Amplitude (A) is the maximum displacement of the oscillatory from the equilibrium position.

Example: On average a human heart is found to beat 75 times in a minute. Calculate its frequency and period.

$$\Rightarrow f = \frac{75}{1\,\text{minute}} = \frac{75}{60\,s} = 1.25/s = \underline{1.25\,Hz}$$

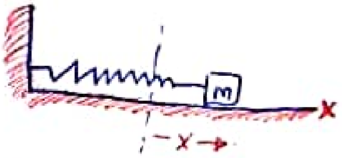
$$T = \frac{1}{f} = \frac{1}{1.25/s} = \underline{0.8\ Sec}$$

→ Simple harmonic motion is a special type of oscillatory motion caused by a restoring force which obeys Hooke's law.

In SHM acceleration

a) is always directly proportional in size but opposite in direction to its displacement (x).

A block of mass m, attached to one end of a spring, of constant k and oscillating in a horizontal frictionless floor, is example of SHM.



$$\boxed{F_s = -kx}$$

The minus (−) sign shows the force is always acting opposite to the displacement and always tries to restore the block back to its equilibrium position.

Newton's 2nd law $F_s = ma$

$$ma = -kx \longrightarrow a = -\left(\frac{k}{m}\right)x = \underline{-\omega^2 x}$$

* k is constant of proportionality called the spring constant or stiffness factor and ω is angular frequency of oscillator.

Characteristics of SHM

1) The amplitude A is constant
2) The frequency and period are independent of Amplitude
3. The fluctuating quantity can be expressed interms of sinusoidal function of a single frequency.

For SHM to occur

- there must be a stable equilibrium position
- there must be no dissipation of energy
- the acceleration is proportional to displacement & opposite in direction.

Displacement, Velocity and acceleration in SHM

- Displacement $\rightarrow X = A\sin\omega t$
- Velocity $= \omega A\cos(\omega t)$
- Acceleration $= -\omega^2 A\sin(\omega t) = -\omega^2 x$

* Maximum Velocity occurs at equilibrium position with $V_{max} = \omega A$

* Maximum acceleration occurs at $X = \pm A$; $a_{max} = \omega^2 A$

Example

An object oscillates with SHM along x-axis. its position Varies with time according to equation $X = (4.00)m\cos(\pi t + \frac{\pi}{4})$ where t is in seconds and angles in radians.

a) Determine A, f, and T of motion

b) Calculate $\vec{V}$, & $\vec{a}$ at any time.

c) Using results of part b, determine position, Velocity & $\vec{a}$ at $t = 1s$

d) determine maximum Speed and maximum acceleration of object.

Solution

Given

$$X = \overset{A}{(4.00)m}\cos(\overset{\omega}{\pi} t + \overset{\phi}{\frac{\pi}{4}})$$ with the general eq. of Simple HM $X(t) = A\cos(\omega t + \phi)$

a) $A = 4m$, $\omega = \pi\,\frac{rad}{s}$ $\rightarrow f = \frac{\omega}{2\pi} = \frac{\pi\,rad/s}{2\pi} = 0.5\,Hz$

$$T = \frac{1}{f} = \frac{1}{0.5} = 2\,sec$$

b) $$\vec{V} = \frac{dx}{dt} = \frac{d(4m\cos(\pi t + \frac{\pi}{4}))}{dt} = -(4\pi)m/s\sin(\pi t + \frac{\pi}{4})$$ //

$$a = \frac{dv}{dt} = -(4\pi)^2\,m/s^2\cos(\pi t + \frac{\pi}{4})$$ //

c) at $t = 1sec$

$$x(t) = 4\cos(\pi t + \frac{\pi}{4}) = 4\cos(\pi(1) + \frac{\pi}{4})$$
$$= 4\cos 5\pi/4 = -2.83\,m$$

$$V(t) = -4\pi\sin(\pi(1) + \frac{\pi}{4})$$
$$= -4\pi\sin\frac{5\pi}{4} = 8.89\,m/s$$

$$a(t) = -(4\pi)^2\cos(\pi(1) + \pi/4) = 27.9\,m/s^2$$

d) $V_{max} = \omega A = 12.56\,m/s$

$a_{max} = \omega^2 A = 39.4\,m/s^2$ //

The Concept of Heat, Work and Internal energy

Heat. Symbol Q and unit joule (J) is Spontaneous flow of energy into or out of a System caused by a d/ce in temperature b/n System and Surroundings.

