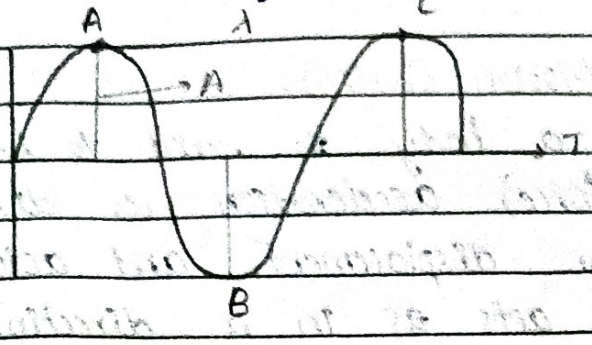
Module - I
Oscillations And Shock Waves

Periodic motion:
Motion repeats with the equal intervals of time is called periodic motion
Types of periodic motion:
i) Oscillatory motion
ii) Vibratory motion



* Displacement (x) = The distance of location of a body from it's mean position at a particular instant of time
* Amplitude (a): The maximum value of displacement that a body can under go either side of its mean position during the oscillation
* Frequency (ν): The number of oscillations per unit time $\nu = \frac{n}{T}$
* Angular frequency (ω) or Angular velocity: It is the angle covered in unit time by a body move in circular motion at that instant of time
$\omega = 2\pi\nu \Rightarrow \omega = \frac{2\pi}{T}$
* Time period (T): It is the time taken by the body to complete one oscillation. T =

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Restoring force:

When a body is oscillating in a medium the action of force whose magnitude is propotional to displacement and acting in a direction opposite to displacement w.r.t. equillibrium position.

By Hooke's law,

$$F \propto -x$$

$$F = -kx$$

Simple Harmonic Motion (SHM):

The motion of a body is said to be SHM if the (restoring force) acceleration is directly propotional to the displacement and acts in a direction and acts ~~as~~ in a direction opposite to that of motion from the equillibrium position.

Restoring force $\propto$ y (Displacement in opp. direction)

$$F_{restoring} \propto -y$$

$y = a\sin\omega t$ $\qquad\qquad$ $x = a\cos\omega t$

~~velocity~~ $= y = a\sin\omega t$

$$\frac{d(y)}{dt} = a\omega\cos\omega t \Rightarrow \text{velocity}$$

$$\frac{d^2y}{dt^2} = -a\omega^2\sin\omega t \Rightarrow \text{acceleration} = \frac{d^2y}{dt^2} = -\omega^2 a\sin\omega t$$

$$\frac{d^2y}{dt^2} = -\omega^2 y \quad [\because a\sin\omega t = y]$$

velocity $= a\omega\cos\omega t$

$= a\omega\sqrt{1-\sin^2\omega t}$ $\quad [\because \cos\omega t = \sqrt{1-\sin^2\omega t}]$

$= \omega\sqrt{a^2 - a^2\sin^2\omega t}$

velocity $= \omega\sqrt{a^2-y^2}$

Note:

* When body at mean position, velocity is maximum, acceleration is zero
* When body at extreme position, acceleration is maximum, velocity is zero.

Expression for SHM

By definition of SHM,

$$F_{restoring} \propto -y$$

$$F_{restoring} = -ky \quad -① \quad [\because K \text{ is a force constant / stiffness factor}]$$

$$K = -\frac{F_{restoring}}{y}$$

[It is the ratio of force exerted on the bod to the displacement]

According to Newton's IInd law,

$$F = ma$$

$$F = m\frac{d^2y}{dt^2} \quad -② \quad \left[\because a = \frac{d^2y}{dt^2}\right]$$

Equating eq^n ① + ②

$$-Ky = m\frac{d^2y}{dt^2}$$

$$m\frac{d^2y}{dt^2} + Ky = 0$$

$$\frac{d^2y}{dt^2} + \frac{K}{m}y = 0 \qquad [\div m]$$

Replacing K/m by ω^2

$$\boxed{\frac{d^2y}{dt^2} + \omega^2 y = 0}$$

$$\omega^2 = \frac{K}{m} \Rightarrow \omega = \sqrt{\frac{K}{m}} \quad \text{— (3)}$$

$$\omega = 2\pi f \quad \text{— (4)}$$

By equating eq^n (3) & (4)

$$2\pi f = \sqrt{\frac{K}{m}}$$

$$\boxed{f = \frac{1}{2\pi}\sqrt{\frac{K}{m}}}$$

W.K.T. $T = \frac{1}{f}$

$$\boxed{T = 2\pi\sqrt{\frac{m}{K}}}$$

Charecteristics of SHM

* It is a to and fro motion
* It is a periodic motion
* Force is propotional to displacement
* Acceleration is in the opposite direction of displacement
* Restoring force is essential for SHM

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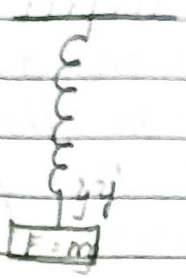
Mechanical Simple Harmonic oscillator

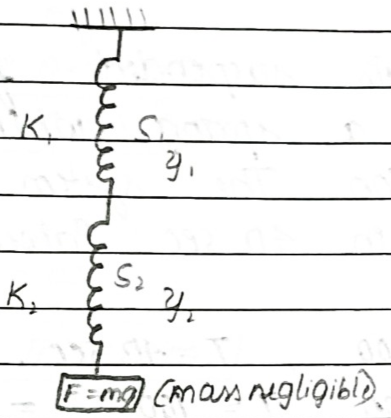


$y = a\sin(\omega t + \phi)$ ϕ = Phase difference
ω = angular velocity

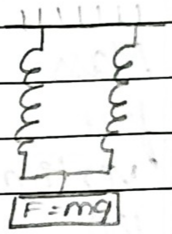
Consider a mass attached to spring of negligible mass which is suspended from a rigid support as showing fig.
The oscillations in the spring are due to restoring force developing the spring

Springs in Series and parallel

Series:



Parallel:



$Y = Y_1 + Y_2$

$F = -Ky$

$y = -\frac{F}{K}$

$\left[\frac{F}{K_s}\right] = +\left[\frac{F}{K_1} + \frac{F}{K_2}\right]$

$\frac{1}{K_s} = \frac{1}{K_1} + \frac{1}{K_2}$

$K_s = \frac{K_1K_2}{K_1+K_2}$

$F_p = F_1 + F_2$

$KY = F$

$K_pY = K_1Y + K_2Y$

$\boxed{K_p = K_1 + K_2}$

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Problems

1) Man wieghing 600N steps on a spring scale machine. The spring in the machine is compressed by 1cm. Find the force constant of the spring.

Given.

$W = F = mg = 600N$

$x = 1cm \Rightarrow 1 \times 10^{-2} m$

$K = ?$

$F = Kx$

$K = F/x \Rightarrow K = \frac{600}{1 \times 10^{-2}}$

$K = 6 \times 10^2 \times 10^2 \Rightarrow \boxed{K = 6 \times 10^4 \ N/m}$

2) Mass of 5Kg is suspended from the free end of a spring when set for vertical oscellation. The system executes 100 oscillations in 40 sec. Calculate Force constant

$m = 5Kg$, $n = 100$, $T = 40$ sec, $K = ?$

Time for oscillation $T = \frac{100}{40} = 2.5$ sec

$T = 2\pi \sqrt{\frac{m}{K}}$

$T^2 = 4\pi^2 \frac{m}{K}$ [squaring on B.S]

$K = 4\pi^2 \frac{m}{T^2}$

$= 4 \times (3.14)^2 \times \frac{5}{(2.5)^2}$

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$= 4 \times 9.856 \times \frac{5}{6.25}$

$= 4 \times 9.856 \times 0.8$

$\boxed{K = 31.53\ N/m}$

3) Mass 0.5Kg posses an extension 0.03m in a spring and the system is set for oscillations Find
i) Force constant
ii) Angular frequency
iii) Time period

$m = 0.5Kg$, $x = 0.03m$ $K = ?$, $\omega = ?$, $T = ?$

$K = F/x$

$F = mg$

$F = 0.5 \times 9.8$

$\boxed{F = 4.9N}$

$K = \frac{4.9}{0.03}$

$\boxed{K = 163.3\ N/m}$

$\omega = \sqrt{\frac{K}{m}} \Rightarrow \omega = \sqrt{\frac{163.3}{0.5}} = \frac{12.76}{0.70}$

$\boxed{\omega = 18.2\ rad/sec}$

$T = 2\pi\sqrt{\frac{m}{K}}$

$T = 2(3.14)\sqrt{\frac{0.5}{163}}$

$T = 6.28\left(\frac{0.70}{12.77}\right) \Rightarrow T = \frac{4.396}{12.77} = 0.34\ sec$

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4) An electric motor weighing 50kg is mounted on force springs each of which as a spring constant 2×10^3 N/m The motor moves only in vertical direction. Find the frequency of system

$m = 50Kg$

$K = 2 \times 10^3 \Rightarrow 2000$

$f = \frac{1}{2\pi}\sqrt{\frac{K_{eff}}{m}}$

$= \frac{1}{2\pi}\sqrt{\frac{4 \times 2000}{50}}$

$= \frac{1}{6.28}\sqrt{160}$

$= \frac{12.64}{6.28}$

$\boxed{f = 2.01\ Hz}$

5) Find the frequency of oscillation of 3 particle executing SHM of amplitude 0.35m If the maximum velocity it can attain is 220 m/s

$a = 0.35m$. $V = 220 m/s$

$V = wa$

$w = \frac{V}{a} \Rightarrow w = \frac{220}{0.35}$

$w = 628.57$ rad/sec

$w = 2\pi f$

$f = \frac{w}{2\pi}$

$f = \frac{628.57}{6.28}$

$\boxed{f = 100 Hz}$

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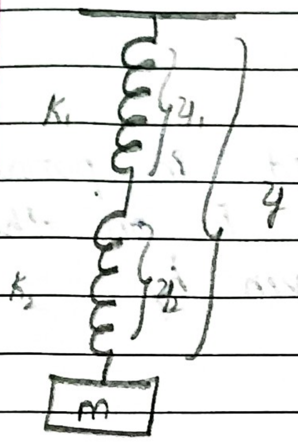
Natural frequency:

When a body exhibits free oscillation the frequency with which oscillation occurs is called natural frequency.

Springs in series and parallel

Consider two springs of negligible masses with force constant K_1 & K_2

Let us calculate effective spring constant when two springs are connected in series to a mass or connected in parallel.



