Lecture 1:
Physics: The Ideal Gas Laws and Hyperbaric Medicine

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building the nation's leading wound care team.

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Hyperbaric Medicine – Physics is important

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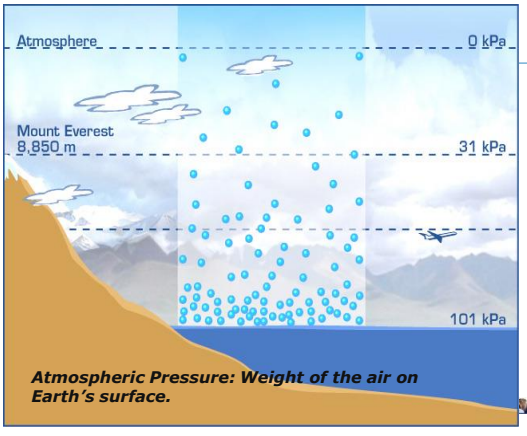
Pressure

- DEFINITION: Force exerted per unit area of surface by molecules in motion.
  - 1 atmosphere = 14.7 psi
  - 1 atmosphere = 760 mm Hg



Atmospheric Pressure

"The weight of the air"

- Acts on all bodies in the atmosphere
- Varies with weather conditions and altitude.

One Atmosphere at sea level

ONE ATA

8000 feet = 0.74 ATA

29,108 feet = 0.31 ATA

Barometric Pressure

- Atmospheric pressure varying with weather
- Expressed in terms of the height of a column of mercury (mmHg)
- Standard barometric pressure is 29.92 inches or 760 mmHg
- Can be measured in Atmospheres
  - —1 ATA = 760 mmHg

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Atmospheres Absolute

- Always included atmospheric pressure (e.g. Atmospheric pressure plus hydrostatic pressure).
- Abbreviated ATA
- Can be measured in pounds per square inch absolute, psia

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Gauge Pressure

- Sea level is starting point.
- Measured in psi
- 0 fsw = 0 psig
- **Does not include atmospheric pressure**
- Difference between absolute pressure and the pressure being measured
- Convert Gauge to Absolute pressure by adding 14.7 psi
- • 14.7 psig = 29.4 psia

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Units of Pressure

- ABSOLUTE PRESSURES :
  - Atmosphere absolute (ATA)
  - Pounds per square inch absolute(psia)
- GAUGE/ RELATIVE PRESSURE
  - Atmospheres, gauge (ATM)
  - Feet of sea water (fsw)
  - Meters of sea water (MSW)
  - Pounds per square inch gauge (psi / psig)
  - Kilopascals (kPa)
  - Megapascals (mPa)

Hydrostatic Pressure

- Pressure produced by the weight of water on anything immersed.
- Combination of both weight of liquid and atmospheric pressure.
- Salt water has greater density than fresh water
  - 33 fsw = 14.7 psi(g) or 1 Atmosphere.
  - Increases by 0.445 psi per fsw
  - Increases by 0.433 psi per ffw

Depth and Pressure

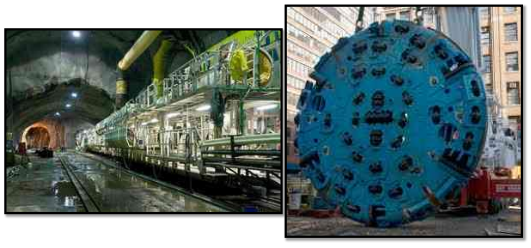
Feet of Sea Water

- 10 fsw =19.5 psia or 1.32 ATA.
- 33 fsw = 29.4 psia or 2 ATA.
- 66 fsw = 44.1 psia or 3 ATA

ATA and HBOT

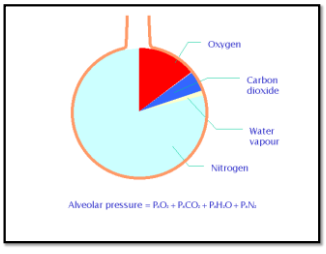
- HBOT prescriptions are usually written in Absolute Pressure (ATA).
- Atmospheric pressure is always included.
- Calculations are often in ATA.

Sandhogs and psi



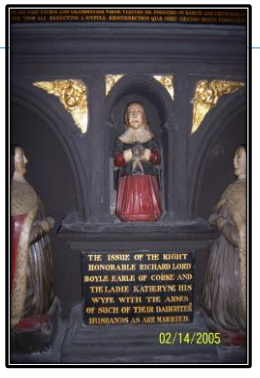
Partial Pressure

- Pressure exerted by a given gas in mixture
- Partial pressure is directly proportional to the gases percentage of the total volume less water vapor.



The Gas Laws

Sir Robert Boyle



Boyle's Law

"At constant temperature, the pressure and volume of a gas are inversely proportional to each other."

