THERMAL PROPERTIES OF MATTER

I. THE GAS LAWS

(A) WHY STUDY GASES?

(1) THEY ARE IMPORTANT TO LIFE!

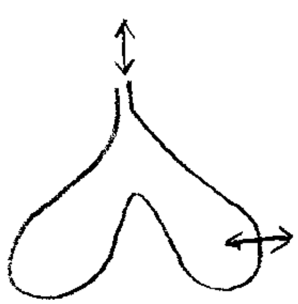
- e.g., Respiration and Blood-Gases
  - Basic to understanding physiology
  - Respiratory Therapy

    What rates, pressures, volumes, gas mixtures required to ventilate a damaged lung, ensuring adequate blood-gas solutes?

(B) WHY STUDY BALLONS AND PISTONS?

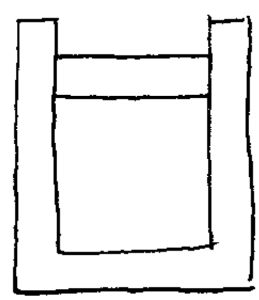
(1) Physiological processes are very complicated. Best to simplify problem first, then work back up to the hard problem.

<u>Lung</u>



(P, V, T, N) all important, but all changing at once in complicated ways

<u>Cylinder/Piston</u>



(P, V, T, N) all important, but easier to change just one variable & see what happens to the other ones

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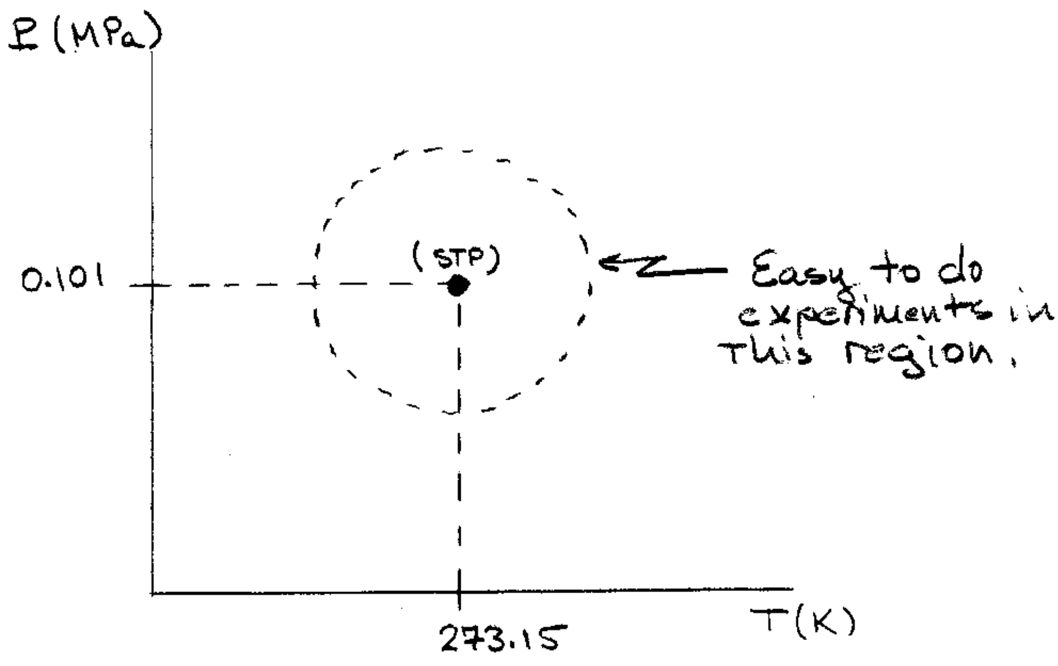
(C) STP (STANDARD TEMPERATURE AND PRESSURE)

(1) Defn: $\boxed{T = 273.15\,K \qquad P = 0.101\,MPa}$

$1\,Pa \equiv 1\,\frac{N}{m^2}$ $\quad 1\,MPa = 10^6\,Pa$ $\quad 0.101\,MPa \cong 1\,atm$

(2) Why these particular values?

- Historical Convenience, Mostly.
    - atmospheric pressure doesn't change that much over time.
    - Ice water serves as a quick, readily-available & cheap constant-temperature reservoir.