When springs are connected in series to a mass The net extension Y is given by $Y = Y_1 + Y_2$
'Y' is the total extension
Y_1 is the extension in spring with force constant K_1
Y_2 is the extension in spring with force constant K_2

If K_s is the effective force constant of the combination

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If F is the force applied on the combination.

$$Y = Y_1 + Y_2 \quad -①$$

$$-\frac{F}{K_s} = -\frac{F}{K_1} - \frac{F}{K_2}$$

$$-\frac{F}{K_s} = -F\left(\frac{1}{K_1} + \frac{1}{K_2}\right)$$

$$\frac{1}{K_s} = \frac{1}{K_1} + \frac{1}{K_2}$$

$$K_s = \frac{K_1 K_2}{K_1 + K_2}$$

Effective force constant of series combination

Springs in parallel

When springs are connected in parallel to a mass the net force F on the system of spring is given by

$$F = F_1 + F_2$$

F_1 is the force on the spring with force constant K_1

F_2 is the force on the spring with force constant K_2

If K_p is the effective force constant of the combination

If Y is the total extension in the combination

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Then we get.

$$F_p = F_1 + F_2$$
$$K_p Y = K_1 Y + K_2 Y$$
$$K_p Y = Y(K_1 + K_2)$$
$$K_p = K_1 + K_2$$

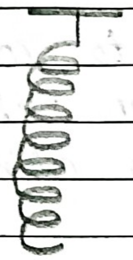
Application of spring

Compression spring:

A compression spring is an elastic coil made of spring steel

It is a spring characteristic is that it observes forces or observes resistance

structure and working.



compression spring are very effective at building, and It has gaps between it's coil in a unloaded state

The distance between the coil is reduced when the spring is loaded and compressed.

Uses

A compression spring can be used as pure energy accumulator, shock absorber Suspensions

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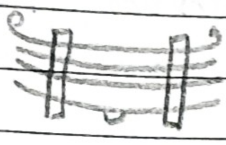
Vibration damper or force generator

Used to reduce the amount of vibration that you feel when a

It absorbs the vibrations generated by the driving shaft.
It is important that not to be overloaded

Leaf springs

Structure and working



Uses
The leaf spring is used to control the height at which the vehicle rides and keep the tires aline on the road.

Leaf springs are most useful for trailers, trucks and tanks haulings and heavy loads

Types of oscillations

i) Free oscillations
ii) Damped oscillation
iii) Forced oscillation

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Theory of Damped oscillation

A body executing vibrations (oscillations) if the amplitude keeps on decreasing because of frictional resistive force offered by the medium in which the oscillations are carried out.

Due to the resistive force the vibrations die ~~not~~ out after some time the motion is said to be damped due to resistive force and hence is called damped oscillations.

$F_{restoring} \propto -y$ (displacement)

$F_{resistive} \propto -vel \left(\frac{dy}{dt}\right)$

By Newton's II law

$F = m\frac{d^2y}{dt^2}$

$F_{restoring} = -ky$; $F_{resistive} = -r\frac{dy}{dt}$

Total force acting on the body

$$F = F_{restoring} + F_{resistive}$$

$$m\frac{d^2y}{dt^2} = -ky - r\frac{dy}{dt}$$

$$m\frac{d^2y}{dt^2} + r\frac{dy}{dt} + ky = 0$$

$$\frac{d^2y}{dt^2} + \frac{r}{m}\frac{dy}{dt} + \frac{k}{m}y = 0 \quad [\div m]$$

$$\frac{d^2y}{dt^2} + 2b\frac{dy}{dt} + \omega^2 y = 0 \quad \text{—(1)} \left[\frac{r}{m} = 2b,\ \frac{k}{m} = \omega^2\right]$$

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The solution for differential equation

$$y = Ae^{\alpha t} \quad [A \text{ is a orbitrary constant}]$$

$$\frac{dy}{dt} = \alpha Ae^{\alpha t}$$

$$\frac{d^2y}{dt^2} = \alpha^2 Ae^{\alpha t}$$

$$① \Rightarrow \alpha^2 Ae^{\alpha t} + 2b\alpha Ae^{\alpha t} + Ae^{\alpha t}\omega^2 = 0$$

$$Ae^{\alpha t}[\alpha^2 + 2b\alpha + \omega^2] = 0$$

$$Ae^{\alpha t} \neq 0$$

$$\alpha^2 + 2b\alpha + \omega^2 = 0$$

$$\frac{-b \pm \sqrt{b^2 - 4ac}}{2a} \Rightarrow \frac{-2b \pm \sqrt{(2b)^2 - 4(1)(\omega^2)}}{2(1)}$$

$$= \frac{-2b \pm \sqrt{4b^2 - 4\omega^2}}{2}$$

$$= \frac{-2b \pm 2\sqrt{b^2 - \omega^2}}{2}$$

$$= -b \pm \sqrt{b^2 - \omega^2}$$

The general solution of differential equation

$$y = A_1 \text{ Exponential } [-b + \sqrt{b^2 - \omega^2}] + A_2 \text{ Exponential } [-b - \sqrt{b^2 - \omega^2}]$$

Damped oscellation

Case I - $b >> \omega$, over damping,

Case II - $b << \omega$ Under damping

Case III - $b == \omega$ Critical damping

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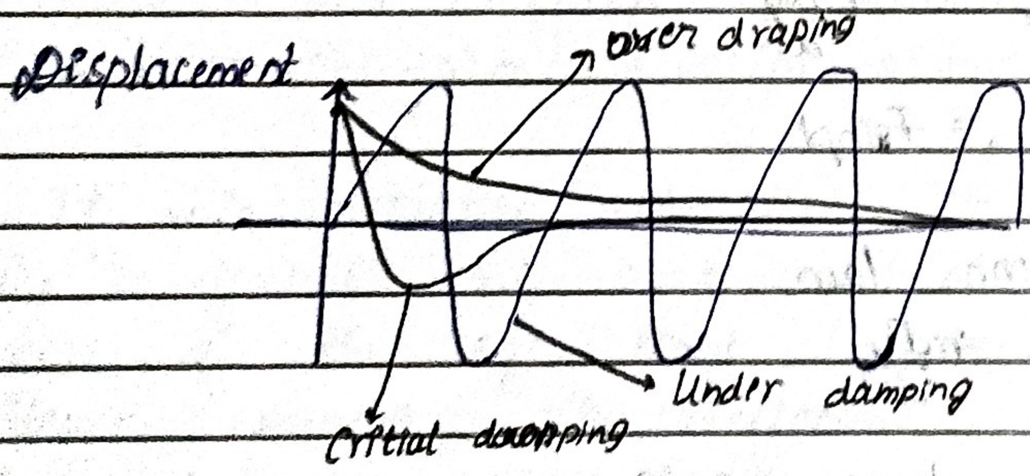
-ion for damped oscillation is $b^2 < 4mk$

Over damping: Oscillations are said to be over damped or heavy damped when the system attains equilibrium state quite slowly without making oscillations. The condition for over damping by $b^2 > 4mk$

Critical damping: When the system approaches equilibrium state quite quickly without making any oscillations is called critical damping. The condition for critical damping is given by $b^2 = 4mk$



Quality factor: The energy ratio of 2π times of energy stored in the system to the energy lost per unit time

$$Q = 2\pi \left[\frac{\text{Energy stored in the system}}{\text{Energy lost per unit time}} \right]$$

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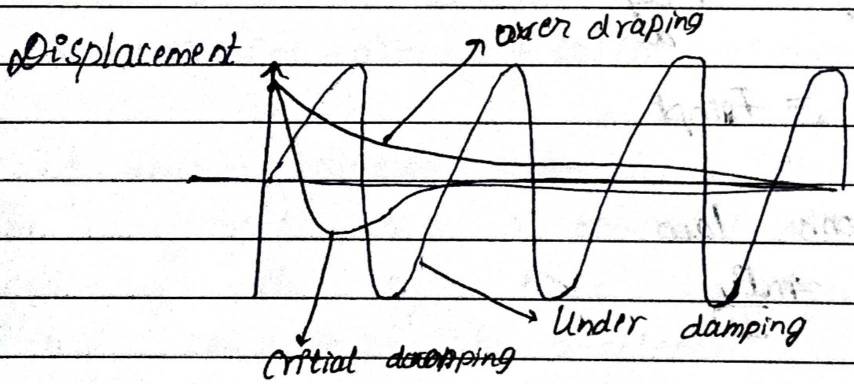
Under damping: Oscillations are said to be under damped or weakly damped if the retarding force is weaker than the restoring force. The amplitude of oscillations decreases with respect to time. The condition for damped oscillation is $b^2 < 4mk$

Over damping: Oscillations are said to be over damped or heavy damped when the system attains equillibrium state quite slowly without making oscillations. The condition for over damping by $b^2 > 4mk$

Critical damping: When the system approaches equillibrium state quite quickly without making any oscillations is called critical damping. The condition for critical damping is given by $b^2 = 4mk$



Quality factor: The energy ratio of 2π times of energy stored in the system to the energy lost per unit time

$$Q = 2\pi \left[\frac{\text{Energy stored in the system}}{\text{Energy lost per unit time}} \right]$$

Theory of Forced Oscillations

When the body is subjected to the external periodic force with it's natural frequency under SHM then the kind of SHM is called "Forced oscillation"

If the body vibrates with the other frequency than its natural frequency then the kind of SHM is called "Forced oscillations"

$$\frac{d^2y}{dt^2} + \frac{k}{m}y + \frac{r}{m}\frac{dy}{dt} = \frac{F}{m}\sin pt$$

$$\frac{d^2y}{dt^2} + \omega^2 + 2b\frac{dy}{dt} = f\sin pt$$

$$F_{restoring} = -ky$$

$$F_{resistive} = -r\frac{dy}{dt}$$

$$F_{external} = F\sin pt$$

Newton's law,

$$F = m\frac{d^2y}{dt^2}$$

Total force acting on the body is

$$F = -ky - r\frac{dy}{dt} + F\sin pt$$

$$m\frac{d^2y}{dt^2} = -ky - r\frac{dy}{dt} + F\sin pt$$

$$\frac{d^2y}{dt^2} + \frac{K}{m}\frac{dy}{dt}y + \frac{r}{m}\frac{dy}{dt} = \frac{F}{m}\sin pt$$

$$\frac{d^2y}{dt^2} + \omega^2 y + 2b\frac{dy}{dt} = f\sin pt \quad \text{—(1)}$$

The gen sol^n for above differential eq^n

$$y = A\sin(pt-\theta)$$

$$\frac{dy}{dt} = A\cos(pt-\theta)p$$

$$\frac{d^2y}{dt^2} = -Ap^2\sin(pt-\theta)$$

Substitute in eq^n (1)

$$-Ap^2\sin(pt-\theta) + \omega^2 A\sin(pt-\theta) + 2bA\cos(pt-\theta)p$$
$$= f\sin(pt-\theta)$$

$$-Ap^2\sin(pt-\theta) + 2bA\cos(pt-\theta)p + \omega^2 A\sin(pt-\theta)$$
$$= f(\sin(pt-\theta)\cos\theta + \cos(pt-\theta)\sin\theta)$$

If this relation ~~holds~~ denotes for all values of t
The co-effecient $\sin(pt-\theta)$ & $\cos(pt-\theta)$ on both sides of the eq^n must be equal
Hence comparing the co-effecient of $\sin(pt-\theta)$ & $\cos(pt-\theta)$ on both side

$$A(\omega^2-b^2)\sin(pt-\theta) + 2bA\cos(pt-\theta)p = f\sin(pt-\theta)$$
$$\cos\theta + f\cos(pt-\theta)\sin\theta$$

$$A(\omega^2-p^2) = f\cos\theta \quad \text{—(2)}$$

$$2bpA = f\sin\theta \quad \text{—(3)}$$

Squaring on BS of eq^n (2) & (3)

