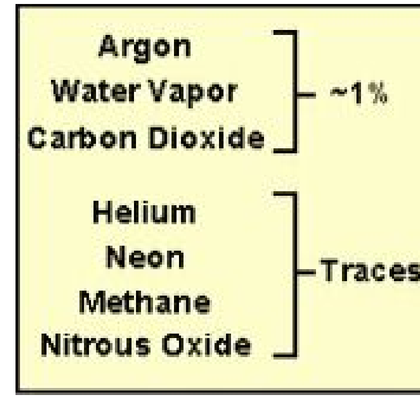
(1 mmHg = Pressure generated by a column of mercury one millimetre high)

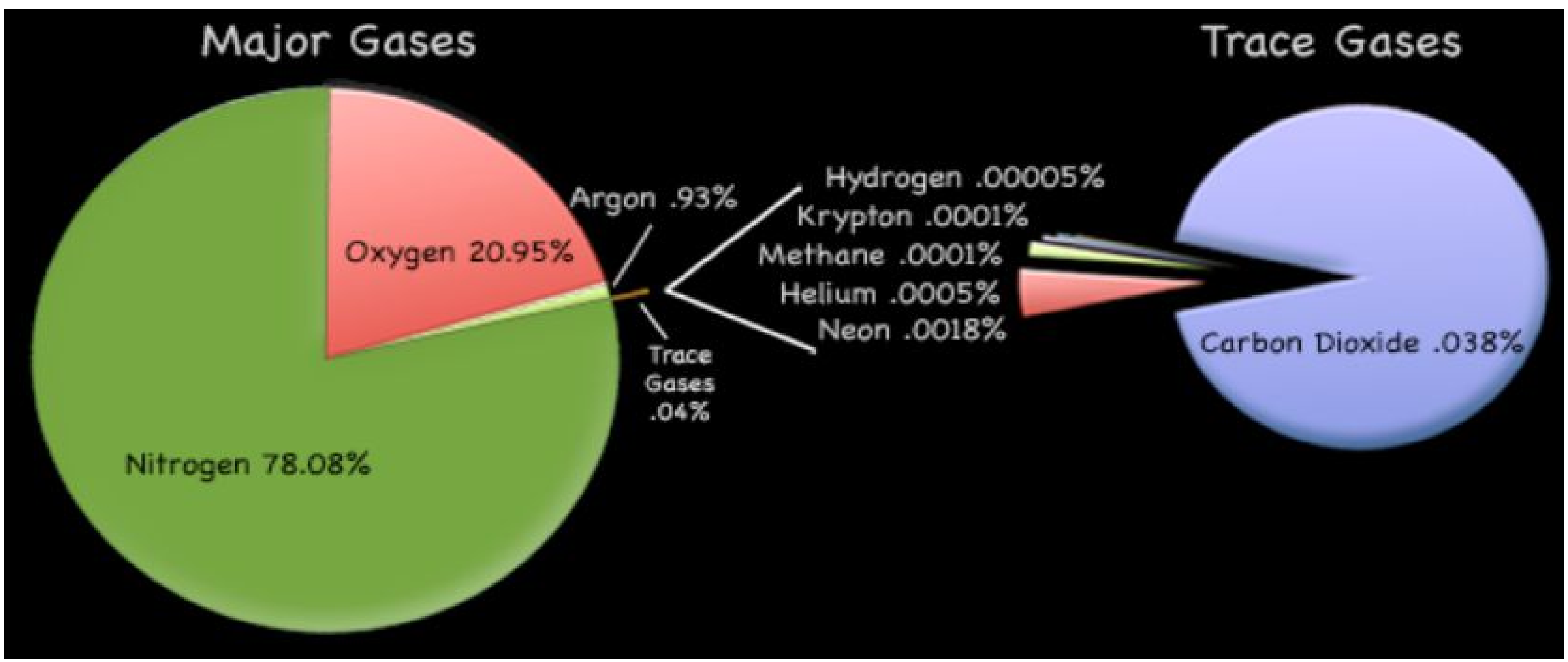


Basic Atmospheric Conditions

Composition of the atmosphere

- **Nitrogen = 78%**
- **Oxygen = 21%**
- **Argon = 0.93%**
- **Carbon dioxide = 0.038%**
- **Water vapor, Neon, Helium, Methane, Krypton etc.**





Gas Laws

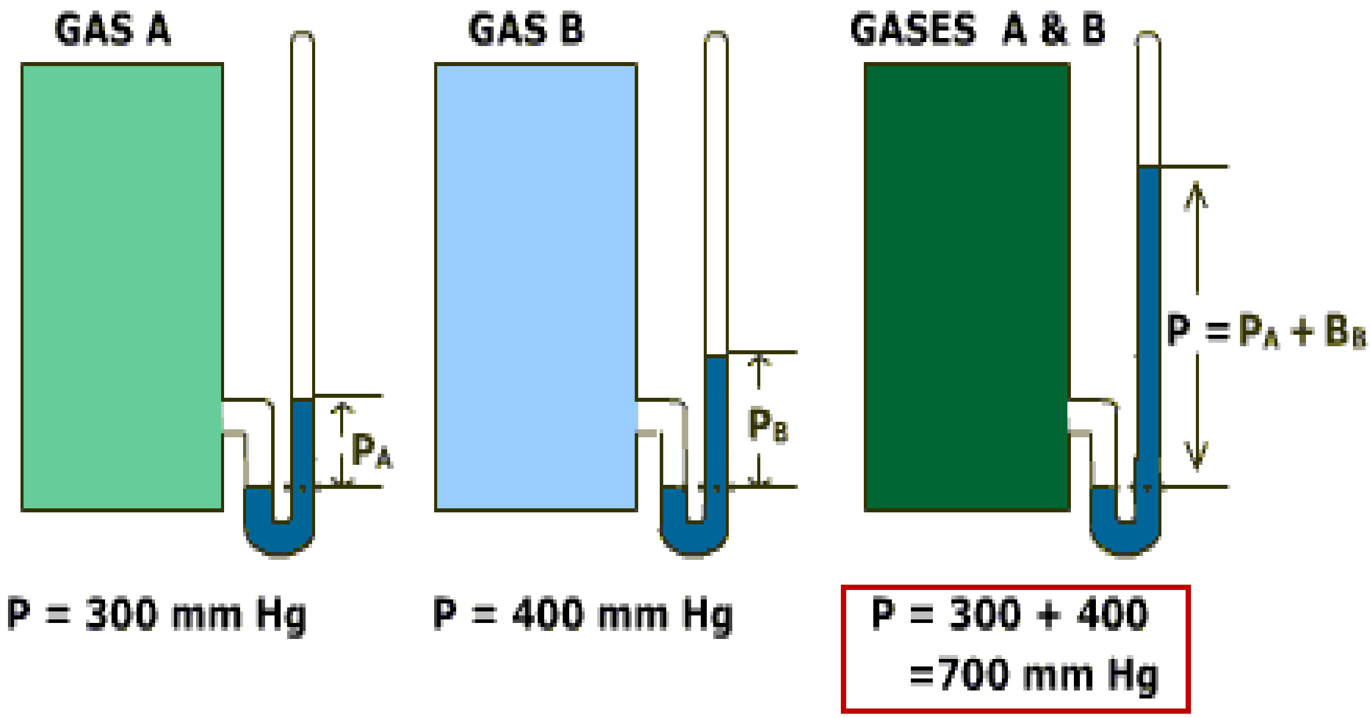
- Dalton's Law
- Fick's Laws of Diffusion
- Boyle's Law
- Ideal Gas Law