Work. Symbol W and Unit joule (J), is a non-Spontaneous energy transfer into or out of a System due to force acting through a displacement.

Work takes many forms, moving a piston or Stirring or running an electrical Current through resistance.

Work is the non-Spontaneous transfer of energy. Heat is microscopic form of energy transfer, involving large no of particles.

A System Cannot posses heat or work. These two are energies that flow into or Out of a System.

Heat transfer Obeys the law of Conservation of energy (if no heat is lost to Surroundings)

$$Q_{\text{lost by hotter object}} = Q_{\text{gained by Cooler Object}}$$

Internal Energy, Symbol U, is defined as the energy associated with the random, disordered motion of the microscopic Components - atoms and molecules.

Specific Heat and Latent Heat

Specific heats:-

Heat flowing into or out of a body (or System) changes the temperature of the body (or System) except during phase changes the temperature remains constant.

→ The quantity of heat Q required to change the temperature of the body of mass m by ΔT is proportional to both mass & ΔT

Mathematically $Q \sim m\Delta T$ → $Q = mc\Delta T$ — C - heat capacity (or Specific heat)

C - the amount of heat required to raise temperature of unit mass of any Substance through a Unit degree.

SI unit is J/kg·K or J/kg·°C

The amount of heat required to change the temperature of n moles of a Substance is: $Q = nC\Delta T$

Latent heats:-

Latent heat is the heat required per unit mass of a Substance to produce a phase change at Constant temperature.

→ the latent heat, Q_L, required to change the phase of "m" mass of a body at Constant temperature is

$$Q_L = \pm mL$$

L - Specific latent heat required to change a phase of 1kg of a Substance at a Constant temperature.

Types of latent heats

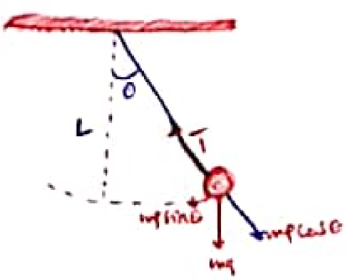
two types

1) Latent heat of fusion (L_f) is the heat absorbed or released when matter melts changing phase from Solid to Liquid form at Constant temperature.

2) latent heat of Vaporization (L_V) is the heat absorbed or released when matter Vaporizes changing phase from liquid to gas phase at constant temperature

The Simple pendulum

A simple pendulum is another mechanical System that exhibits periodic motion.



The force of gravity is the only force that acts on the pendulum.

The pendulum bob moves along a circular arc, rather than back and forth in a straight line.

Hooke's law ⟶ $T = 2\pi\sqrt{L/g}$

L - length
g - gravity
T - ~~Tension~~ period

* Period of simple pendulum does not depend on mass but only length & free fall acceleration.

Eg. A rock swings in a circle Constant speed on the end on a string, making 50 revolutions in 30 sec. What is frequency and period for this motion

Soln

$f = \frac{50\,rev}{30\,sec} = 1.67\ rev/sec = 1.67\ Hz$

$T = \frac{1}{f} = \frac{1}{1.67} = 2\ sec$

Energy of Simple Harmonic Oscillator

In the absence of friction, the total energy of a block-Spring System is constant and equal to the sum of kinetic and potential energies.

$PE = \frac{1}{2}kx^2 \qquad KE = \frac{1}{2}mv^2$

Total energy of the oscillator performing SHM is $\boxed{E = \frac{1}{2}kA^2}$

* Energy of SHM is Constant & proportional to square of Amplitude.

Wave and Its charectristics

* Wave is a disturbance from normal or equilibrium Conditions that travels, or Propagates, Carrying energy and momentum through Space without the transport of matter

* Pulse is a single disturbance travelling into a medium.

Wave Supplies energy to the particles in a medium to set them in motion.

Terminologies in Wave

Crests / Thoughts: are positions in a wave with maximum displacements above/below the equilibrium position.

Amplitude (A) :- is the maximum displacement from equilibrium position

Displacement (y) :- is position of a wave from equilibrium position at any time

Xample 1

How much heat energy is required to a change a 40g ice Cube from a solid at −10°c to steam at 110°c.

