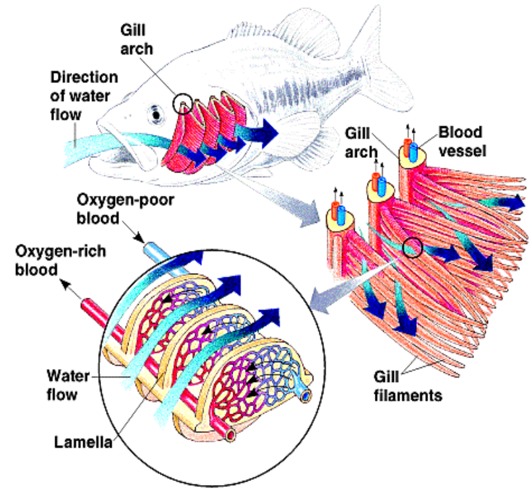
GAS EXCHANGE AND TRANSPORT



I. INTRODUCTION: Heterotrophs oxidize carbon cmpds using O_2 to generate CO_2 & H_2O. This is cellular respiration

II. HOW GAS ENTERS A CELL
- A. The composition of air: 79% N_2+ 21% O_2 + 0.1% other
- B. The diffusion of oxygen into water
- C. The passage of O_2 into cells

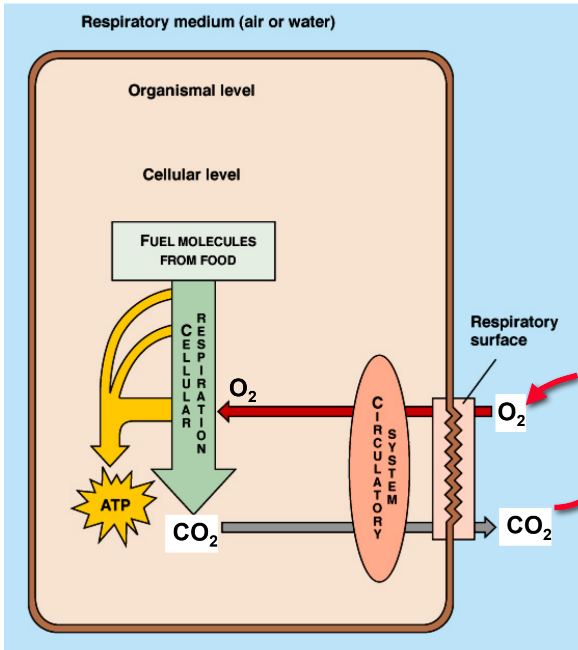
III. THE EVOLUTION OF RESPIRATION
- A. Diffusion of O_2 is passive & driven by difference in O_2 concentration (dC/dx)
  1. Mathematical relationship called Fick's Law of Diffusion
  2. Rate of diffusion = R = D x A x dC/dx (D is diffusion ceff.; A is surface area; dC/dx is concentration gradient)
  3. Evolutionary changes optimize R; favor certain parameters
- B. Limitations of simple diffusion
- C. Increasing the diffusion surface area (A), and decreasing dx
- D. Enclosing the respiratory organ

IV. FROM AQUATIC TO ATMOSPHERIC BREATHING: THE TRACHEA & THE LUNG

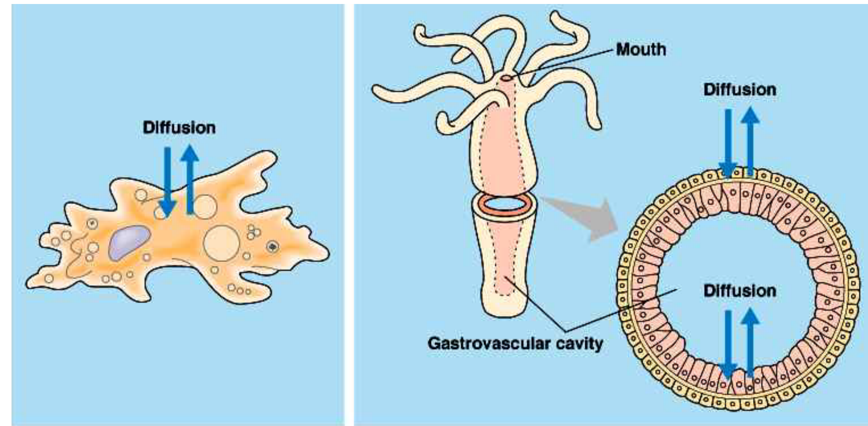
VI. THE MECHANICS OF HUMAN BREATHING
- A. Structure of the respiratory system,
- B. Mechanics of breathing
  1. Expansion & contraction of lung is passive; follows intrapleural pressure
  2. Diaphragm descends & walls of chest cavity expand with inhalation
  3. Rib cage & diaphragm return to original positions with exhalation: air leaves
  4. The problem of air/water surface tension - role of surfactant; role of mucus