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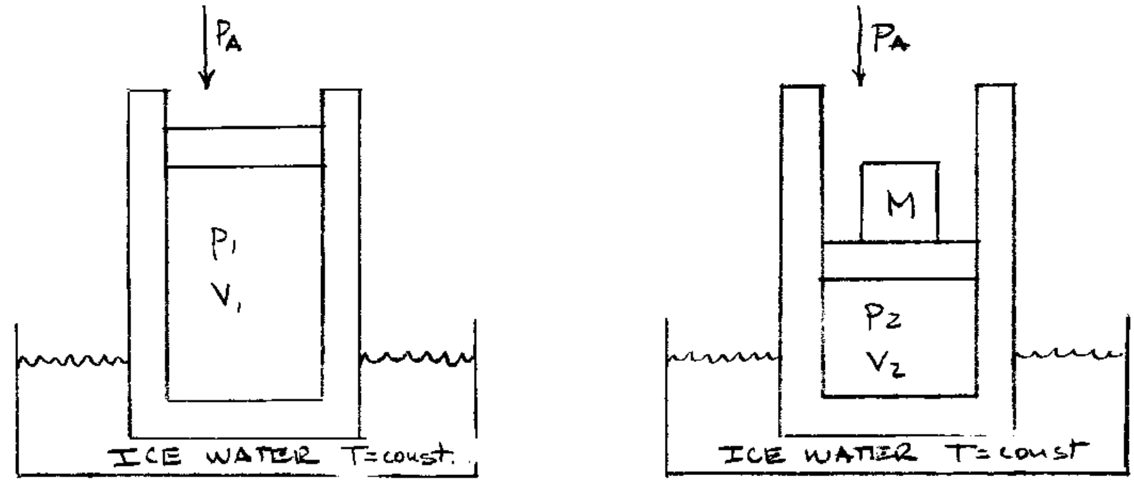
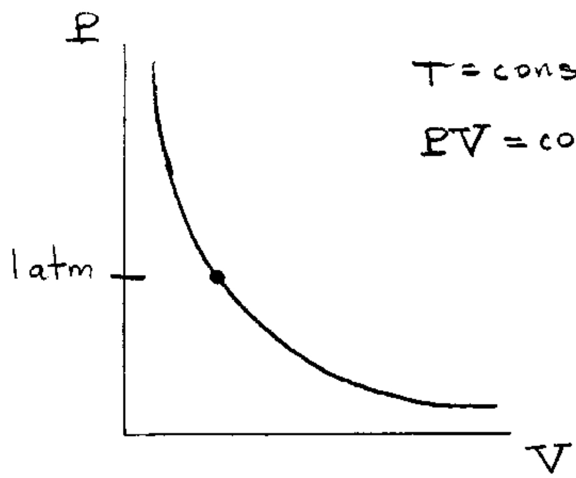
(D) P vs. V at T = const. (Boyle's Law, ca. 1662)





T = const.

PV = const.