Solution

To raise the temperature of the ice to 0°c we need

$$\Delta Q_{ice} = m_{ice} C_{ice} \Delta T = 0.04\,kg \left(0.49 \frac{kcal}{kg \cdot °c}\right) 10°c$$

$$= 0.196\,kcal$$

To melt the ice we need

$$\Delta Q_{ice} = m_{ice} L_{ice} = 0.04\,kg \,(80\,kcal/kg) = 3.2\,kcal$$

To raise the temperature of 100°c we need

$$\Delta Q_{ice} = m_{water} C_{water} \Delta T = 0.04\,kg \left(1 \frac{kcal}{kg\,°c}\right) 100°c = 4\,kcal$$

To raise the temperature of the system to 110°c we need

$$\Delta Q_{ice} = m_{system} C_{system} \Delta T = 0.4\,kg \left(0.48\,kcal/(kg\,°c)\right] 10°c = 0.192\,kcal$$

To boil the water need

$$\Delta Q_L = m_{water} L_{water} = 0.04\,kg \left(540\,k \frac{cal}{kg}\right) = 21.6\,kcal$$

Therefore total heat energy required is

$$\Delta Q = (0.96 + 3.2 + 4 + 21.6 + 0.192)\,kcal = 29.188\,kcal$$

Ex2 If 90g of molten lead at 327.3°c is poured into a 300g Casting form made of iron and initially at 20°c. What is the final ~~tem~~ temperature of the system? Assume no energy loss to env't.

Soln The melting point of lead is 327.3°c. Assume the final temperature of the system is T.

- The amount of energy released by the lead as it solidifies is

$$\Delta Q_L = m_{lead} L_{lead} = 0.09\,kg \,(2.45 \times 10^4\,J/kg) = 2205\,J$$

- The amount of energy released as it cools is

$$\Delta Q = m_{lead} C_{lead} \Delta T = 0.09\,(128)(327.3 - T) = (11.52)(327.3 - T)$$

The energy is absorbed by the iron, for the iron

$$2205 + (11.52)(327.3 - T) = m_{iron} C_{iron} \Delta T = 0.3\,(448)(T - 20)$$

$$5975.5 - (11.52)T = 134T - 2688$$

$$8663.5 = 145.52T$$

$$T = 59.5°c$$

Example - 1

5000 J of heat are added to two moles of an ideal monatomic gas, initially at a temperature of 500 k. while the gas performs 7500 J of work. What is the final temperature of the gas?

Solution

$$\Delta U = Q + W$$

$$= 5000 - 7500$$

$$= -2500 J$$

from equation $\Delta U = nC\Delta T \rightarrow \Delta U = \frac{3}{2} nR\Delta T$

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

$$-2500 = \frac{3}{2}(2)(8.31)\Delta T$$

$$\Delta T = -100 k$$

$$\Delta T = T_f - T_i$$

$$-100k = T_f - 500k$$

$$T_f = 400 k$$

Example - 2

2000 J of heat leaves the system and 2500 J of work is done on the system.

What is the change in internal energy of the s/m.?

Soln

$Q = -2000 J$

$W = 2500 J$

$$\Delta U = Q + W$$

$$= -2000 J + 2500 J$$

$$\boxed{\Delta U = 500 J}$$

Activity 1 A 1 mol sample of an ideal gas is kept at 0.0°c during an expansion from 3.0L to 10L

a) How much work is done on the gas during expansion?

Solution

$$W = nRT \ln\left(\frac{V_f}{V_i}\right)$$

$$= (1 mol)(8.31 J/mol\cdot k)(273 k) \ln\left(\frac{10}{3}\right)$$

$$= 2.73 \times 10^3 J$$

b) How much energy transferred by heat occurs with the surroundings in this process

$\Delta U = 0$

$$\Delta U = Q + W$$

So

$$Q = W$$

$$Q = W = 2.73 \times 10^3 J$$

Bernoulli's Equation

* The Sum of pressure, kinetic energy per unit volume, and gravitational potential energy per unit volume has the same value at all points along a streamline.

This is called Bernoulli's Equation

$$P_1 + \frac{1}{2}\rho V_1^2 + \rho g h_1 = P_2 + \frac{1}{2}\rho V_2^2 + \rho g h_2$$

ρ - density
V - Velocity
P - Pressure

Example

Water circulates throughout a house in a hot water heating system. If the water is pumped at a speed of 0.50 m/s through a 4 cm diameter pipe in basement under pressure of 3.03×10^5 pa. What will be velocity and pressure in a 2.6cm diameter pipe on the 2nd floor 5m above?