These physical laws help explain how air is moved in & out of the body

1. Dalton's Law

Law of Partial Pressures:

The total pressure of a mixture of non-reacting gases is equal to the sum of the pressures of the individual gases



John Dalton
(1766 -1844)

1. Dalton's Law

If we know the total atmospheric pressure (760 mmHg) & the relative abundances of gases (% of gases), we can calculate individual gas effects:

P_{atm} x % of gas in atmosphere

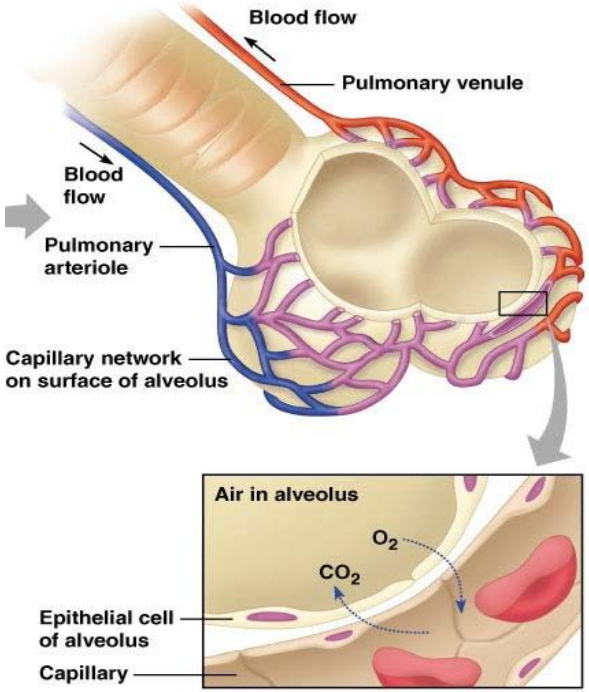
= Partial pressure of any atmospheric gas

e.g. P_{O_2} = 760 mmHg x 21%

= **160 mmHg**

2. Fick's Laws of Diffusion

- Factors that affect rates of diffusion
  - Concentration gradient
  - Distance to diffuse
  - Solubility of particles
  - Temperature



Solute moves from region of high concentration to low concentration
(at a rate which is directly proportional to the concentration gradient)

Adolf Eugen Fick
(1819 - 1901)

2. Fick's Laws of Diffusion

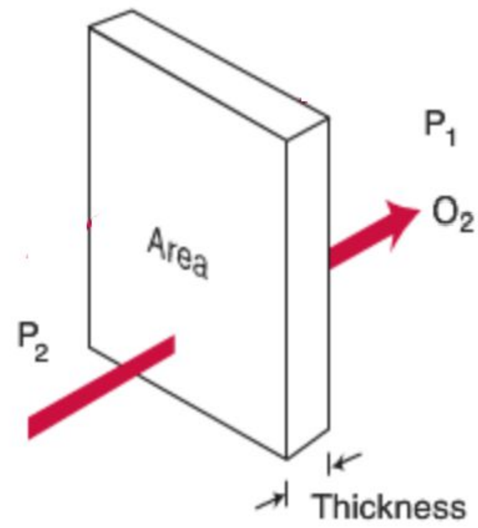
Diffusion constant (depends on solubility of gas and temperature)

