RESPIRATORY PHYSIOLOGY

M. F. Din

Respiration

- All those processes that maintain the normal levels of oxygen and carbon dioxide in the body

- Internal (Cellular) respiration
  - This is the oxidation of substrate to release energy (and CO2)
- 'External respiration'
  - This is the absorption of oxygen and the removel of carbondioxide from the body

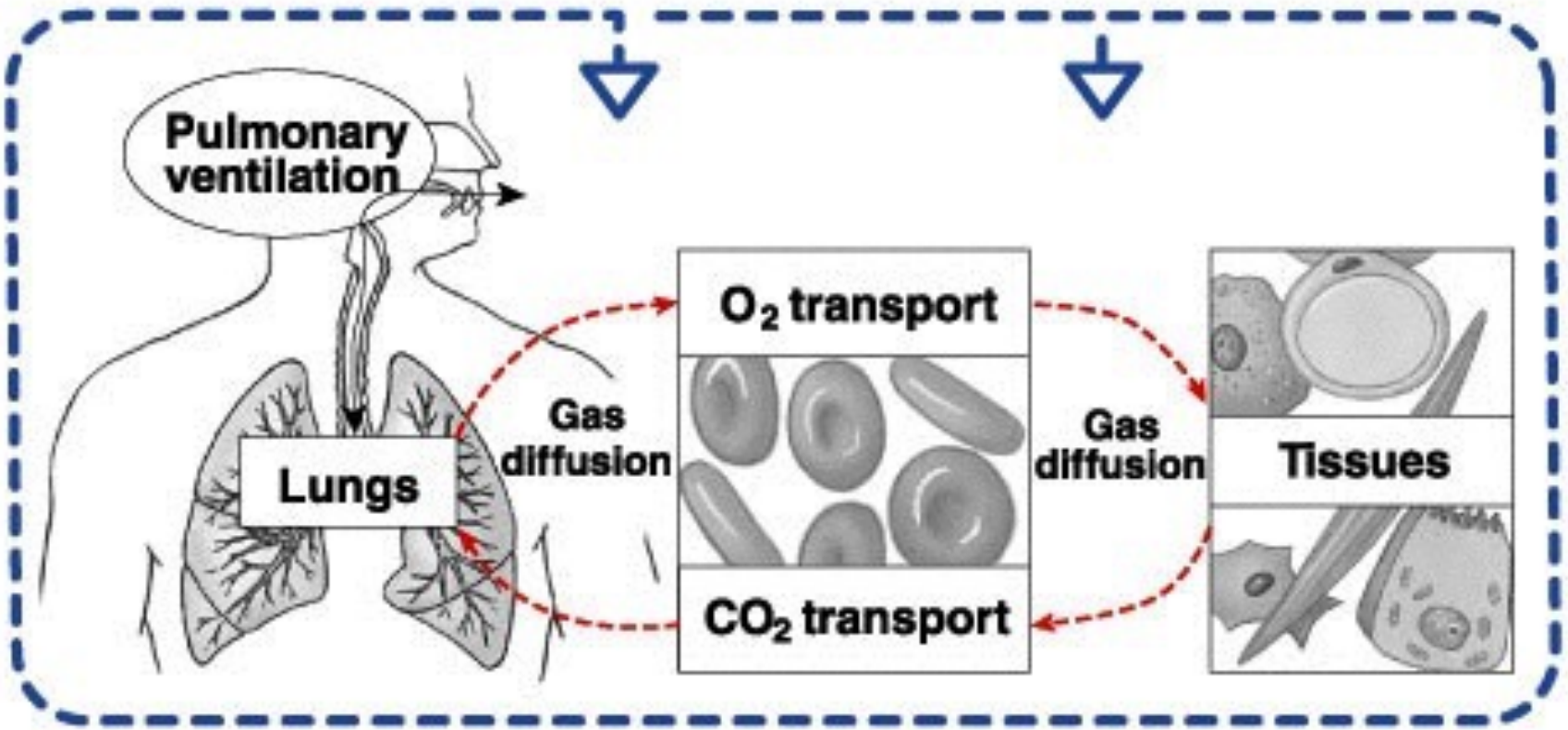
Aim of respiration

- To maintain
  - Pa O_2
  - Pa CO_2
  - pH

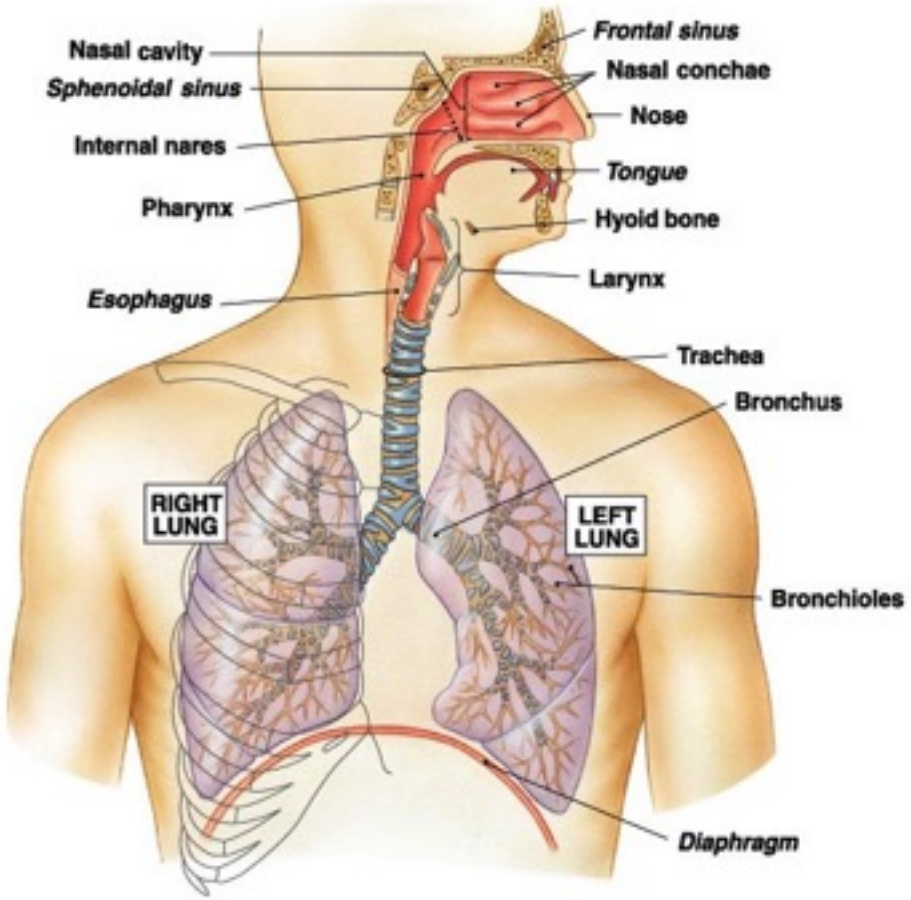
Steps of respiration

- Ventilation
- Diffusion
- Gas transport
- Tissue gas exchange

Control of all the above

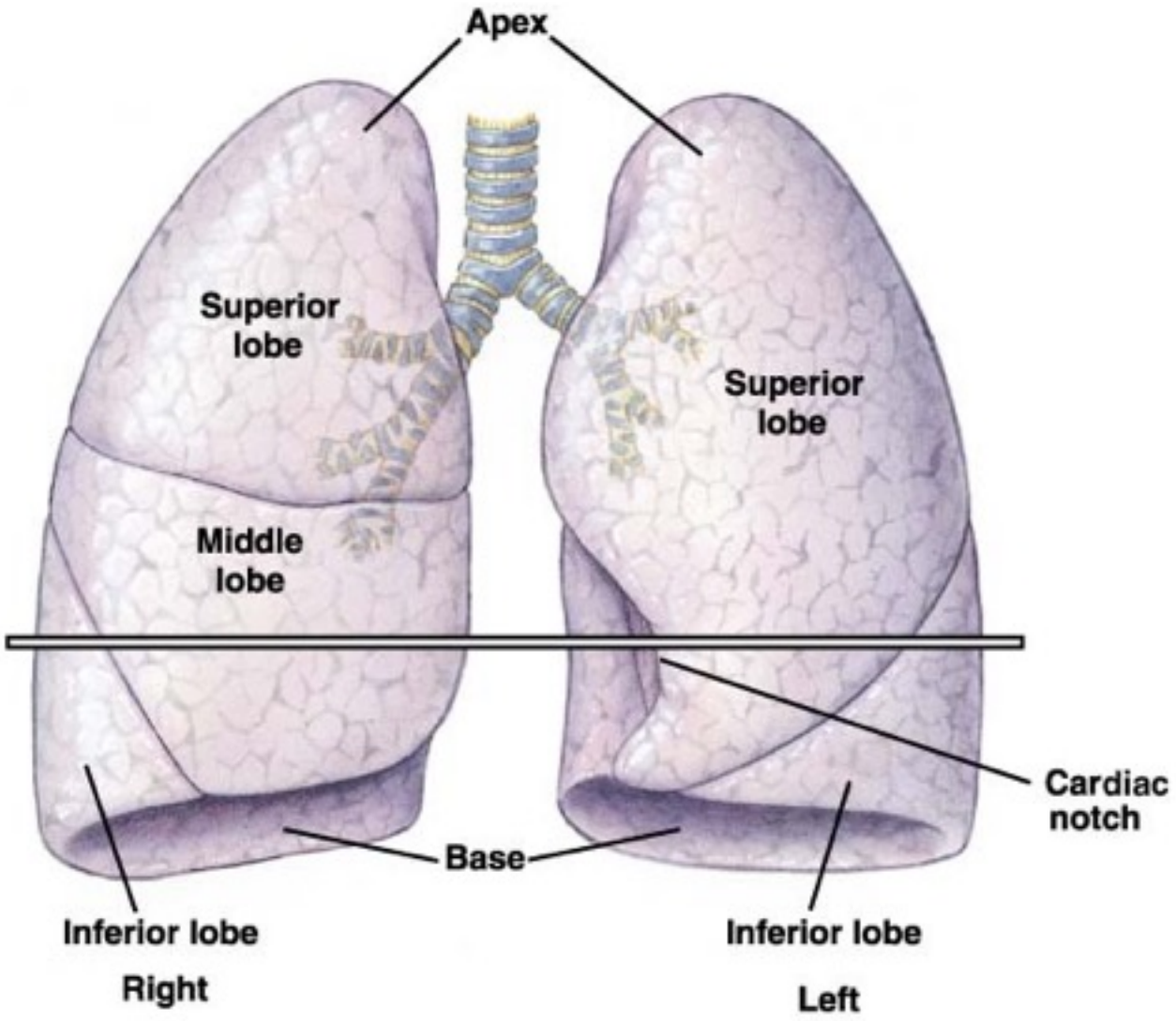

Pulmonary ventilation
Lungs
Gas diffusion
O_2 transport
CO_2 transport
Gas diffusion
Tissues

