FICK'S LAW

Adolf Fick, 1858

Fick's law of diffusion of a gas across a fluid membrane:

Rate of diffusion = $KA(P_2–P_1)/D$

Wherein:

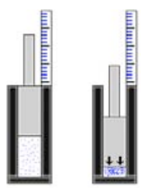
- K = a *temperature-dependent* diffusion constant.
- A = the surface area available for diffusion.
- $(P_2–P_1)$ = The difference in concentration (partial pressure) of the gas across the membrane.
- D = the distance over which diffusion must take place.

Properties of "Ideal" Gases

- Gases are composed of molecules whose size is negligible compared to the average distance between them.
  - Gas has a low density because its molecules are spread apart over a large volume.
- Molecules move in random lines in all directions and at various speeds.
  - The forces of attraction or repulsion between two molecules in a gas are very weak or negligible, except when they collide.
  - When molecules collide with one another, no kinetic energy is lost.
- The average kinetic energy of a molecule is proportional to the absolute temperature.
- Gases are easily expandable and compressible (unlike solids and liquids).
- A gas will completely fill whatever container it is in.
  - i.e., container volume = gas volume
- Gases have a measurement of pressure (force exerted per unit area of surface).
  - Units: 1 atmosphere [atm] (≈ 1 bar) = 760 mmHg (= 760 torr) = 14.7 psi = 0.1 MPa

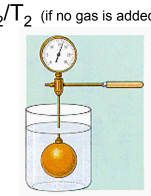
Boyles Law

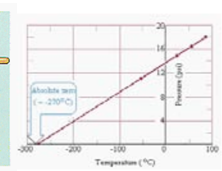
- Gas pressure (P) is **inversely** proportional to gas volume (V)
- $P \propto 1/V$
  $\therefore$ ↑V→↓P ↑P→↓V ↓V→↑P ↓P→↑V
- $\therefore$ $P_1V_1=P_2V_2$ (if no gas is added/lost and temperature is held constant)
  - ↓V → also ↑density



Amontons Law

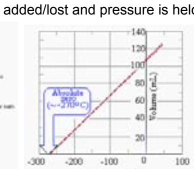
- Gas pressure (P) is **directly** proportional to absolute gas temperature (T in °K)
  - 0°C = 273°K
- $P \propto T$
  $\therefore$ ↑T→↑P ↑P→↑T ↓T→↓P ↓P→↓T
- $\therefore$ $P_1/T_1=P_2/T_2$ (if no gas is added/lost and volume is held constant)





Charles Law

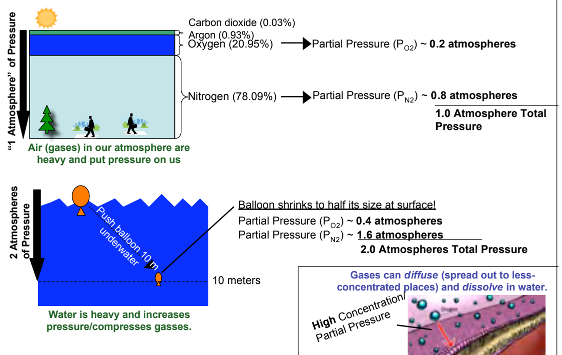
- Gas volume (V) is **directly** proportional to absolute gas temperature (T in °K)
  - 0°C = 273°K
- $V \propto T$
  $\therefore$ ↑T→↑V ↑V→↑T ↓T→↓V ↓V→↓T
- $\therefore$ $V_1/T_1=V_2/T_2$ (if no gas is added/lost and pressure is held constant)



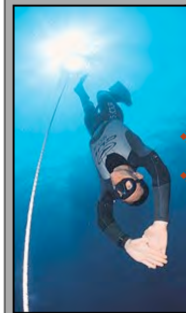
$\therefore$ Combined Gas Law

- Combining Boyles, Amontons & Charles Laws:
- $\therefore$ $P_1V_1/T_1= P_2V_2/T_2$ (if no gas is added/lost)
  - P_1 = initial pressure
  - V_1 = initial volume
  - T_1 = initial absolute temperature
  - P_2 = final pressure
  - V_2 = final volume
  - T_2 = final absolute temperature
- **Ideal Gas Law**: $PV=nRT$
  - n = total number of gas molecules in the vessel
  - R = constant

Gas Exchange: notes



Also note: When carbon dioxide (CO_2) dissolves in water, it creates an *acid* (carbonic acid → lower pH).