Difference in partial pressure of gas on either side of barrier to diffuse

$$\text{Rate of diffusion} = k \times A \times \frac{(P_2 - P_1)}{D}$$

Area for gas exchange

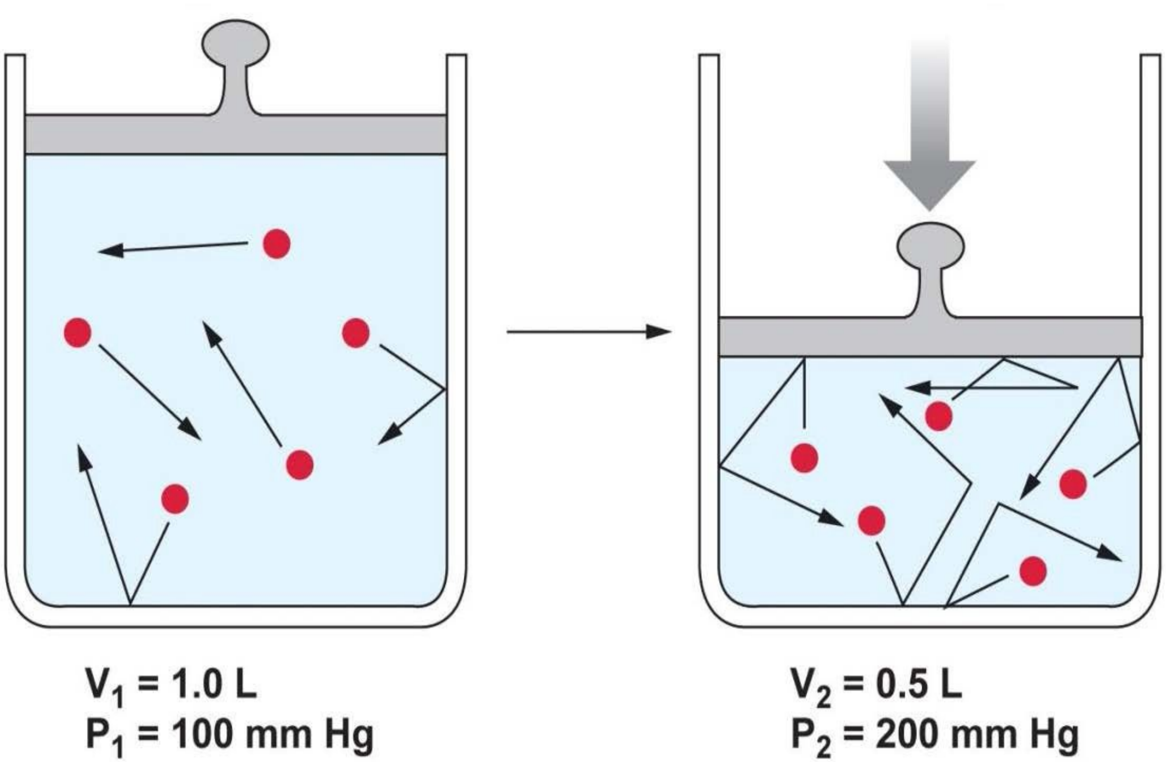
Distance (thickness of barrier to diffusion)



3. Boyle's Law

Pressure & volume of a gas in a system are inversely related

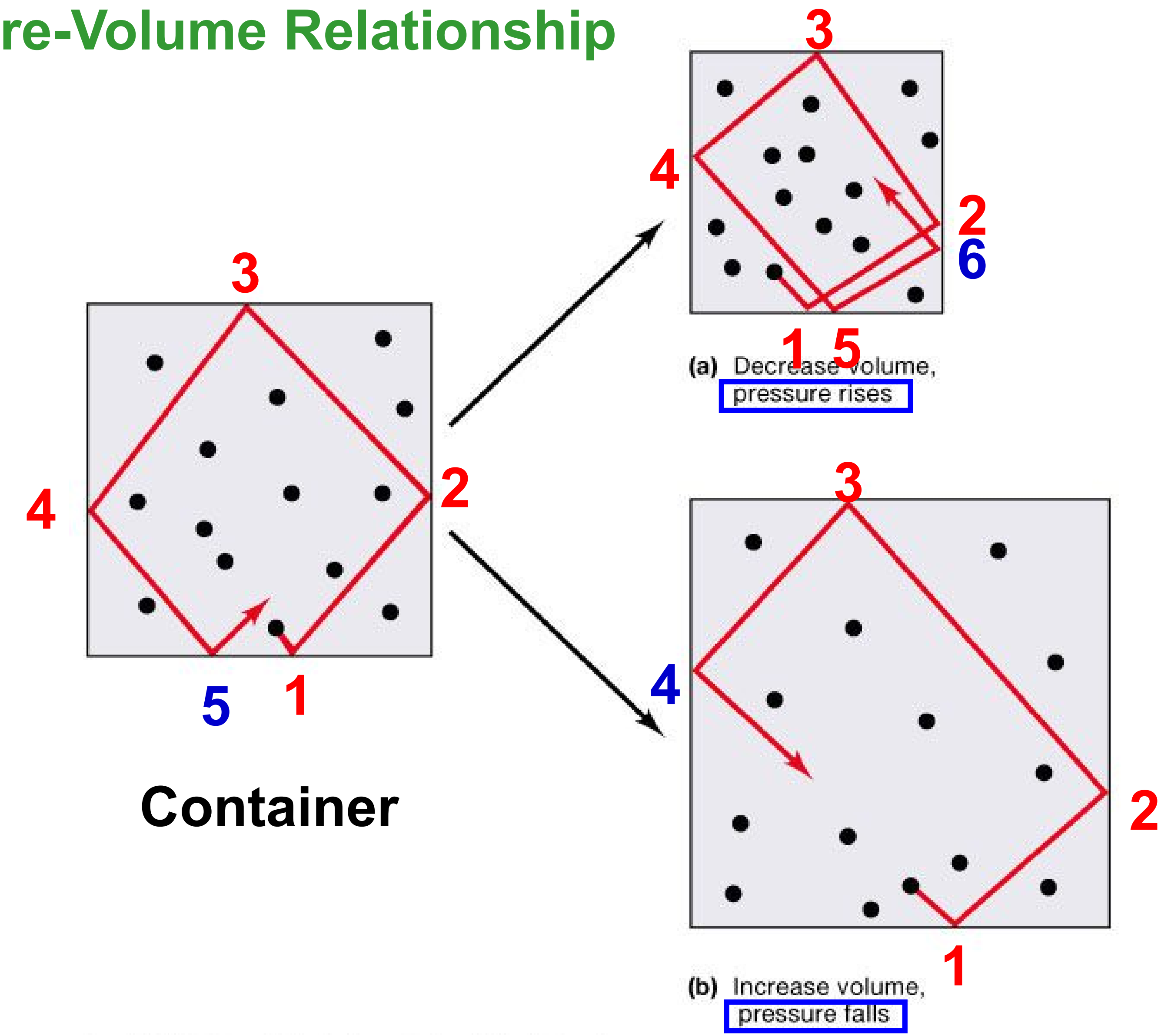
$P_1V_1 = P_2V_2$



Robert Boyle
(1627- 1691)