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$$A^2(\omega^2-p^2)^2 = f^2\cos^2\theta \quad -④$$

$$4b^2p^2A^2 = f^2\sin^2\theta \quad -⑤$$

Adding eq^n ④ & ⑤

$$A^2(\omega^2-p^2)^2 + 4b^2p^2A^2 = f^2(\sin^2\theta+\cos^2\theta)$$

$$A^2(\omega^2-p^2)^2 + 4b^2p^2A^2 = f^2$$

$$A^2[\omega^2-p^2]^2 + 4b^2p^2 = f^2$$

$$A = \sqrt{\frac{f^2}{(\omega^2-p^2)^2+4b^2p^2}}$$

$$A = \frac{f^2}{\sqrt{\omega^2-p^2+4b^2p^2}}$$

Divide eq^n ③ by ②

$$\frac{f\sin\theta}{f\cos\theta} = \frac{2bpA}{A(\omega^2-p^2)}$$

$$\tan\theta = \frac{2bp}{\omega^2-p^2}$$

$$\theta = \tan^{-1}\left(\frac{2bp}{\omega^2-p^2}\right)$$

Case 1 : When driving frequency is low
$p \ll \omega$ $p \simeq 0$

Case 2 : The amplitude of the vibration is given by $p \simeq \omega$

$$A = \frac{f}{\sqrt{(\omega^2-p^2)^2+4b^2p^2}}$$

$$A = \frac{f}{\omega^2}$$

$$\theta = \tan^{-1}\left(\frac{2bp}{\omega^2-p^2}\right)$$

$$\theta = \tan^{-1}(0) = 0$$

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This shows that the amplitude of the vibration is independent of force the amplitude depends on magnitude of the applied force & the force constant
The force & the displacement are always in phase

When $P = \omega$ i.e the frequency of force is equal to the frequency of body the amplitude of vibration is given by

$$A = \frac{f}{\sqrt{(\omega^2 - p^2)^2 + 4b^2p^2}} = \frac{f}{2b\omega} = \frac{f}{\frac{r}{m}\omega}$$

$$= \frac{f/m}{r\omega}$$

$$\theta = \tan^{-1}\left(\frac{2bP}{\omega^2 - p^2}\right) = \tan^{-1}\left(\frac{2bP}{0}\right) = \tan^{-1}(\infty)$$

$$\theta = \pi/2$$

Thus, The amplitude of the vibration is covered by damped & for small damping force the amplitude of vibration is quite large hence the displacement laggs behind the force $= \pi/2$

Case 3: $P >> \omega$ The frequency of the force is greater then the natural frequency ω of the body.

$$A = \frac{f}{\sqrt{(0^2 - p^2)^2 + 4b^2p^2}}$$

$$A = \frac{f}{(-p^2)^2 + 4b^2p^2} = \frac{f}{-p^2 + 2bP}$$

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$$= \frac{-f}{p^2}$$

$$\theta = \tan^{-1} \frac{2bp}{(\omega^2 - p^2)}$$

$$\therefore = \tan^{-1}\left(\frac{2bp}{0^2 - p^2}\right)$$

$$= \tan^{-1}\left(\frac{2bp}{-p^2}\right) = \frac{0}{p^2}$$

$$\theta = \tan^{-1}(-0)$$

$$\boxed{\theta = \pi}$$

Thus, This case the amplitude a goes on decreasing & phase difference tends towards π

Resonance, Sharpness of resonance

Sharpness of resonance: The ratio of change in the amplitude to the change in the frequency.

$$\text{Sharpness of Resonance} = \frac{\text{change in amplitude}}{\text{change in frequency}}$$

$$= \frac{A_{max} - A_{min}}{(p - \omega)} \quad -①$$

$$A_{max} = \frac{F/m}{2bp} \; -① = \frac{F/m}{r/m\,\omega} \Rightarrow \frac{F}{r\omega}$$

$$A = \frac{f}{\sqrt{(\omega^2 - p^2)^2 + 4b^2p^2}}$$

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$$= \frac{F/m}{\sqrt{(\omega^2-p^2)^2+4b^2p^2}} \quad [(\omega^2-p^2)^2=0]$$

$$= \frac{F/m}{\sqrt{4b^2p^2}}$$

$$= \frac{F/m}{2bp}$$

$$= \frac{F/m}{2b\omega} \quad -③ \quad [p=\omega]$$

Substitute ② & ③ in ①

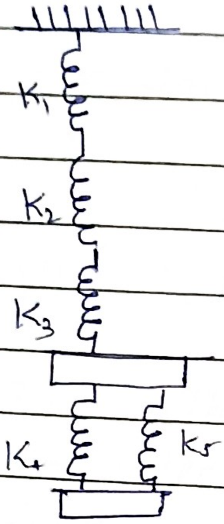
$$= \frac{\frac{F/m}{2bp\omega} - \frac{F/m}{2bp}}{(p-\omega)}$$

$$= \frac{\frac{F/m}{2b}\left[\frac{1}{p\omega} - \frac{1}{p}\right]}{(p-\omega)}$$

$$= \frac{\frac{F/m}{2b}\left[\frac{\cancel{(p-\omega)}}{p\omega}\right)}{\cancel{(p-\omega)}}$$

$$= \frac{F/m}{2bp\omega}$$

1) In the 2 mass spring system shown in the figure $K_1 = 2000$ ~~m~~ N/m , $K_2 = 1500$ N/m K_4 & K_5 are equal to 500N/m. Find mass such that the system has a natural frequency of 10 Hz $K_3 = 3000$ N/m



$$\frac{1}{K_s} = \frac{1}{K_1} + \frac{1}{K_2} + \frac{1}{K_3}$$

$$= \frac{1}{2000} + \frac{1}{1500} + \frac{1}{3000}$$

$$\frac{1}{K_s} = 5 \times 10^{-4} + 6.66 \times 10^{-4} + 3.33 \times 10^{-4}$$

$$= 14.99 \times 10^{-4} \simeq 15 \times 10^{-4}$$

$$= \cancel{0.06666 \times 10^{4}} = 6666 \text{ N/m}$$

$$= \cancel{6.6666 \text{ N/m}}$$

$$K_p = 500 + 500$$

$$= 1000 \text{ N/m}$$

$$\frac{1}{K_{eff}} = \frac{1}{667} + \frac{1}{1000}$$

$$= \cancel{1.499 + 0.0001}$$

$$\frac{1}{K_{eff}} = \cancel{1.5} \Rightarrow \cancel{0.66 \text{ N/m}}$$

$$= 0.0014 + 0.001$$

$K_{eff} =$

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2) Three particle executing SHM in a straight line with a period of 25 sec, 5 sec after it has crossed the equellebrium point the velocity is found to be 0.7m/s Find the displacement at the end of 10 sec also find the amplitude of oscellation

$t = 5$ sec $\quad T = 25$ sec $\quad v = 0.7$ m/s

$y = a \sin\omega t$

$\omega = 2\pi f$

$= 2 \times 3.14 \times$

$= 0.25$

$a = \cancel{a} = \frac{\cancel{v}}{\omega}$

$a = a\omega\cos\omega t$

$a = \frac{V}{\omega\cos\omega t}$

$= \frac{0.7}{0.25 \cos(0.25)(5)}$

$= \frac{0.7}{0.25(0.99)}$

$= \frac{0.7}{0.24} \quad a \Rightarrow 2.86$ m

$y = a\sin\omega t$

$= 2.8 \sin(0.25)(50)$

$= 2.8 \cancel{(0.027)} \quad \cancel{4.36} \quad 0.04 \quad \Rightarrow 0.112$ m

$y = \cancel{0.05} \quad \cancel{12.20} \quad \cancel{1.28}$

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3. A Sonometer wire under tension is plucked and left free for vibrations. Find it's frequency of vibrations if the mid point on the string attains a maximum velocity of 1.57 m/s when it's amplitude of oscillation is 5mm. Read the vibration as SHM.

$V = 1.57$

$\cancel{\nu} = \cancel{5}$ $\quad \omega = ?$

$a = 5mm$

$\cancel{2\pi f} =$

$V = a\omega$

$\omega = \frac{V}{a}$

$2\pi f = \frac{1.57}{5 \times 10^{-3}}$

$= \frac{1.57}{6.28 \times 5 \times 10^{-3}}$ $\qquad = \frac{1.57}{31.4 \times 10^{-3}}$

$= 0.05 \times 10^{3}$

$\boxed{f = 50 \ Hz}$

4. A body of mass 500 g is attached to a spring and the system is driven by an external periodic force of amplitude 15N & frequency 0.796 Hz. The spring extends by a length of 88 mm under the given load. Calculate the amplitude of oscillation if the resistance co-effecent of the medium is 5.05 Kg/s

$m = 500 \times 10^{-3} = 0.5\,kg$
$F = 15N$
$f = 0.796\,Hz$
$y = 88 \times 10^{-3}m = 0.88\,m$
$2b = 5.05\,kg/s$

$F = r\frac{dy}{dt} \Rightarrow 15 = 0.05 \times \frac{dy}{dt}$ $\quad w = 2\pi f$

$\frac{dy}{dt} = \frac{15}{0.05}$ $\quad = 6.28$

$\boxed{p = 4.99\,m}$

$\boxed{\frac{dy}{dt} = 300\,m/s}$

$\cancel{A} = \frac{\cancel{F/m}}{\cancel{2bP}}$ $\quad w = \sqrt{\frac{K}{m}}$

$K = \frac{F}{x} = \frac{15}{0.88} = \cancel{17.04\,N/m} = 55.56\,N/m$

$\cancel{w} = \sqrt{\frac{\cancel{17.04}}{\cancel{0.5}}} \Rightarrow \sqrt{\cancel{34.08}} \Rightarrow \cancel{5.83}$

$w = \sqrt{\frac{\cancel{55.56}}{\cancel{0.5}}} = \cancel{3.33}$

$\cancel{2b \Rightarrow 5.}$

$w = \sqrt{\frac{55.6}{0.5}} = 10.54$

$2b = \frac{5.05}{2} \Rightarrow 0.25$

$A = \frac{F/m}{\sqrt{4b^2P^2 + (w^2 - P^2)^2}}$

$= \frac{15/0.5}{\sqrt{4(0.25)^2(4.99)^2 + ((\cancel{0.25})^2 - (4.99)^2)^2}}$ $\quad 10.5$

$= \frac{30}{\sqrt{4(0.0625)(24.90) + (24.90 - 0.\cancel{0625})^2}}$ $\quad 110.25$

$= \frac{30}{\sqrt{6.225 + (\cancel{616.90})}}$ $\Rightarrow \frac{30}{\cancel{94.96}}$ $= 0.3$

73.7 $\quad 7267.4 \quad 85.28$

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Shock waves

~~Acc~~:

Acostic waves These are the normal waves (Sound speed 331 m/s)

Frequency of sound → 20-20KHz

Types of waves

i) Subsonic → $M<1$

ii) Transonic → $0.8<M<1.2$

iii) Supersonic → $M>1$

iv) Hypersonic → $M>5$

Mach number,

$$M = \frac{\text{speed of object}}{\text{speed of sound}}$$

Shock waves:

A shock wave is narrow surface that manifests as a discontinuity in a fluid medium in which it is propogating with supersonic speed. The disturbance is characterized by sudden increase in pressure, temperature and density of the gas through which it is propogating

