Thermal Physics

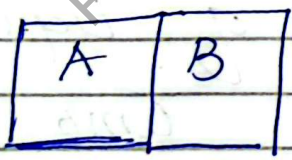
Temperature

"Measure of average kinetic energy of all the molecules of a substance"

Thermal equalibrium

"When there is no net transfer of heat (Thermal energy) blw. two objects then they are in Thermal equilibrium"

In thermal equilibrium temperature of both objects is equal.



A and B Two objects

$T_A > T_B$ (Temperature of A is greater then temp of B

Net heat will transfer from A to B. When there is no net transfer of heat then they are called in thermal equilibrium

Physics With Yameen

A device used to measure temperature is called Thermometer. Thermometer is based on property of a substance that changes with temperature and this property is called **thermometric property**.

Examples of thermometric properties

(i) Density of Liquid

as density of Liquid changes with temp so this can be used as thermometric property.

$$\rho = \frac{m}{V}$$

$\rho \downarrow$ so $V \uparrow$ with temp

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Mercury in glass thermimeter uses this property

(ii) Volume of gas at constant pressure

$PV \propto T$ (Q Level)

If P: constant

then $V \propto T$

So Volume of gas at constant pressure can be used as thermometric property

Physics with Yameen

iii) Resistance of metal wire

Resistance increases with increase in temperature.

iv) Potential difference (emf) Thermocouple.

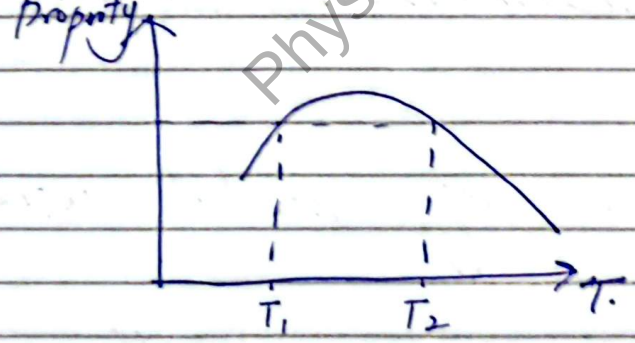
Thermometric property should be

i) Reverseble

of the property increases with temp increase then it should decrease as temp is decreased.

ii) It can be linear or non-linear

iii) It should be one-to one function with temperature (Monotonic) : Each value of temp should give unique value of property



This is not one-one function (Not monotonic)

Two different temperatures give same property.

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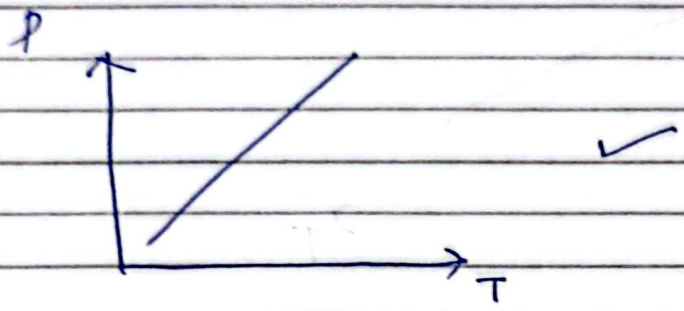
So it cant be used as thermometer.

P: property



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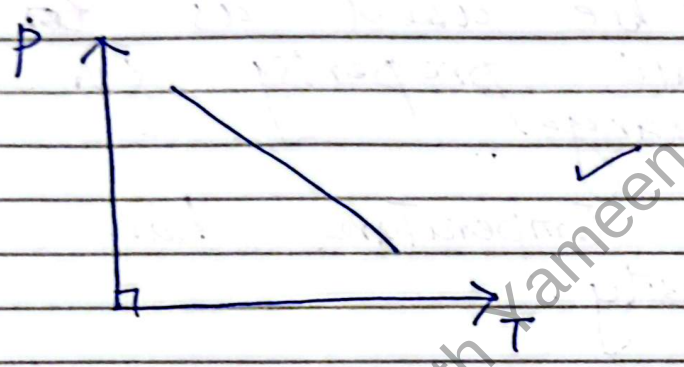