3. Boyle's Law

Pressure-Volume Relationship

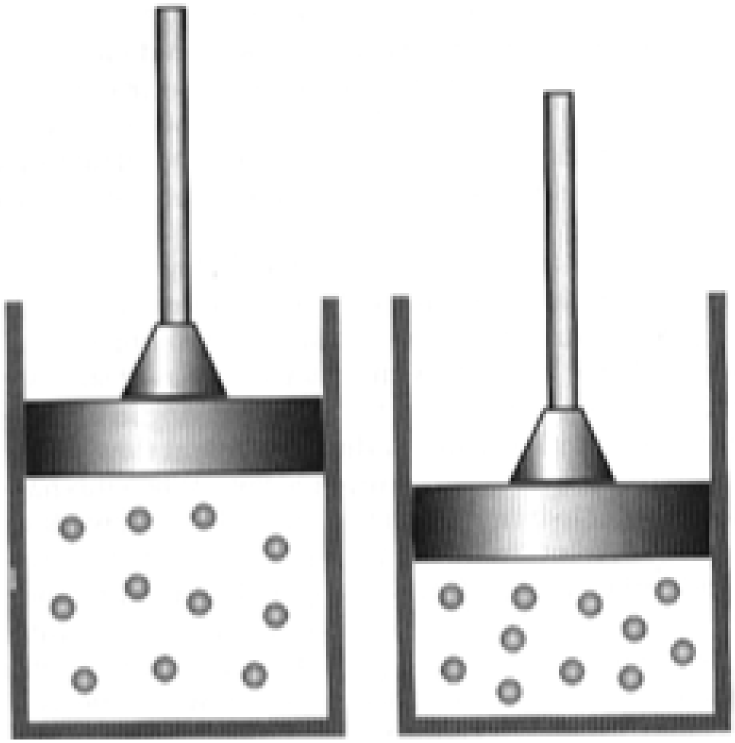


3. Boyle's Law

Physics of Breathing

Volume changes lead to pressure changes, which lead to the flow of gases to equalize pressure

$$\Delta V \rightarrow \Delta P \rightarrow U$$



3. Boyle's Law

In our body

Thoracic cavity (container) expands
→ Volume UP
→ Pressure DOWN

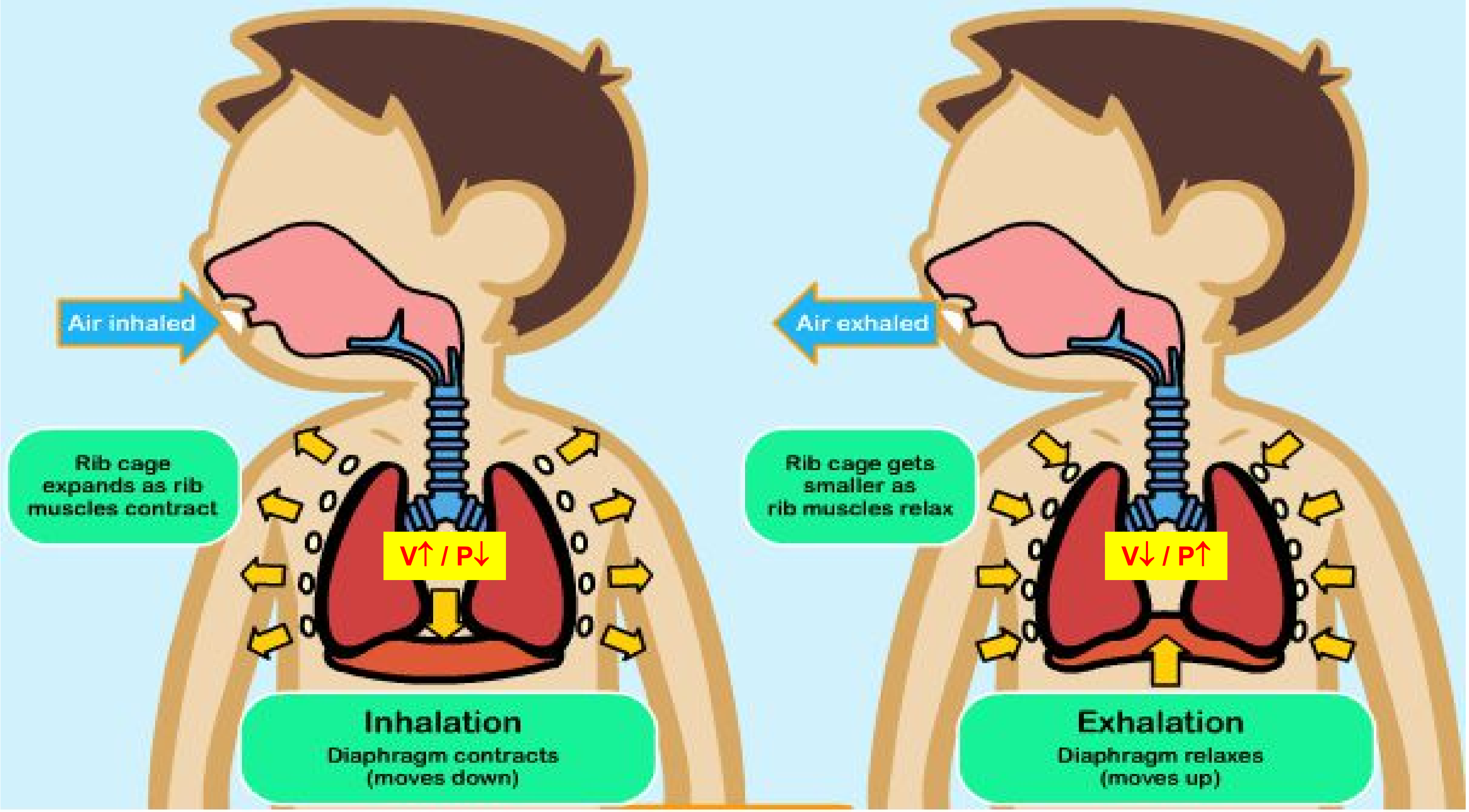
- If pressure <760 mmHg, what happens?

Thoracic cavity (container) shrinks
→ Volume DOWN
→ Pressure UP

- If pressure >760 mmHg, what happens?