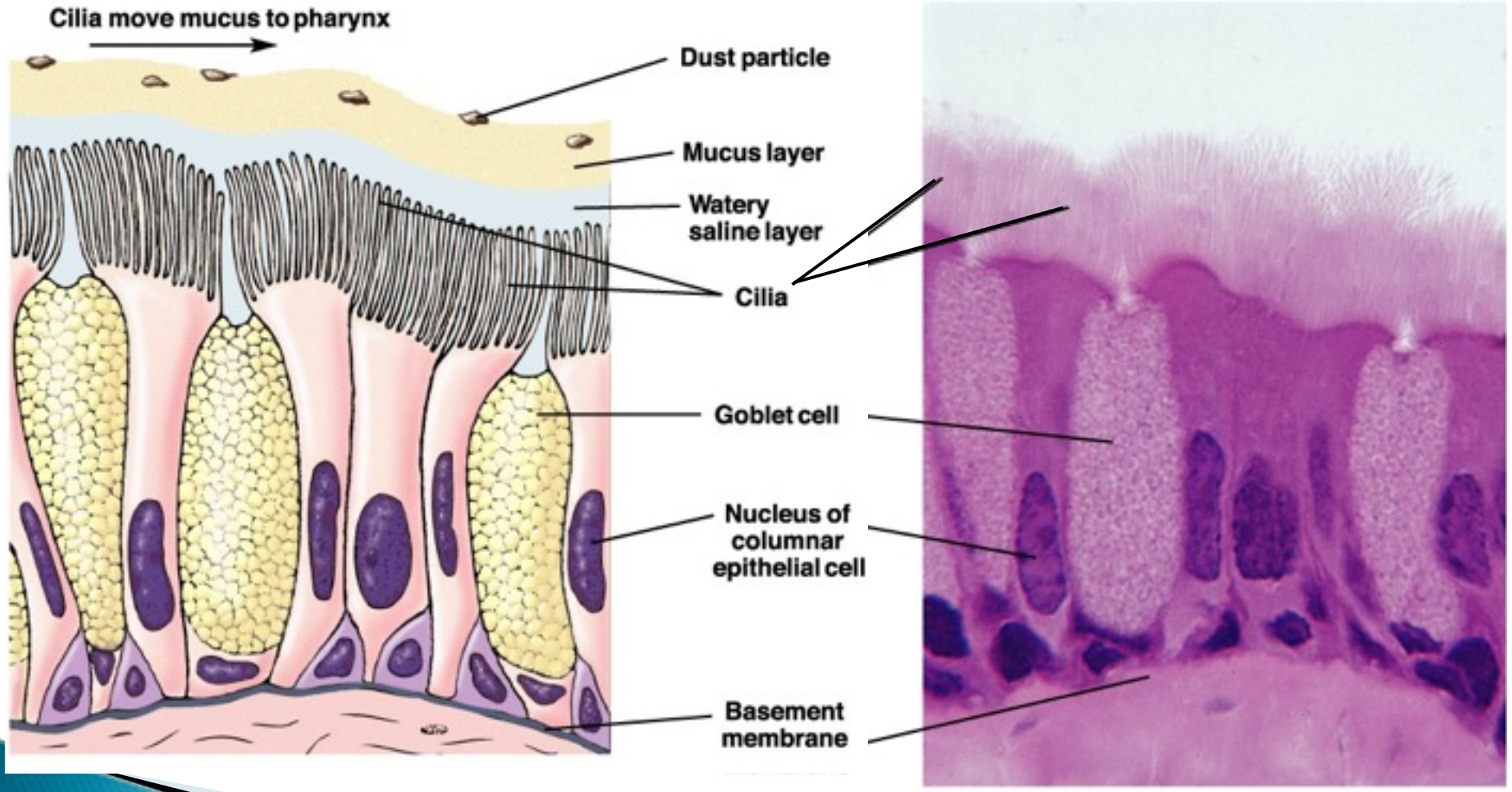
Respiratory System Divisions

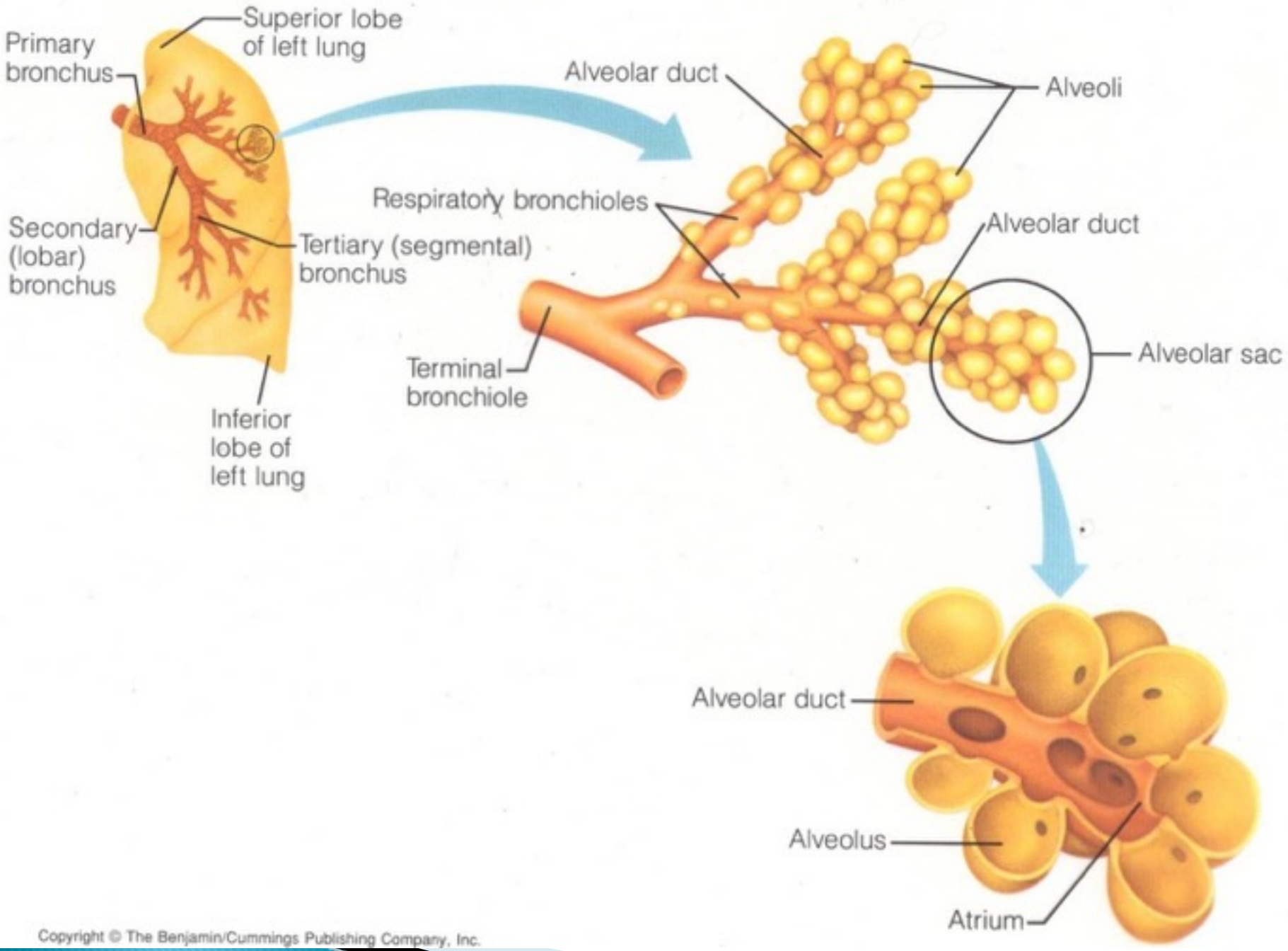


- Upper tract
  - Nose, pharynx and larynx
- Lower tract
  - Trachea, bronchi, lungs

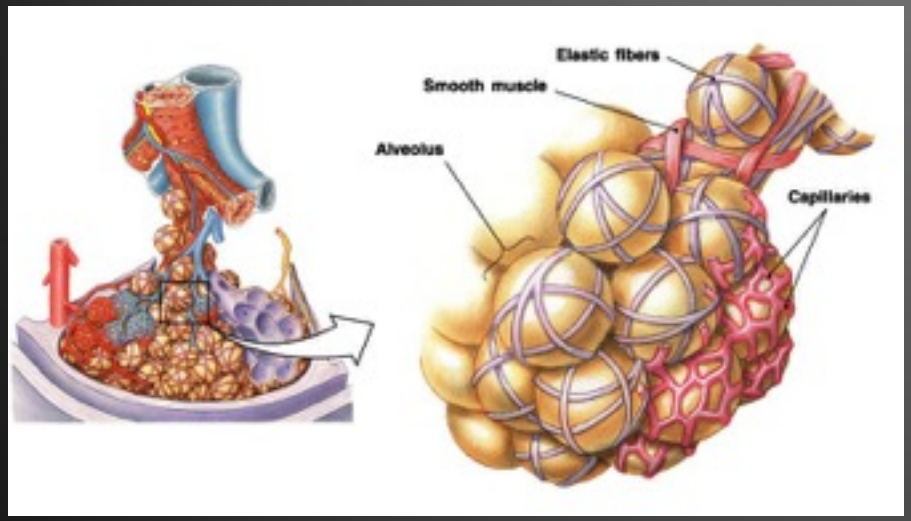
(c) External anatomy of lungs
Externally, the right lung is divided into three lobes and the left lung into two.

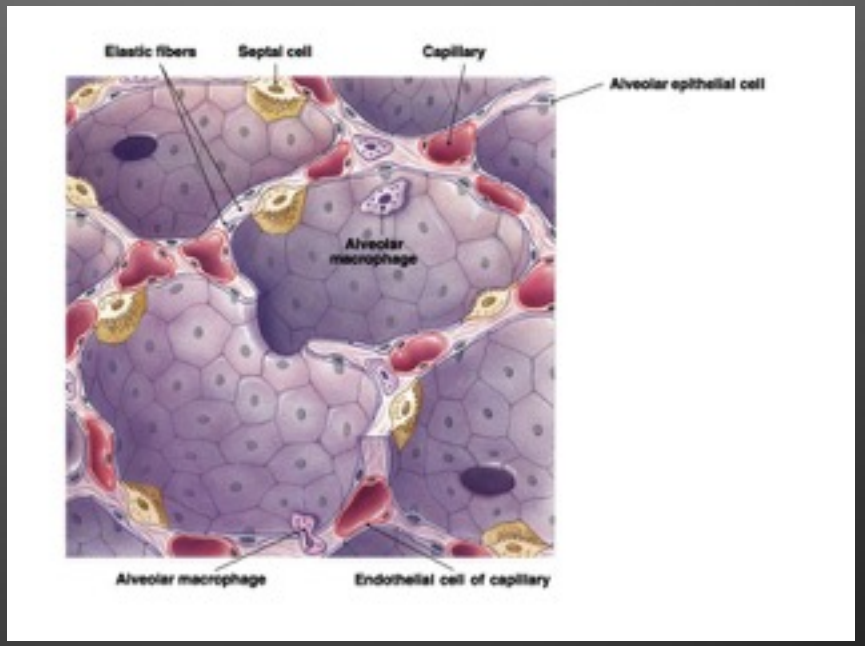



Cilia move mucus to pharynx
Dust particle
Mucus layer
Watery saline layer
Cilia
Goblet cell
Nucleus of columnar epithelial cell
Basement membrane