Mach number

It is the ratio of speed of an object to the speed of the sould in the surrounding medium

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$M = \frac{\text{Speed of object}}{\text{Speed of sound}} \Rightarrow M = \frac{V_o}{V_s}$

Types of waves

~~1) Subsonic~~

~~2) Transonic~~

1) Subsonic

The waves which are travells with in the speed less than the speed of sound in a medium are called subsonic waves ($M < 1$)

2) Transonic

The speed overlapping b/w subsonic and supersonic speed is the transonic waves ~~(M~~ ($0.8 < M < 1.2$)

3) Supersonic

The waves which travel with speed greater than the speed of sound in a medium are called supersonic waves ($M > 1$)

4) Hypersonic

If the mach number of the moving object is greater than 5 such waves are called hypersonic waves. ($M > 5$)

Properties of shock waves

* Shock waves travel in a medium with the mach number greater than 1
* Shock waves obey the law of fluid ~~[illegible]~~ dynamics

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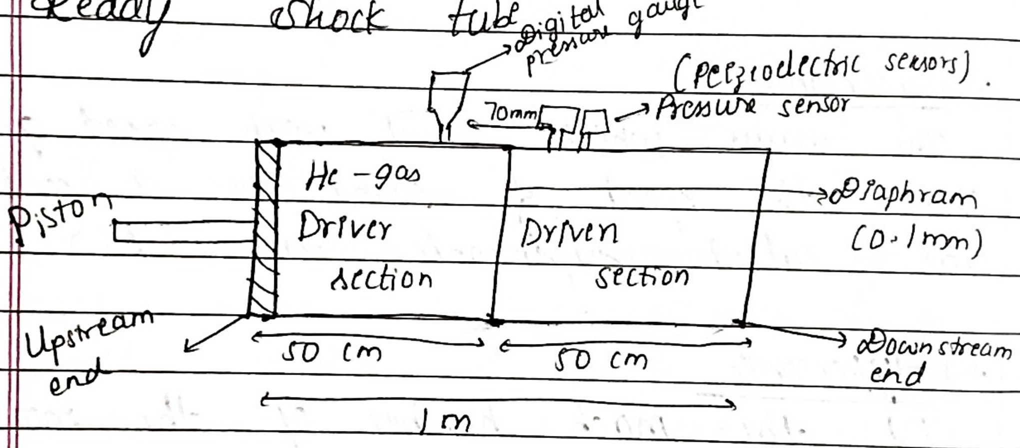
* When shock waves pass through a medium, the entropy of the system increases
* When shock waves pass through a medium the changes are adiabatic
* General wave properties cannot be associated with shock waves

Mach angle

Mach angle is half of the vertex angle of a mach cone whose sign is the ratio of speed of the sound to the speed of the moving body.

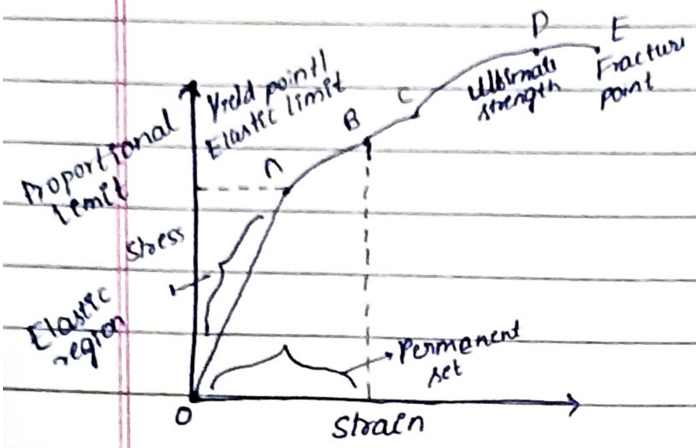
$$\theta = \sin^{-1}\left(\frac{1}{M}\right)$$

Reddy shock tube



It has is divided into two section as driver section & driven section

Stress - Strain Curve



1) OA → Elastic region → Hooke's law is applied
2) AB → Elastic limit or Yield point → There is a loss of propotionality b/w stress and strain
3) BC → Permanent set →
4) CD → Ultimate strength
5) DE → E pt → Fracture point → Where the deforms

1) Consider a bar of uniform cross section fixed at one end and loaded at other the stress - strain relation could be understand by plotting the stress-strain curve
1) The region OA is the elastic region in which Hooke's law is observed with the propotionality of stress v/s strain
2) Between the points A and B the material ~~accelerates~~ exhibits elastic material but lost the propotionality b/w stress and strain the point B is called Elastic limit or yield point.
3) Between the points B and C The material posses permanent strain and plastic behaviour is observed ~~once~~ it ~~is~~ then the material is said to be in permanent set.

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4) The point D corresponds to the maximum stress that the material can with stand and is called point of ultimate strain
5) At the point 'E' material brakes and the body no more exists in single piece Hence, point 'E' is called fracture point
6) In the region DE strain hardening and strain softening is observed

Elastic Modulii:
1) Young's Modulus, longitudanal stress → linear strain
2) Bulk Modulus, Compressive stress → Volume strain
3) Rigidity Modulus, Shearing stress → Shearing strain

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Limiting values for σ

$Y = 2n(1+\sigma)$

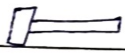
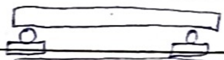
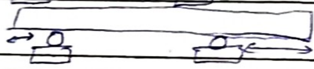
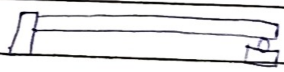
$Y = 3K(1-2\sigma)$

$2\eta(1+\sigma) = 3K(1-2\sigma)$

Bending of Beams:

1) Wieght than stress applied
2) Cross sectional area
3) No shearing forces

Types of Beam

1) Cantilihear → 
2) Simply supported → 
3) Over hanging → 
4) Contenous Beam → 
5) Fixed ended → 
6) Cantilever simply supported → 

Bending moment & Expression for bending momen-

The moment of applied couple due to which the beam bends longitudnally is called bending moment

Consider a Beam. Let AB, CD and EF be three layers before applying the ~~Low~~ load Hence, AB = CD = EF. The beam bend ~~AB~~= by applying load Hence, AB extends A'B' Similarly, EF contracts to E'F' but the layer CD remains same even after the action of load Hence. Its called neutral surface

$1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 4p^6$

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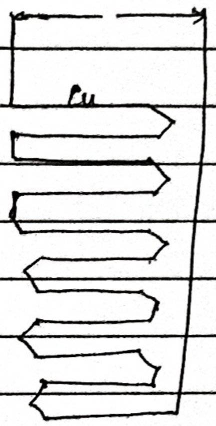
Disadwantages:
* The output voltage reduced is low.
* The Stray magnetic field can introduce errors in output voltage. Hence the accuracy is low.

Thermo-pile: Thermo-pile is an electronic device that converts ~~electr~~ thermal energy to electrical energy. This composed of several thermo-couples connected usually in series or less commonly in parallel

Construction:



The output voltage of single thermo-couple is extremely small so, a number of couples are connected in series or parallel to get a large output. The arrangement of this number of thermo-couple is called thermo-pile

Working: These thermo-couples are arranged to out the cold and hot areas and the hot junctions are isolated thermally from the cold junction. Due to the temp^r variations The thermo EMF across the two materials

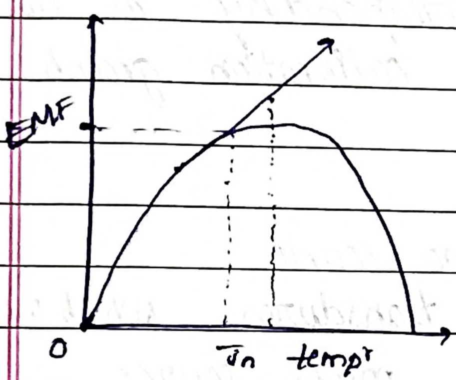
The Beam forms an arc of a circle of radius 'R' and subtends an angle θ. The layer A'B' is concentric to CD and EF the radius R+r

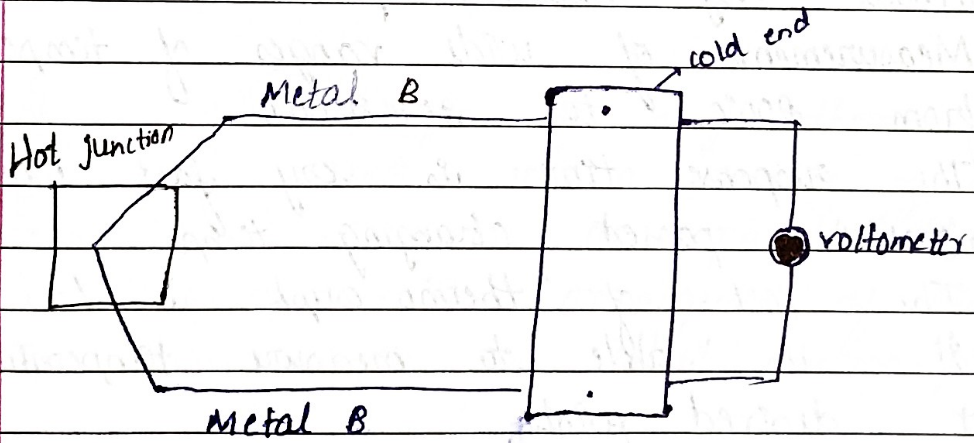
Thermo-couple & thermopile

Thermo-couple:

principle: It is based on the principle of sea-back effect

Defn: A thermo couple is a transducer that converts thermal energy into electrical energy





Consider dessimal metals A & B which are
The thermo-couple is connected or joined at two ends

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Measurement of temperature

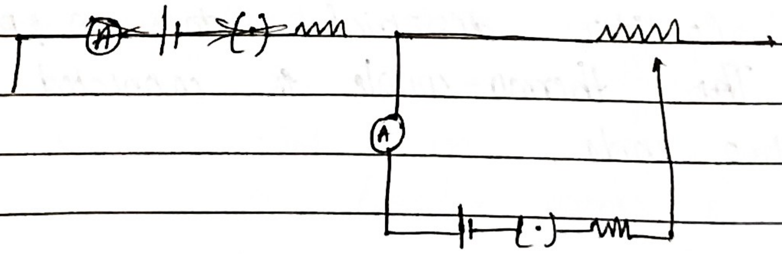
The thermo couple is calibrated by studying by variation of thermo EMF as a function of the temperature of hot junction keeping the temperature in temperature of cold junction (0°C). The graph of thermo EMF v/s temp hot junction is plotted this graph is known as calibration graph.

The hot junction is placed in a bath of unknown temperature and the EMF developed in the thermo couple is noted using voltmeter.

The temperature corresponding to this EMF is found from the calibration graph.