Inspiration vs. Expiration

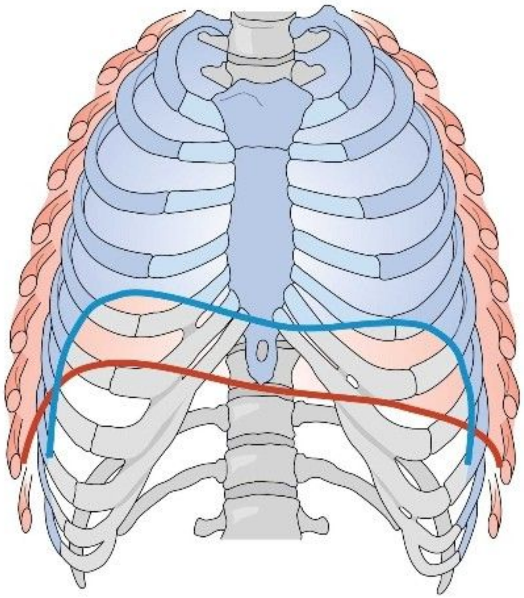
Inspiration	Expiration

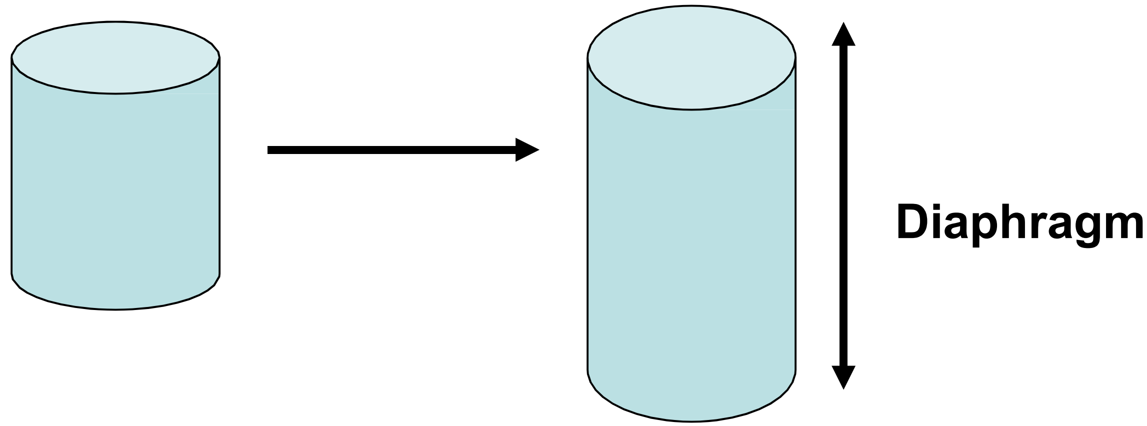


$P_{alv} < P_{atmos}$
→ air molecules flow into lungs

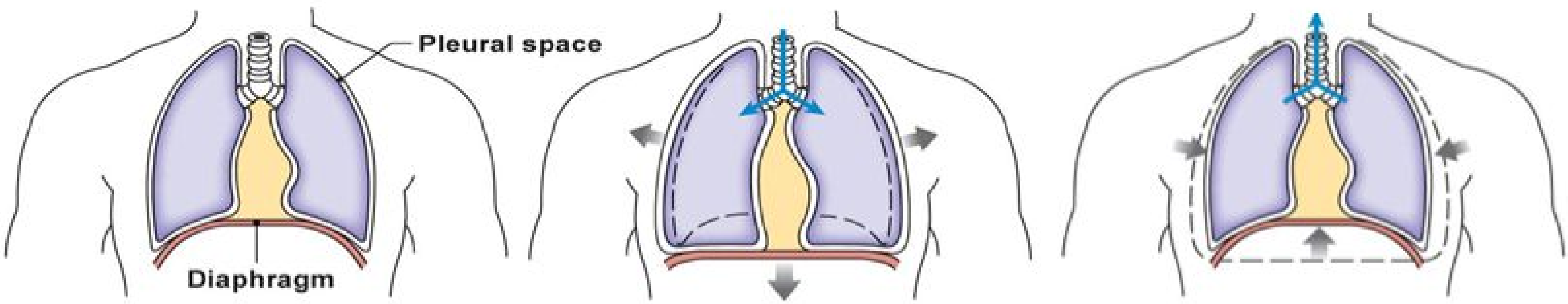
$P_{alv} > P_{atmos}$
→ air molecules flow out of lungs

Involvement of Diaphragm





Changing length of thoracic cavity

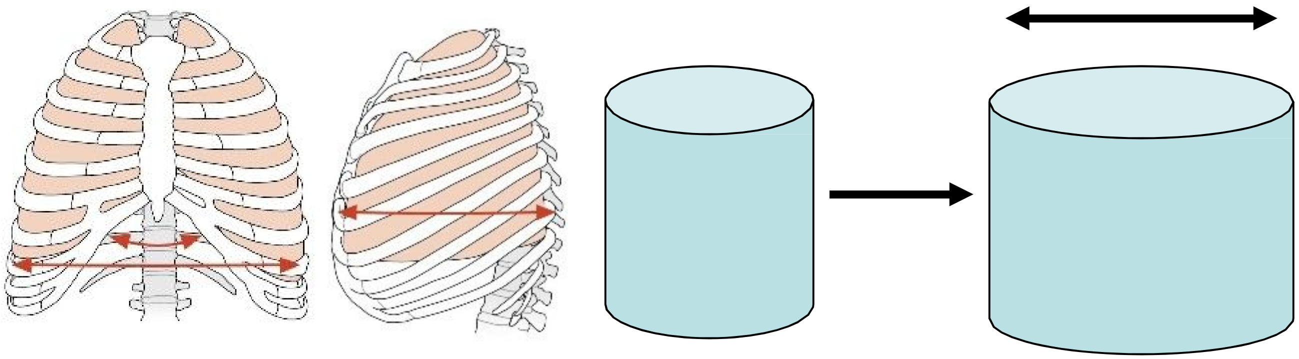


(a) At rest, diaphragm is relaxed.