Alveolus and Respiratory Membrane





300 million alveoli

0.33mm diameter

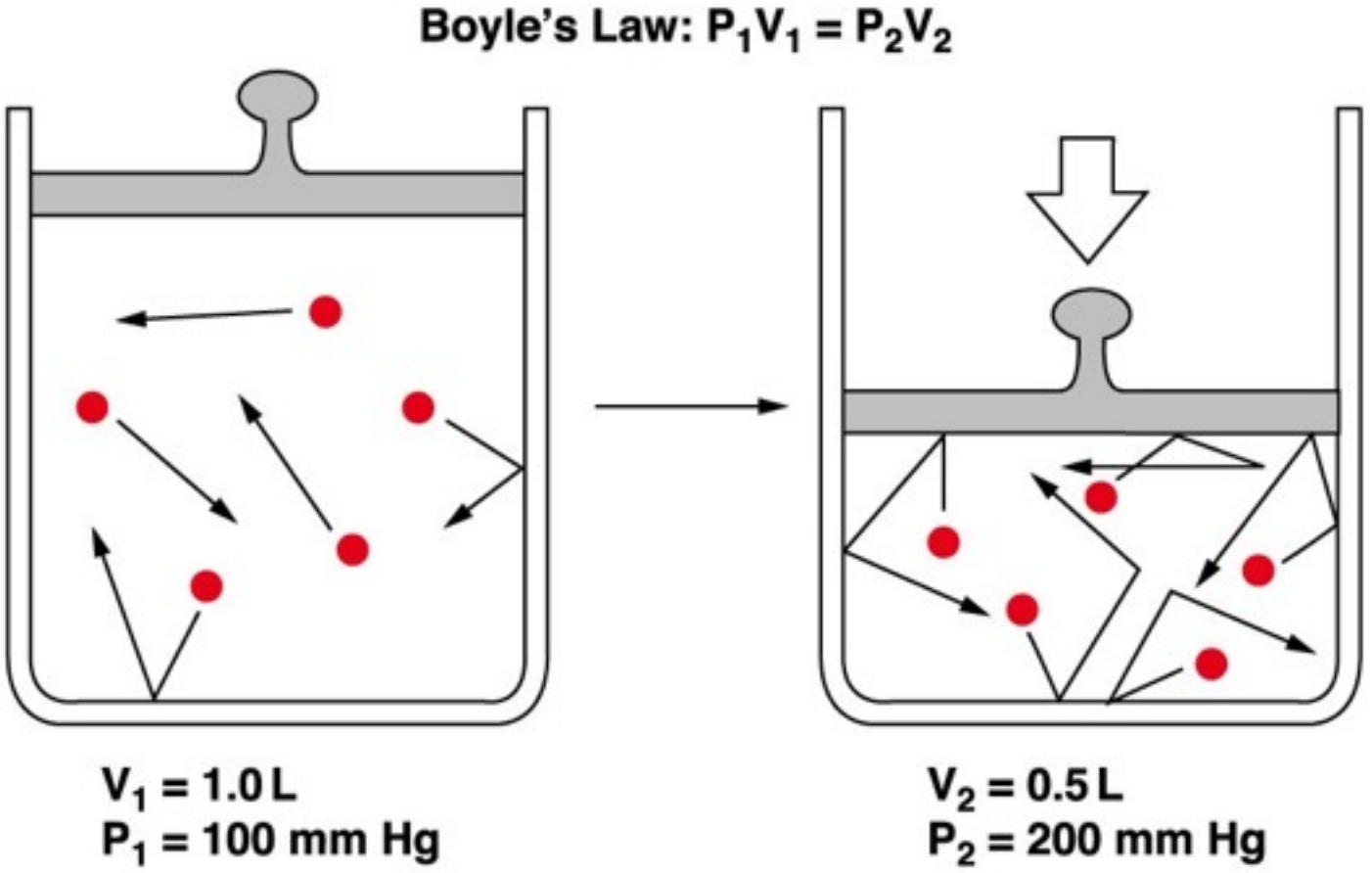
0.5 micron thickness

Large surface area- 70m^2

Basic physics of gases

PHYSICAL PRINCIPLES OF GAS EXCHANGE
Properties of GASES

Boyle's Law: Presssure ∝ 1/V



Partial Pressure = pressure exerted by any one gas in a mixture

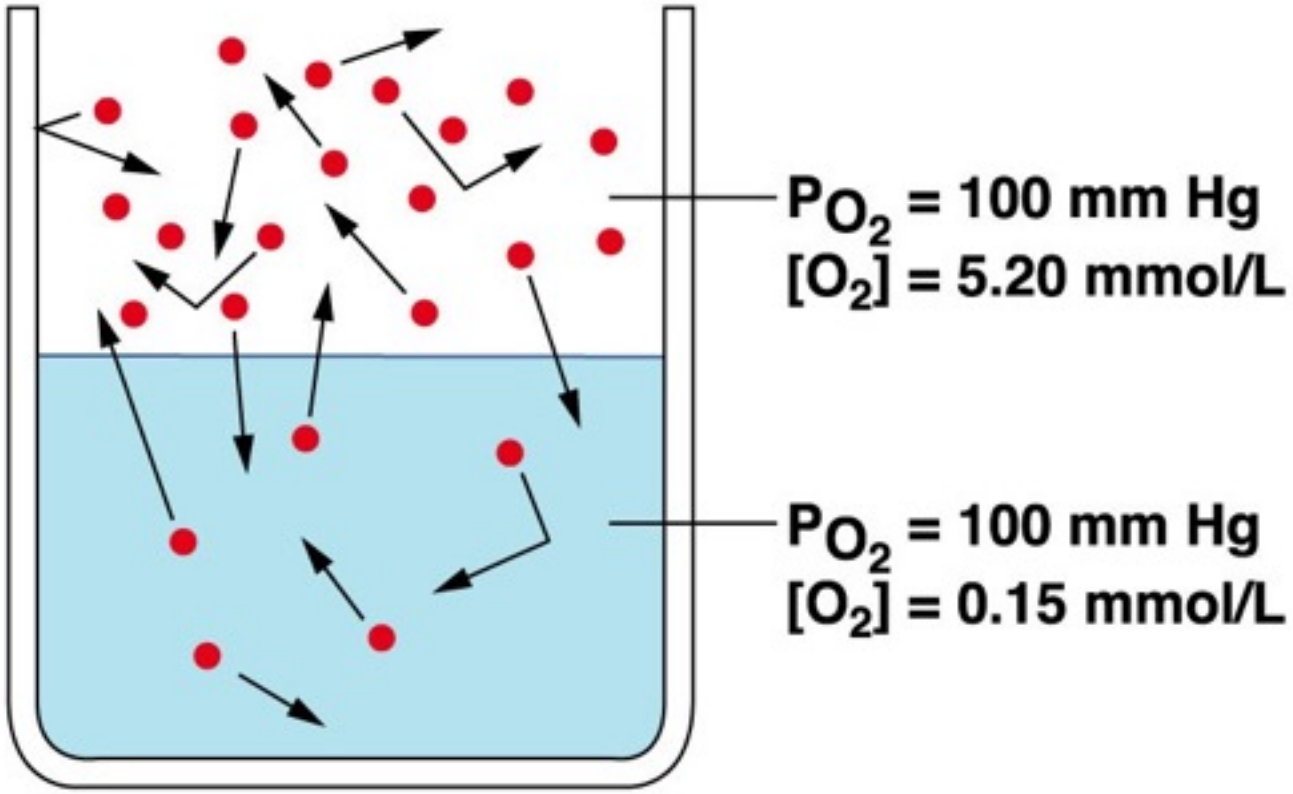
Partial Pressure = total pressure x fraction of total represented by the gas (Dalton's law), i. e.,

$$P_{gas} = P_{total} \times f_{gas}$$

Composition of Air

	Dry atm. air %		Partial pressure mm Hg	Accounting for water vapor pressure = 47mmHg mm Hg
O_2	20.9	(0.21x760)	160	149
CO_2	0.04	(0.0004x760)	0.3	0.3
N_2 & other	79	(0.79x760)	600	564
total	100		760	713

At equilibrium, P_{O_2} in air and water is equal. Low O_2 solubility means concentrations are not equal.

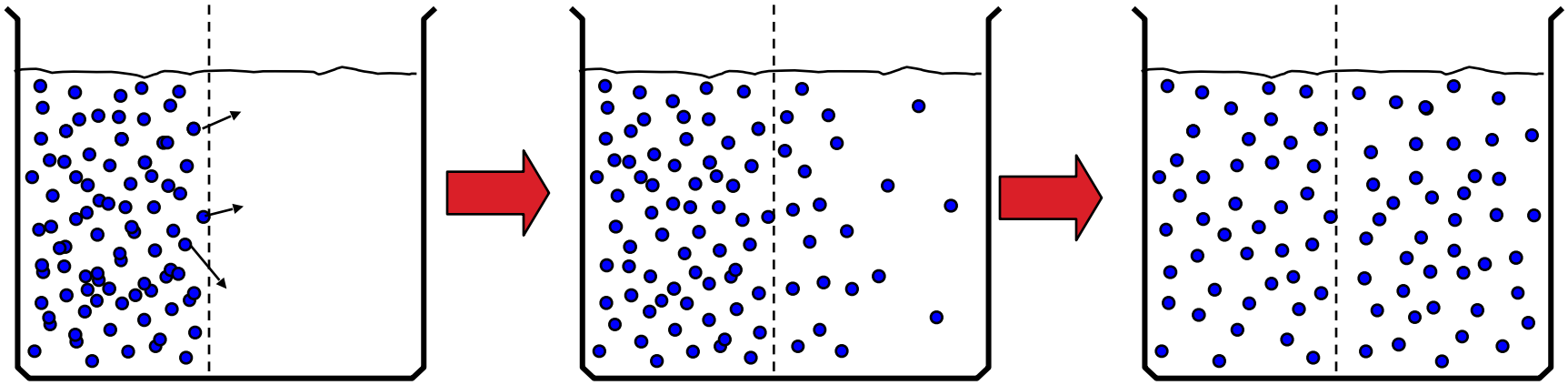


Henry's Law:

Conc. of gas in solution = partial pressure of gas X solubility coefficient

e.g., $[O_2]$ in moles/L: $[O_2] = P_{O_2} \times S_{O_2}$

What is DIFFUSION?



How fast is DIFFUSION?

Diffusion distance (μm)	Time required for diffusion
1	0.5 msec
10	50 msec
100	5 seconds
1,000 (1 mm)	8.3 minutes
10,000 (1 cm)	14 hours

Fick's Law of Diffusion

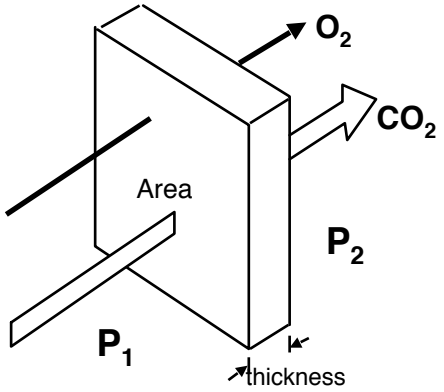
$$\text{Rate of diffusion} = dm/dt = D \cdot A \cdot \frac{dC}{dx}$$

A = area available for diffusion

C = concentration of the substance

x = the distance for the diffusion

D = the diffusion coefficient



$$\text{Rate of Diffusion} \propto \frac{\text{Area x Concentration}}{\text{Distance}}$$

The strategy in the evolution of the respiratory apparatus

- ↑ **available surface area**
- ↓ **distance required for diffusion (i.e., thickness)**