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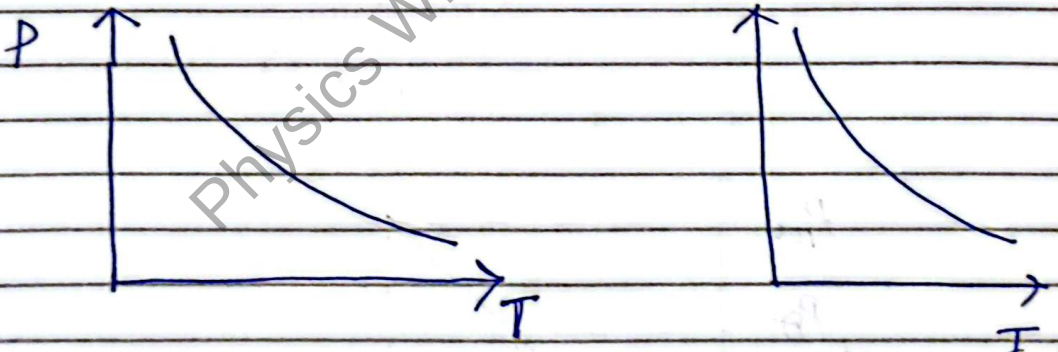
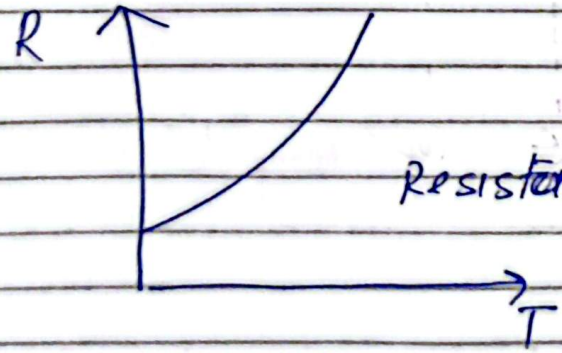


(R of thermistor)

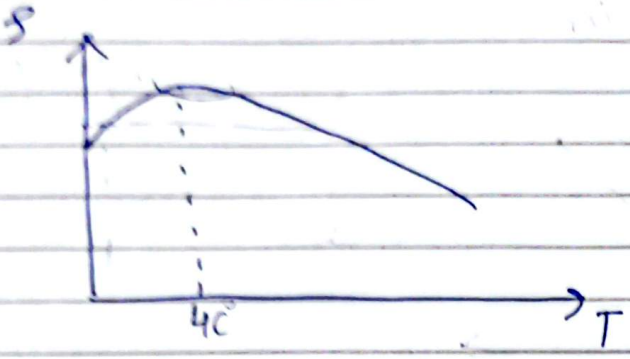


Resistance of metal wire

These are all possible graphs.

Physics With Yameen

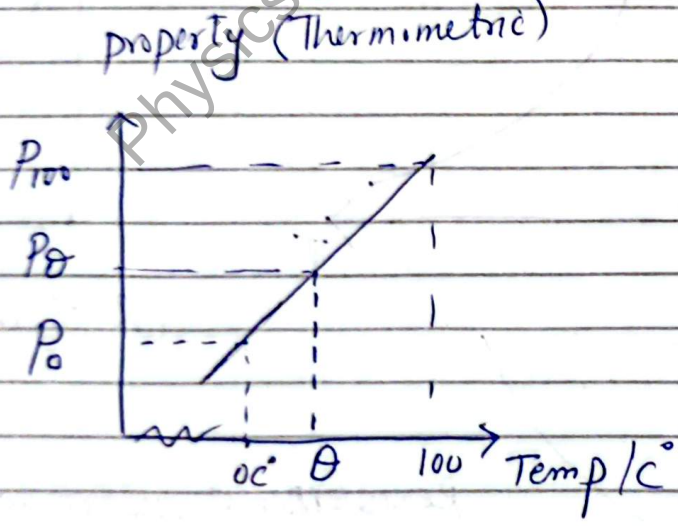
Density of water



This can be used as ~~too~~ thermometric property for whole range.

* Different Temperature have same density.

Empirical formula



P: property

as it is straight line so gradient same

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$$\frac{P_{100} - P_0}{100} = \frac{P_\theta - P_0}{\theta}$$

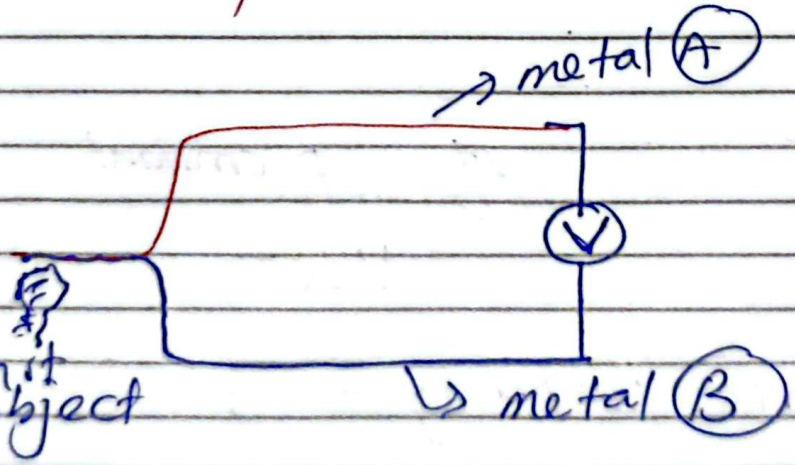
$$\theta^\circ_c = \frac{P_\theta - P_0}{P_{100} - P_0} \times 100$$

In case of mercury thermometer property is length (l)

$$\theta^\circ_c = \frac{l_\theta - l_0}{l_{100} - l_0} \times 100$$

This is valid for linear scale.