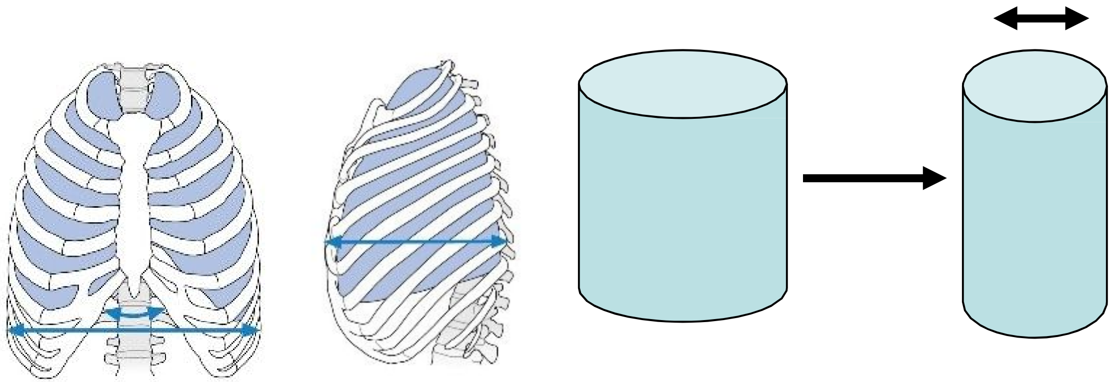
(b) Diaphragm contracts, thoracic volume increases.

(c) Diaphragm relaxes, thoracic volume decreases.

Involvement of Rib Cage



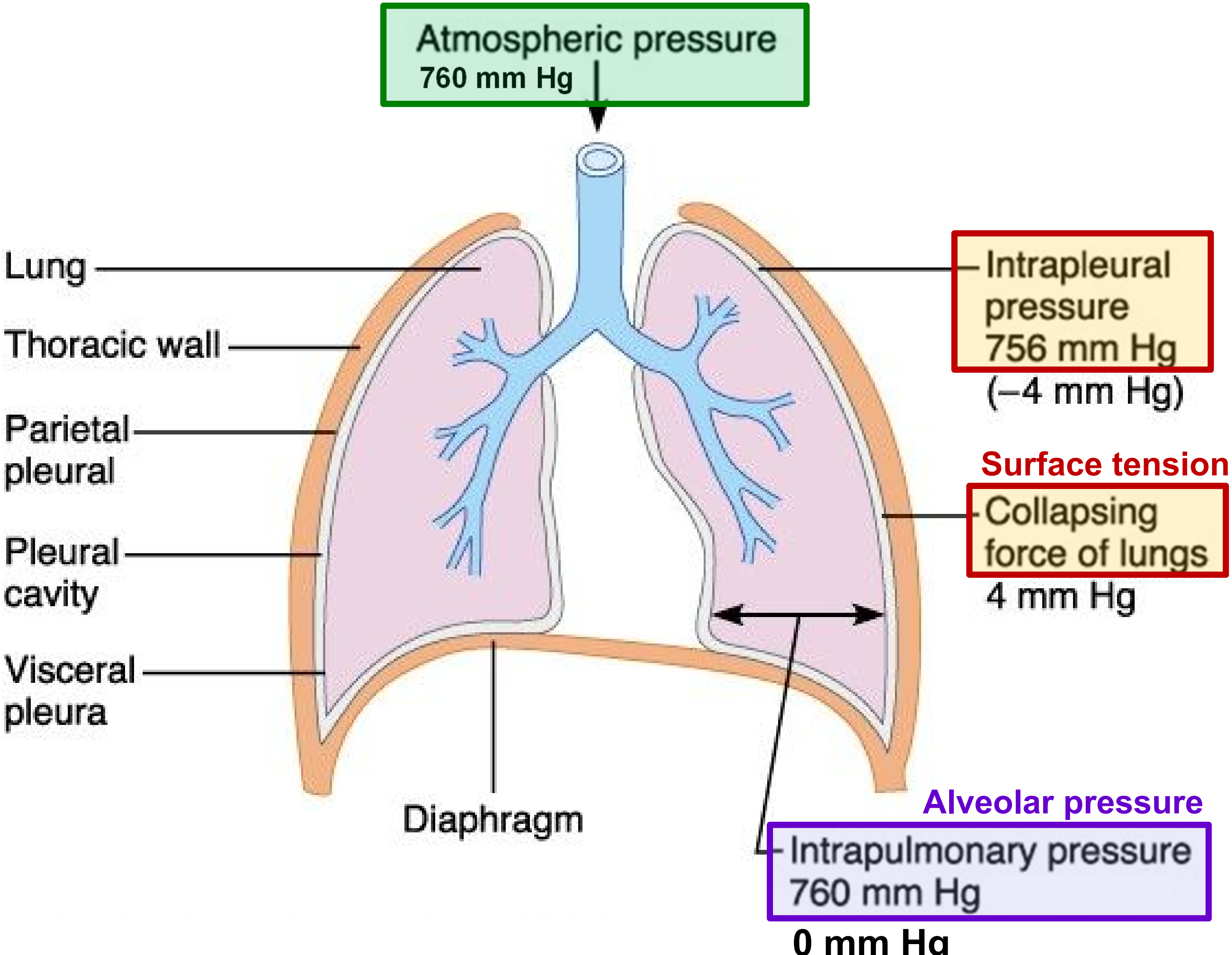
Rib cage elevation



Rib cage lowering

Changing circumference of thoracic cavity

Pressure Relationships in the Thoracic Cavity



Pressure Relationships in the Thoracic Cavity

Respiratory pressure is always described **relative to atmospheric pressure**

- Atmospheric pressure (P_{atm}):
  - Pressure exerted by the air surrounding the body

