Gas Exchange in Animals

Uptake of O_2 from environment and discharge of CO_2

Respiratory medium
water for aquatic animals, air for terrestial

Respiratory surface
skin, gills, lungs

Circulatory System

O_2/CO_2 binding proteins
hemocyanin, hemoglobin, etc.

Tissues

1

Gas Exchange between Respiratory Surface, Blood in Circulatory System, and Tissues

Gas concentration measured in partial pressure

Atmospheric pressure is 760 mmHg.

O_2 is 21% of atmosphere, so P_{O2} = 160 mmHg

CO_2 is .03% of atmosphere, so P_{CO2} = .23 mmHg

Concentration of gas in solution is also expressed as partial pressure.

Gas moves from high concentration to low concentration.

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Active Pumping to transport gases from respiratory surface to tissues

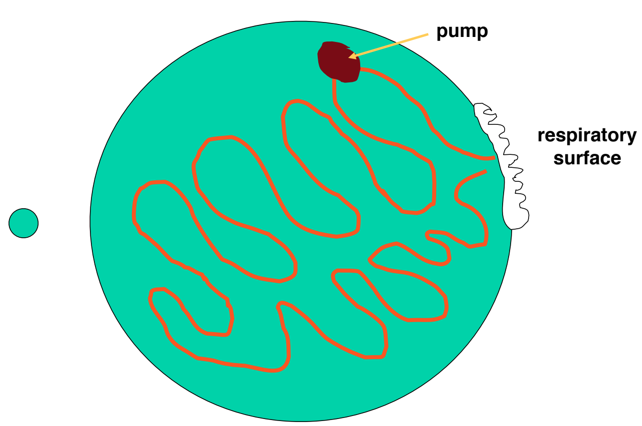

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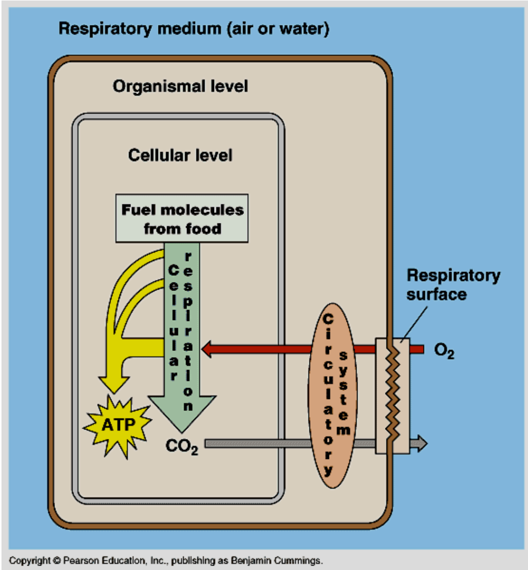
Figure 42.18 The role of gas exchange in bioenergetics



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Two Adaptations

1. Specialized respiratory surfaces to increase surface area exposed to respiratory medium w/o bigger body

   surface is moist, so:

   gas-> H_20 -> surface -> body

2. Circulatory system to carry gas from respiratory surface to tissues deep in body.

   more efficient & increased O_2 carrying capacitiy with specialized proteins bind O_2 and release it at tissues

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Simple Animals

Earthworm
uses entire skin as repiratory surface, so must be moist
(lungs on the on the outside)

some amphibians too...

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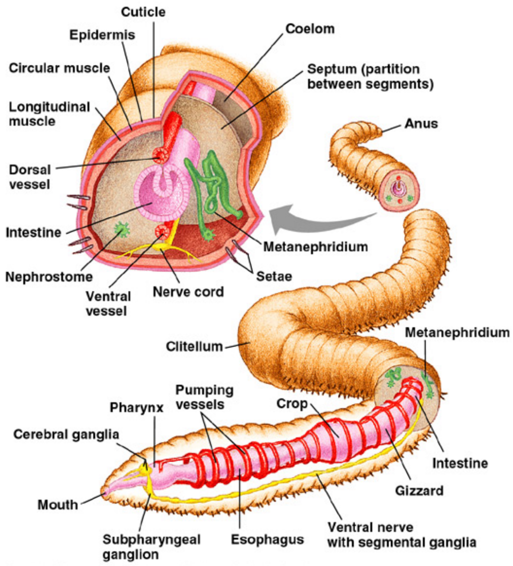
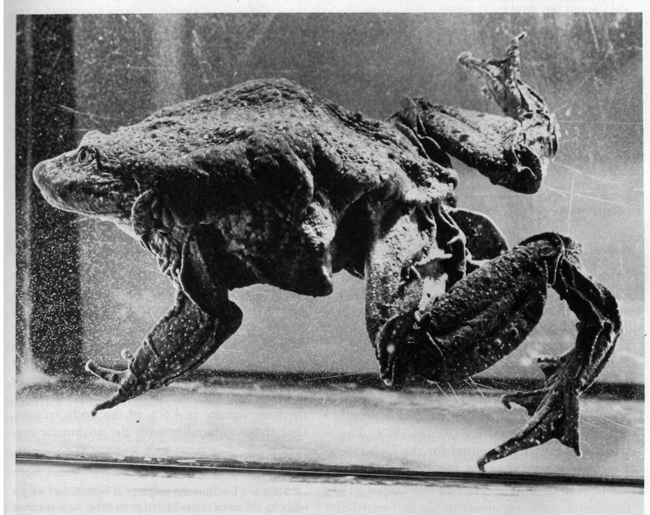