VII. HOW RESPIRATION WORKS: GAS TRANSPORT AND EXCHANGE
- A. Close association of respiratory and circulatory systems
- B. Hemoglobin and gas transport
  1. Hemoglobin: O_2 carrier protein within blood of many animals
  2. Oxygen-hemoglobin dissociation curve
     - a. Correlates partial pressure of O_2 and binding to hemoglobin
     - b. Curve also shifted with activities, e.g., pH & CO_2
  3. Carbon monoxide (CO) is a poison because of high affinity to Hb
- C. The exchange process
  1. O_2-rich air interfaces with O_2-poor blood at alveoli
  2. O_2-loaded blood reaches systemic capillaries where CO_2 is high
  3. Simultaneously, blood gives up its O_2 & absorbs CO_2 from tissues
     - a. Carbonic anhydrase catalyzes: $CO_2 + H_2O \longrightarrow H_2CO_3$
     - b. H_2CO_3 dissociates to form, $H_2CO_3 \rightarrow HCO_3 + H^+$, no catalyst needed
  4. Blood cells carry CO_2 back to lungs where CO_2 is lost and O_2 is taken up

VIII. REGULATION OF VENTILATION
- A. Regulatory centers in the central nervous system
- B. Chemoreceptors sense the level of O_2 and CO_2

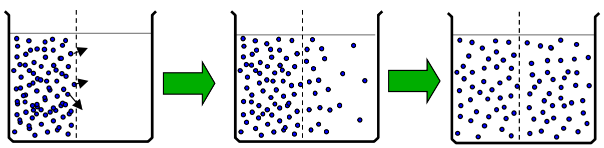


Very small animals can exchange gas without a specialized respiratory apparatus



(a) Single cell (b) Two cell layers

What is DIFFUSION?



start intermediate equilibrium

How fast is DIFFUSION?

Diffusion distance	Time required for diffusion
1-10 µm	1-50 msec
1 mm - 1 cm	10 min - 10 hr

CONCLUSION?

DIFFUSION is fast at small distances and slow at long distances

Fick's Law of Diffusion

Adolf Fick

Rate of diffusion = $\mathbf{R} = D \times \mathbf{A} \times \dfrac{\mathbf{dC}}{\mathbf{dx}}$

A = area available for diffusion

C = concentration of the substance

x = the distance for the diffusion

D = the diffusion coefficient

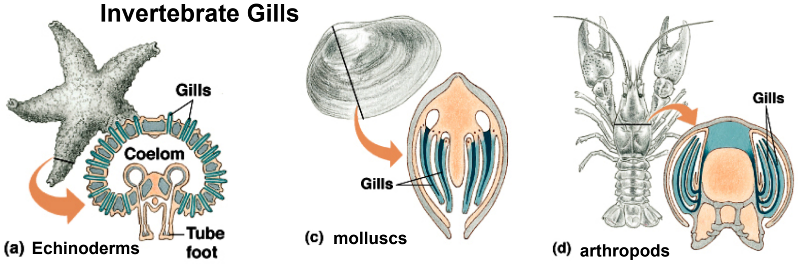
$$\text{Rate of Diffusion} \propto \frac{\text{Area} \times \text{Concentration}}{\text{Distance}}$$

What is the strategy in the evolution of the respiratory apparatus?