- Intrapulmonary pressure (P_{alv}):
  - Pressure within the alveoli

Always equalizes itself with atmospheric pressure eventually

- Intrapleural pressure (P_{ip}):
  - Pressure within the pleural cavity

Pressure Relationships in the Thoracic Cavity

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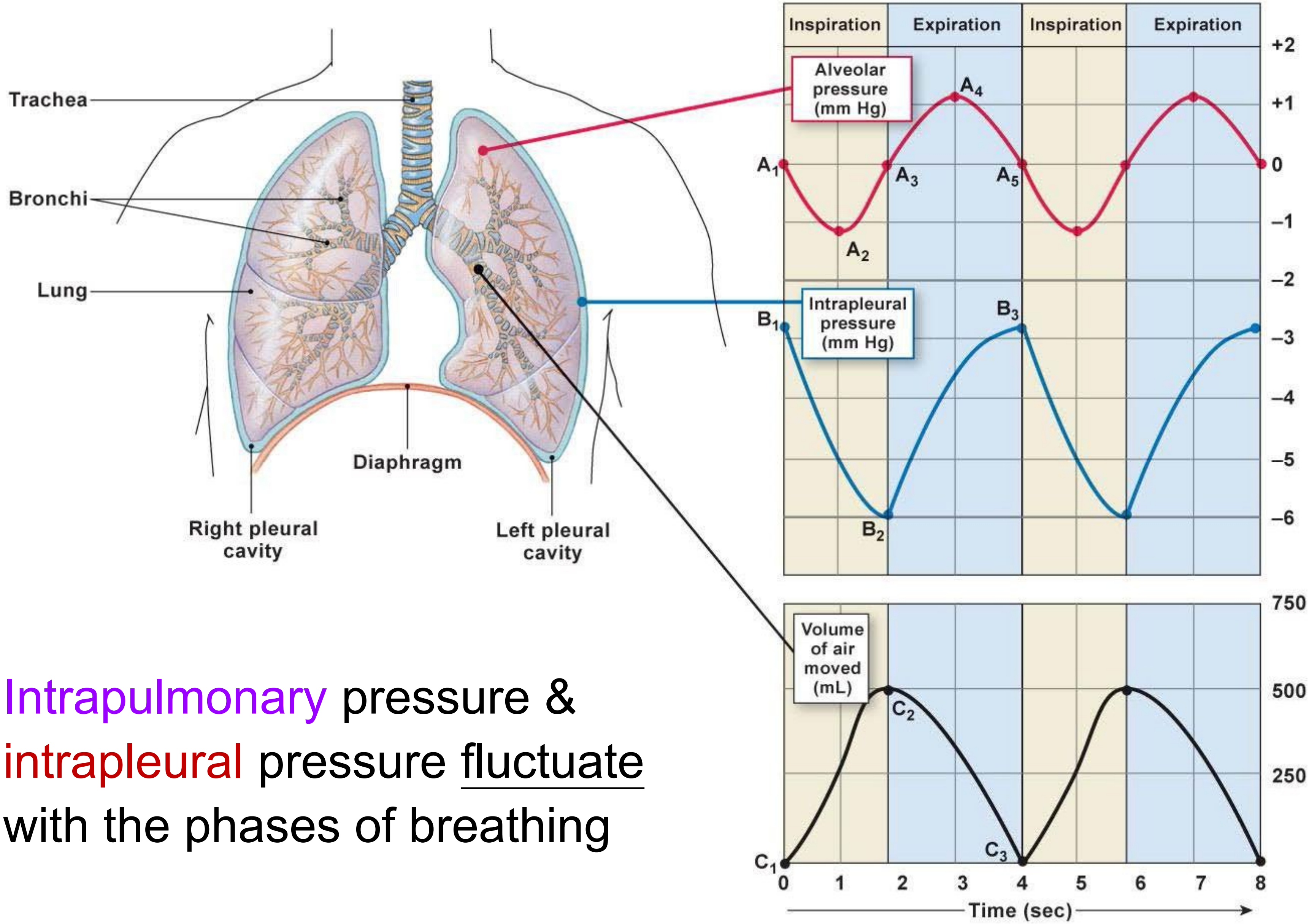
>