A FROG THAT BREATHES THROUGH ITS SKIN The Titicaca frog (*Telmatobius culeus*) lives in the depths of Lake Titicaca at 3812 m altitude. This animal does not surface to breathe and obtains oxygen entirely by diffusion through the skin surface, which is highly vascularized and enlarged by loose folds. [Courtesy of Victor H. Hutchison, University of Oklahoma]



Gills

Outfoldings of body surface specialized for gas exchange in H_20

Total surface area can be much greater than rest of body

Dense capillaries brought close to H_20

Good: don't need to worry about keeping surface moist, because bathed in H_20

Bad: O_2 concentration is low in H_20 compared to air, so gills must be very efficient

Figure 42.0 External gills of a salmon

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Gill Mechanisms to increase efficiency

Increase Ventilation

Flow of respiratory medium over respiratory surface
Fish pump water thru gills to get fresh H_20 supply
But takes lots of energy

Counter-Current Exchange

In gill capillaries, blood flows against water current
so highest possible $[O_2]_{water}$ -> $[O_2]_{blood}$ gradient is maintained.

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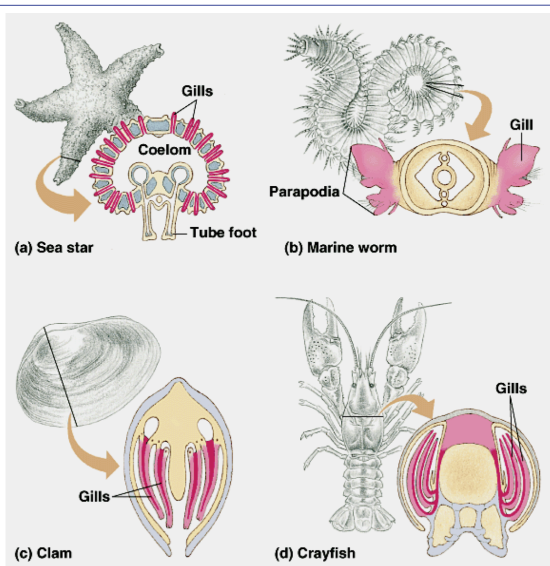
Figure 42.19 Diversity in the structure of gills, external body surfaces functioning in gas exchange



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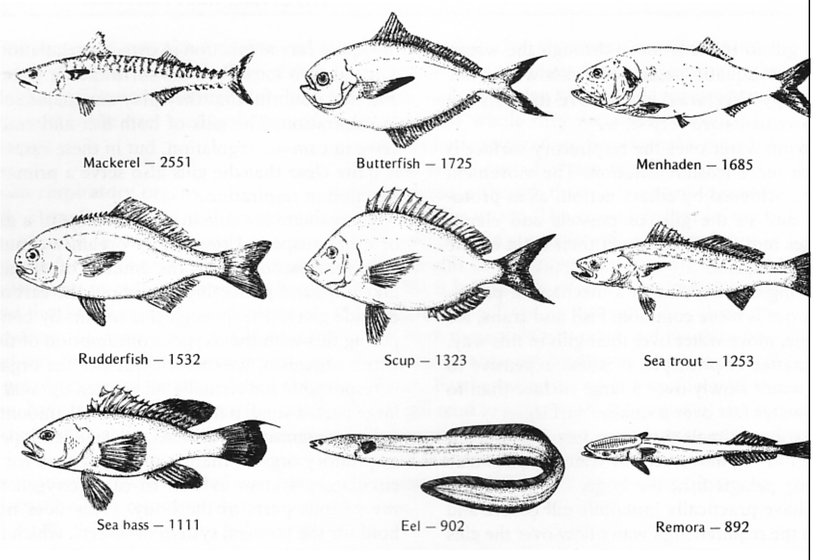
Surface Area of Gills (cm^2 per g BW) is higher in Active Fish



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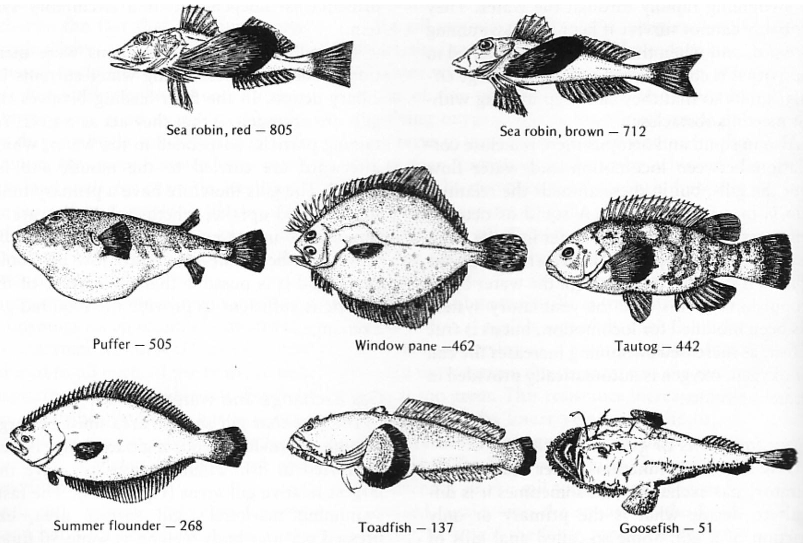
Surface Area of Gills (cm^2 per g BW) is lower in Less Active Fish