- ↑ **available surface area**
- ↓ **distance required for diffusion**

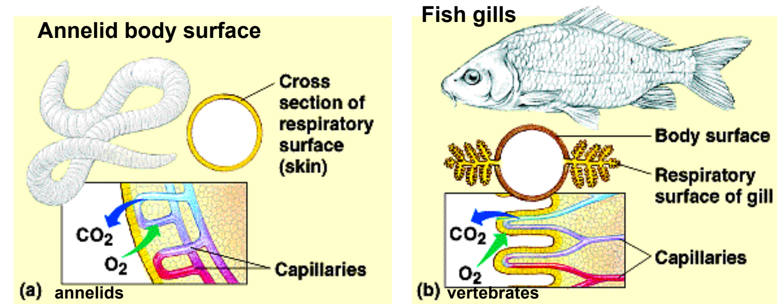
Respiratory Surface: The interface over which gas exchange occurs between environment and body fluids

Invertebrate Gills



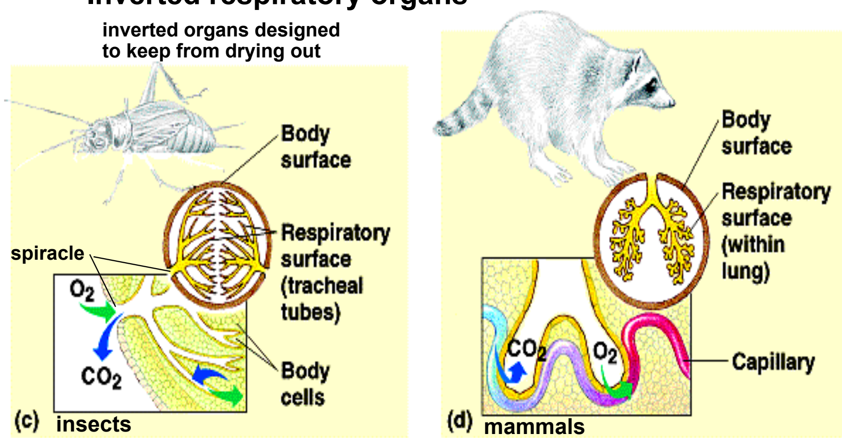
So…….. the strategy is to <u>increase the surface area</u> and <u>decrease the distance</u> that has to be accommodated for diffusion of gases from the atmosphere (in this case sea water) and the body fluid.