Example

- A diver inflates a balloon with 100 ml air at 33 fsw. What will be the volume when he reaches surface?

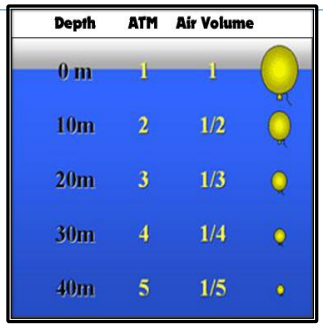
The formula: $P_1V_1 = P_2V_2$

$29.4(100)=14.7x$

$2940=14.7x$

$200=x$

Boyle and Bubbles



Relevance to Hyperbaric Medicine

- Descent (compression) –
  - — Ear Squeeze
  - —Tooth pain
  - —Sinus Squeeze
  - —Collectively known as Barotrauma •
- Ascent (decompression) – Pneumothorax
  - —Air Gas Embolism (AGE)
  - —Reason the bag of peanuts are over inflated on the airplane

REAL LIFE EXAMPLES

Boyle to the rescue

- Patient is pressurized to 2.4 ATA
- RN notes an enlarging bubble in the air break oxygen tubing
- The tech the evening has assembled the tubing incorrectly.
- Two one way valves result in a bubble in the tube
- Your Plan is…….

Charles Law

Charles Law

- At Constant pressure, the Volume of a gas is directly proportional to temperature (Kelvin).
- that is,
- As temperature increases, volume increases.
- As temperature decreases, volume decreases

Proportional Relationship

$$\frac{V_1}{T_1} = \frac{V_2}{T_2}$$

Example

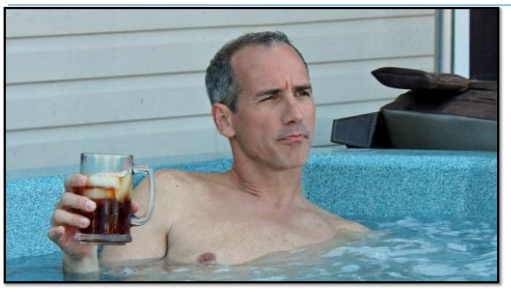
- At 200K, the volume of a gas is 100 ML. The temperature is raised to 300K, what will the new volume be?

Formula: V1/T1 = V2/T2

100/200 = x/300

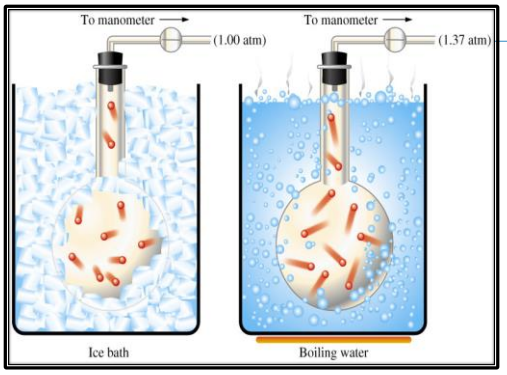
(.5)(300) = x

150cc



Gay-Lussack

As Temperature increases, Pressure increases, when volume remains constant



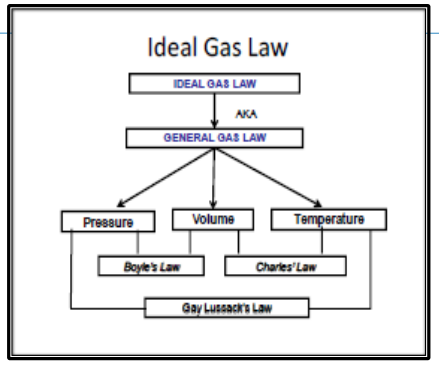
Clinical Relevence

- Reason a scuba tank left in sun will explode.

-not really they are vented.

- This is why a patient feels warm during chamber compression.
- This is why a patient feels cool during chamber decompression.

Increased Temperature in the chamber increases pressure



Dalton

- Developed atomic theory of matter
- Devised system of chemical symbols
- Formulated theory combination of different elements occurs in simple numerical ratios by weight.
- Elements are composed of tiny, indestructible particles called atoms that are all alike and have the same atomic weight.