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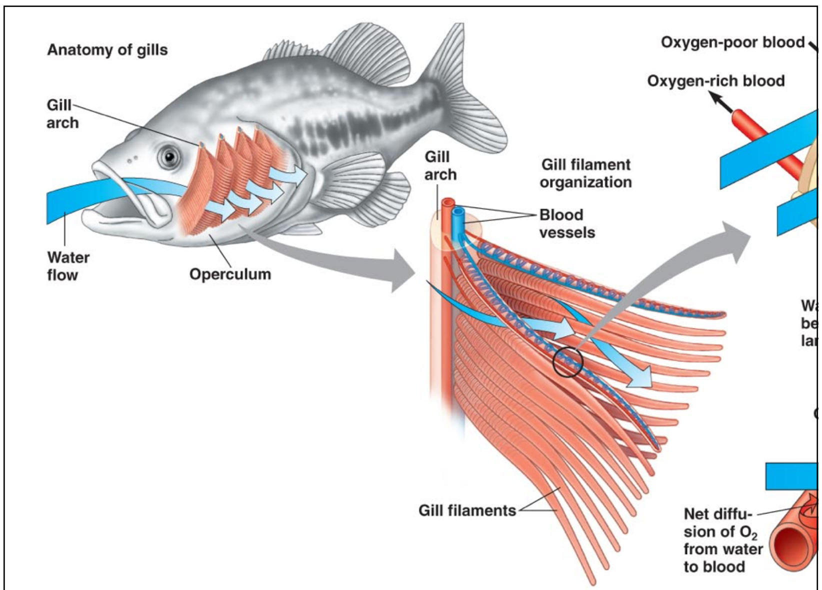

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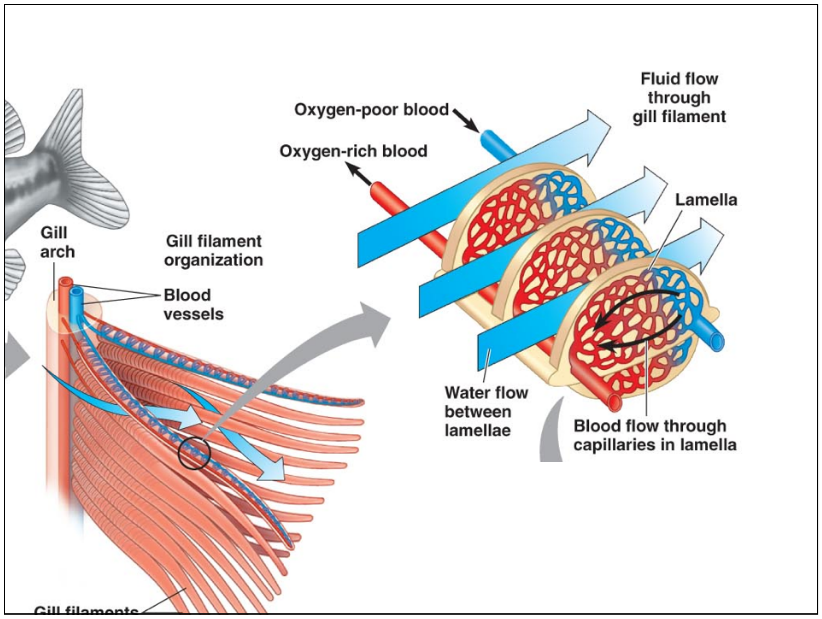

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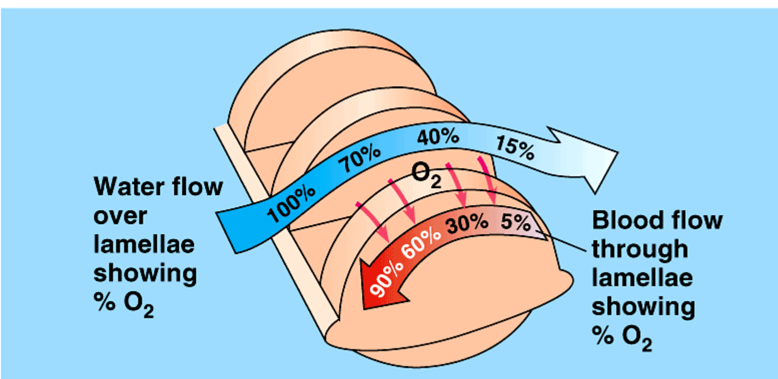
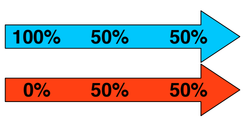
Counter-Current Exchange



If blood and water flow in same direction:



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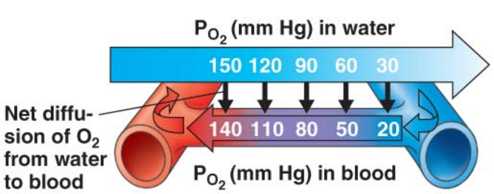
Counter-Current Exchange



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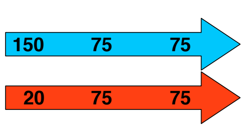