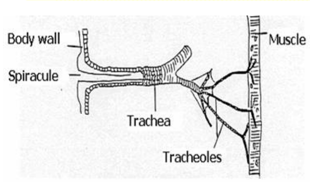
Respiratory Organs

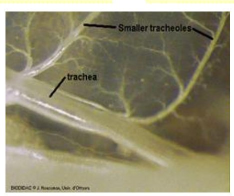


Inverted respiratory organs

inverted organs designed to keep from drying out



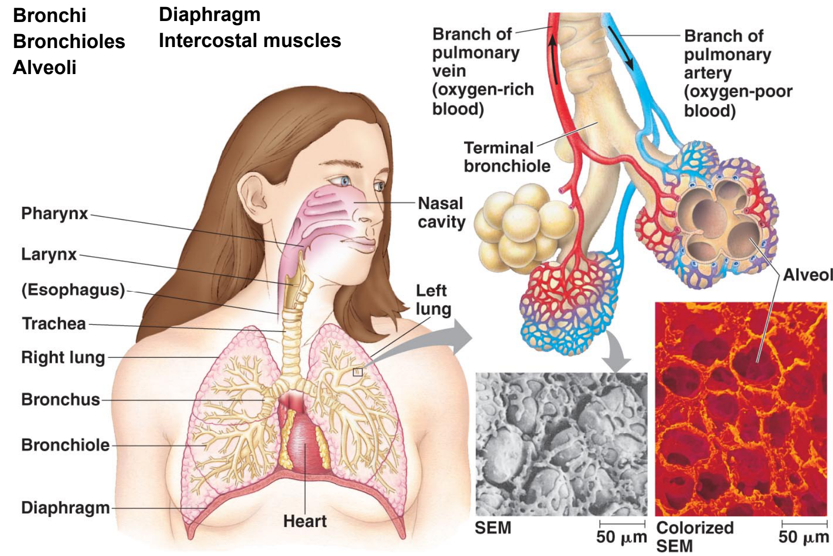




The Mammalian Respiratory System

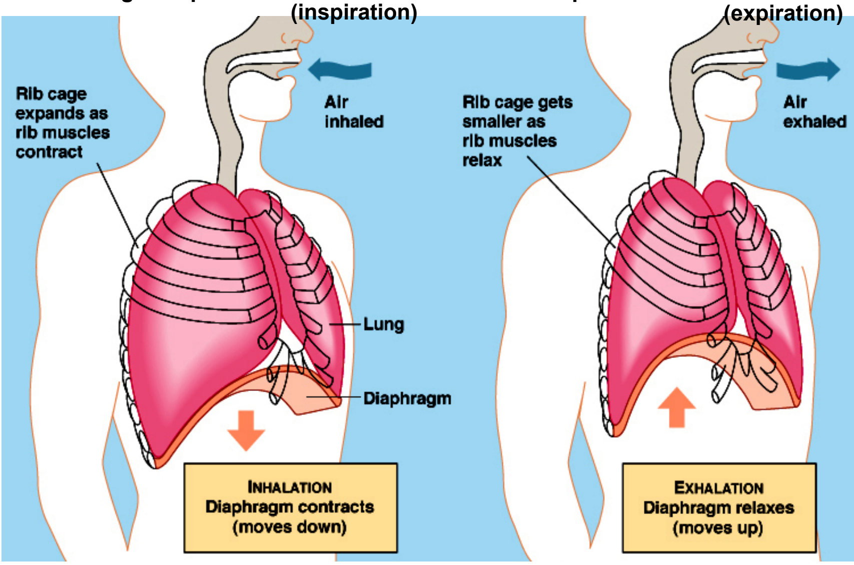
Respiratory Structures

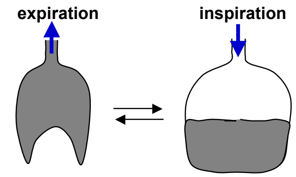
Trachea	Thoracic cavity
Bronchi	Diaphragm
Bronchioles	Intercostal muscles
Alveoli	



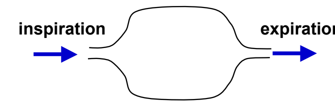
How we breathe (mechanics)

Negative pressure inhalation (inspiration) | Positive pressure exhalation (expiration)



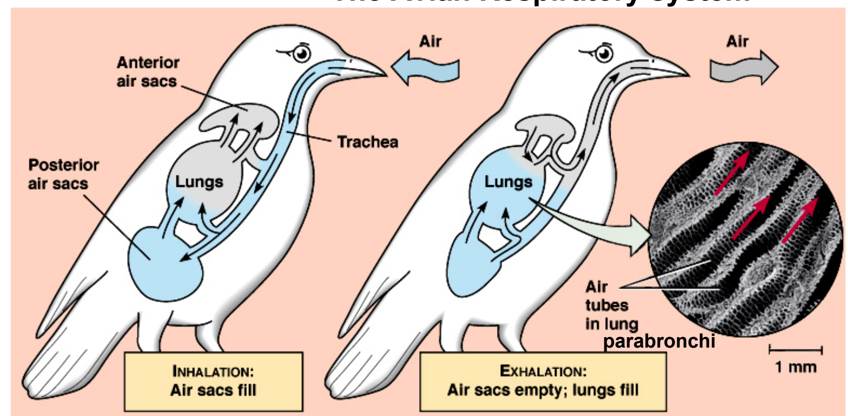


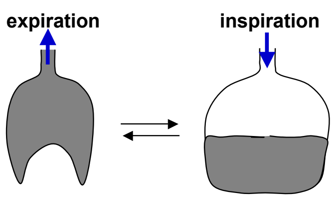
How mammals breathe



How birds breathe

The Avian Respiratory system





How mammals breathe

Tidal Breathing → Inspiration

Tidal Breathing → Expiration

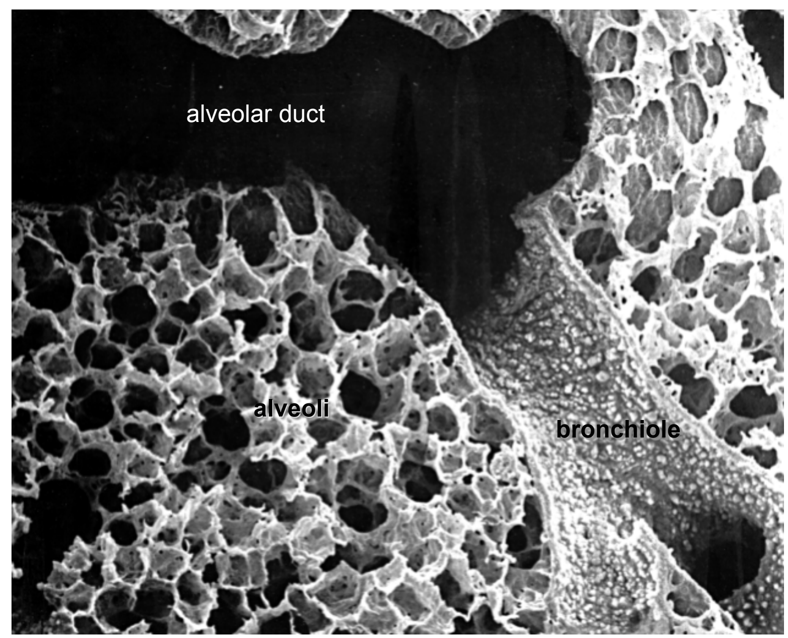
How much air do we breathe per minute? ⟶ Minute Volume