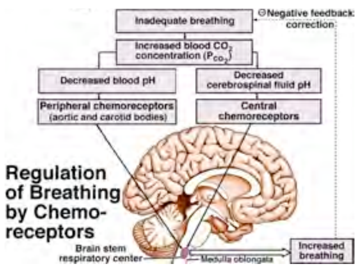


Gas Exchange

diving

- Diving: potential hazards
- Why seals can dive so long (and avoid the hazards)

Regulation of the drive to breathe



- Increasing P_{CO_2} decreases pH, stimulating you to breathe

c.f., **Fig. 42.28**

Free diving & shallow-water blackout

- Free diving = breath-hold diving
- Hyperventilate → ↓P_{CO_2} in blood → you don't feel the need to breathe → dive long & deep.
- Diving →↑depth →↑P_{O_2}, so you extract more O_2 from air.
- With low P_{CO_2} in blood, you still don't feel the need to breathe.
- Ascent →↓depth →↓↓P_{O_2}.
- ↓P_{O_2} in blood to brain → loss of consciousness

SCUBA: self-contained underwater breathing apparatus
Decompression Sickness (Bends)

- SCUBA: breathing air at ambient pressure
- At 30 meters depth, your whole body feels a pressure of 4 atm (1+3) -- including the air in your lungs.
- Diving →↑depth →↑P_{N_2}. N_2 dissolves in tissues.
- Ascent →↓depth →↓P_{N_2} (decompress). N_2 tissues comes out of solution → microbubbles.
- If enough microbubbles form, may collect in tissues & small vessels causing bends.

SCUBA: self-contained underwater breathing apparatus
Air Embolism

- SCUBA: breathing air at ambient pressure
  - At depth, lungs filled with air at high pressure
- Ascent →↓depth →↓total pressure.
  - ↓P →↑V
  - If holding your breath, lung volume overexpands
- Alveoli rupture → air bubbles into bloodsream
- Bubbles may lodge in tissues & small vessels causing stroke, heart attack, etc..

SCUBA: self-contained underwater breathing apparatus

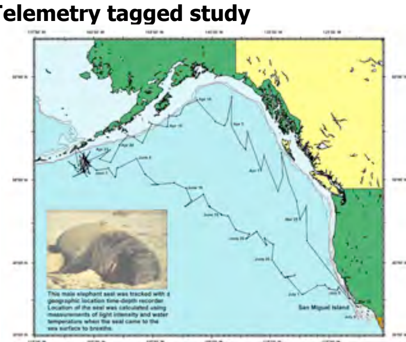
The 3 Rules!

- **Don't panic!**
  - **You brought air with you — no need to rush**
  - **Stop! — Breathe! — Think!**
- **Never hold your breath!**
  - **if breathing compressed air**
- **Ascend slowly!**
  - **Allow your body to adapt gradually**

Elephant Seals

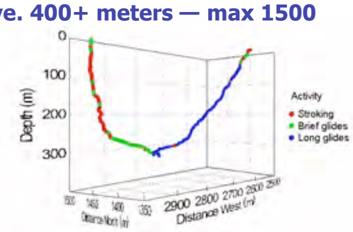
Elephant seal dives:

- **Telemetry tagged study**



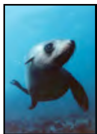
Elephant seal dives:

- **Swim 90 km/day**
- **Underwater 90% of time**
- **Ave. dive = 24 min — max 2 hr — with 2.5 min surface intervals**
- **Dives ave. 400+ meters — max 1500 meters**



It's not in the lungs

- **Lung volume ≈ 4.6% of body volume for all mammals -- including marine mammals.**
- **Marine mammals don't rely on the air in their lungs while underwater.**



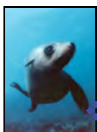
Marine mammals have 2 kinds of tricks:

- Use oxygen slowly.
- Store a lot of oxygen.