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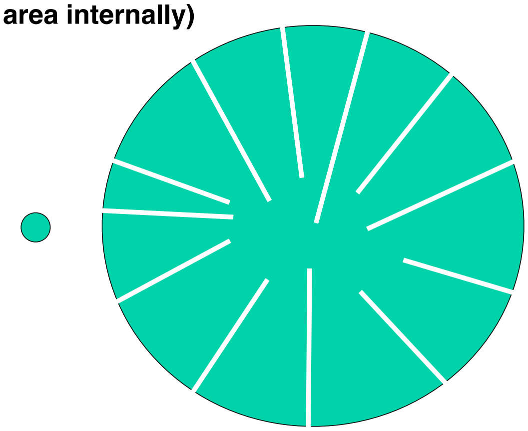
Facilitate diffusion with tubes into volume (increase surface area internally)



e.g. insects

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Tracheal Systems

In air, O_2 and CO_2 are at higher concentrations and diffuse much better than in water.

Therefore, air can diffuse into body via tubes. Can fold up moist respiratory surface and put it inside the body to reduce evaporation.

Terrestrial Insects

Use tracheal system connected to atmosphere via spiracles. Tracheoles run in close contact with all tissues, especially muscles.
Pumping of muscles can cause some ventilation of air tubes.

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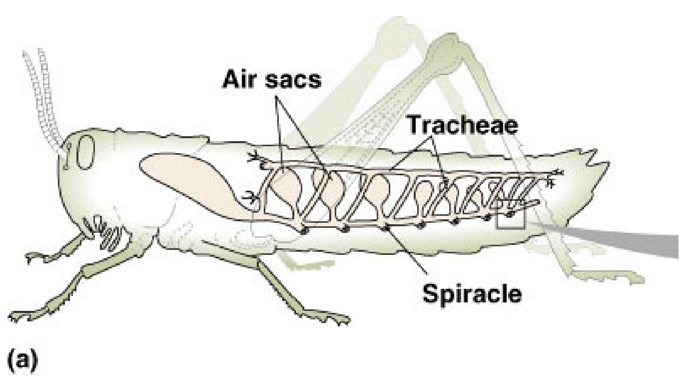

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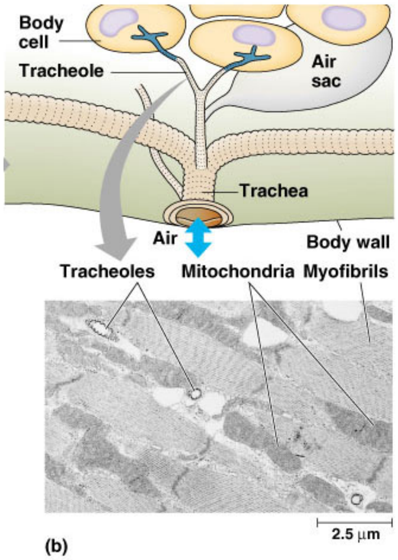

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Mammalian Lungs

Fold up moist respiratory surface and put it inside the thorax. In humans, 100 m^2 surface area.

human surface area = 6 m

Anatomy:
mouth -> larynx -> glottis -> trachea->bronchi -> bronchioles -> alveoli

Alveoli
millions of air sacs with thin moist walls and network of capillairies = respiratory surface of mammals

recall breaking surface tension within alveoli at birth is problem for terrestial animals.

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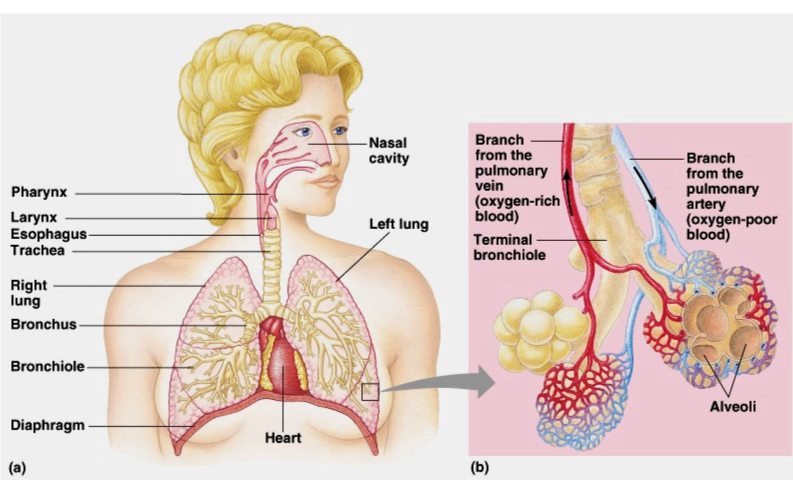
Figure 42.23ab The mammalian respiratory system



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Ventilation

Breathing to move air in & out of lungs
-> increase O2 and decrease CO2 within alveoli

positive pressure breathing:
push air into lungs with mouth (frogs)