- Intrapleural pressure (P_{ip}):
  - Pressure within the pleural cavity

Always higher than intrapleural pressure

Pressure Relationships in the Thoracic Cavity

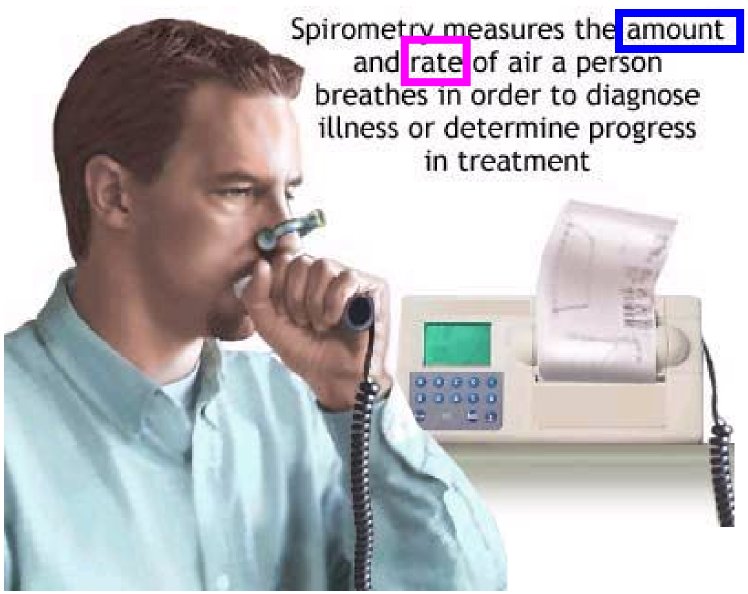


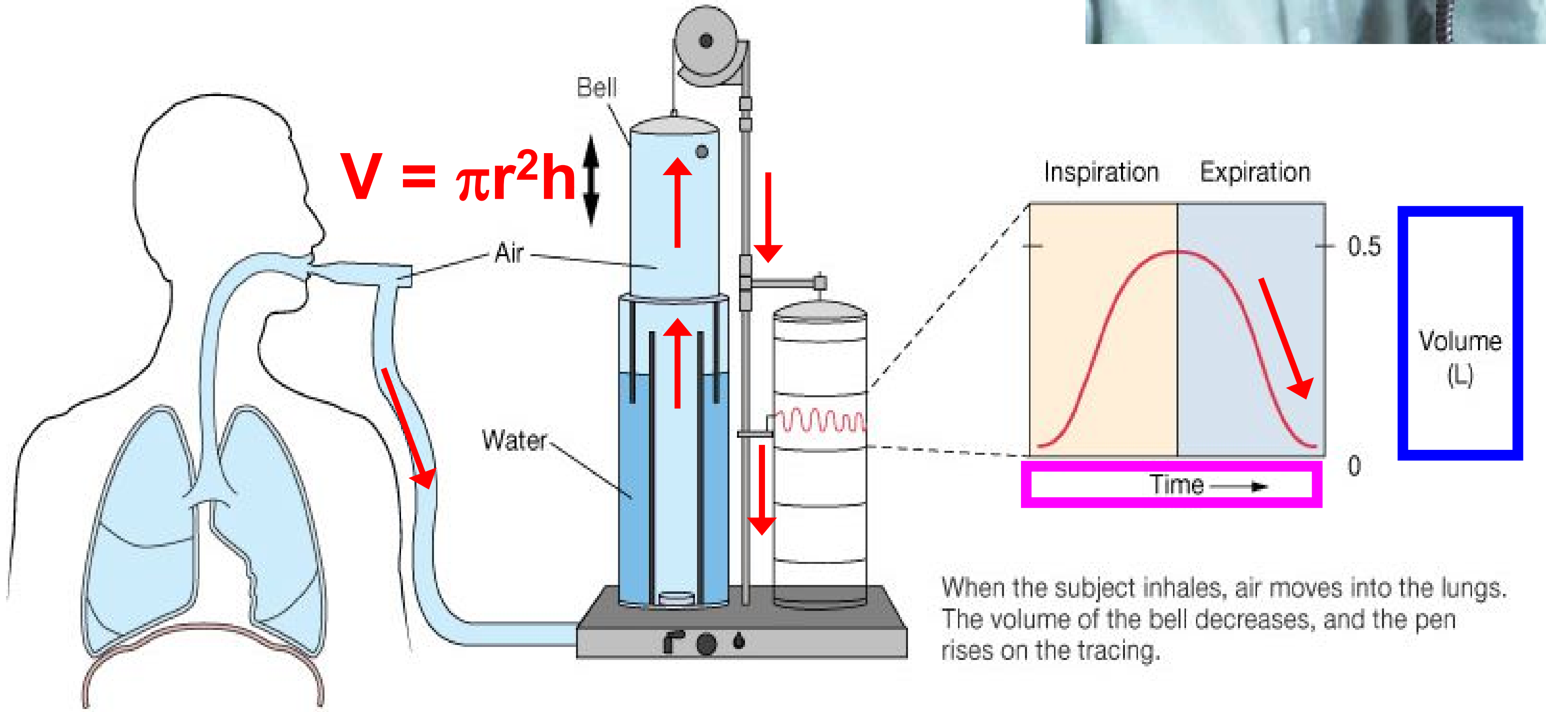
Intrapulmonary pressure & intrapleural pressure fluctuate with the phases of breathing

Pulmonary Function Test

Spirometer: an instrument to measure the volume & rate of air inspired & expired by the lungs

- A hollow bell is inverted over water
- Bell is displaced as **patient breathes** into a connecting mouthpiece
- A graph is plotted on a rotating drum





When the subject inhales, air moves into the lungs. The volume of the bell decreases, and the pen rises on the tracing.

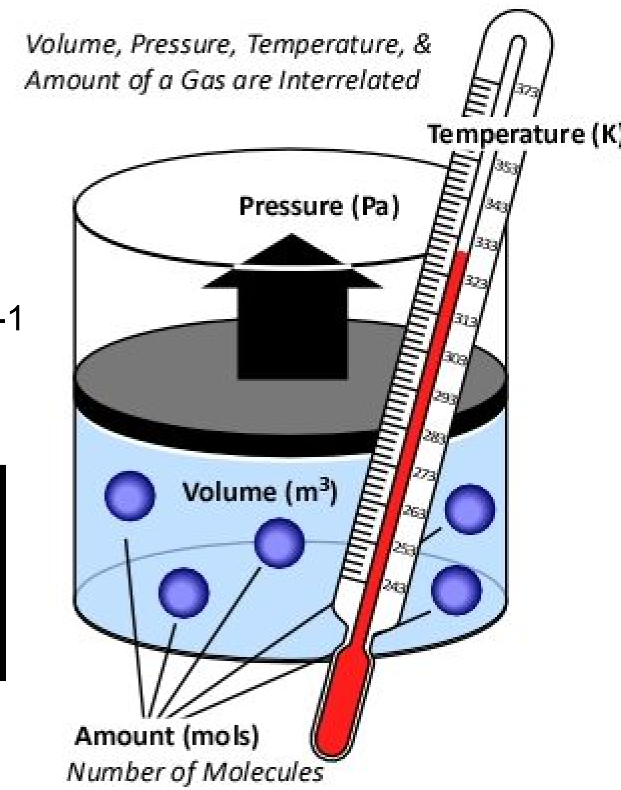
4. Ideal Gas Law

Pressure & volume of a container of gas is directly related to the temperature of the gas & number of molecules in the container:

$PV = nRT$

- n = No. of moles of gas molecules
- T = Absolute temperature
- R = Universal gas constant = 8.3145 J $K^{-1}mol^{-1}$

$$P = \frac{nRT}{V} \qquad V = \frac{nRT}{P} \qquad n = \frac{PV}{RT} \qquad T = \frac{PV}{nR} \qquad R = \frac{nT}{PV}$$



Key Points

Respiratory System

- Upper & lower tracts
- Respiratory & conducting zones

Mechanics of Breathing

- Inspiration & expiration

Basic Atmospheric Conditions

Dalton's Law

- Total pressure of a mixture of gases = sum of the pressures of individual gases

Fick's Laws of Diffusion

- Solute moves from region of high concentration to low concentration

Boyle's Law

- $P_1V_1 = P_2V_2$
- Breathing: Movement of diaphragm & rib → change in volume of thoracic cavity (ΔV) → ΔP → U

Pressure relationships in the thoracic cavity

- Atmospheric pressure (P_{atm}), intrapulmonary pressure (P_{alv}), intrapleural pressure (P_{ip})

Pulmonary function test : Spirometer

Ideal Gas Law

- $PV = nRT$