Given

$V_1 = 0.5\ m/s$ $\quad V_2 = ?$

$h_1 = 0m$ (basement) $\quad h_2 = 5m$

$d_1 = 4cm = 0.04m$ $\quad d_2 = 2.6cm = 0.026m$

$A_1 = \pi r_1^2 = \pi(d_1/2)^2$ $\quad A_2 = \pi(d_2/2)^2 = 1.69 \times 10^{-4}\pi$

$= 0.0004\pi$

$P_1 = 3.03 \times 10^5$ pa $\quad P_2 = ?$

Solution

from Equation of Continuity

$$A_1 V_1 = A_2 V_2$$

$$V_2 = \frac{A_1 V_1}{A_2} = \frac{(0.0004\pi)(0.5)}{1.69 \times 10^{-4}\pi} = 11.83\ m/s$$

from Bernoulli's Equation

$$P_2 = P_1 + \frac{1}{2}\rho V_1^2 + \rho g h_1 - \frac{1}{2}\rho V_2^2 - \rho g h_2$$

$$= P_1 + \frac{1}{2}\rho(V_1^2 - V_2^2) + \rho g(h_1 - h_2)$$

$$= 3.03 \times 10^5 + \frac{1}{2}(1.0 \times 10^3)[0.5^2 - 11.83^2] + (1 \times 10^3)(9.8)[0 - 5]$$

$$P_2 = 1.84 \times 10^5\ pa$$

The first law of thermodynamics

The 1st law of thermodynamics states that "The change in internal energy of a system is equal to the sum of the heat flow into the system and the work done on the s/m.

In equation $\boxed{\Delta U = Q + W}$

ΔU - change in internal energy

$W = P\Delta V$ - Work done on the s/m

- P - pressure
- ΔV - Volume

The first law of different thermodynamic s/ms

Isolated System:- is a system which does not exchange heat with its surroundings and no work is done on the external environment.

$\boxed{\Delta U = 0 \text{ or } U = \text{Constant}}$ The internal energy of an isolated system is constant.

Cyclic process:- Engines operate in cycles, in which the system, example, a gas - periodically returns to its initial state.

Since, the system returns to its initial state, the change in internal energy in one complete cycle is zero.

$$\Delta U = 0 \longrightarrow \text{so, } Q = W$$

Isochoric process:- In a constant volume process, the volume of the system stays constant.

Consequently, $W = 0 \longrightarrow \Delta U = Q$

→ All the heating entering the system goes into increasing internal energy

Adiabatic process:- The system does not exchange heat with its surroundings, $Q = 0 \longrightarrow \Delta U = W$

Isothermal process:- It is a process which involves no change in temperature of the system.

If the process occurs at constant temperature then there is no change in the internal energy of the system so ΔU.

The 1st law for isothermal

$$\Delta U = Q + W \longrightarrow 0 = Q + W$$

$$\boxed{Q = -W}$$

For ideal gas in isothermal process

$$\boxed{W = nRT \ln\left(\frac{V_f}{V_i}\right)}$$

Isobaric Process:- the expansion or compression occurs at constant pressure. Any work done by the system will result in an increase in volume.

The work done on pressure - volume graph is equal to area under PV graph

For isobaric $W = P\Delta V = P(V_f - V_i)$

1st law of isobaric process $\longrightarrow \Delta U = Q + W$ or $\boxed{\Delta U = Q - P\Delta V}$

$$\boxed{= Q - P(V_f - V_i)}$$

CHAPTER-5

Simple Harmonic Motion

5.1.1 Periodic and Oscillatory Motion

When a body repeats its path of motion back and forth about the equilibrium or mean position, the motion is said to be periodic.

Types of Oscillatory motion

There are two types of oscillatory motion < Linear oscillation & Circular oscillation

Example of linear oscillation

1. Oscillation of mass spring system
2. Oscillation of fluid column in U-tube
3. Oscillation of floating cylinder
4. Oscillation of body dropped in a tunnel along earth diameter.
5. Oscillation of strings of musical instruments.

Example of Circular Motion

1. Oscillation of Simple pendulum
2. Oscillation of Solid sphere in a cylinder
3. Oscillation of circular ring suspended on a nail
4. Oscillation of balance wheel of a clock
5. Rotation of earth around the Sun

Oscillatory System

Oscillatory are the basic blocks of waves. Oscillatory systems are of two types mechanical and non-mechanical systems.