Ventilation

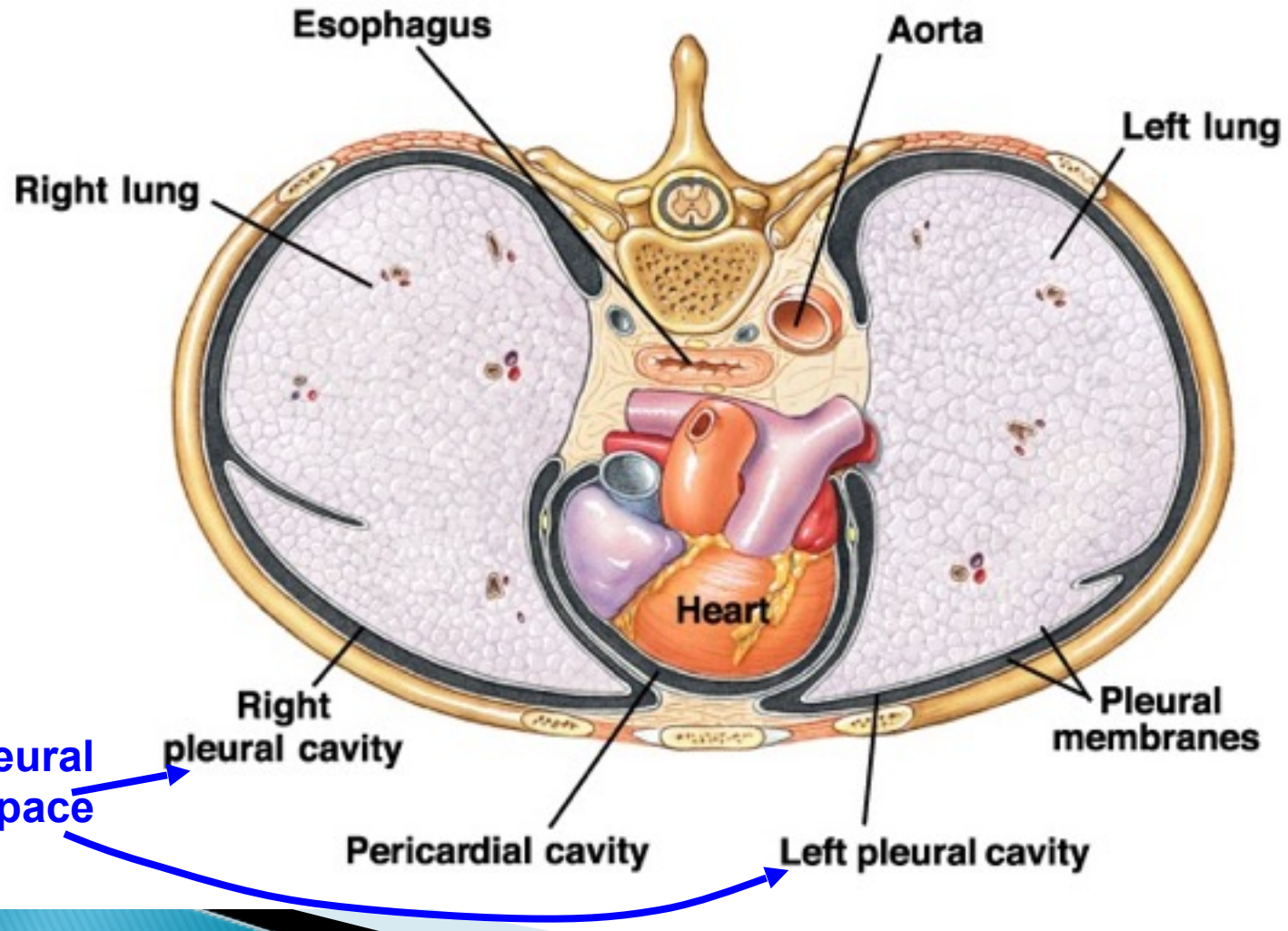
- The process of breathing in and out

Ventilatory apparatus

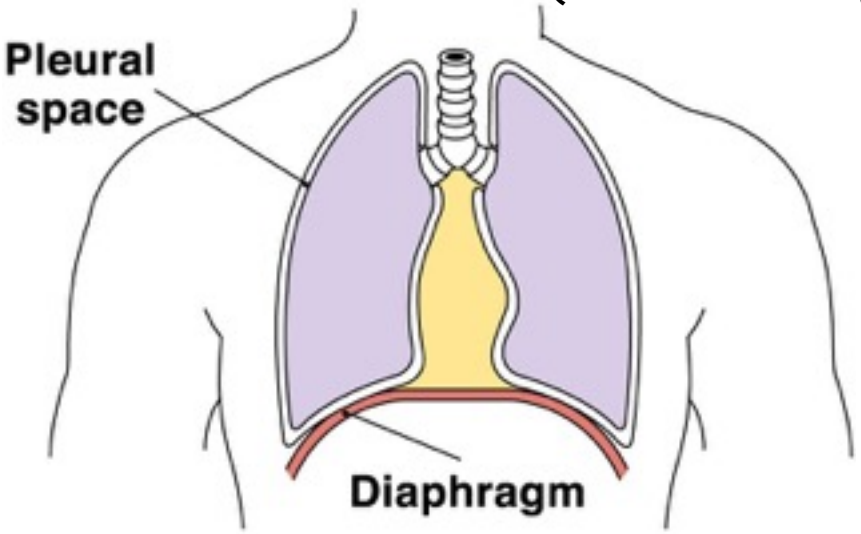
- Chest wall
  - Ribs
  - Intercostals
- The lungs
- The pleural space
- Muscles of respiration
  - Inspiratory
  - Expiratory

Sectional view of chest (Thoracic Cavity)

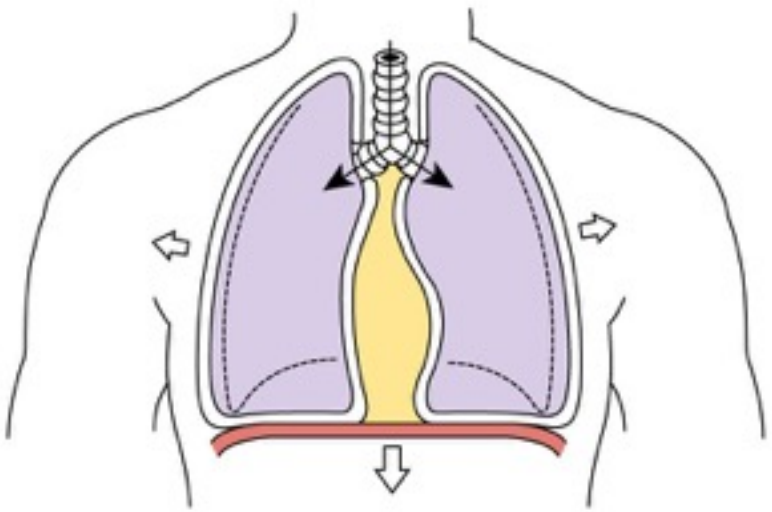
Each lung is enclosed in two pleural membranes. The pleural fluid and space are much smaller than illustrated. The esophagus and aorta pass through the thorax between the pleural sacs.



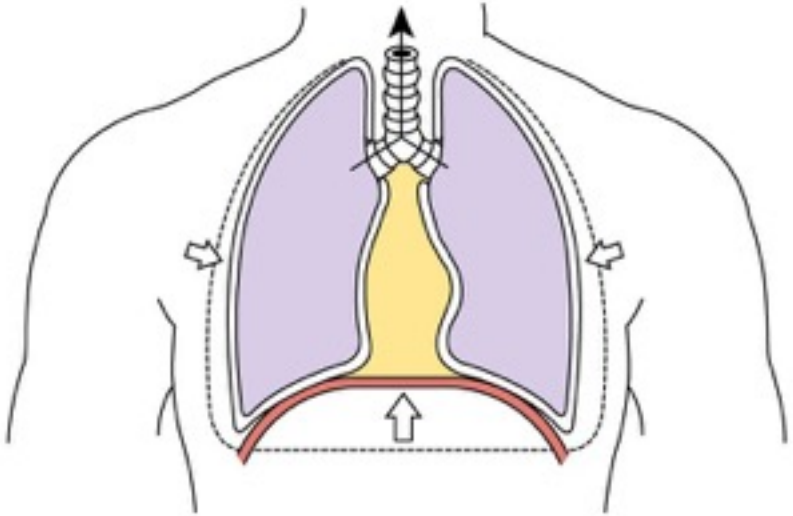
Quiet breathing- diaphragmatic



At rest, diaphragm is relaxed

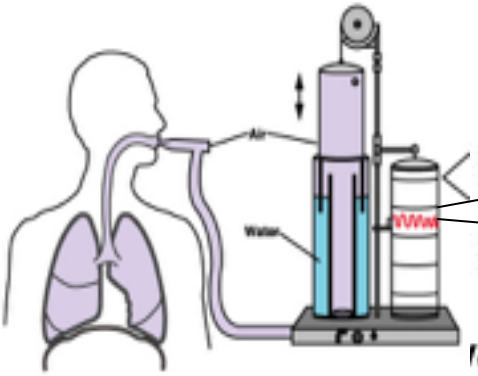


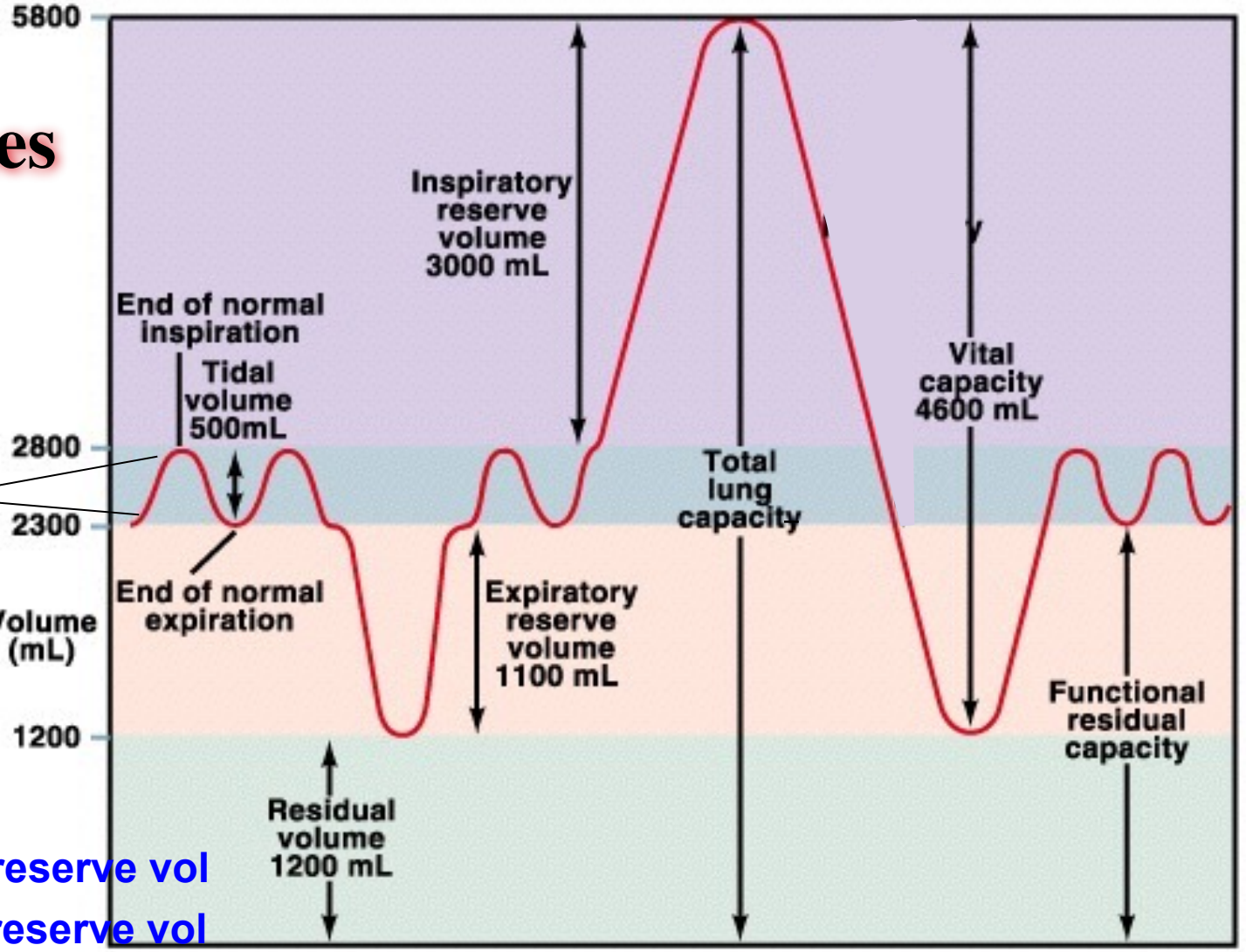
Diaphragm contracts, thoracic volume increases.



Diaphragm relaxes, thoracic volume decreases.

Lung Volumes





V_T = Tidal volume

ERV = expiratory reserve vol

IRV = inspiratory reserve vol

RV = residual vol

FRC = functional residual capacity

Vital capacity

Total lung capacity

Minute Volume = $\dot{V}$ = V_T x resp. rate

e.g., 0.5 L/breath x 12 breaths/min = 6 L/min

Work of Breathing

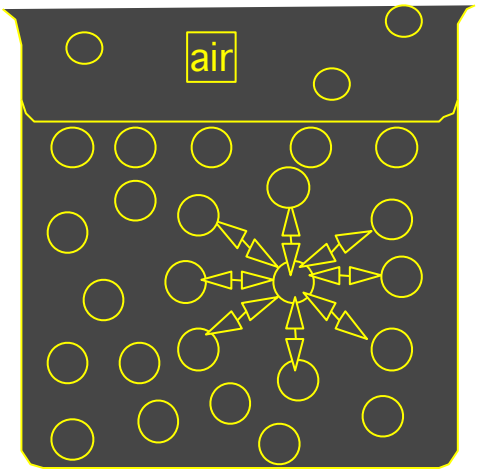
Compliance Work: force to expand lung against its elastic properties

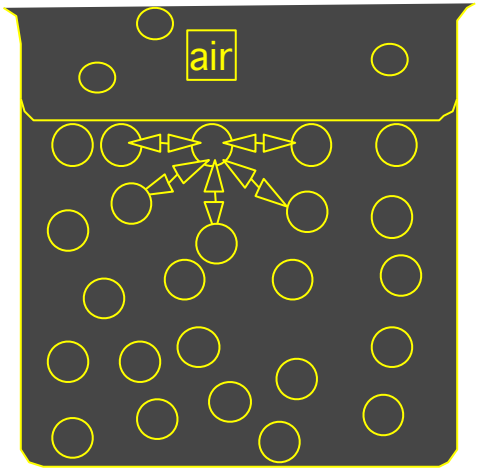
Force to overcome viscosity of lung & chest wall

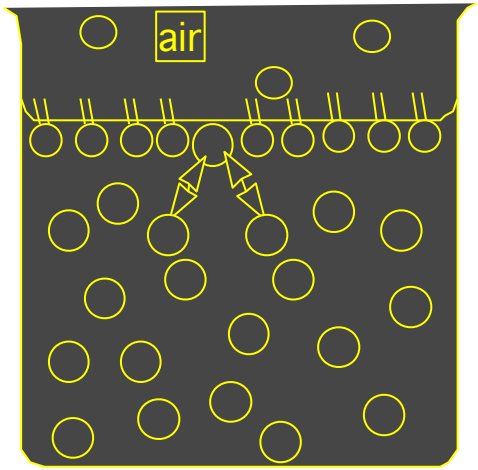
Airway Resistance Work: force to move air through airways

Surface tension

What is **surface tension**?