Minute Volume = tidal volume x respiratory rate

ml/min = ml/breath x breaths/min

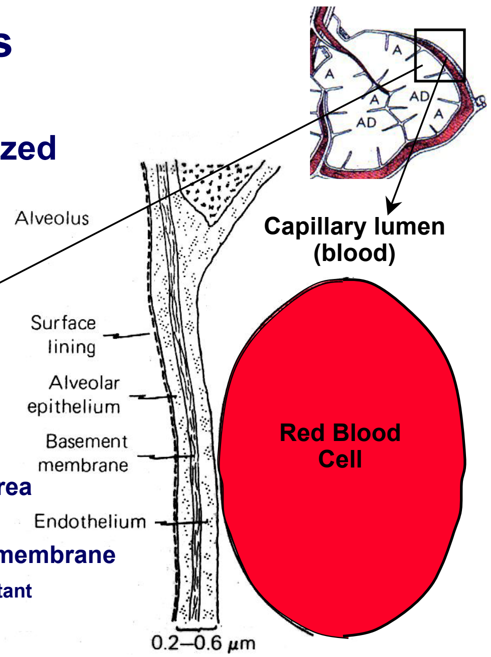
an example

6000 ml/min = 500 ml/breath x 12 breaths/min



Where do gases exchange?

What are the specialized adaptations?



1. Large alveolar surface area

2. Extremely thin alveolar membrane

AGAIN!! Geometry is important

Getting gases to and from cells

First: Composition of Atmospheric Air

O_2	21%	= 100%
N_2	79%	
CO_2	<0.1%	

At sea level, atmospheric pressure ~ 760 mm Hg

What part of the atm. pressure does O_2 represent?

21% of 760 mm Hg = 160 mm Hg = PO_2

What part of the atm. pressure does CO_2 represent?

0.04% of 760 mm Hg = 0.3 mm Hg = PCO_2

How gases are carried in the blood

(values given in….. ml gas/ 100 ml blood)

	O_2	CO_2
as dissolved gas	0.3	2.6
in a combined form	19.5	46.4
How combined?	$Hb(O_2)_4$	HCO_3^- combined w/ Hb H_2CO_3

$$4O_2 + Hb \rightleftharpoons Hb(O_2)_4$$

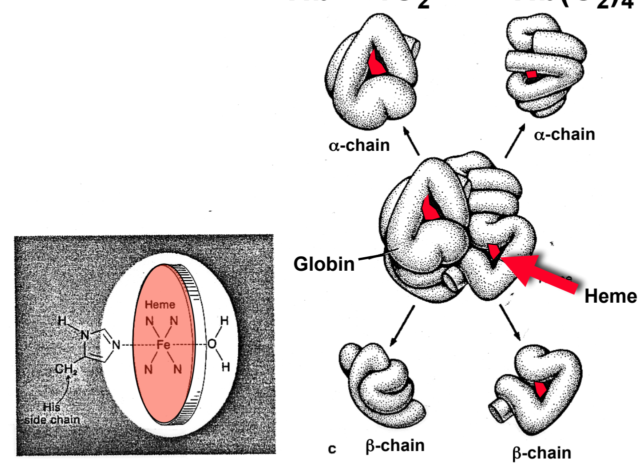
$$CO_2 + H_2O \overset{CA}{\rightleftharpoons} H_2CO_3 \rightleftharpoons H^+ + HCO_3^-$$