Mechanical Oscillatory Systems:- in this type of a system a body itself changes its position. For mechanical oscillation two things are especially responsible, inertia and restoring force.

Non-mechanical Oscillatory Systems:- the body itself doesn't change its position but its physical property varies periodically.

Period → (T):- is the time required to complete one full cycle of vibration or oscillation.

Frequency → (f):- The frequency is the number of complete oscillations or cycles per unit time.

The frequency of wave is given by $f = \frac{1}{T}$

Chapter Questions and problems

1. A 200kg load is hung on a wire having a length of 4.00 m, cross-sectional area $0.2\times10^{-4}\,m^2$ and Young Modulus $8\times10^{10}\,N/m^2$ what is increase in length?

Given

$l_0 = 4\,m$

$A = 0.2\times10^{-4}\,m^2$

$Y = 8\times10^{10}\,N/m^2$

$m = 200\,kg$

$\Delta l = ?$

From Young Modulus

$$Y = \frac{\frac{F_L}{A}}{\frac{\Delta l}{l_0}} = \frac{F_L l_0}{A \Delta l}$$

$F_L = mg$

So.

$$\Delta l = \frac{F_L l_0}{A Y} = \frac{mg\, l_0}{A Y_0}$$

$$\Delta l = \frac{200\,kg\,(9.8\,m/s^2)(4\,m)}{0.2\times10^{-4}\,m^2 \times 8\times10^{10}\,N/m} \approx 4.91\,mm$$

Answer

$\Delta l = 4.91\,mm$

2. A steel wire of diameter 1mm can support a tension of 0.2kN. A steel cable to support a tension of 20kN should have diameter of what order of magnitude?

Given

$d_1 = 1\,mm$

$F_1 = 0.2\,kN$

$F_2 = 20\,kN$

$d_2 = ?$

From Young modulus

$$Y = \frac{F l_0}{\Delta l A} \longrightarrow A = \frac{F l_0}{\Delta l Y}$$

Let A_1 - Cross-sectional Area of steel wire

A_2 - " " " of steel cable

$$A_1 = \frac{F_1 l_0}{Y \Delta l} \qquad A_2 = \frac{F_2 l_0}{Y \Delta l} \longrightarrow \text{So, } \frac{A_2}{A_1} = \frac{\frac{F_2 l_0}{Y \Delta l}}{\frac{F_1 l_0}{Y \Delta l}} = \frac{F_2}{F_1}$$

$$\frac{A_2}{A_1} = \frac{F_2}{F_1}$$

$$A_1 = \frac{\pi d_1^2}{4} \qquad A_2 = \frac{\pi d_2^2}{4}$$

$$\frac{\frac{\pi d_2^2}{4}}{\frac{\pi d_1^2}{4}} = \frac{F_2}{F_1} \longrightarrow \frac{d_2^2}{d_1^2} = \frac{F_2}{F_1}$$

$$d_2^2 = d_1^2 \times \frac{F_2}{F_1}$$

$$d_2^2 = (1\times10^{-3}\,m)^2 \times \frac{20\,kN}{0.2\,kN} = 10^{-6}\times100 = 10^{-4}$$

$$d_2 = \sqrt{10^{-4}\,m^2} = 10^{-2}\,m$$

$$d_2 = 10\,mm$$

3. A 30 kg hammer strikes a steel spike 2.30 cm in diameter while moving with a speed of 20 m/s. The hammer rebounds with speed 10 m/s after 0.11 s. What is the average strain in the spike during impact?

$\Delta p = F \cdot \Delta t = m(V_f - V_i)$

Impulse = Δp

Given

$m = 30$ kg

$\Delta t = 0.11$ s

$V_i = 20$ m/s

$V_f = -10$ m/s (rebounds)

Strain = ?