Thermocouple thermometer.



potent emf is developed b/w two metal A and (B)

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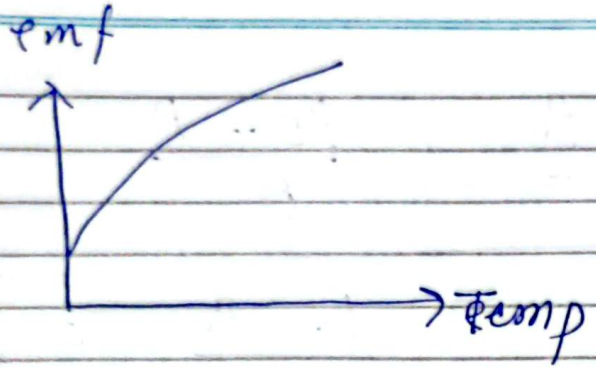
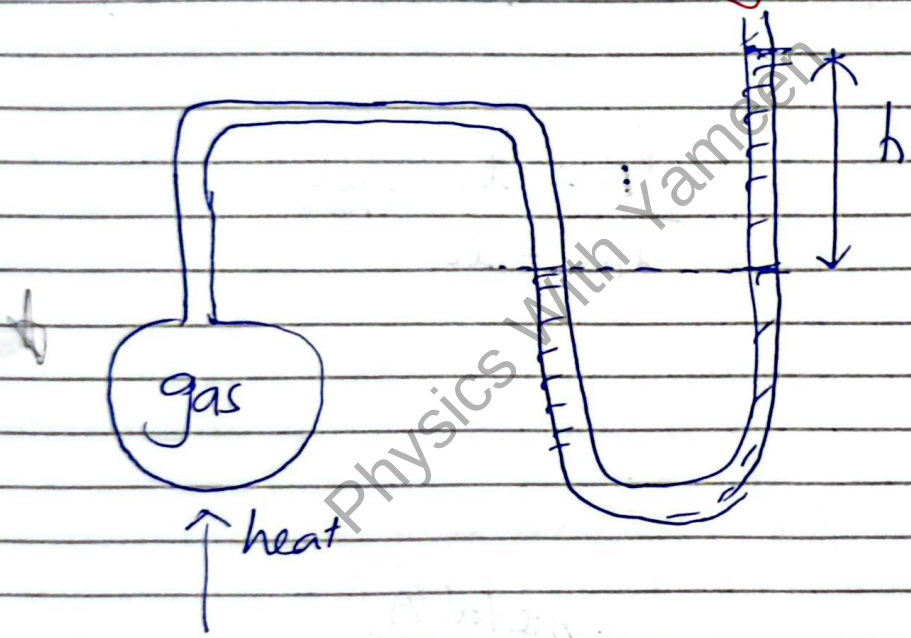


Constant pressure gas thermometer



Physics With Yameen

$PV = nRT$ $\therefore$ if P: constant

$V \propto T$ $\therefore$

Thermometric property $= V$

$V = Ah$ as A: constant

$V \propto h$ $h \propto T$

$T/K = T/C^\circ + 273.15$

Specific Heat capacity (c)

Thermal energy (Q)

m: mass of substance

$Q \propto m$

$Q \propto \Delta T$ — ΔT: Change in temp

$Q \propto c$ — c: Specific heat capacity

$$\boxed{Q = mc\Delta T}$$:

$$c = \frac{Q}{m\Delta T} \quad J\,kg^{-1}K^{-1}$$

$m = 1kg$, $\Delta T = 1K$ or $1C^\circ$

$c = Q$

amount of heat energy required to raise the temp of 1kg of substance by 1k or $1C^\circ$ is known as specific heat capacity.