$\boxed{\text{Ex.}}$ $P_1 = 1.00$ atm, $V_1 = 100.\ \text{cm}^3$

$P_2 = 1.10$ atm, $V_2 = ?$

$$PV = \text{const.}$$

$$\Rightarrow \quad P_1 V_1 = P_2 V_2$$

$$V_2 = \frac{P_1 V_1}{P_2}$$

$$= \frac{(1.00\ \text{atm})(100.\ \text{cm}^3)}{(1.10\ \text{atm})}$$

$$V_2 = 90.9\ \text{cm}^3$$

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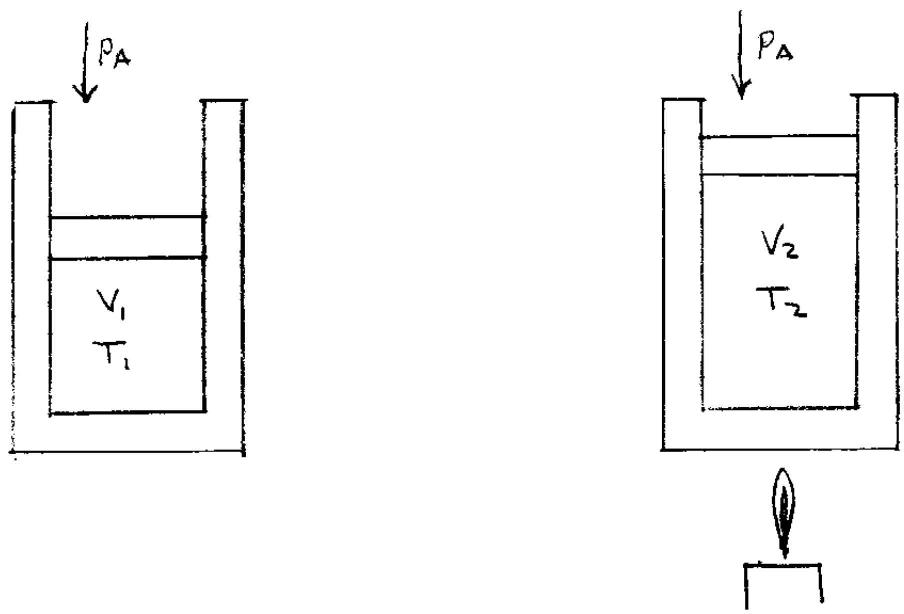
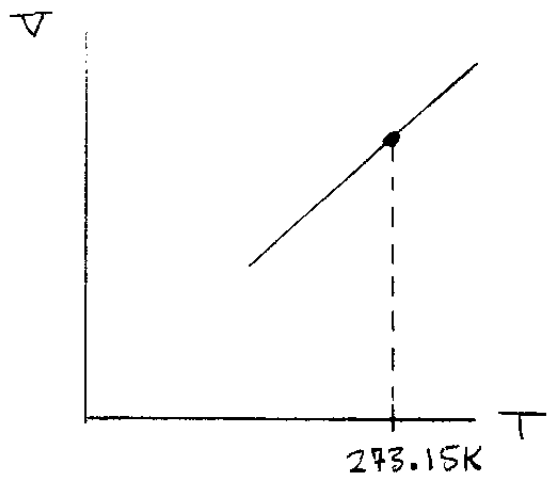
(E) V vs. T at $P = \text{const.}$ (Charles' Law, ca. 1787)





$P = \text{const.}$

$\frac{V}{T} = \text{const.}$

$\boxed{\text{Ex:}}$ $V_1 = 1.25\,m^3$, $T_1 = 273.15\,K$ $\quad P_1 = P_2 = p_A = 0.101\,MPa$

$V_2 = \,?$, $T_2 = 300.\,K$

$$\frac{V}{T} = \text{const.}$$

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

$$V_2 = V_1\left(\frac{T_2}{T_1}\right) = (1.25\,m^3)\left(\frac{300.\,K}{273.15\,K}\right)$$

$$V_2 = 1.37\,m^3$$

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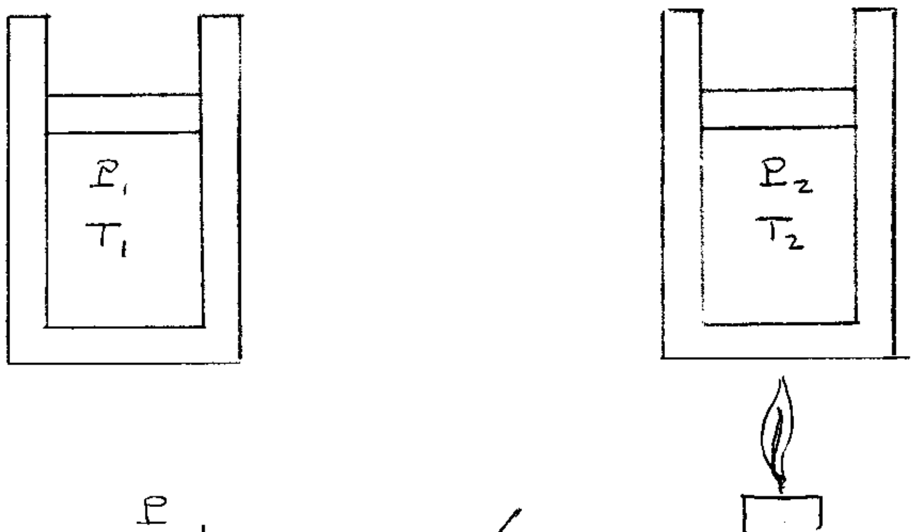
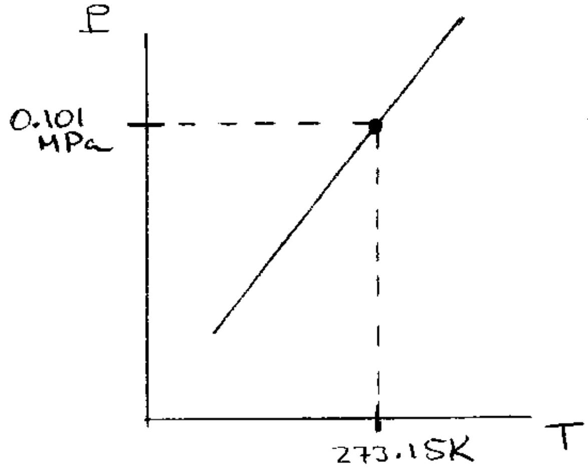
(F) P vs. T at V = const. (Gay-Lussac's Law, ca. 1802)