Solution

$$\text{Stress} = \frac{F}{A}$$

$$F \cdot \Delta t = m(V_f - V_i)$$

$$F \times 0.11 = 30(-10-20)$$

$$F = \frac{-900}{0.11} = 8.18 \times 10^3 \text{ N}$$

$$A = \pi\left(\frac{d}{2}\right)^2 = \pi\left(\frac{2.3}{2} \times 10^{-2}\right)^2$$

$$\text{Stress} = \frac{8.18 \times 10^3 \text{ N}}{\pi \times \left(\frac{2.3}{2} \times 10^{-2}\right)^2}$$

$$\boxed{\text{Stress} = 1.97 \times 10^7 \text{ N/m}^2}$$

$$\text{Strain} = \frac{\text{Stress}}{Y} = \frac{1.97 \times 10^7}{2 \times 10^{11}} = 9.85 \times 10^{-5}$$

4. If the shear stress in steel exceeds about 4×10^8 N/m², the steel ruptures. Determine the shearing force necessary to

a) shear a steel bolt 1 cm in diameter

b) punch a 1 cm diameter hole in a steel plate 0.5 cm thick

Solution

a) $\text{Stress} = \frac{F}{A} \rightarrow$ $\boxed{\text{Force applied} = \text{Stress} \times \text{Area}}$

$r = \frac{d}{2} = \frac{1}{2} = 0.5$ cm

$r = 5 \times 10^{-3}$ m

$$F = 4 \times 10^8 \text{ N/m}^2 \times \pi r^2$$

$$= 4 \times 10^8 \text{ N/m}^2 \times \pi(5 \times 10^{-3})^2$$

$$= 3.14 \times 10^4 \text{ N}$$

b) The Area over which shear stress occurs is equal to the circumference of the hole times its thickness

Thus, $A = (2\pi r)t = 2\pi(5 \times 10^{-3} \text{ m})(5 \times 10^{-3} \text{ m}) = 1.57 \times 10^{-4} \text{ m}^2$

So $F = A \times \text{stress}$

$$= (1.57 \times 10^{-4} \text{ m}^2)(4 \times 10^8 \text{ N/m}^2)$$

$$F = 6.28 \times 10^4 \text{ N}$$

CHAPTER - 4
HEAT AND THERMODYNAMICS

Thermodynamics is a science of the r/ship b/n heat, work, temperature & energy.
↳ deals with the transfer of energy from one system to another / from one form to other)

Heat is defined as the flow of energy from one object to another. This flow of energy is caused by a difference in T°. Heat can flow → if they are in thermal contact.

Two objects are in thermal equilibrium if they are in close contact that allows either allows to gain energy from other, but nevertheless no energy transferred.

Experimentally, if object A is in thermal equilibrium with object B, and object B is in thermal equilibrium with object C, then, object A is in thermal equilibrium with object C. → This is called the Zeroth law of thermodynamics.

* Thermometers measure temperature according to well-defined scales of measurement
  The three most common T°-scales are Fahrenheit, Celsius and Kelvin.
  → Temperature scales are created by identifying two reproducible temperatures
  The freezing and boiling T° of water at standard atmospheric pressure used.
  * Freezing point of water is 0°c and boiling point is 100°c. [degree Celsius]
  * Freezing point of water is 32°F and boiling point is 212°F (degree Frenheit)

* $T_F = \frac{9}{5} T_C + 32$ $\qquad$ $T_K = \frac{5}{9}(T_F - 32) + 273.15$
* $T_C = \frac{5}{9}(T_F - 32)$ $\qquad$ $T_F = \frac{9}{5}(T_K - 273.15) + 32$
* $T_K = T_C + 273.15$

Thermal Expansion

Thermal expansion is the change in size or volume of a given system as its temperature changes. Example Expansion of alcohol, expansion of hot air

→ Linear thermal expansion
The increase in length Δl of a solid is proportional to its initial length, l_0 and the change in its temperature ΔT. the proportionality constant is called the coefficient of linear expansion α.

$\boxed{\Delta l = \alpha l_0 \Delta T}$ → $l = l_0(1 + \alpha \Delta T)$ $\qquad$ $\alpha = \frac{l_0}{\Delta l}\Delta T$

→ Areal Expansion
$\Delta A = \beta A_0 \Delta T \Rightarrow A = A_0(1 + \beta \Delta T)$ → $\boxed{\beta = 2\alpha}$ — Coefficient

↳ it has units K^{-1} and $(C^{\circ})^{-1}$

→ Volume Expansion

9) Calculate the absolute pressure at an ocean depth of $1.0 \times 10^3 m$. Assume that the density of the water is $1.025 \times 10^3 kg/m^3$ and that $P_{atm} = 1.01 \times 10^5 Pa$

Solution

Given

$h = 1.0 \times 10^3 m$

$\rho = 1.025 \times 10^3 kg/m^3$

P_{atm} or $P_o = 1.01 \times 10^5 pa$

$P_{absolute} = ?$

Soln

$P_{abs} = P_{gauge} + P_{atm}$

$= \rho g h + P_{atm}$

$= (1.025 \times 10^3 kg/m^3)(9.81 m/s^2)(1 \times 10^3 m) + 1.01 \times 10^5 pa$

$P_{absolute} = 1.01 \times 10^7 pa$

END OF CH-3

5) Lead has a greater density than iron, and both are denser than water.
Is the buoyant force on a lead object greater than, less than or equal to the buoyant force on an iron object of the same Volume?