Adwantages of thermo-couple

- This is a active transdures which works without any external power source
- Measurement of wide ranges of temperature from 200°C to ~~208~~ 2800°C.
- The response time is very fast which can measure passed changing temp
- The cost of thermo-couple is low
- It is able to measure temperatures at desired points



$1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 4p^{10}$

DATE: PAGE:

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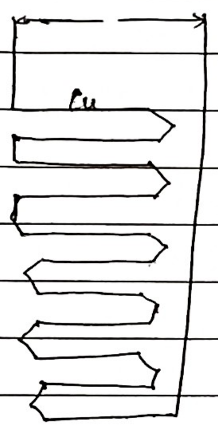

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Peltier co-effecient: The heat absorbed in unit time is directly proportional to current

$$\frac{H}{t} \propto I$$

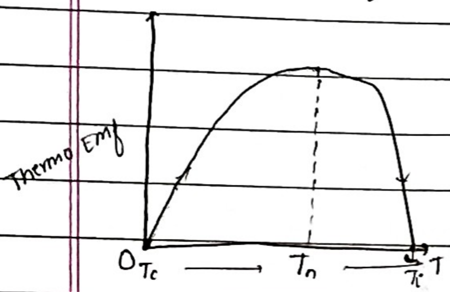
$$\frac{H}{t} = \pi_{ab} I \Rightarrow H = \pi_{ab} I t \Rightarrow H = \pi_{ab} q \quad [It = q]$$

$$\pi_{ab} = \frac{H}{q} \Rightarrow \pi_{ab} = H/It$$

The amount of heat absorbed or evolved at the junction of two dissimilar metals when 1A of current flows through it for one second

Thermo - Electric materials

Variation of thermo-Emf with the temperature



$T_n \rightarrow$ Neutral temperature

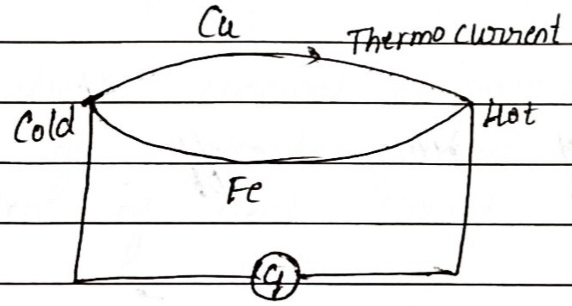
$T_i \rightarrow$ Inversion temperature

Let us take Cu-Fe thermocouple with Galvonometer G in the circuit. Let the temperature of the cold end B as 0°C. Now, the temperature of hot junction is gradually increased and the corresponding thermo-EMF is moded

A graph is plotted between the temperature of the hot junction and thermo EMF

- When both the junctions are at the same temperature (0°C) then thermo EMF is also zero
- As a temperature of the hot junction increases thermo EMF also increases till it becomes maximum

- The temperature at which thermo EMF becomes maximum is called neutral temperature. It is represented by T_n
- When the temperature of the hot junction is increased beyond neutral temperature. The thermo-EMF starts decreasing instead of increasing.
- At another particular temperature of the hot junction the thermo EMF becomes zero on heating slightly further.
- The direction of the thermo EMF is reversed and is called inversion temperature



<u>Relation between Neutral temp^r and Inversion temp^r</u>

$$e = at + \tfrac{1}{2} bt^2 \quad -(1)$$

$$\frac{de}{dt} = a + bt \quad -(2)$$

where ⓐ and ⓑ are the Seeback co-effecient

$t = T_1 - T_n$

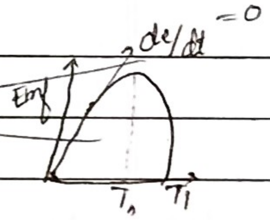
When $T = T_n$

$0 = a + bT_n$

$T_n = -a/b$

~~When, $T = T_1$~~

~~$0 = a + bT_1$~~



$0 =$

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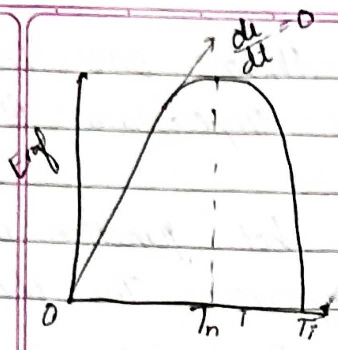


when $T = T_i$

$$0 = aT_i + \frac{1}{2} bT_i^2$$

$$0 = T_i(a + \tfrac{1}{2} bT_i)$$

$$0 = a + \tfrac{1}{2} bT_i$$

$$T_i = -2a/b$$

$$\boxed{T_i = 2T_n}$$

Thermo - Electric Power

The rate of change of EMF with respect to temperature is called Thermo - Electric power

$$\frac{de}{dT} = P$$

In terms of Peltier co-eff

$$\Pi = PT$$

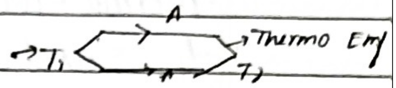
Figure of merit : Thermo- Electric system is defined by device effeciency and it depends on electrical conductivity, thermal conductivity and see back co-effecient all of these changes on temp^r

The maximum effeciency of the energy conversion process and a given temp^r in the material is determined by the figure of merit. which is indicated as

$$3T = \frac{\alpha^2 \sigma T}{K}$$

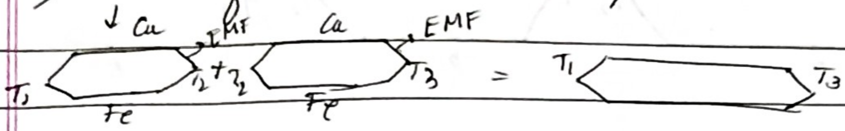
$\alpha \rightarrow$ Seeback co-effecient
$\sigma \rightarrow$ Electrical conductivity
$K \rightarrow$ Thermal conductivity
$T \rightarrow$ temp^r

Laws of thermo - ~~Elasticity~~ Electricity:

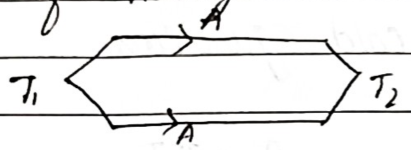
1) law of homogeneous metals → 

2) law of intermediate metals → 

3) law of intermediate temperatures →



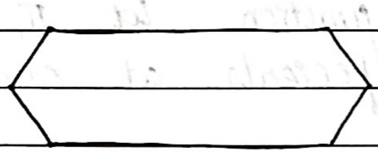
1) law of homogeneous metal



Thermo-electric current cannot be sustain in a circuit of single homogeneous material by the application of heat allowed

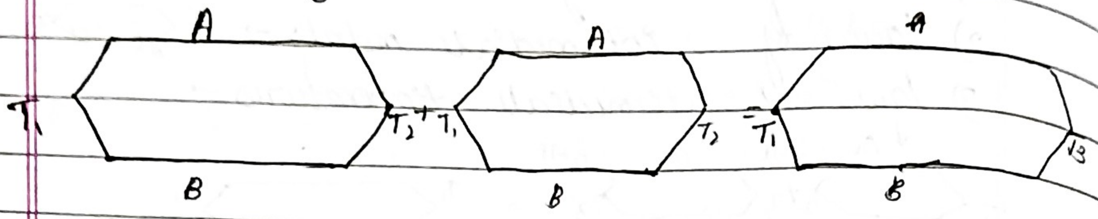
The thermal EMF produced by two thermocouples at T_1 and T_2 is independent of the temperature variation

2) law of intermediate metals: A third metal may be inserted into a thermo-couple system without affecting the EMF generated If and only if the junctions with the third metal are kept at the same temperature

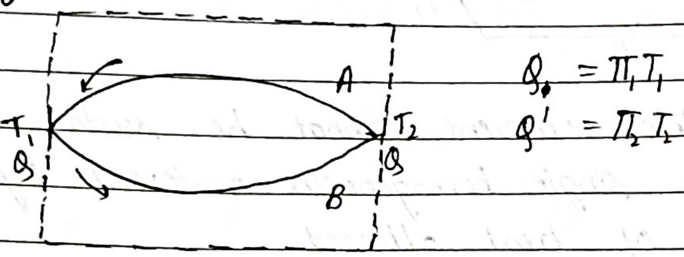


3) law of   : The sum of EMFs developed by a thermo couple with its junctions at temperatures t_1 and t_2 and with it's junction at temperature t_2 and t_3 will be

the same as the EMF developed if the thermo-couple junctions are at temperatures t_1 and t_3



Expression for thermo-EMF in terms of temp^r of hot and cold junctions



$Q = \Pi_1 T_1$

$Q' = \Pi_2 T_2$

Consider circuit of two dissimilar metals A and B with two junctions. Let T_1 & T_2 be the temperatures of cold and hot junctions. The electric current flows through the circuit due to seeback effect. Due to the flow of electric current through hot and cold junction, the Peltier effect will be in action which results in the absorption of heat by hot junction and loss of heat at cold junction. Let Π_1 & Π_2 be the Peltier co-efficients at cold & hot junctions.

$Q = \Pi_1 q$ at temp^r T_1

$Q' = \Pi_2 q$ at temp^r T_2

$e = (\Pi_2 - \Pi_1) q$

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Considering the process as similar to Caurnot's Engine, hot junction is represented as cold junction is represented as c

By def^n $\dfrac{\pi_1 q}{T_1} = \dfrac{\pi_2 q}{T_2}$

$$\frac{\pi_1}{T_1} = \frac{\pi_2}{T_2}$$

$$\frac{\pi_1}{\pi_2} = \frac{T_1}{T_2}$$

$$\frac{\pi_2}{\pi_1} = \frac{T_2}{T_1}$$

$$\frac{\pi_2}{\pi_1} - 1 = \frac{T_2}{T_1} - 1$$

$$\frac{\pi_2 - \pi_1}{\pi_1} = \frac{T_2 - T_1}{T_1}$$

$$\pi_2 - \pi_1 = \frac{\pi_1}{T_1}(T_2 - T_1)$$

$$e = \pi_2 - \pi_1$$

$$e = \frac{\pi_1}{T_1}(T_2 - T_1)$$

$$e \propto T_2 - T_1$$

EMF $\propto$ difference in temp^r

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Thermo-pile

-Adwantages and Disadwantages of Thermo-pile

* Does not ~~mao~~ need any external power supply.
* It gives a stable response to radiation which is gone from temperature measuring goals
* It has stable response charecteristics and available in small sizes and it is less costly
* Thermo-pile is a non-contact temperature detecting device that uses IR Radiation to transfer heat
* It generates large output voltage due to the usage several thermo-couple devices
*

Disadwantages

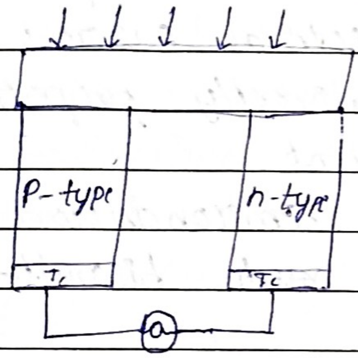
* The thermo-pile that are not within conductive material to depend them from static discharges and fields.
* These can be damage due to stress and reverse in the polarity of the power supply
* These should not be directly exposed to moisture or sunlight because this may cause the deposition of corrosion on the device.
* This device should not be operated with dirty ~~of~~ or oily fingures because the dust will affect the device performance for better performance

It is needed to be cleaned with cotton swabs

Thermo - Electric Generators:

Thermo- Electric generators are the devices that converts the temperature differences that is generated between the two sections into the electrical form of energy when a load is properly connected

Construction and Working



Construction: The simplest thermo -Electric generator consists thermo -couple comprising two semiconductor thermo-element which are connected electrically in series and thermally in parallel

∴ The p-type & n-type semiconductor are interconnected through a metal. The load is connected to free and tough p & n - type semiconductors

Semiconductors are used due to the high electrical conductivity and low thermal conductivity

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Heat is pumped into one-side of the couple and rejected from the opposite end. The electrons present at the hot end would be at higher energy level as compared to the electrons present at the cold end. Hence, The hot electrons tends to move towards the cold end due to the temperature gain. When temperature gradient is produced b/w two ends the electrons start flowing from one end to another end. and create a potential difference at the electrical current is produced which is directly propotional to temperature gradient.