CA = carbonic anhydrase

Structure of hemoglobin (Hb): the major protein in RBCs

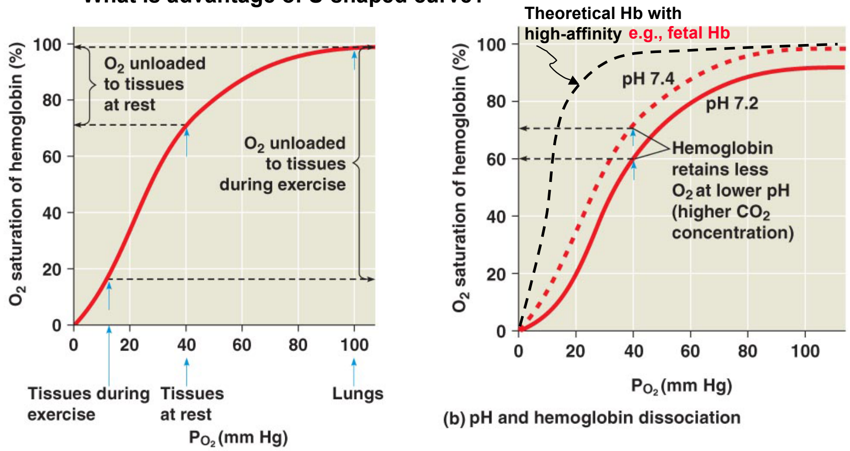
4 globin + 4 heme = hemoglobin (Hb)

$$Hb + 4O_2 \rightleftharpoons Hb(O_2)_4$$



Hemoglobin-Oxygen Association

What is advantage of S-shaped curve?



(a) P_{O_2} and hemoglobin dissociation at pH 7.4

(b) pH and hemoglobin dissociation

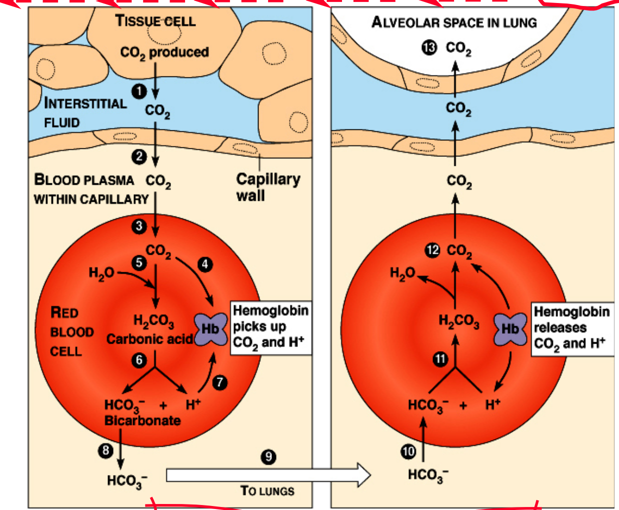
$$Hb + 4O_2 \leftrightarrow Hb(O_2)_1 \leftrightarrow Hb(O_2)_2 \leftrightarrow Hb(O_2)_3 \leftrightarrow Hb(O_2)_4$$

Carriage of Carbon Dioxide

tissues

$$CO_2 + H_2O \overset{CA}{\rightleftarrows} H_2CO_3 \rightleftarrows H^+ + HCO_3^-$$

lungs



(a) CO_2 transport from tissues

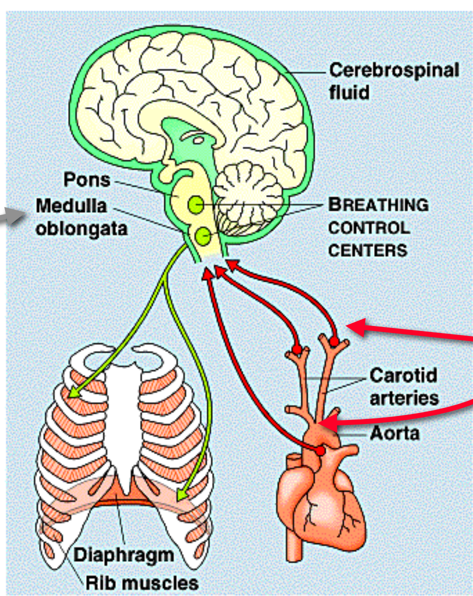
(b) CO_2 transport to lungs

How do we breathe subconsciously and rhythmically?

Automatic control of breathing ⟶ Regulated by blood gases

responds to

↑ PCO_2



responds to

↓ PO_2