Water: $c = 4.2\,J\,g^{-1}C^\circ$

$C = 4.2\,J\,g^{-1}\,K^{-1}$

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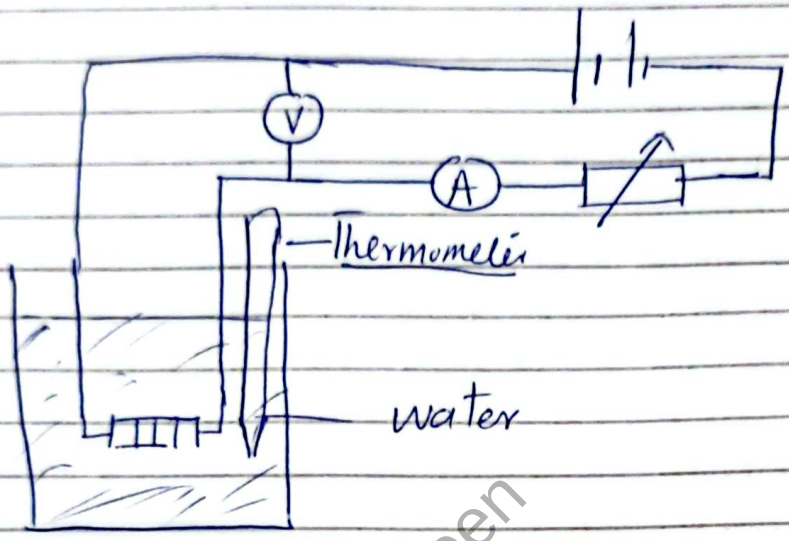
$c = 4200\ J\ kg^{-1}\ K^{-1}$

Copper: $c = 385\ J\ kg^{-1}\ K^{-1}$



heat by the heater is supplied to water and surrounding

VIt : Thermal energy supplied by the heater

$$VIt = mc\Delta T + h \rightarrow (1)$$

h: heat energy lost to surrounding

Now take 2nd reading by adjusting variable resistor

Physics With Yameen

$$V_2 I_2 t = mc\Delta T_2 + h \rightarrow (2)$$

subtract (1) from (2)

$$V_2 I_2 t - V_1 I_1 t = mc\Delta T_2 - mc\Delta T_1$$

$$\frac{(V_2 I_2 - V_1 I_1)t}{m(\Delta T_2 - \Delta T_1)} = c$$

This equation will be used to find specific heat capacity.

put c in any equation to find heat lost to surrouding.

both equations can be written in terms of power

$$V_1 I_1 = \frac{mc\Delta T_1}{t} + K$$

Physics With Yameen

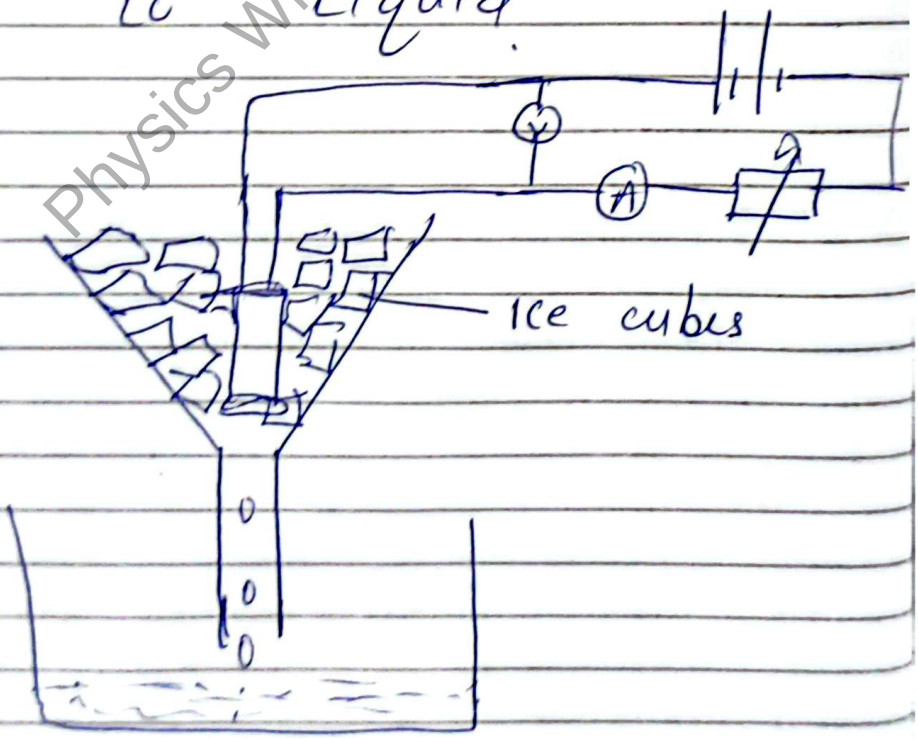
Latent heat of fusion

$$Q = m L_f$$

$$L_f = \frac{Q}{m} \quad : \text{J/kg}$$

amount of heat energy required to change the state of 1kg of substance from solid to Liquid.

Physics With Rameen



heat gained by ice = heat energy from heater + heat energy from surrounding

t: time

$$m_1 L_f = V_1 I_1 t + h \quad (1)$$

Now change settings of variable resistor

$$m_2 L_f = V_2 I_2 t + h \rightarrow (2)$$

(h) = heat energy from the surrounding

Subtract (1) from (1)

$$(m_2 - m_1) L_f = V_2 I_2 t - V_1 I_1 t$$

$$L_f = \frac{V_2 I_2 t - V_1 I_1 t}{m_2 - m_1}$$

Physics With Rameen

2nd method

write equation of power

$$V_1 I_1 + h = \frac{m}{t} L_f \rightarrow (1)$$

$\frac{m}{t}$: rate of mass

h : rate of heat energy from surrounding

t: same.