Dalton's Law

- The total pressure exerted by a mixture of gases is equal to the sum of the partial pressures of each of the different gases making up the mixture.
- Pt= Pa+Pb+Pc
- Pt=The total pressure of a gas mixture.
- Pa+Pb+Pc= the individual pressures of each component

Partial Pressures

Dalton's Gas Law

- **Total Pressure = Σ Partial Pressure- $PO_2 = FO_2 \times ATA$**

pO_2 = .21 * 1 ata = .21 ata

pN_2 = .79 * 1 ata = .79 ata

p_{total} = .21 ata + .79 ata = 1.00 ata

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Practical Terms

- The partial pressure is the same proportion to the total pressure of a mix of gases as its number of molecules are to the total number of molecules in the mixture.
- Remember: Percentages only define the ratios between the number of molecules in a mix.
- **Partial pressure is responsible for the physiological effects of the individual gas.**

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Henry's Law and the Head on your Beer

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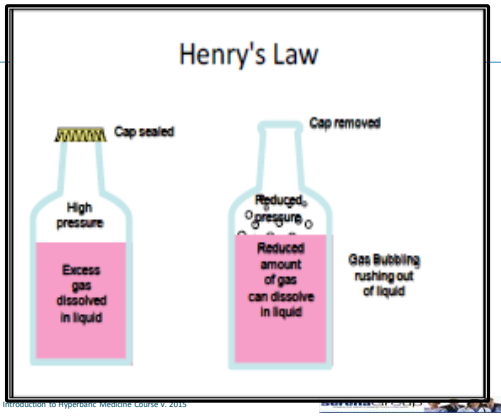


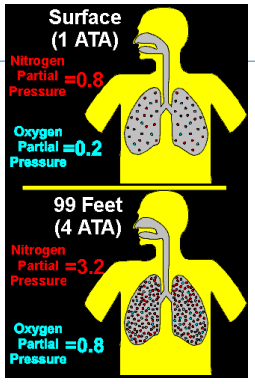
Henry's Law

The volume of gas dissolved in a liquid is directly proportional to the partial pressure of the gas in contact with the liquid

Clinical Relavence

- The greater the pressure, the more of the gas dissolved in the liquid. – Explains the uptake of nitrogen
- • The less the pressure, the greater the return to the gaseous state – Explains Decompression injury

- Clinical Relevance—bending tenders



A combination of Boyle's, Dalton's, and Henry's laws say that at depth, increased density of gas molecules will increase the amount of those gases entering the blood.

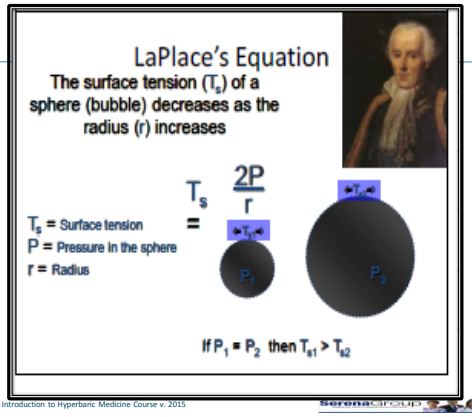
Henry and Dalton: Gas Diffusion

- The difference between the partial pressure of a gas inside a liquid and its outside partial pressure will cause the gas to diffuse in or out of the liquid and will also control the rate of diffusion.

Example: At 66 fsw, pPN2 = 3 atm * 0.79
= 2.4 atm

Blood	Diffusion Direction	Tissue
pPN_2 = 2.4 atm	→	pPN_2 = 0 atm

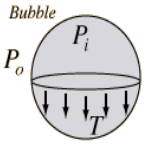
As a diver descends, inspired gases diffuse into tissues; as a diver ascends, gases diffuse out of tissues and into the blood



Mathematics

For a bubble with two surfaces providing tension, the pressure relationship is:

$$P_i - P_o = \frac{4T}{r}$$



Blaise Pascal

Pressure exerted at any point upon a confined liquid is transmitted equally throughout.

Pascal's Law

Does Blood Pressure change with changing ambient pressure?

No!

As pressure distributes evenly throughout the body, the pumping action of the heart will generate the same BP. As long as the BP monitor reads "0" at depth, the reading will remain the same.

Boyle and Pascal

Fill the cup with beer and descend.

Gas Law Summary

- **Boyle's Law** – At a constant temperature, the pressure and volume of a gas are inversely proportional to each other.
- **Charles' Law** – At a constant pressure, the volume of gas is directly proportional to the temperature. As temperature increases, volume increases; as temperature decreases, volume decreases.
- **Gay-Lussac's Law** – At a constant volume, when temperature increases, pressure increases. As temperature increases, pressure increases; as temperature decreases, pressure decreases.
- **Dalton's Law** – The total pressure exerted by a mixture of gasses is equal to the sum of the partial pressures of each of the different gases making up the mixture.
- **Henry's Law** – The volume of a gas dissolved in a liquid is directly proportional to the partial pressure of the gas in contact with the liquid.
- **Laplace's Equation** – The surface tension of a sphere decreases as the radius increases.
- **Pascal's Law** – Pressure exerted at any point on a confined liquid is transmitted equally throughout the

Extra Credit from St. James Gate

Thank You

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