Surface tension

- Causes the distention of the lung in the expiration stage to be very dificult
- May result in collapse of smaller alveoli
- The negative pressure may result in fluid entry into the alveoli

- To compensate for this the lining of lungs secrete SURFACTANT

Dead space

- This is the portion of the airway that does not participate in gaseous exchange

- Anatomical dead space
  - this the portion of the airway that does not have alveoli and therefore cannot participate in gaseous exchange
  - 150ml

Physiological dead space = TOTAL DEAD SPACE

physiological V_D = anatomical V_D + alveolar V_D

The alveolar dead space would be those alveoli- bearing areas that are not participating in exchange.

This would be pathological

eg lack of circulation or very thich barrier

In the normal person, physiological dead space equals anatomical dead space

THE SPIROMETER

- Old version
  - spirometer bell
  - kymograph pen

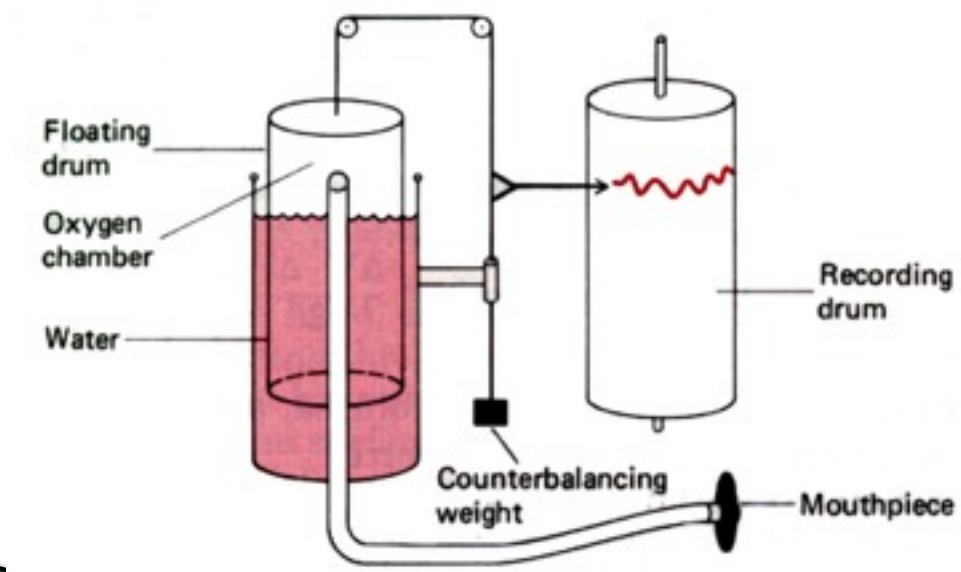
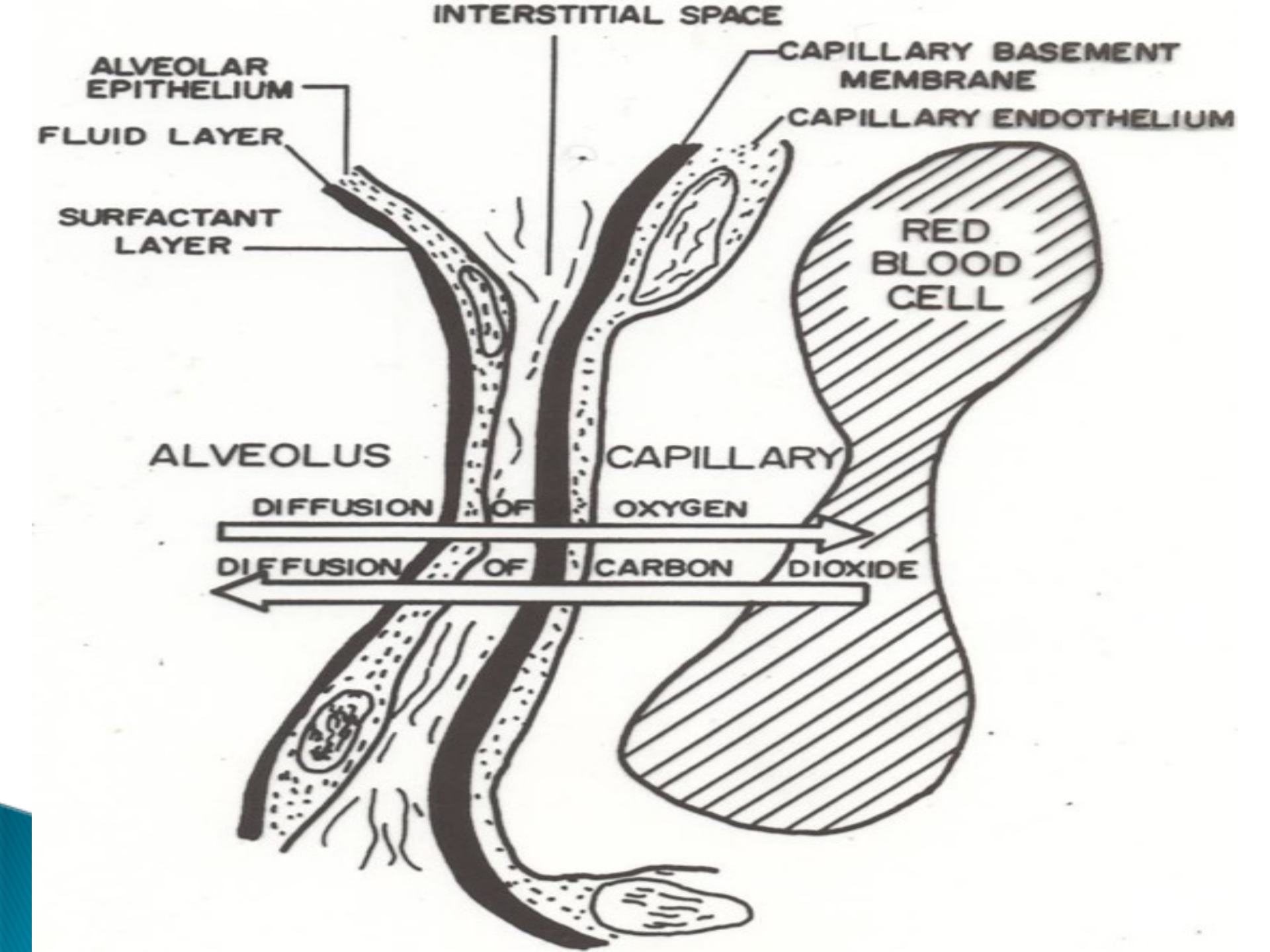


Figure 39–4. A spirometer.

- New version
  - portable

Blood Gas Exchange 'diffusion'

- This is the exchange of gases across the Blood-gas barrier
- Is passive
- Occurs along the gas pressure gradients
- Is dependant on
  - Ventilation
  - Perfusion

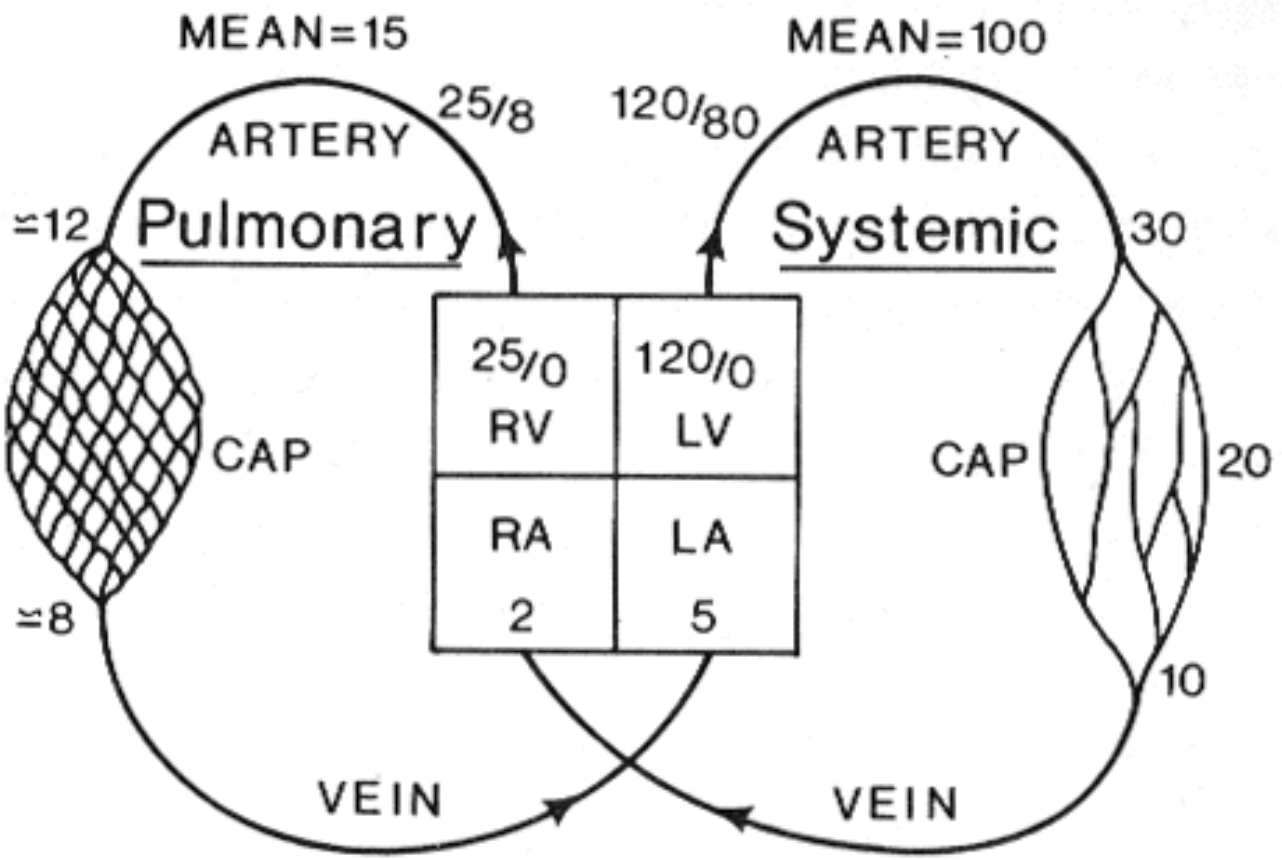

INTERSTITIAL SPACE
ALVEOLAR EPITHELIUM
CAPILLARY BASEMENT MEMBRANE
CAPILLARY ENDOTHELIUM
FLUID LAYER
SURFACTANT LAYER
RED BLOOD CELL
ALVEOLUS
CAPILLARY
DIFFUSION OF OXYGEN
DIFFUSION OF CARBON DIOXIDE

‘Alveolar air’

- This is the air in contact with alveoli
- Volume: 2L
- Each breath adds and takes away 350ml
- The composition remains relatively constant
- Can be sampled by the last 10ml of expired air.