$V_2 I_2 + h = \frac{m_2}{t} L_f \rightarrow (2)$

Be sure subtract 2 and (1) to find L_f

~~First method~~ 2nd method

Switch off the heater for time t and measure mass of water collected let say (m_1) is collected then switch on the heater for same time and measure mass of water collected say (m_2)

$m = m_2 - m_1$

$Q = mL_f$

$VIt = mL_f$

$L_f = \frac{VIt}{m}$

Physics With Yameen

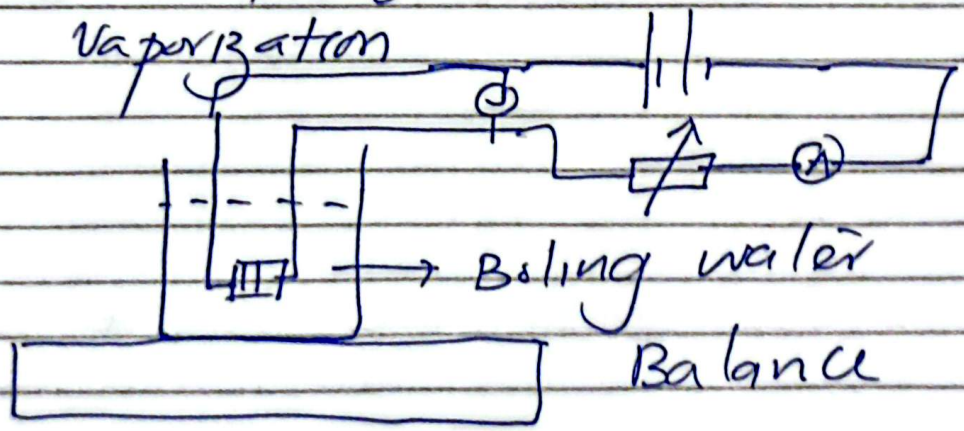
Specific Latent heat of vaporization of water

$$Q = mL_v$$

$$L_v = \frac{Q}{m} \qquad J/kg$$

$m = 1kg \qquad L_v = Q$

Amount of heat energy required to change the state of 1kg of Liquid to gas at constant temperature. is called specific latent heat of vaporization



V.I.P

$$V_1 I_1 t = m_1 L_v + h \quad (1)$$

$$V_2 I_2 t = m_2 L_v + h \quad (2)$$

Physics With Rameen

Ideal gas Equation

Ideal gas

gas which obeys Ideal gas equation $PV = nRT$ for all values of pressure Volume and temperature.

P: pressure in pascal

V: Volume in m^3

T: Thermodynamic temperature (temperature in kelvin)