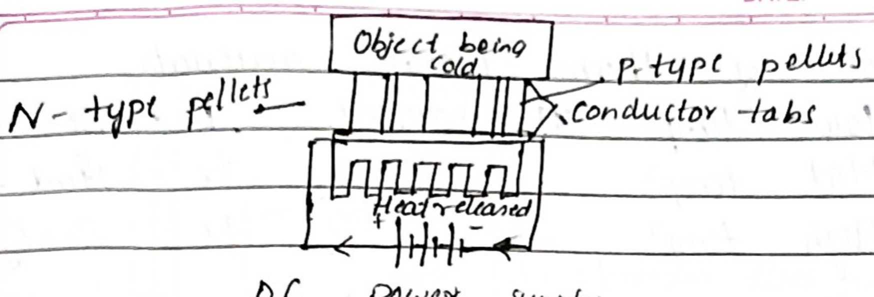
The commonly used semiconductors in TEG are ~~this~~ ~~much~~ bismuth-telluride and silicon-germanium.

Applications:

TEG's enhances the fuel performance of cars by converting heat liberated into electricity.

Seeback power generation is utilized to provide power for the spacecraft.

Thermo-electric generators are implemented ~~as~~ to provide the power for remote stations such as weather systems, relay networks and others.



Thermo-Electric coolers are solid state heat pump used in applications where temperature stabalization cycling or cooling below ambient temperature

It is based on the peltier-effect that is when electric current is passed in a circuit consisting of two dissimila metals heat is evolved at one end and absorbed at other end

Construction:

Thermo-electric cooler consists of an array of bismuth - tellaride semiconductor that have been ~~dough~~ doped ~~sot~~ so that the conduction of electricity will be higher and these two pallets are connected electrically in series ~~an~~ but thermally in parallel the conducting tabs connect the semiconductors to the hot end and the cold end ~~an~~

The metalized ceramic substrait provide the platform for the pallets

The size of the thermo-electric power varies 0.2 - 2mm Thermo-electric cooler can function singularly or in groups in series connection

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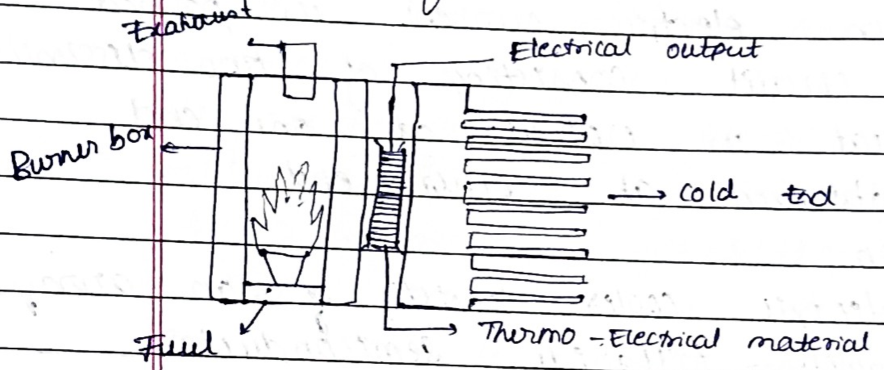
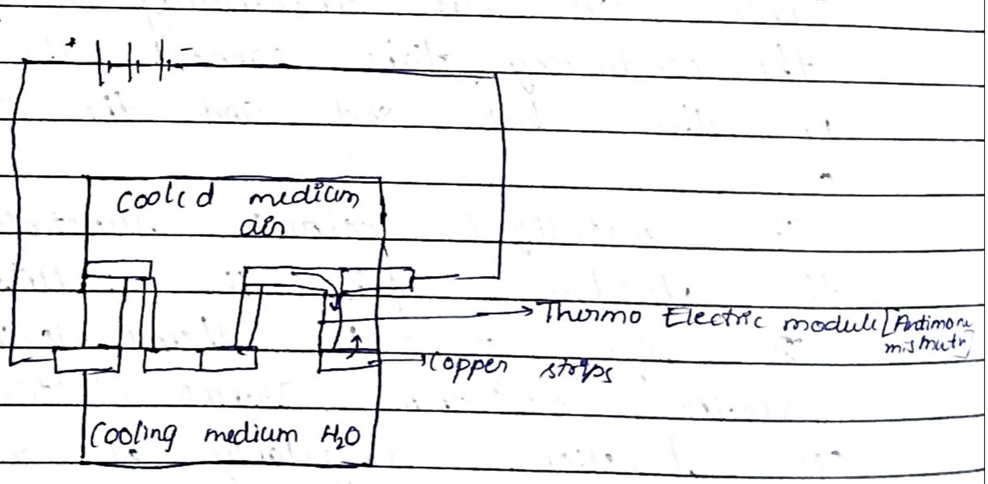
Types of thermo - Electric materials
1) low tempr TE material. Ex - Bi - Te
2) Mid tempr Ex - Lead - Tellaride
3) High tempr Ex - Si - Ge

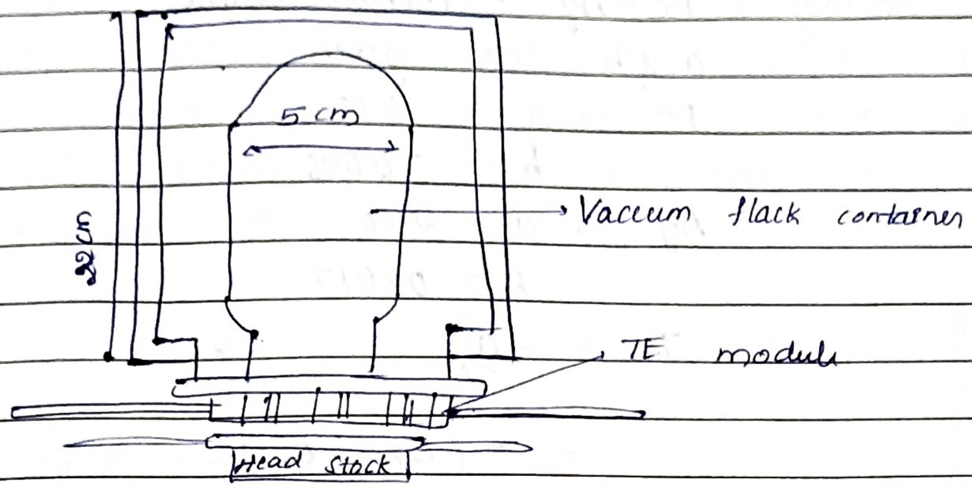
Applications on TEG:
- Exhaust of automobiles
- Refrigarator
- Space programming devices.

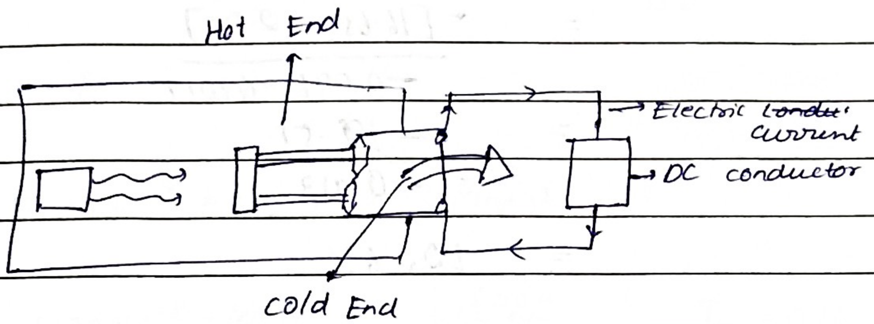
Exhaust of automobile:



- Thermo - Electric Refrigeration







1) State and Explain Seeback Effect and Hence Define Seeback co-effecient.
2) Discuss the variation of thermo-EMF with respect to tempr
3) Define neutral tempr, inversion tempr and hence reduce relation b/w ~~them~~ T_i & T_n
4) Explain the principal, construction & working of thermo couple with neat diagram.
5) Describe radio isotope TEG and automobile TEG.

1 Calculate the Neutral tempr for Iron silver thermo couple the values of ~~A & B~~ are 16.685 ~~[illegible]~~ and −0.096 for iron and 2.86 and 0.017 for silver respectively.

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$T_n = \frac{-a}{b}$ Fe - Ag - thermo couple.

a & b are given.

Fe $\rightarrow$ a = 16.65

b = -0.096

Ag $\rightarrow$ a = 2.86

b = 0.017

$T_n = -a/b$

$$= \frac{-[a_{Fe} - a_{Ag}]}{b_{Fe} - b_{Ag}}$$

$$= \frac{-[16.65 - 2.86]}{-0.096 - 0.017}$$

$$= \frac{-13.51}{-0.113}$$

$= 122.6°C$

2. Calculate the Iron cadmium thermo-couple the value of a & b are 17.5 & -0.1 for iron and for cadmium these value are 3 & 0.08

Fe $\rightarrow$ a = 17.5

b = -0.1

Cd $\rightarrow$ a = 3

b = 0.08

$T_n = -a/b$

$$= -\frac{[a_{Fe} - a_{Cd}]}{b_{Fe} - b_{Cd}}$$

$$= \frac{-[17.5 - 3]}{-0.1 - 0.08}$$

$$= \frac{-14.5}{-0.18}$$

$= 80.5°C$

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3\. The neutral temp^r of a thermo-couple is 300°c when it is kept at temp^r differences 100°C & 0°C. The EMF generated is 1300mV Calculate the value of co-efficien gs ~~an~~ a & b

$T_n = 300°c$ $e = 1300 \times 10^{-3} V$ $T_c = 0°$ $T = 100°c$

$t = 100°c$

~~$EMF = a + 1/2 bT^2$~~

~~$1300 \times 10^{-6} = a + \frac{1}{2} b 300$~~ ^{150} ~~$\frac{1300}{150} \times 10^{-6} = a + b$~~

$$e = at + \frac{1}{2} bt^2$$

$1300 \times 10^{-3} = a(100) + \frac{1}{2} b (100)^2$

$1300 \times 10^{-3} = 100a + \frac{1}{2} b 10000$ ^{5000} $T_n = -a/b$

$1300 \times 10^{-3} = 100a + 5000b$ — ① $300 = -a/b$

$1300 \times 10^{-3} = 100[a + 50b]$ $a = -300b$

$\frac{1300 \times 10^{-3}}{100} = a[-300b + 50b]$

$13 \times 10^{-3} = -250b$

$b = \frac{13 \times 10^{-3}}{250} = \frac{13 \times 10^{-4}}{25}$

$b = $ ~~-0.052×10^{-3}~~ 5.2×10^{-3}

~~① → $1300 \times 10^{-3} = 100a + 5000(-5.2 \times 10^{-3})$~~

~~$1300 \times 10^{-3} = 100a - 26000 \times 10^{-3}$~~

~~$27300 \times 10^{-3} = 100a$~~

~~$a = 27$~~

$T_n = \frac{-a}{b}$

$300 = \frac{-a}{0.5 \cdot 2 \times 10^{-4}}$

$1.56 \times 10^{-4} = -a \Rightarrow a = 0.156$

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1. The EMF of thermo couple is 1200 μV when working b/w 100°C & 0°C it's neutral tempr is 300°C find the values of a & b.