Use oxygen slowly:

The Diving Reflex:

- Heart rate slows
- Blood pressure decreases
- Peripheral circulation decreases
- Spleen shrinks: more blood into circulation

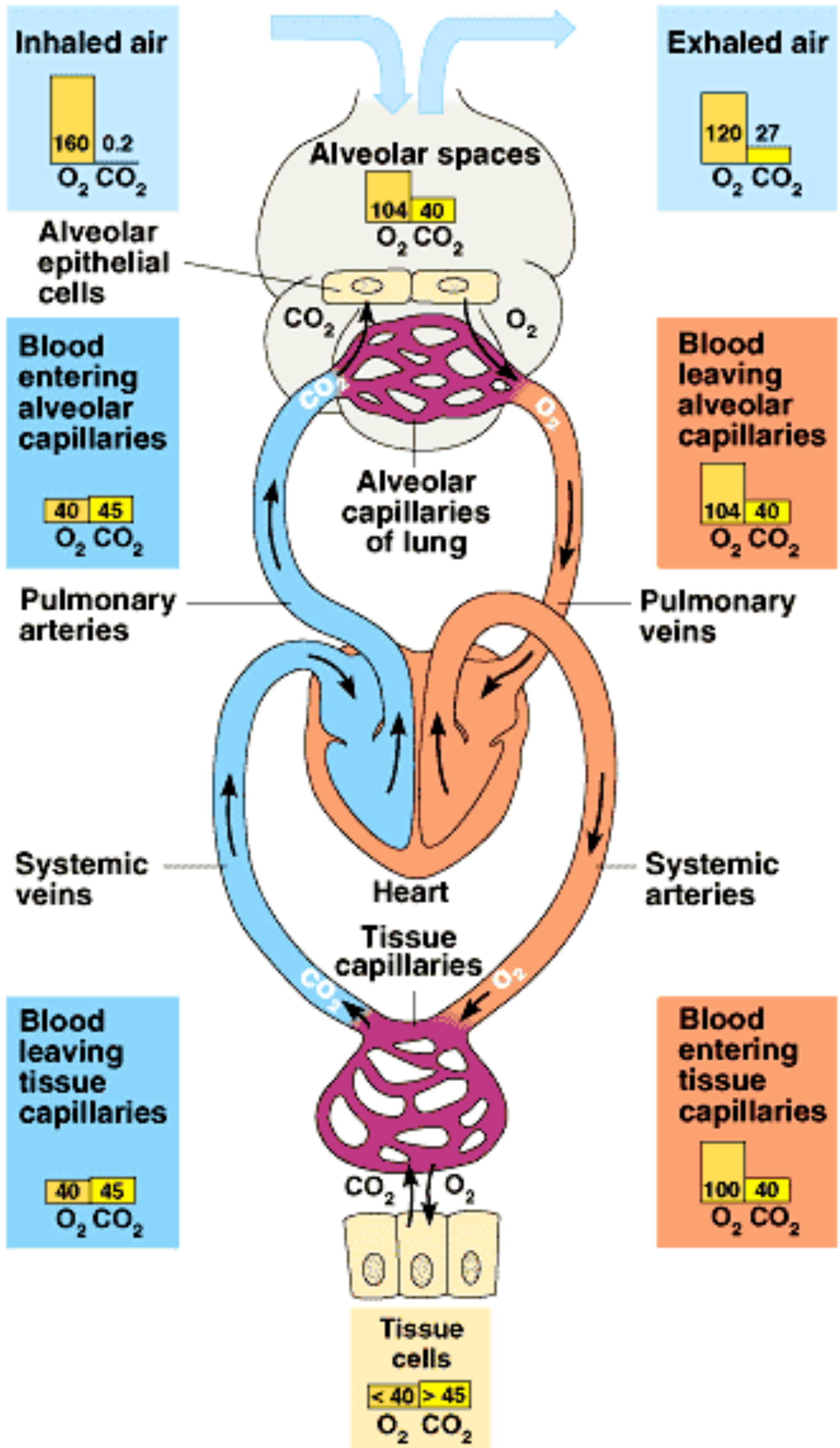


***Store a lot of oxygen*:**

- Large blood volume
- High concentration of red cells
- High concentration of hemoglobin in red cells
- High concentration of myoglobin in muscle

Why can they dive so much better than us?

Why don't they get air embolisms?
Why don't they get the bends?
Why don't they get shallow water blackout?



c.f., **Fig. 42.29**

O_2 & CO_2 diffuse from high concentration to low concentration.