$V = \text{const.}$

$\frac{P}{T} = \text{const.}$

$\boxed{\text{Ex:}}$ $P_1 = 0.101\,\text{MPa}$ $\quad T_1 = 273.15\,\text{K}$ $\quad V = \text{const.}$

$P_2 = \,?$ $\quad T_2 = 293.\,\text{K}$

$$\frac{P}{T} = \text{const.}$$

$$\Rightarrow \frac{P_1}{T_1} = \frac{P_2}{T_2}$$

$$P_2 = P_1 \left(\frac{T_2}{T_1} \right)$$

$$= (0.101\,\text{MPa}) \left(\frac{293.\,\text{K}}{273.15\,\text{K}} \right)$$

$$= 0.108\,\text{MPa}$$

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(G) P vs. (N/V) → (particle density) (No Name)

For $(N/V) \ll 1$ (small) (low-density)

II. THE IDEAL GAS LAW

(A) Combining first three above gas laws:

$$PV = \text{const.}$$

$$\frac{V}{T} = \text{const.}$$

$$\frac{P}{T} = \text{const.}$$

$$(PV)\left(\frac{V}{T}\right)\left(\frac{P}{T}\right) = (\text{const.})(\text{const.})(\text{const.}) = \text{const.}$$

$$\frac{P^2V^2}{T^2} = \text{const}$$

$$\frac{PV}{T} = \text{const.}$$

$$P \sim \frac{T}{V}$$

but,

$$P \sim \left(\frac{N}{V}\right)$$

$$P \sim \frac{NT}{V}$$

OR

$$PV \sim NT$$

$$\boxed{PV = Nk_BT}$$

Ideal Gas Law

k_B = "Boltzmann's Constant"

Experimentally, $\boxed{k_B = 1.38 \times 10^{-23}\ J/K}$

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Also can be written

$$\boxed{PV = nRT}$$

where $n = \#$ of moles of gas molecules

(1 mole $= 6.02 \times 10^{23}$ molecules)

$R = 8.315 \frac{J}{mol \cdot K}$ ("Universal Gas Constant")

- Note that the Ideal Gas Law contains all of the information we have learned about gases so far.

$$PV = Nk_BT$$

$$\Rightarrow \quad \frac{PV}{NT} = k_B = \text{const.}$$

$$\Rightarrow \quad \boxed{\frac{P_1 V_1}{N_1 T_1} = \frac{P_2 V_2}{N_2 T_2}}$$

$\boxed{\text{Ex!}}$ $N = \text{const}$ $T = \text{const}$ $\Rightarrow P_1V_1 = P_2V_2$, etc.

(Boyle's Law)

$P = \text{const}$, $N = \text{const}$ $\Rightarrow \frac{V_1}{T_1} = \frac{V_2}{T_2}$

(Charles' Law)

$V = \text{const}$, $N = \text{const}$ $\Rightarrow \frac{P_1}{T_1} = \frac{P_2}{T_2}$

(Gay-Lussac's Law)

$\boxed{\Rightarrow \text{All you need is the Ideal Gas Law}}$

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(B) WHY "IDEAL"

(1) Recall that our supporting evidence for these "Laws" was only obtained from experiments "around" STP.

(2) We reasoned that $p \sim (N/V)$, but what if (N/V) is <u>not</u> small (i.e., high-density)? What happens when we try to put two molecules into a space smaller than their own size?

(3) "Ideal" means "Under normal conditions":

- Near atmospheric pressure
- Near normally-observed temperatures
- Densities small enough to ignore that molecules have a size.
- Other conditions are also understood, but with more complicated theories.