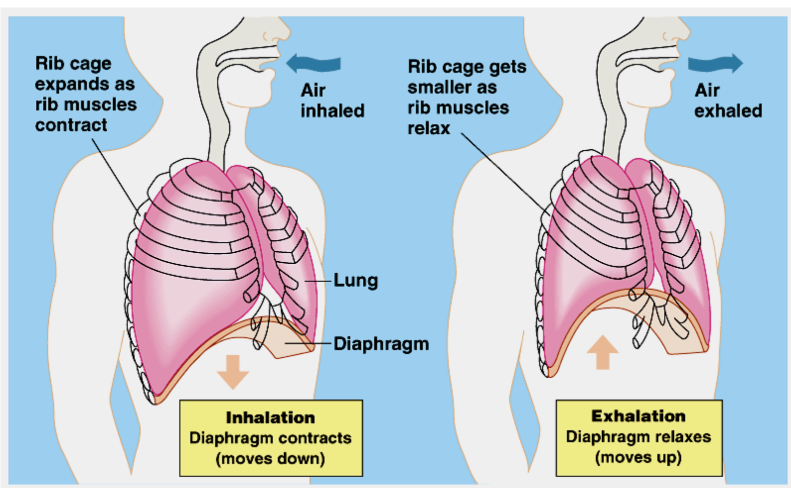
negative pressure breathing:
suck air into lungs using diaphragm (mammals)

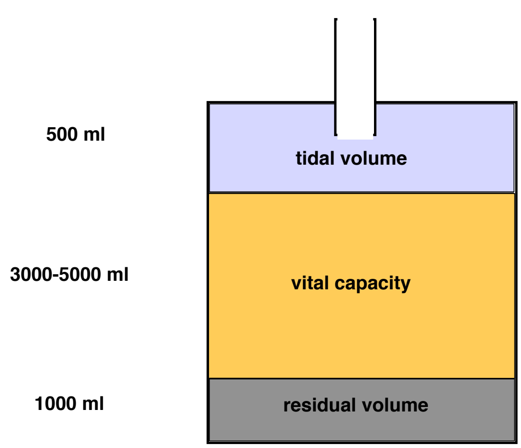
Tidal Volume
500 ml = normal breath

Vital Capacity
3400 (f) - 4800ml (m) in young humans = maximum breath

Residual Volume
left over air not exhaled -- inceases with age or disease, making ventilation less efficient

Figure 42.24 Negative pressure breathing





Disease state (like emphysema)

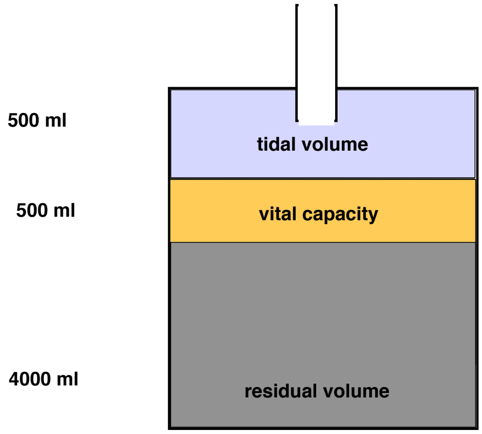


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Figure 42.25 The avian respiratory system

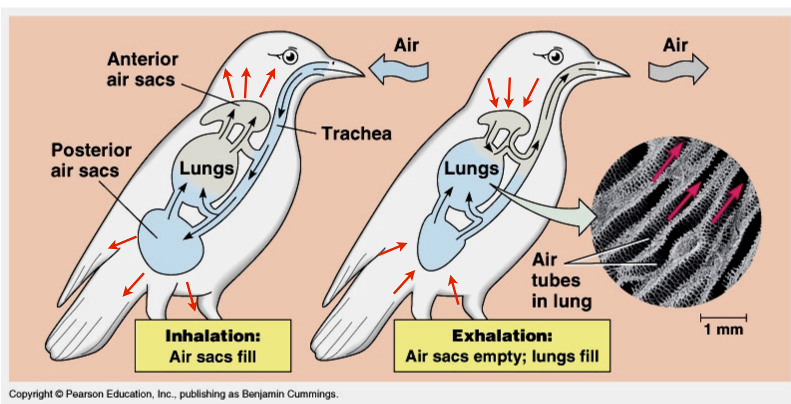

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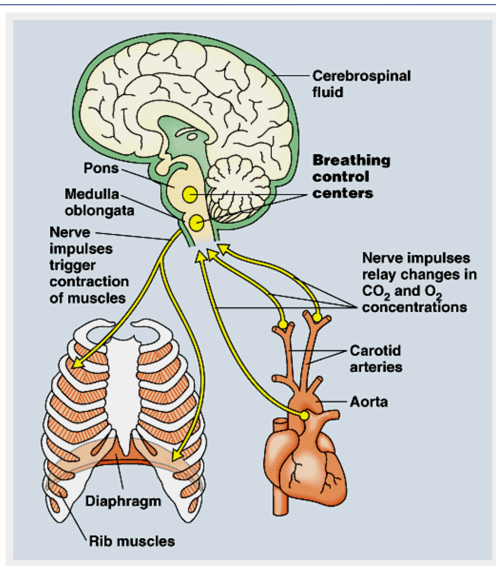
Figure 42.26 Automatic control of breathing



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Control of Breathing

1. Control centers in brain set up basic rhythm

   Periodic inhalation caused by rhythmic motor nerve firing.