Pulmonary circulation

Characteristics of the Pulmonary Circulation



Ventilation-Perfusion matching

Matching respiration & blood flow: the Ventilation-Perfusion Ratio

Ventilation

Alveolar ventilation, $\dot{V}_A$

$\dot{V}_A = (V_T - V_D) \times$ resp. rate

$= (0.5 - 0.15) \times 12 = 4.2$ L/min

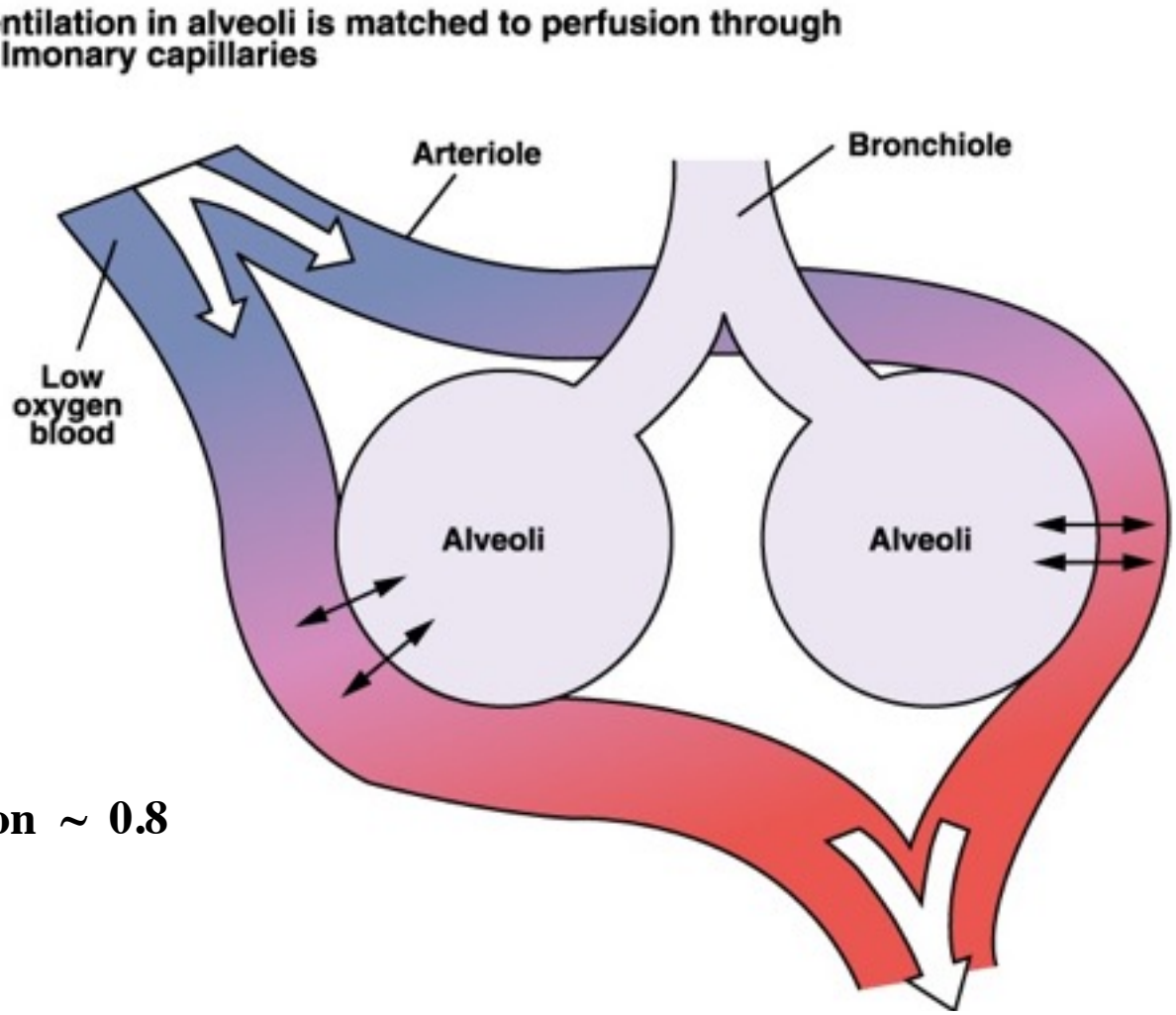
Perfusion

Cardiac output = C.O. = $\dot{Q}$

$\dot{Q}$ = stroke vol. x heart rate

$= (0.086) \times 70 = 6.0$ L/min

$$\frac{\dot{V}_A}{\dot{Q}} = \textbf{ventilation/perfusion } \sim \textbf{ 0.8}$$

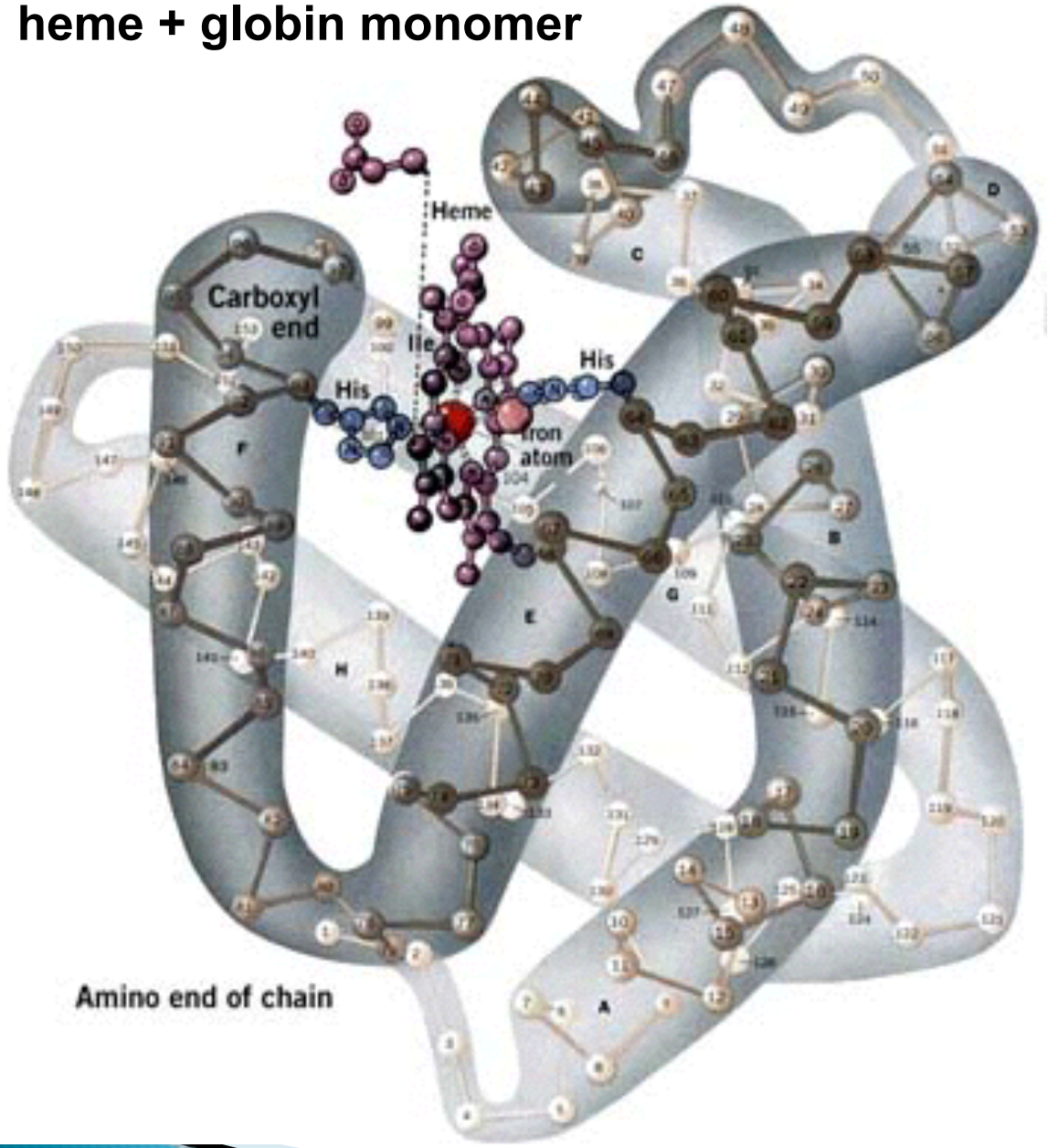


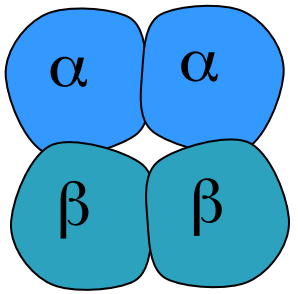
Blood Gas transport

Oxygen transport

- Minor
  - Dissoved- 3% of total
  - In arteries- 0.3ml/100ml of blood
  - Not sufficient for body requirement
- MAJOR
  - In combination with haemoglobin
  - 97%