Thermodynamic temperature scale does not depend on property of a substance

n: Number of mole

R: molar gas constant

$R = 8.31\ J\ K^{-1}\ mol^{-1}$

Physics With Yameen

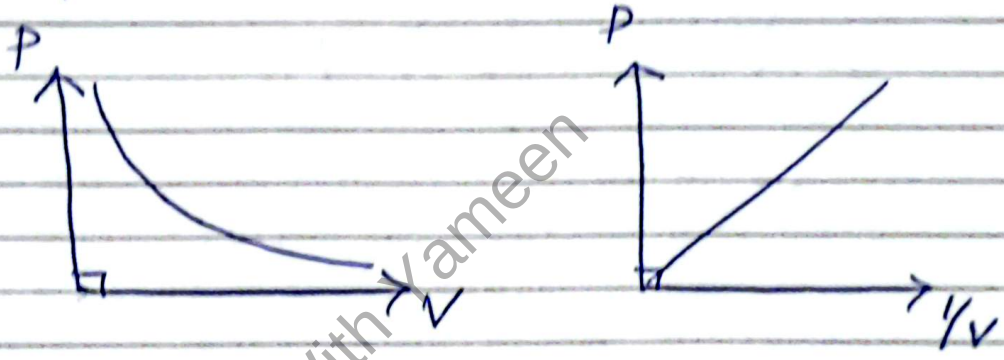
$PV = nRT$

This combines all gas laws

① If T: constant, n: constant

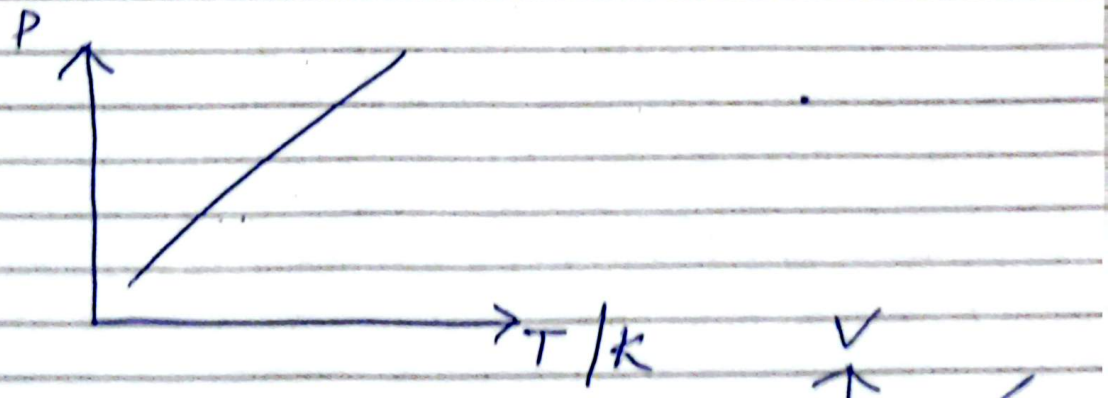
PV: constant

$P \propto 1/V$



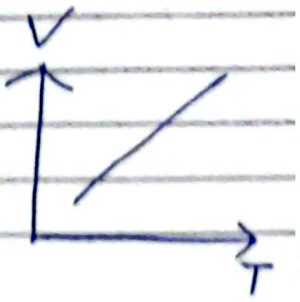
② If V: constant, n: constant

$P \propto T$



③ P: constant, n: Cnt.

$V \propto T$



Physics With Yameen

$$n = \frac{N}{N_A}$$

N = Number of molecules

N_A = Avogadro constant

$$pV = nRT$$

$$pV = \frac{N}{N_A} RT$$

$$pV = N \left(\frac{R}{N_A}\right) T$$

$\frac{R}{N_A} = k$ Boltzmann constant

$$\boxed{pV = NkT}$$

$$k = 1.38 \times 10^{-23} \ JK^{-1}$$

of fixed mass (mole) of gas has initial values P_1, V_1, T_1 and

Physics With Yameen

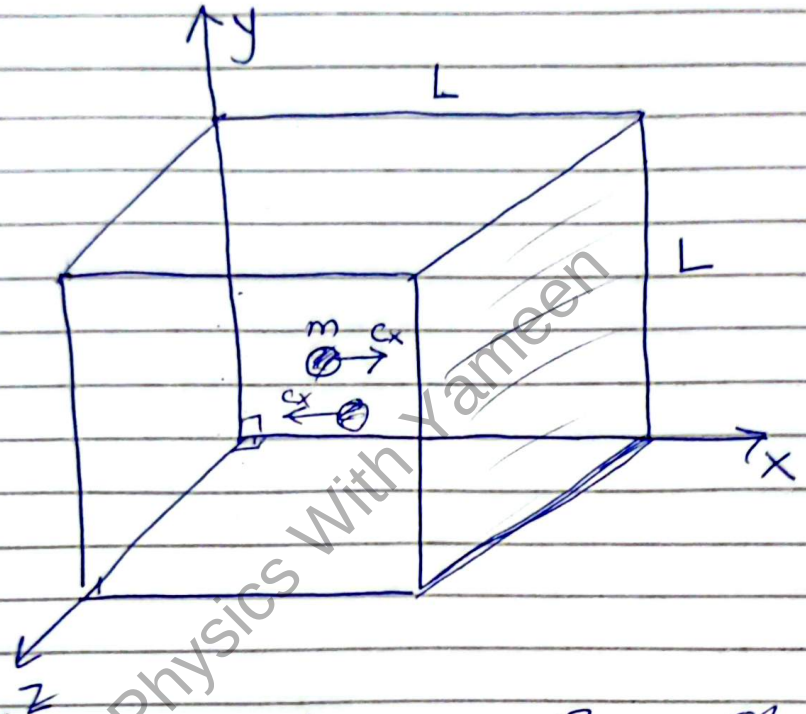
final values P_2, V_2, T_2

Then

$$\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2}$$

Physics With Yameen

Kinetic molecular Theory

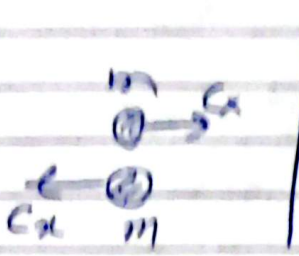


Physics With Yameen

Consider a container of shape cube of length L

Consider a molecule of mass m moving with velocity c_x along x-axis. molecules collide with shaded wall elastically and

bounces back with same speed c_x



Change in momentum

$$\Delta p = -mc_x - (mc_x)$$

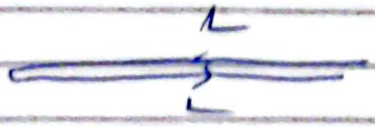
$$\Delta p = -2mc_x$$

$$F = \frac{\Delta p}{\Delta t} = \frac{\Delta p}{t} \rightarrow (1)$$

Physics With Yameen

Assumption:

Δt: time of collision is taken as time between two successive collision with the same wall



$$t = \frac{2L}{c_x}$$

$$F = \frac{-2mC_x}{\frac{2L}{C_x}}$$

$$F = -\frac{2mC_x^2}{2L}$$

Force on wall

$$F = \frac{mC_x^2}{L}$$

Pressure

$$P = \frac{F}{A}$$

$$P = \frac{\frac{mC_x^2}{L}}{A} \qquad A = L^2$$

$$P = \frac{mC_x^2}{L \cdot L^2}$$

$$P = \frac{mC_x^2}{L^3}$$

$$P = \frac{mC_x^2}{V} \rightarrow (1)$$

Physics With Yameen

In general molecule will have three compment of velocity

$c = c_x +$ $\quad c = \begin{pmatrix} c_x \\ c_y \\ c_z \end{pmatrix}$

c: velocity

c_x: comp alng x-direction

c_y: Compment of velocity y-direct

c_z: " " z-direction

$$c^2 = c_x^2 + c_y^2 + c_z^2$$

$$\langle c^2 \rangle = \langle c_x^2 \rangle + \langle c_y^2 \rangle + \langle c_z^2 \rangle$$

Physics With Yameen

Assumption

$$\langle c_x^2 \rangle = \langle c_y^2 \rangle = \langle c_z^2 \rangle$$

mean square velocity alng all direction is same.

$$\langle c^2 \rangle = \langle c_x^2 \rangle + \langle c_x^2 \rangle + \langle c_x^2 \rangle$$

$$\langle c^2 \rangle = 3\langle c_x^2 \rangle \qquad \langle c_x^2 \rangle = \frac{\langle c^2 \rangle}{3}$$

$$P = \frac{m\langle c_x^2 \rangle}{V}$$

$$P = \frac{m\langle c^2 \rangle}{3V}$$

If there are N molecules

$$P = \frac{Nm\langle c^2 \rangle}{3V} \rightarrow (2)$$

Nm : total mass of gas

V : Volume " "

$\frac{Nm}{V}$ = ρ density

$$P = \frac{\rho\langle c^2 \rangle}{3}$$

from (2)

$$P = \frac{Nm\langle c^2 \rangle}{3V}$$

$$PV = \frac{Nm\langle c^2 \rangle}{3} \rightarrow (3)$$

Physics with Yameen

We know

$$pV = NKT$$

using (3)

$$NKT = \frac{Nm\langle c^2\rangle}{3}$$

$$KT = \frac{m\langle c^2\rangle}{3}$$

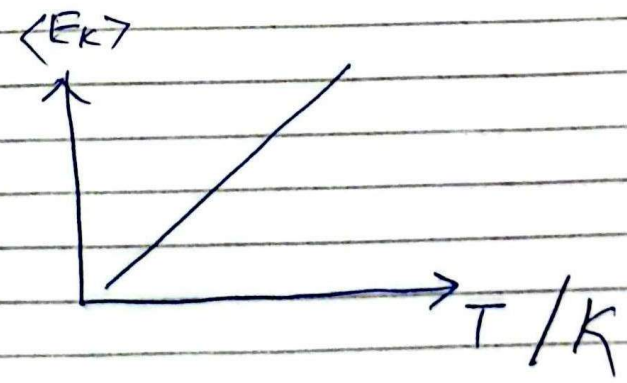
$$3KT = m\langle c^2\rangle \rightarrow (4)$$

$$\frac{3KT}{2} = \frac{m\langle c^2\rangle}{2}$$

$$\boxed{\frac{3KT}{2} = \langle E_K\rangle}$$

Physics With Yameen

$\langle E_K\rangle \propto T$



From (4)