Soln The buoyant force of a liquid on an object is equal to the weight of liquid displaced by it.
⇒ Since the lead object and iron object have the same Volume, both of them displace the same amount of water. Hence buoyant force is the same.

6. When an object is immersed on a liquid at rest, why is the net force on an object in the horizontal direction is equal to zero?

Solution The pressure is the same on points that are at the same level but on opposite sides, so net force along horizontal equals to zero.

7. When water freezes, it expands by about 9.0%. What pressure increase would occur inside your automobile engine block if the water in it froze? (The bulk modulus of ice is $2\times10^9\ N/m^2$)

Solution

$$B = \frac{\Delta P}{\Delta V/V} \longrightarrow \Delta p = B \times \frac{\Delta V}{V_i}$$

Given

$\Delta V = 9\%\,V$

$\Delta V = 0.09\,V$

$V_i = 1V$

$$= (2\times10^9\ N/m^2) \times \left(\frac{0.09\,V}{1V}\right)$$

$$\Delta p = 0.18\times10^9\ N/m^2$$

$$\Delta p = 1.8\times10^{10}\ N/m^2$$

8. A 40cm tall glass is filled with water to a depth of 30cm
A. What is the gauge pressure at the bottom of glass?
B. What is the absolute pressure at the bottom of glass?

Solution

Given $h = 30cm = 0.3m$, $g = 9.81\ m/s^2$, $\rho_{water} = 1\times10^3\ kg/m^3$

a) $P_{gauge} = \rho g h = (1000)(9.81)(0.3)$

$= 2.9\times10^3\ pa$

b) $P_{absolute} = P_{gauge} + P_{atm}$

$= 2.9\times10^3\ pa + 1.01\times10^5\ pa$

$P_{absolute} = 1.04\times10^5\ pa$

Example

Suppose that the tension in the Cable is 940N as the actor reaches the lowest Point. What diameter should a 10 m long steel wire have if we do not want it to stretch more than 0.5 cm under these conditions?

Solution

From definition of Young modulus

$F = 940N$

$l_0 = 10m$

$\Delta l = 0.5cm = 0.005m$

$d = ?$

$$Y = \frac{F/A}{\Delta l / l_0} \longrightarrow \boxed{A = \frac{F l_0}{Y \Delta l}}$$

Since we are asked diameter we can get it from Area

Also $Y = 20 \times 10^{10}\ N/m^2$ -- for steel wire

So
$$A = \frac{(940N)(10m)}{(20 \times 10^{10}\ N/m^2)(0.005m)}$$

$$\boxed{A = 9.4 \times 10^{-6}\ m^2}$$

Because of radius of wire $\longrightarrow A = \pi r^2$

$$r = \sqrt{\frac{A}{\pi}} = \sqrt{\frac{9.4 \times 10^{-6} m^2}{\pi}} = 1.7 \times 10^{-3} m = \underline{1.7mm}$$

so. $\boxed{d = 2r = 2(1.7mm) = 3.4mm}$

Activity

A solid brass sphere is initially surrounded by air, and the air pressure exerted on it is $1.0 \times 10^5\ N/m^2$. The sphere is lowered into the ocean to depth where the pressure is $2.0 \times 10^7\ N/m^2$. The Volume of sphere in air is $0.50 m^3$. By how much does this Volume change once the sphere is submer

Solution

From definition of bulk modulus

$$B = \frac{-\Delta P}{\Delta V / V_i} \longrightarrow \Delta V = -\frac{V_i \Delta P}{B}$$

