

Ideal gases

low density gases :

- microscopic billiard/pool : elastic shock between atoms (molecules)
- no intermolecular forces (well separated atoms)

energy (internal energy) of gas

kinetic energy of atoms/molecules
=> any change in energy results in a Temp change

exp Boyle - Mariotte

exp. observation (Boyle, 17th century)

P.V = constant for a given T

exp. observation :

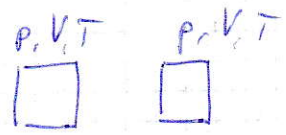
(J. Charles 18th-19th Cent, J. Gay-Lussac)

P.V = const * T (const is > 0)

exp Gay-Lussac

const = ... ?

take 2 containers



P.V/T = const

-> merge as one system



P.2V/T = const'

hence : const proportional to nb of gas molecules (amount of gas) (const' = 2 * const)

and, def : const = k_B * N (N = nb molecules, k_B = other constant...!)

and P.V = N * k_B * T

k_B = 1.38 * 10^-23 J/K, Boltzmann constant (value found exp.)

N = n * N_A

N_A = 6.022 * 10^23 mol^-1, Avogadro number
n = nb of moles (mol)

def : 1 mol of a substance contains N_A elements (atoms or molecules) (measure of the amount of a gas, here)

thus

P.V = N * k_B * T = n * N_A * k_B * T

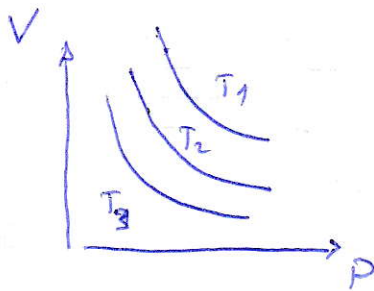
ideal gas law

P.V = n * R * T, R = N_A * k_B = 8.314 J/mol.K

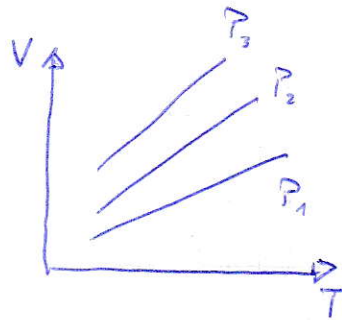
(slide) univ. gas constant

note [P.V] = N/m^2 * m^3 = N.m = J energy/work
Universal gas constant

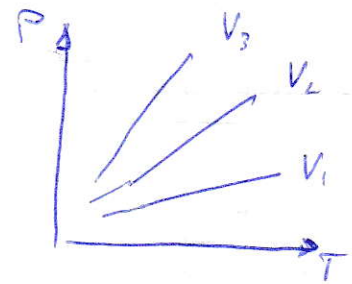
a) schematic behavior $PV = n \cdot R \cdot T$ take $n = \text{const}$ (e.g. 1 mol)



$T_1 > T_2 > T_3$
isotherms



$P_1 > P_2 > P_3$
isobars



$V_1 > V_2 > V_3$
isochores

b) $PV = n \cdot R \cdot T$, take $n = 1$, N_A molecules

exp show
molvolumen

$$V = \frac{R \cdot T}{P} \approx \underline{22.7 \text{ l}} = 22.7 \cdot 10^{-2} \text{ m}^3$$

at standard pressure
& temperature (STP)

$$P = 100 \text{ kPa}$$

$$T = 273.15 \text{ K}$$

$$R = 8.314 \frac{\text{J}}{\text{mol} \cdot \text{K}}$$

$$P \cdot V = n \cdot R \cdot T$$

- relation between P , V and T for an ideal gas
 - correction required ~~at~~ when gas density increases
- state equation
(gas law)

exp Boyle Mariotte : $P V = \text{const}$
works really?

exp Gay Lussac : $\frac{P}{T} = \text{const}$ for $V = \text{const}$

measure P for various T
for fixed volume of gas V
(He)

- R.T boiling water
 - 0°C
 - N₂ liquid 77K
- | write values
+ plot

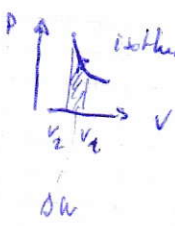
examples of expansion of gas (ideal) from V_1 to V_2 at $T = \text{const}$

work: $\Delta W = \int_{V_1}^{V_2} P \cdot dV = \int_{V_1}^{V_2} n \cdot R \cdot T \cdot \frac{dV}{V} = n \cdot R \cdot T \cdot (\ln V_2 - \ln V_1)$

isotherm ($T = \text{const}$)

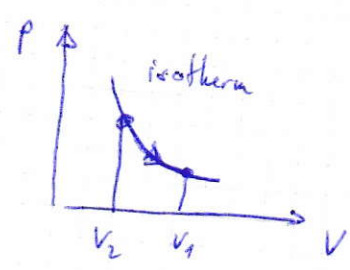
$PV = nRT$
 $P = \frac{nRT}{V}$

$\Delta W = nRT \ln \frac{V_2}{V_1}$ (1)



b) energy required to fill a nitrogen (N_2) gas bottle from ambient pressure (1 bar) to 200 bar (in the bottle)

$P_1 = 1 \text{ bar}$
 $P_2 = 200 \text{ bar}$
 $V_1, T_1 = 300 \text{ K}$
 $V_2 = 50 \text{ l}$
 $T_2 = 300 \text{ K}$
 $= T_1 = T$



isotherm: $P_1 V_1 = P_2 V_2$, so $V_1 = \frac{P_2 V_2}{P_1}$

ideal gas: $P_2 V_2 = nRT$, and $n = \frac{P_2 V_2}{RT}$

from eq (1) above:

$\Delta W = n \cdot R \cdot T \cdot \ln \frac{V_2}{V_1} = \frac{P_2 V_2}{RT} \cdot RT \cdot \ln \frac{V_2}{\frac{P_2 V_2}{P_1}}$

$= P_2 \cdot V_2 \cdot \ln \frac{P_1}{P_2}$, indep. of T

$\Delta W = 2 \cdot 10^7 \frac{\text{N}}{\text{m}^2} \cdot 5 \cdot 10^{-2} \text{ m}^3 \cdot \ln \left(\frac{1 \text{ bar}}{200 \text{ bar}} \right) = -5.3 \cdot 10^6 \text{ J}$

$1 \text{ bar} = 10^5 \text{ Pa}$
 $= 10^5 \frac{\text{N}}{\text{m}^2}$

$1 \text{ l} = 10^{-3} \text{ m}^3$

→ energy required: $5.3 \cdot 10^6 \text{ J}$
 $(\approx 1.47 \text{ kWh})$

fridge $\sim 200 \text{ kWh/year}$
~~computer $\sim 0.1 \text{ kWh}$~~