$$EMF = 1200 \times 10^{-6} V$$

$$e = at + \frac{1}{2} bt^2$$

$$1200 \times 10^{-6} = a(100) + \frac{1}{2} b(100)^2$$

$$1200 \times 10^{-6} = 100[a + 50b]$$

$$T_n = -a/b$$

$$300 = \frac{-a}{b} \Rightarrow a = -300b$$

$$12\cancel{00} \times 10^{-6} = \cancel{100} - 250b$$

$$b = \frac{12 \times 10^{-6}}{-250} \Rightarrow b = \frac{12 \times 10^{-6}}{25 \times 10^{1}}$$

$$b = -0.48 \times 10^{-7}$$

$$T_n = \frac{-a}{b} \qquad b =$$

$$300 = \frac{-a}{-0.48 \times 10^{-7}}$$

$$144 \times 10^{-7} = a \Rightarrow a = \cancel{144}\ 0.144 \times 10^{-4}$$

2. The EMF of a thermo couple is given by $e = 1600T$ Find neutral tempr & peltier co effecient

$$e = 1600T - 4t^2$$

$$e = at + \frac{1}{2} bt^2$$

$$a = 1600 \quad b = 4$$

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$\frac{de}{dt} = a + \frac{1}{2} 2bt$

$\frac{de}{dt} = a + bt$

$\pi = t \frac{de}{dt}$

$\pi = t[a + bt]$

$\boxed{\pi = 1600t + 4t^2}$

The neutral temperature is 270°C & the tempr inversion 525°C Calculate the tempr of cold junction.

$T_n - T_c = T_i - T_n$

T_c

7. The tempr of cold junction and neutral tempr of thermo couple are 15° & 280°C

$T_i =$

$T_c + T_i = 2T_n \Rightarrow$

$\frac{\cancel{15 + 280}}{2} = T_n$

$T_i = 2T_n - T_c$

$= 2(280) - 15$

$= 560 - 15$

$\boxed{T_i = 545°C}$

8. For thermo-couple the neutral tempr is 270°C where in ith cold junction is at 20°C, what will be the neutral tempr and tempr of inversion when tempr of cold junction is increased to 40°C

$T_i = 2T_n - T_c \Rightarrow T_i = 2(270) - 20 \Rightarrow 540 - 20 = \underline{520°C}$

$T_i = 2T_n - T_c \Rightarrow 2T_n = \frac{T_i + T_c}{2} = \frac{520 + 40}{2} =$

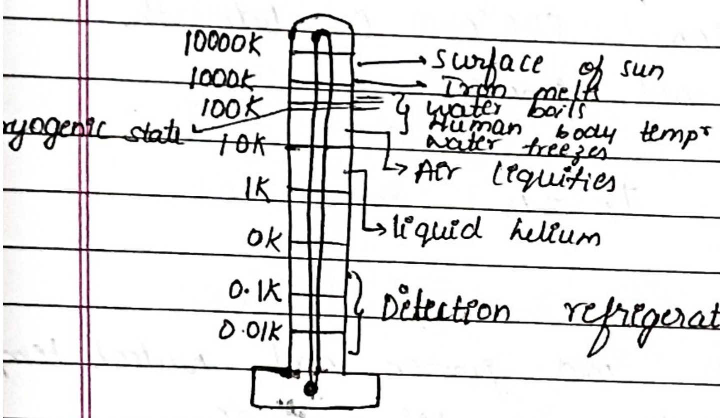
Module - IV

Cryogenics

study production of low tempr → cryogenics

Less than 123 K

Cryogenics is the branch of physics which deals with the study of the production of low tempr and thier effect on the matter



Joule - Thomsons Effect

If a gas initially having at constant high pressure is allowed to suffer throttle expansion through the corous plug of silk, cotton which has a number of fine to a region of constant low pressure adiabatically. The change in the tempr of gas is observed. This effect is called Joule - Thomson's or Joule - Kelvin effect

adiabatic → No exchange of energy or tempr

$\frac{1}{v^2}$ $\frac{v^{-2+1}}{-2+1}$ $-\frac{v^{-1}}{-1}$ $-\frac{1}{v}$

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Joule - Thomson co-effecient

One mode of gas is allowed to expand through a porous plug from a pressure P_1 and volume V_1 to P_2 and V_2 let the temperature changes from T_1 to T_2 due to Joule - thomson effect

Net external work done by the gas $= P_2V_2 = P_1V_1$

Now, the work done by overcoming by the forces is the workdone is given by

$P = \frac{a}{V^2}$ where a is constant

Total internal work done by the gas when it expands from V_1 to V_2

$$\int_{V_1}^{V_2} P.dv = \int_{V_1}^{V_2} \frac{a}{V^2} dV$$

$$= \left.-\frac{a}{V}\right]_{V_1}^{V_2} \Rightarrow -\left[\frac{a}{V_2} - \frac{a}{V_1}\right] \rightarrow \frac{a}{V_1} - \frac{a}{V_2} \quad -②$$

Total work done by the gas is given by

$W =$ [Ext + Int] work done

$$W = [P_2V_2 - P_1V_1] + \frac{a}{V_1} - \frac{a}{V_2} \quad -③$$

By Vander wall eq^n

$$\left(P + \frac{a}{V^2}\right)(V - b) = RT$$

$$PV = RT + Pb - \frac{a}{V} + \frac{ab}{V^2}$$

$$PV = RT + Pb - \frac{a}{V} \quad [\text{neglating } \frac{ab}{V^2}$$

$$P_1V_1 = RT_1 + P_1b - \frac{a}{V_1}$$

$$P_2V_2 = RT_2 + P_2b - \frac{a}{V_2}$$

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$$W = \left[RT_2 + P_2 b - \frac{a}{V_2} - \left[RT_1 + P_1 b - \frac{a}{V_1}\right]\right] + \frac{a}{V_1} - \frac{a}{V_2}$$

$$\cancel{W = RT_2 + P_2 b - \frac{a}{V_2} - RT_1 - P_1 b + \frac{a}{V_1} + \frac{a}{V_1} - \frac{a}{V_2}}$$

$$\cancel{W = RT_1 + P_1 b - RT}$$

$$W = RT_2 + P_2 b - \frac{a}{V_2} - RT_1 - P_1 b + \frac{a}{V_1} + \frac{a}{V_1} - \frac{a}{V_2}$$

$$W = RT_2 - RT_1 + P_2 b - P_1 b + \frac{2a}{V_1} - \frac{2a}{V_2}$$

$$W = R[T_2 - T_1] - b[P_1 - P_2] + 2a\left[\frac{1}{V_1} - \frac{1}{V_2}\right] \quad \text{— (4)}$$

$$PV = RT \Rightarrow V = \frac{RT}{P}$$

$$V_1 = \frac{RT_1}{P_1}, \quad V_2 = \frac{RT_2}{P_2}$$

Use the temp^r changes in a small amount

$$T_1 = T_2 = T$$

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

Substituting V_1 & V_2 for eq^n (4)

$$W = R(T_2 - T_1) - b(P_1 - P_2) + \frac{2aP_1}{RT} - \frac{2aP_2}{RT}$$

$$W = R(T_2 - T_1) - b(P_1 - P_2) + \frac{2a}{RT}[P_1 - P_2]$$

$$W = -R\,\partial T - b(P_1 - P_2) + \frac{2a}{RT}[P_1 - P_2]$$

$$W = \left[\frac{2a}{RT} - b\right](P_1 - P_2) - R\,\partial T \quad \text{— (5)}$$

Since, The gas is thermally insulated The energy necessary for doing this work is drawn from the kinetic energy of molecule Hence the kinetic energy decreases resulting in fall of temp^r by ∂T

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$$W = \left[RT_2 + P_2 b - \frac{a}{V_2} - \left[RT_1 + P_1 b - \frac{a}{V_1}\right]\right] + \frac{a}{V_1} - \frac{a}{V_2}$$

$$\cancel{W = RT_2 + P_2 b - \frac{a}{V_2} - RT_1 - P_1 b + \frac{a}{V_1} + \frac{a}{V_1} - \frac{a}{V_2}}$$

$$\cancel{W = RT_1 + P_1 b - RT}$$

$$W = RT_2 + P_2 b - \frac{a}{V_2} - RT_1 - P_1 b + \frac{a}{V_1} + \frac{a}{V_1} - \frac{a}{V_2}$$

$$W = RT_2 - RT_1 + P_2 b - P_1 b + \frac{2a}{V_1} - \frac{2a}{V_2}$$

$$W = R[T_2 - T_1] - b[P_1 - P_2] + 2a\left[\frac{1}{V_1} - \frac{1}{V_2}\right] \quad \text{—(4)}$$

$$PV = RT \Rightarrow V = \frac{RT}{P}$$

$$V_1 = \frac{RT_1}{P_1}, \quad V_2 = \frac{RT_2}{P_2}$$

Use the temp^r changes in a small amount

$$T_1 = T_2 = T$$

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

Substituting V_1 & V_2 for eq^n (4)

$$W = R(T_2 - T_1) - b(P_1 - P_2) + \frac{2aP_1}{RT} - \frac{2aP_2}{RT}$$

$$W = R(T_2 - T_1) - b(P_1 - P_2) + \frac{2a}{RT}[P_1 - P_2]$$

$$W = -R\,\partial T - b(P_1 - P_2) + \frac{2a}{RT}[P_1 - P_2]$$

$$W = \left[\frac{2a}{RT} - b\right](P_1 - P_2) - R\,\partial T \quad \text{—(5)}$$

Since, The gas is thermally insulated The energy necessary for doing this work is drawn from the kinetic energy of molecule Hence the kinetic energy decreases resulting in fall of temp^r by ∂T

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The heat loss is given by

$$C_v \partial T = (P_1 - P_2)\left(\frac{2a}{RT} - b\right) - R\partial T$$

$$(C_v + R)(\partial T) = \left(\frac{2a}{RT} - b\right)(P_1 - P_2)$$

(C_p)