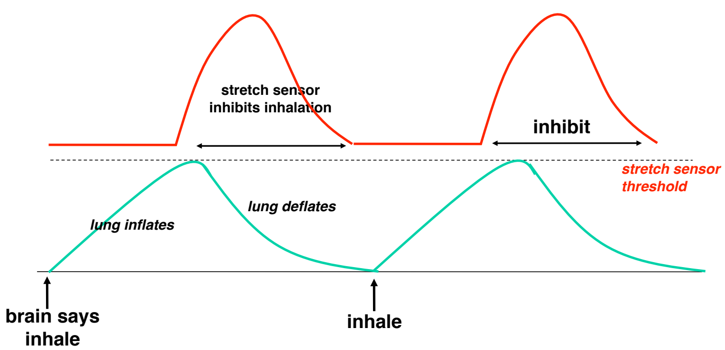
   Inhalation is terminated by feedback from lung stretch sensors that inhibit the motor nerves.

2. If CO_2 gets too high, CO_2 -> HCO_3^- -> lower pH (more acidic).

   Drop in pH in brain makes control centers speed up.

Control of Breathing

Control centers in brain set up rhythm:
periodic inhalation that is terminated by feedback from lung stretch sensors.

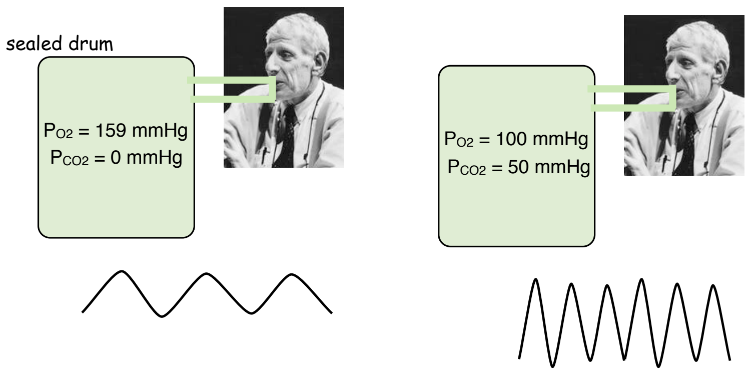


Breathing rate is regulated by blood pH and CO_2

- When CO_2 levels are high, breating rate increases to blow off CO_2
- In low CO_2 conditions, breathing rate does not change (even if O_2 levels are dangerously low)
- *example: pilots at high altitude*

Jonathan Miller, The Body in Question, part 4 (6/6) (youtube: X3dDQQcWhyU)

Rebreathing air: CO_2 drops as O_2 drops; breathing rate increases



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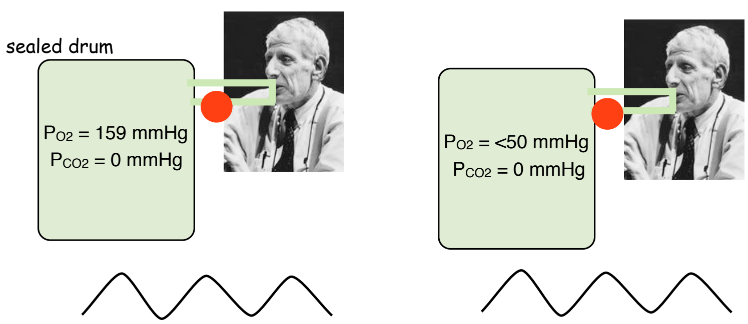
Rebreathing air with **CO_2 filter**: O_2 drops but CO_2 stays low.
Breathing rate does not increase, brain runs out of oxygen



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CO_2 and Bicarbonate act as a pH Buffer in the blood

Buffer - a chemical added to a solution to keep the pH constant by preventing rapid changes in [H^+]

As acid is added to a buffer, it absorbs the new [H^+].
---> so little or no change in pH

As base is added to a buffer, it gives up [H^+] to replace the ones sucked up by the base.
---> so little or no change in pH

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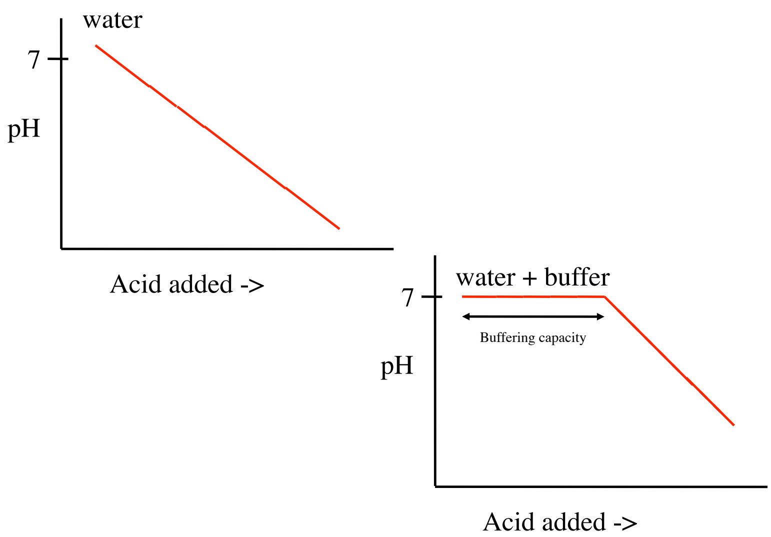