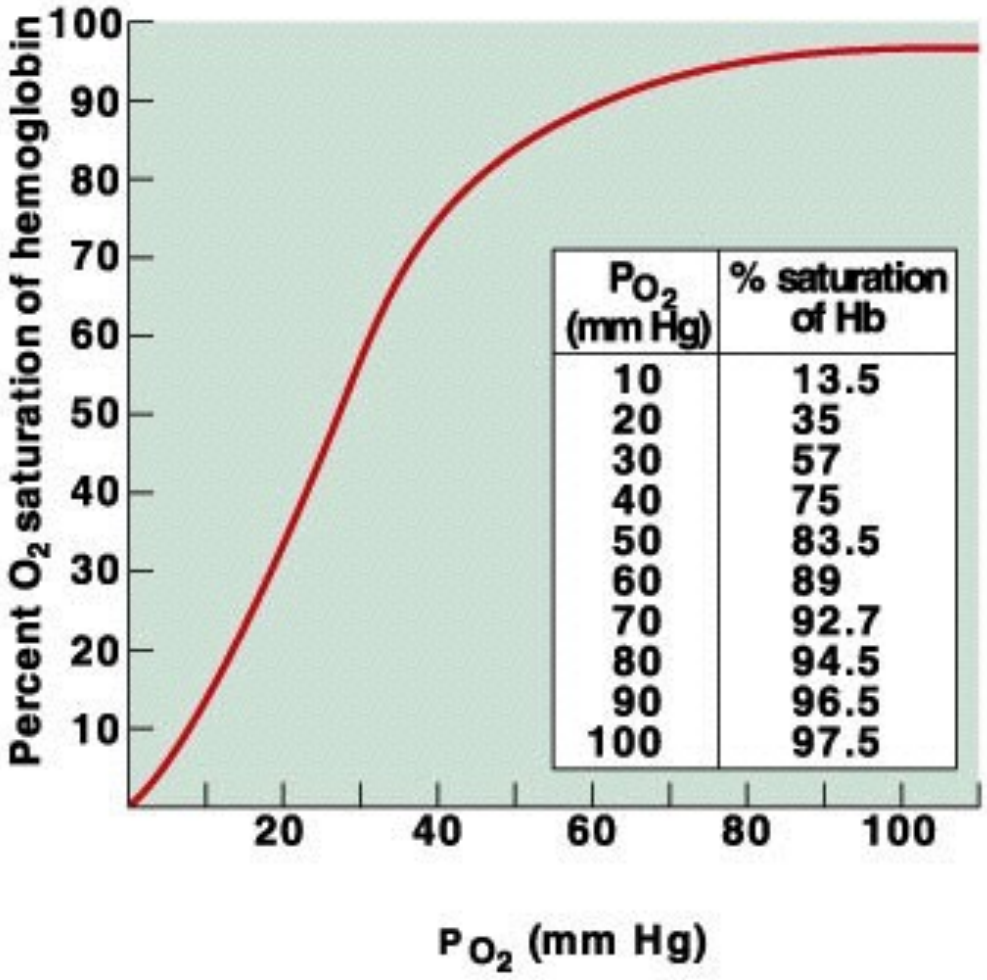
heme + globin monomer





Hemoglobin molecule
tetramer, 2α2β

Oxygen–Hemoglobin Dissociation Curve

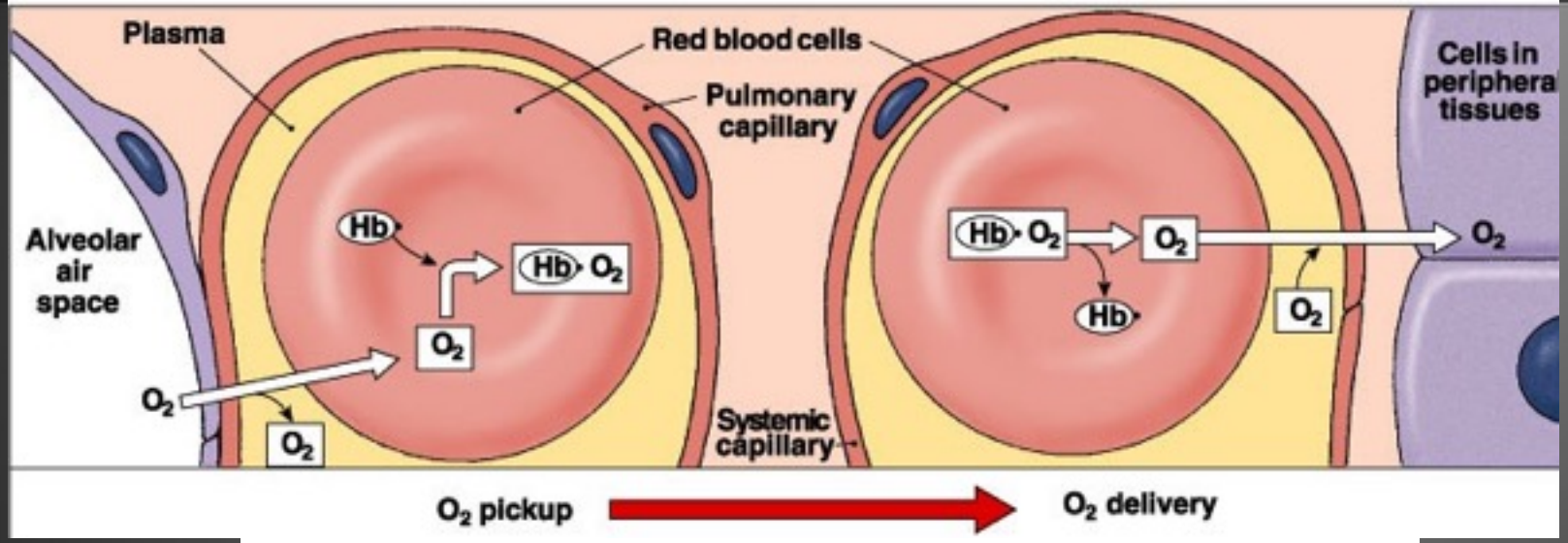


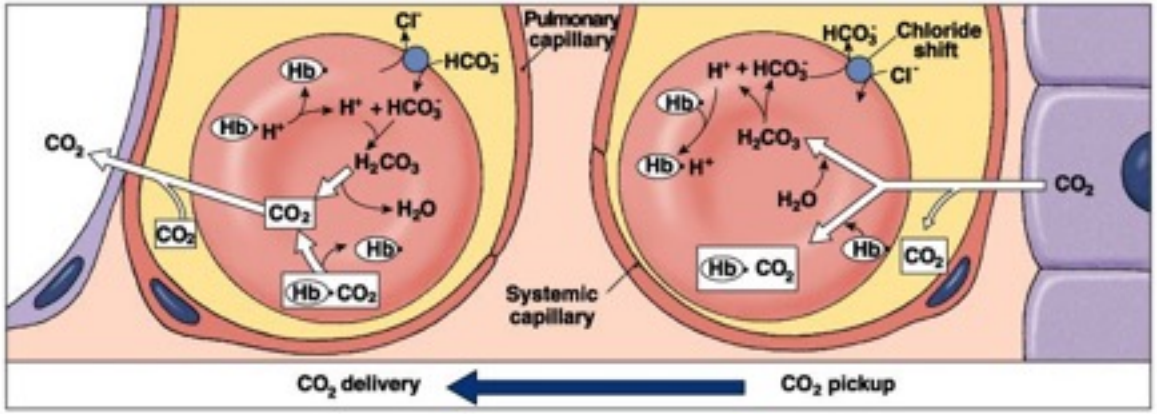
P_{O_2} (mm Hg)	% saturation of Hb
10	13.5
20	35
30	57
40	75
50	83.5
60	89
70	92.7
80	94.5
90	96.5
100	97.5

Carbondioxide transport

- Dissolved- 10%
- As Bicarbonate- 70%
- As Carbamino compounds- 20%

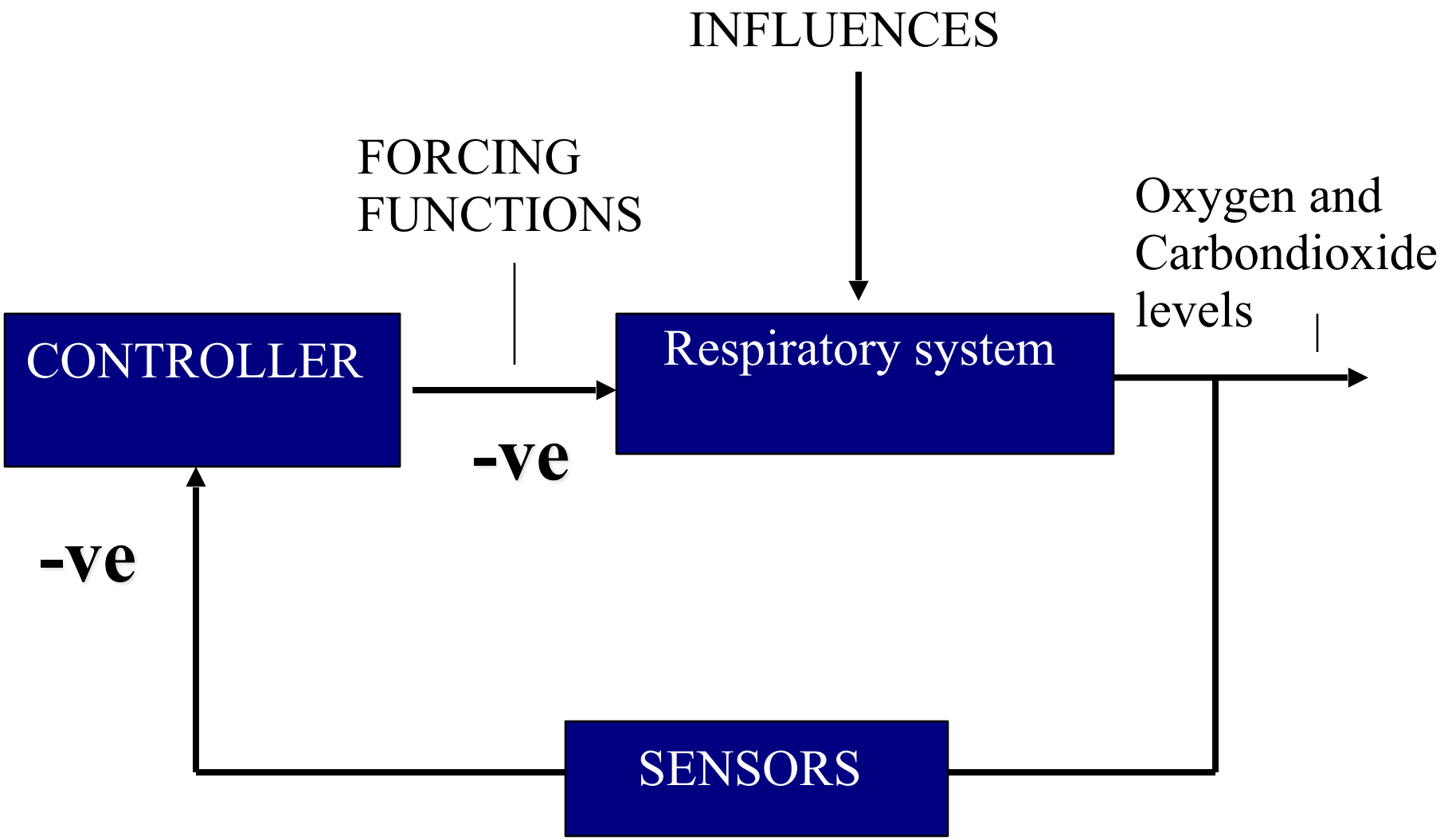
Blood tissue gas exchange


Plasma
Red blood cells
Pulmonary capillary
Cells in peripheral tissues
Alveolar air space
Hb
Hb·O2
O2
O2
O2
Hb·O2
O2
Hb
O2
O2
Systemic capillary
O2 pickup
O2 delivery


Cl⁻
HCO3⁻
Pulmonary capillary
HCO3⁻
Chloride shift
Hb
H⁺ + HCO3⁻
H⁺ + HCO3⁻
Cl⁻
Hb·H⁺
H2CO3
Hb·H⁺
H2CO3
CO2
CO2
H2O
CO2
CO2
Hb
Hb
Hb·CO2
Hb·CO2
Systemic capillary
CO2 delivery
CO2 pickup