$$m\langle c^2\rangle = 3kT$$

$$\langle c^2\rangle = \frac{3kT}{m}$$

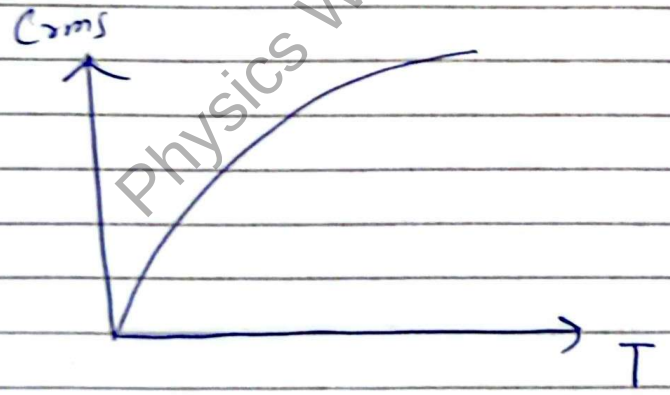
$$\langle c^2 \rangle = \frac{3kT}{m}$$

$$\langle c^2 \rangle \propto T$$

$$\sqrt{\langle c^2 \rangle} = \sqrt{\frac{3kT}{m}}$$

$$c_{rms} = \sqrt{\frac{3kT}{m}}$$

$$c_{rms} \propto \sqrt{T}$$



$$c_{rms}(T_1) = \sqrt{\frac{3kT_1}{m}}$$

$$c_{rms}(T_2) = \sqrt{\frac{3kT_2}{m}}$$

$$\frac{c_{rms}(T_1)}{c_{rms}(T_2)} = \sqrt{\frac{T_1}{T_2}}$$

Physics With Yameen

Avogadro constant (N_A)

Number of nuclei in 12 gram of Carbon-12

Mole (n)

Amount of substance containing 6.02×10^{23} particles (molecules or atom)

Physics With Yameen

Internal Energy

particles of any substance vibrate (solid, ~~liq~~) and move (gas) so they have kinetic energy and they have inter molecular forces due which they potential energy. Both potential energy and kinetic energy are random.

Define Internal energy

Sum of random distribution of kinetic energy and potential energy of all the molecules of a substance is called internal energy of the substance

It is represented by U

Change in internal energy = ΔU

$$U = \overset{\text{Sum}}{\Sigma} E_k + \overset{\text{Sum}}{\Sigma} E_p$$

Internal energy of an Ideal gas

As there are no ~~inter~~ forces b/w particles

Potential energy is

$$U = \Sigma E_k$$

Dependence on Temperature

We know, average K.E molecule

$$E_k = \frac{3}{2} KT$$

If there are N molec

$$U = \frac{3}{2} NKT$$

If N is constant

$$\Delta U = \frac{3}{2} NK\Delta T$$

$$\Delta U \propto \Delta T$$

Physics with Yameen

$$U = \overset{\text{Sum}}{\Sigma} E_K + \overset{\text{Sum}}{\Sigma} E_p$$

Internal energy of an Ideal gas

As there are no intermolecular forces b/w particles so

Potential energy is zero (0)

$$U = \Sigma E_K$$

Dependence on Temperature

We know, average K.E of single molecule

$$E_K = \frac{3}{2} KT$$

If there are N molecules

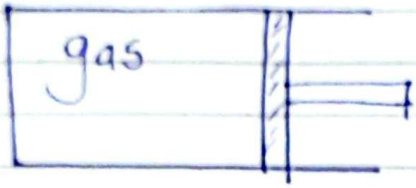
$$U = \frac{3}{2} NKT$$

If N is constant

$$\Delta U = \frac{3}{2} N K \Delta T$$

$$\Delta U \propto \Delta T$$

Physics With Yameen



How can we increase the internal energy of this gas?

There are two methods

① Supply Heat energ (Q)

② Do some Work on the gas (compress it)

Physics With Yameen

First Law of thermodynamics

Increase in internal energy is equal to sum of thermal energy supplied to the system and work done on the system.

$\Delta U = Q + W$

this is basically law of conservation of energy

Sign convention

+Q : Thermal energy supplied to the system

−Q : thermal energy taken out from the system

+W : Work is done on the system (compression)

−W : Work is done by the system

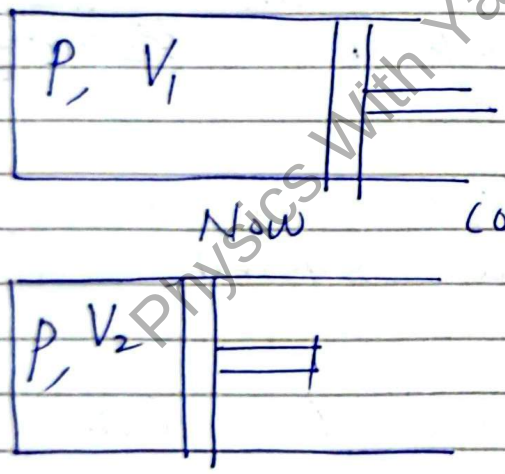
+ΔU : Increase in internal energy

−ΔU : Decrease in internal energy.

Physics With Kameen

If an ideal gas is compressed or expanded ~~but~~ constant temperature then change in internal energy is zero. ($\Delta U \propto \Delta T$)

Work done at constant pressure.



Physics With Yameen

$$W = P \Delta V$$

$$W = P (V_1 - V_2)$$

Work is done on gas