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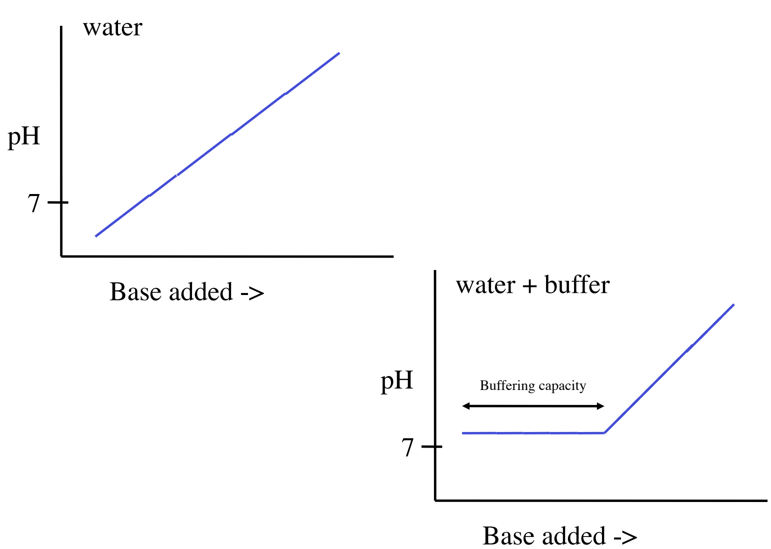

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Bicarbonate: The natural buffer in the blood

Carbonic acid — *Bicarbonate*

$CO_2 + H_20 \rightleftharpoons H_2CO_3 \rightleftharpoons HCO_3^- + H^+$

if pH ↑ , then need more H+

$CO_2 + H_20 \rightleftharpoons H_2CO_3 \rightharpoonup HCO_3^- + H^+$

↓

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↓

$CO_2 + H_20 \rightharpoonup H_2CO_3 \rightleftharpoons HCO_3^- + H^+$

So if blood pH rises (more basic), keep CO_2 -- *don't* breathe out

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if pH ↓ , then need to absorb more H^+

$H_2CO_3 \rightleftharpoons HCO_3^- + H^+$

$CO_2 + H_2O \rightleftharpoons H_2CO_3 \rightleftharpoons HCO_3^- + H^+$

$CO_2 + H_2O \rightleftharpoons H_2CO_3 \rightleftharpoons HCO_3^- + H^+$

So if blood pH drops (more acid), breath **off** CO_2

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pH and Breathing

If blood pH is too high (basic) breathe less to retain CO_2:

more CO_2 -> more bicarbonate + more H^+

If blood pH is too low (acidic) breathe more to blow off CO_2:

less CO_2 -> less bicarbonate + less H^+

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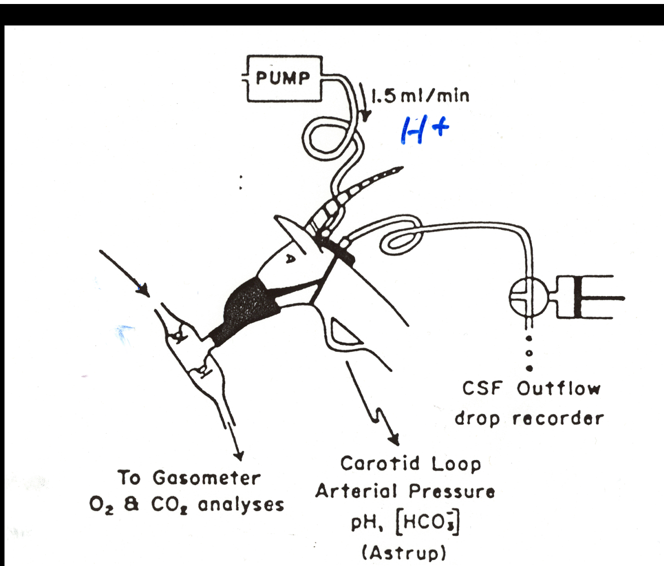

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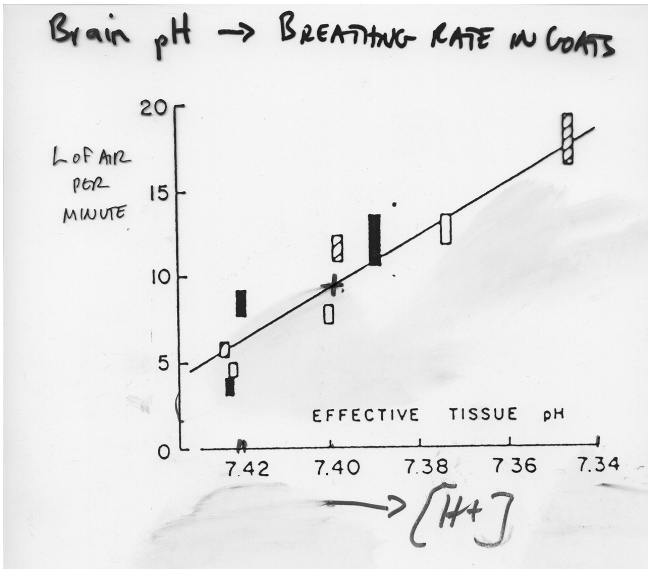

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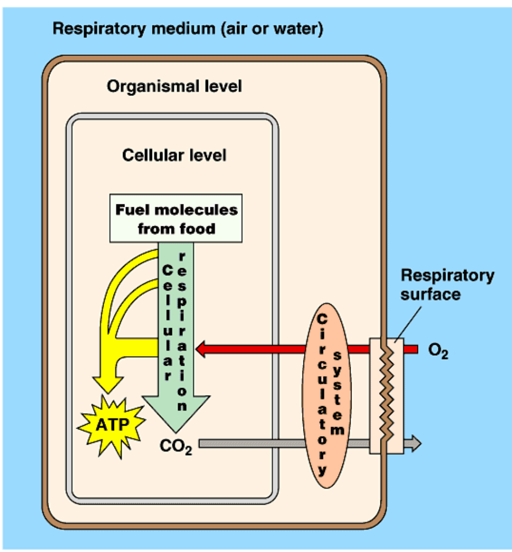

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Gas Exchange between Respiratory Surface, Blood in Circulatory System, and Tissues

Gas concentration measured in partial pressure

Atmospheric pressure is 760 mmHg.