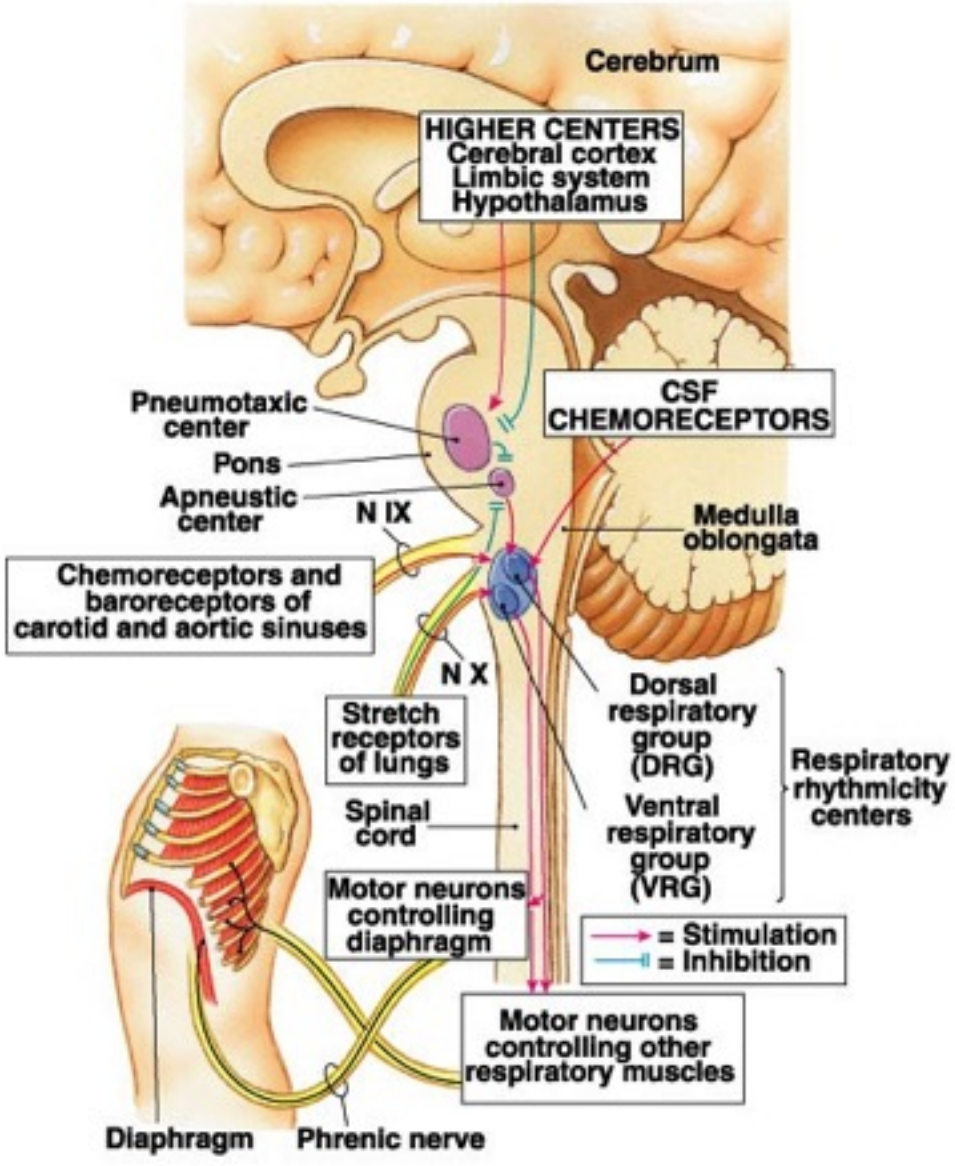
Control of respiration

- Aim is to maintain physiological levels of
  - Oxygen
  - Carbondioxide
  - pH

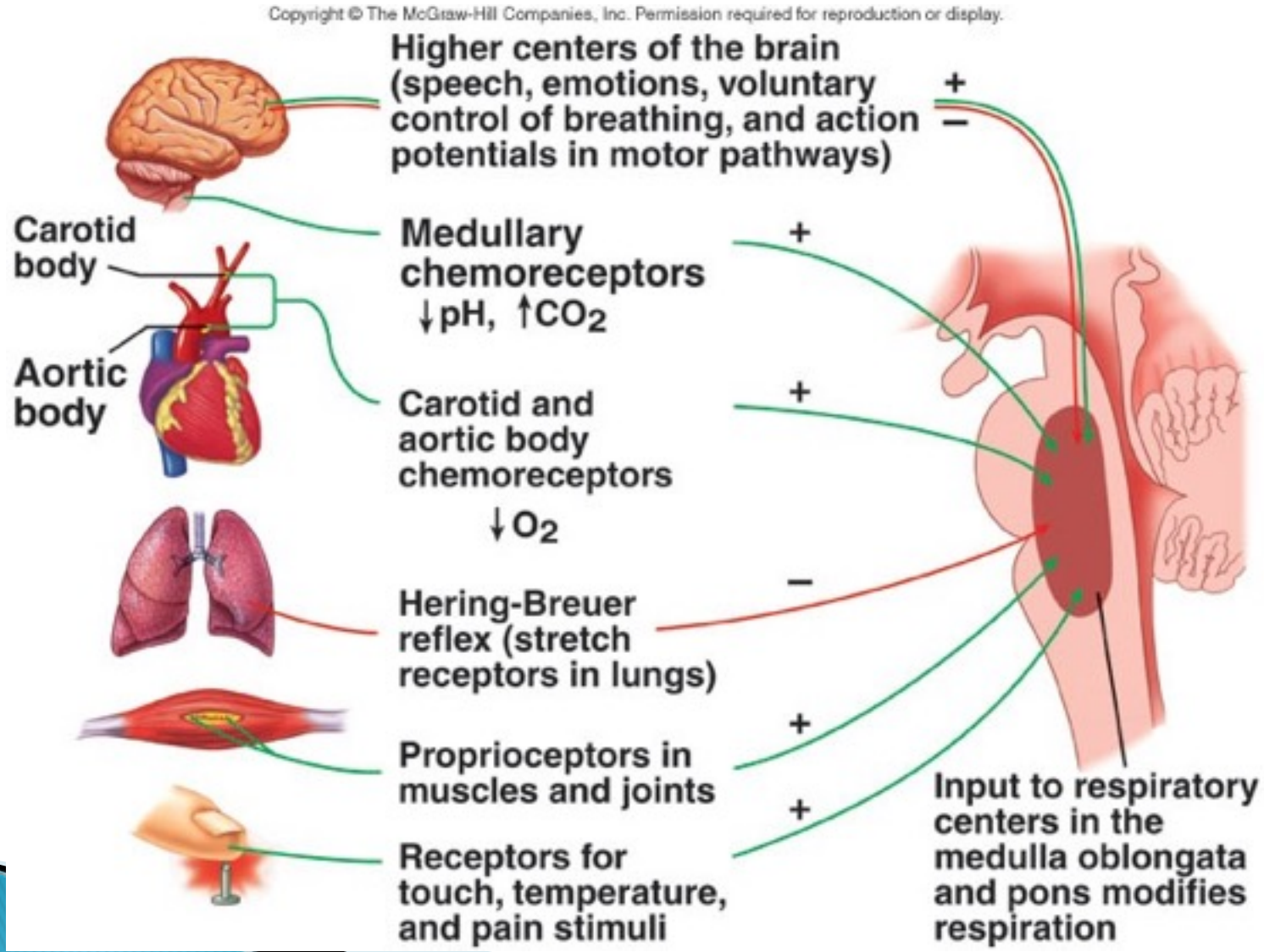


CONTROL MODEL

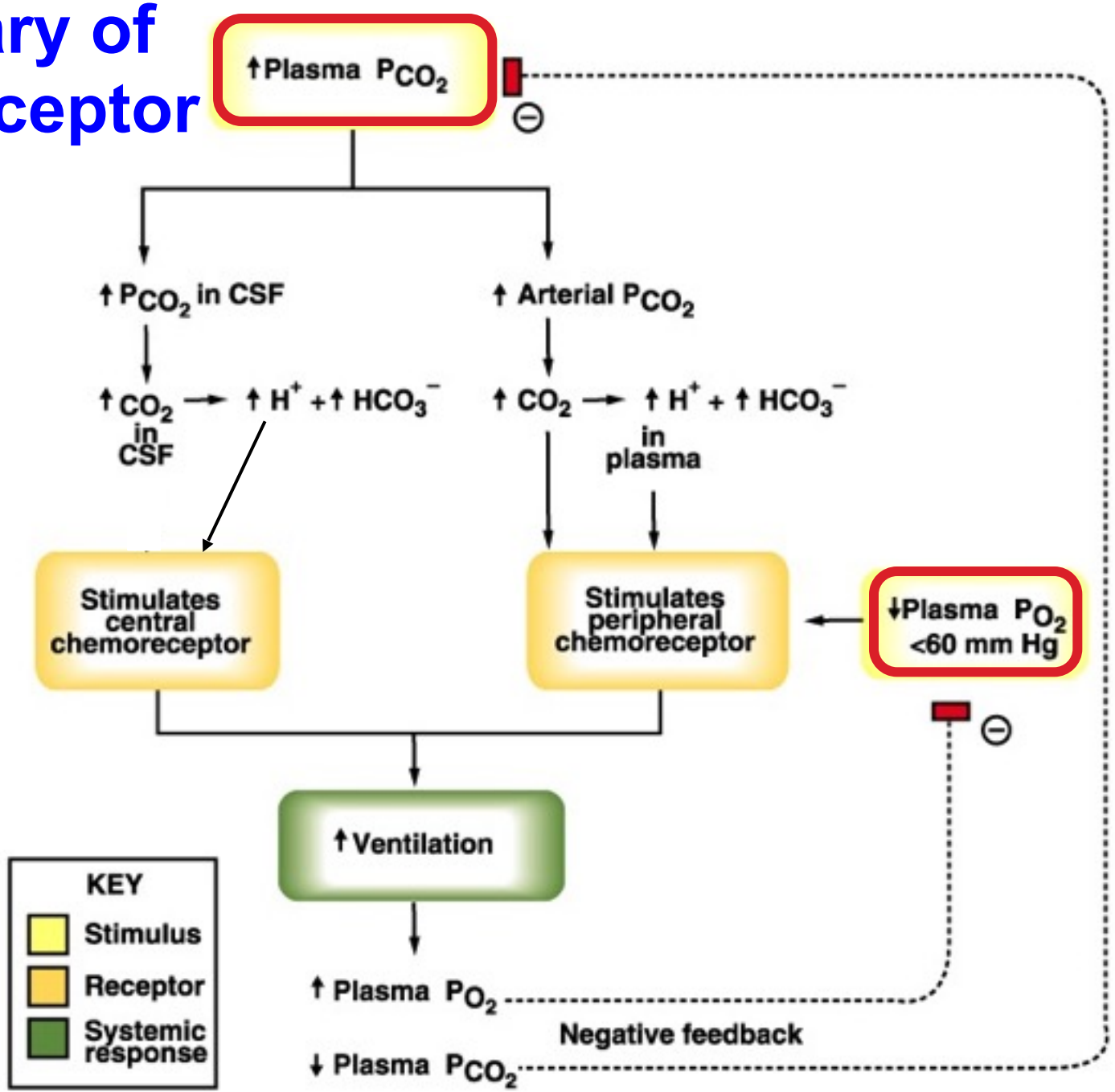
Respiratory Structures in Brainstem



Input to Resp. centres

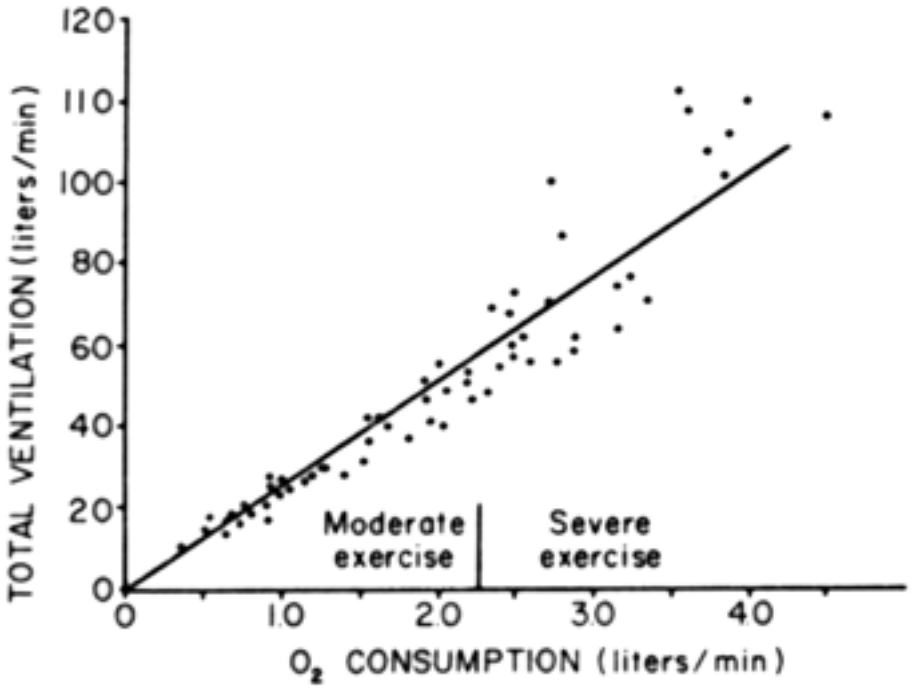


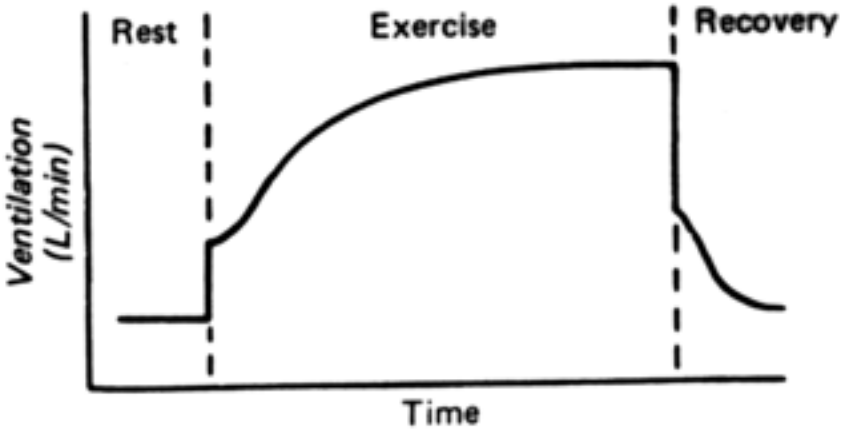
A Summary of Chemoreceptor Reflexes



- Hypercapneic ventilatory drive
  - Important in short term, in the long term the pH changes in CSF are buffered so becomes ineffective.
  - Is the one driving resp in most physiological instances
- Hypoxic ventilatory drive
  - Very powerful, more important when low oxygen levels

Responses of the Respiratory System to Exercise





Non respiratory function of respiratory tract

- Olfaction
- Air conditioning
- Voice
- Defense:
  - Immune
    - Cellular
    - secretory
  - Reflexes
    - Cough
    - sneeze
- Metabolic
  - Secretion
  - conversion
- Circulatory
  - Filter
  - ‘reservoir’

Thank you