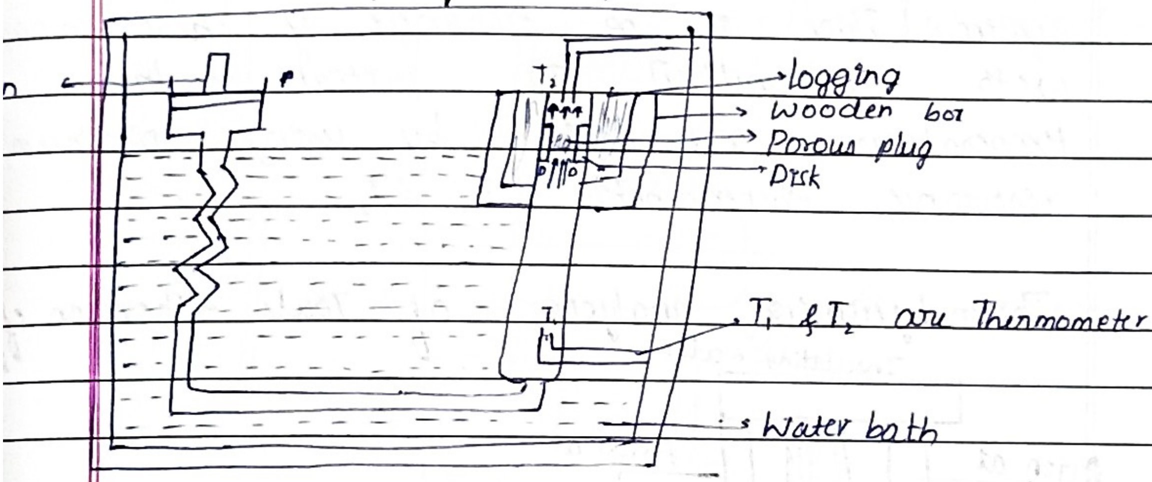
$$C_p \, \partial T = \left(\frac{2a}{RT} - b\right)(P_1 - P_2)$$

$$\partial T = \frac{P_1 - P_2}{C_p}\left(\frac{2a}{RT} - b\right)$$

Joule Thomson ~~constant~~ co-effecient

$$U_{JT} = \frac{\partial T}{\partial P} = \frac{-1}{C_p}\left[\frac{2a}{RT} - b\right]$$

Porous plug Experiment



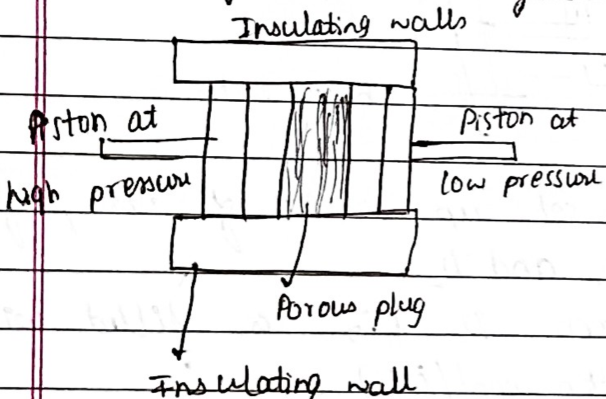
1. The experiment set up consists of two perforated brass - descs D_1 and D_2
2. The space between D_1 & D_2 is filled with porous plug [cotton, wool/silk]
3. The porous plug arrangment is fitted in a wooden box which is surrounded by cotton to avoid the exchange of heat energy with the surrounding.

4. T_1 & T_2 are the platinum thermometers
5. The piston is fixed at the top to apply pressure
6. The whole arrangement is kept in water bath

Procedure:

The experimental gas passed slowly and uniformly to the porous plug keeping the high pressure which can be read using pressure gauge. During the passage to the porous plug The gas is throttled The seperation b/w molecules increases due to which the volume of the gas increases against the atmospheric pressure As the experimental set up kept in an adiabatic system [There is no exchange of heat energy with surrounding] The initial & final temperatures are noted by using platinum resistance thermometer T_1 & T_2

Thermodynamics analysis of Joule-Thomson effect



Work done by the piston 1 on the gas $= P_1A_1dx = P_1V_1$

Work done by the piston 2 on the gas $= P_2A_2dx = P_2V_2$

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Net external workdone = $(P_2V_2 - P_1V_1)'$

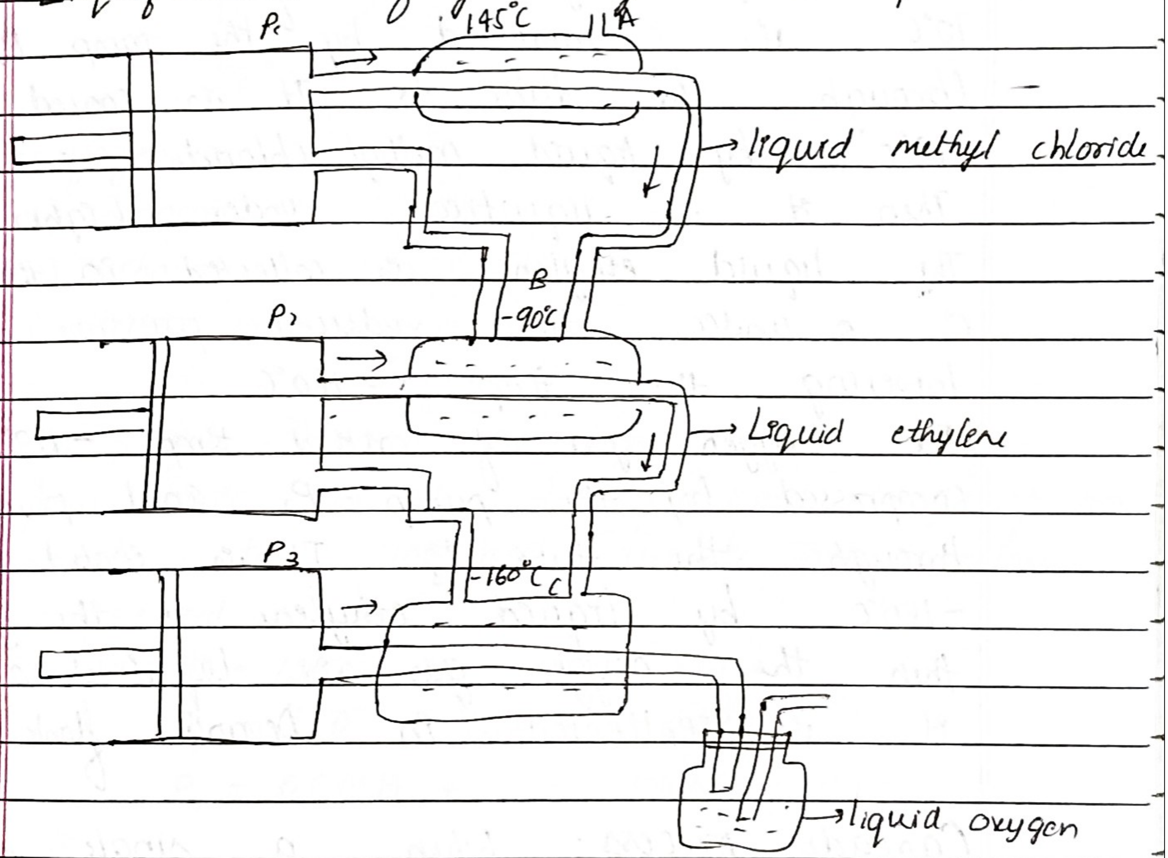
Let W be the work done by gas in overcoming intermolecular force of attraction

i) Below Boyles tempr : If $P_2V_2 > P_1V_1$
$P_2V_2 - P_1V_1$ = +ve cooling effect

ii) When $P_2V_2 = P_1V_1$ = +ve workdone cooling effect

iii) When $P_1V_1 > P_2V_2 \Rightarrow$ -ve workdone heating effect

Liquification of gas by cascade process



Construction

The apparatus consists of compression pumps P_1 P_2 and P_3, T_1 T_2 & T_3 are the tubes which are surrounded by the outer jackets A,B and C. The Devar's flask is used to called

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12:13

liquid oxygen

Working:

The methyl chloride gas of critical tempr 145°c is compressed by the pump P_1 through the tube T_1. It is cooled by the water filled in the jacket A.

Here the methyl chloride reaches tempr lower than it's critical tempr. Then It is liquified under high pressure. The liquid methyl chloride is collected in the jacket B and Evapo-rates under the reduced pressure by lowering the temperature to −90°c

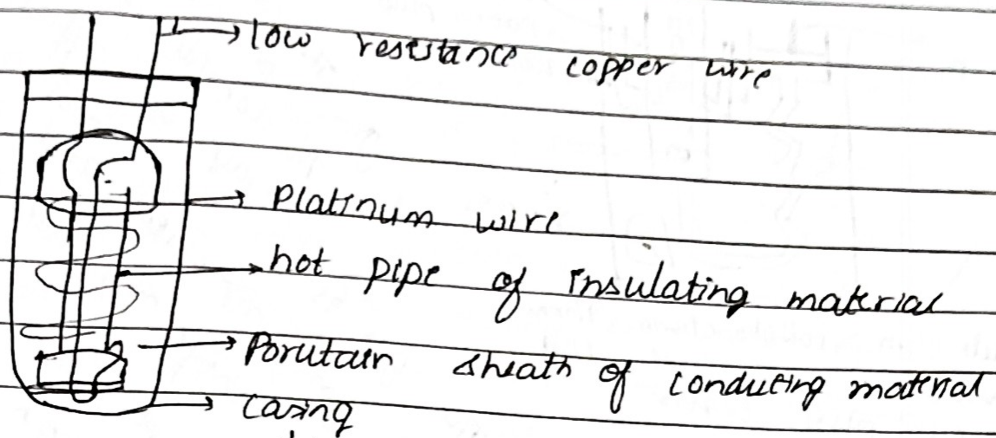
The Ethylene glass is of critical tempr 10°C is compressed by the pump P_2 through the tube t_2. It is cooled to −90°c by liquid methyl chloride.

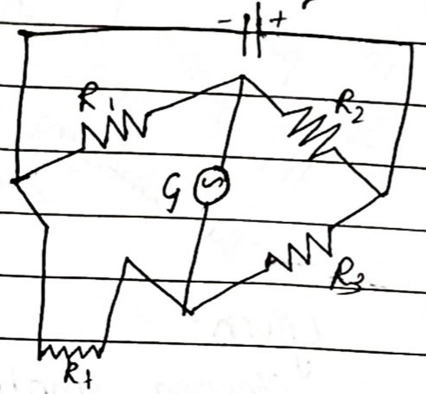
Then It is liquified under higher pressure. The liquid ethylene is collected in the jacket C under the reduced pressure and lowering the tempr −160°C

The Oxygen gas of critical tempr −119°C is compressed by the pump P_3 and passed through the tube T_3. It is cooled to −160°c by liqued ethylene in the jacket C, then the oxygen gas is liquified and it is collected in Devar's flask

Cascade process: When a single stage is not enough to produce the desired results the process taking place in a number of stages in a sequence is used for the purpose of liquification of gas

Platinum resistance thermometer





Cryogenics:

1) Aerospace
2) Tribology
3) Food processing

Q1. In Joule-Thomson experiment temp^r changes from 100°C to 150°C for pressure change of ~~20~~ 20MPa to 170MPa Calculate Joule Thomson co-effecient

$T_1 = 100°C = 100+273 = 373\,K$

$T_2 = 150° = 150+273 = 423\,K$

$P_1 = 20MPa$ $P_2 = 170MPa$

$\frac{\partial T}{\partial P}$ Joule Thomson Coeffecient $= \mu_{JT} = \frac{\partial T}{\partial P}$

$= \frac{T_2 - T_1}{P_2 - P_1} = \frac{50K}{150MPa} = \frac{1}{3}\,K/MPa$