O_2 is 21% of atmosphere, so P_{O2} = 160 mmHg

CO_2 is .03% of atmosphere, so P_{CO2} = .23 mmHg

Concentration of gas in solution is also expressed as partial pressure.

Gas moves from high concentration to low concentration.

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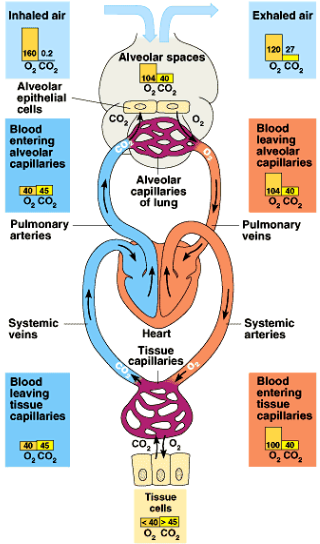
Figure 42.27 Loading and unloading of respiratory gases

O_2
- Air: 160
- Lung: 100
- Pulmonary arteries: 40
- Arteries: 100
- Tissue: < 40
- Veins: 40



CO_2
- Air: 27
- Lung: 40
- Pulmon. arteries : 45
- Veins: 45
- Tissue: > 45

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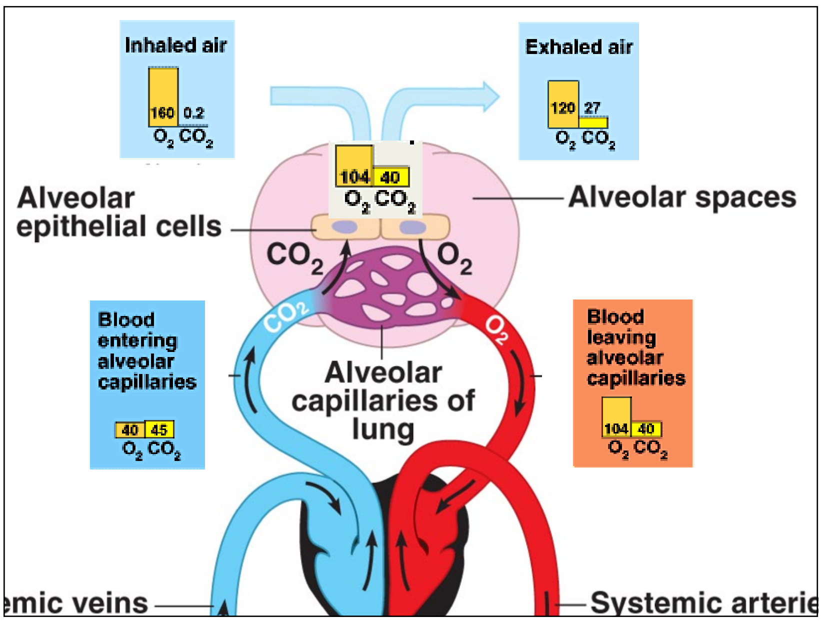

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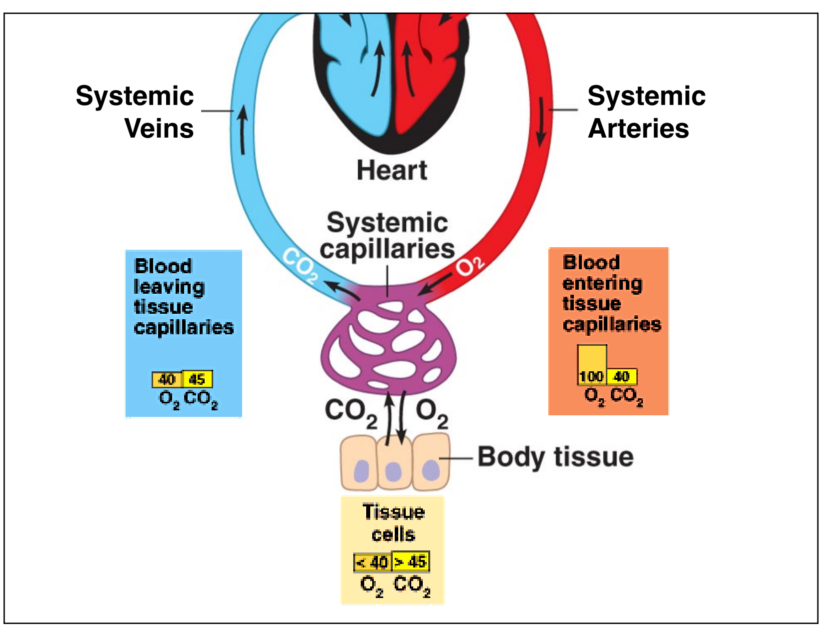

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