Given

$P_i = 1.0 \times 10^5\ N/m^2$

$P_f = 2.0 \times 10^7\ N/m^2$

$V_i = 0.5 m^3$

$\Delta V = ?$

$B = 6.1 \times 10^{10}\ N/m^2$ for Brass

So, $\Delta P = P_f - P_i \approx P_f = 2.0 \times 10^7\ N/m^2$

b/c final pressure so much greater than initial pressure

$$\Delta V = -\frac{(0.5m^3)(2.0 \times 10^7\ N/m^2)}{6.1 \times 10^{10}\ N/m^2}$$

$\boxed{\Delta V = -1.6 \times 10^{-4}\ m^3}$ → -ve sign indicat decrease in volume

Elasticity Moduli:

The stress will be proportional to the strain if the stress is sufficiently small. In this regard, the proportionality constant known as elastic modulus depends on the material being deformed and on the nature of deformation.

$$\text{Stress} = \text{elastic modulus} \times \text{strain}$$

There are 3 types of elastic modulus

1. **Young's Modulus:** is the ratio of tensile stress to tensile strain.

   It measures the resistance of a solid to a change in its length and typically used to characterize a rod or wire stressed under either tension or compression.

$$Y = \frac{\text{tensile stress}}{\text{tensile strain}} = \frac{F_\perp / A}{\Delta l / l_0}$$

Y - has unit of force per unit area

$$Y \Rightarrow F/A = N/m^2$$

2. **Shear Modulus:** it is the measure of the resistance to motion of the planes within a solid parallel to each other.

   A material having large shear modulus is difficult to bend.

$$S = \frac{\text{Shear Stress}}{\text{Shear strain}} = \frac{\Delta F / A}{x/h}$$

Its SI units pascal

3. **Bulk Modulus:** it is measures the resistance of solids or liquids to changes in their volume

   A material having a large bulk modulus doesn't compress easily.

$$B = \frac{\text{Volume stress}}{\text{Volume strain}} = \frac{-\Delta F / A}{\Delta V / V_0} = \frac{-\Delta P}{\Delta V / V_0}$$

- a negative sign is included in this defining equation, so that B is always positive
- An increase in pressure (+ve ΔP) causes a decrease in volume negative (ΔV) and vice versa.

- Strain Energy is the energy stored in a stretched wire.

  If x is due to applied force F,

$$\text{Strain Energy} = \frac{1}{2} k x^2$$

Density and pressure in Static fluids

Density (ρ) is the quantity of mass (m) per Unit Volume (V) of a body with SI unit kg/m^3 and given by $\boxed{\rho = \frac{m}{V}}$

Specific gravity (SG) is the ratio of density of a substance to the density of another Substance w/c is taken as Standard.

⇒ The density of pure water at 4°c = $1.0 \times 10^3 \ kg/m^3$ - taken as Standard

- The SG is dimentionless quantity and the same in any s/m of measurement

Examples The density of aluminum is $2.7 \times 10^3 \ kg/m^3$

∴ the SG of Al is $SG = \frac{2.7 \times 10^3 \ kg/m^3}{1.0 \times 10^3 \ kg/m^3} = \underline{2.7}$

Example A solid Sphere made of wood has a radius of 0.1m. The mass of Sphere is 1.0 kg. Determine a) density b) SG

Solution: The Volume of Sphere wood is $V = \frac{4}{3}\pi r^3$

Given

r = 0.1m

m = 1 kg

$= \frac{4}{3}\pi (0.1)^3 = \underline{4.18 \times 10^{-3} \ m^3}$

So a) density → $\rho = \frac{m}{V} = \frac{1 \ kg}{4.18 \times 10^{-3} m^3} = \underline{239 \ kg/m^3}$

b) SG → $SG = \frac{\text{density of wood}}{\text{density of water}} = \frac{239 \ kg/m^3}{1 \times 10^3 \ kg/m^3}$

$SG = \underline{0.239}$

Pressure: is the ratio of force acting perpendicular to surface Area (A) on w/c the force acts.

- SI Unit N/m^2, called pascal (pa)
- Another pressure Unit is atmosphere (atm) equal to 101.3 kpa w/c is average pressure, exerted by the Earth's atm at sea level

$\boxed{P = \frac{F_\perp}{A}}$

→ pressure produced by the column of fluid of height h and density ρ is given by $\boxed{P_{fluid} = \rho g h}$

Note that

- All points at same level in a fluid have same pressure
- Fluid Pressure increase with increase in the depth of fluid.
- Fluid pressure does not depend on the shape of container

Atmospheric Pressure is the pressure due to weight of atmosphere exerted on the Surface of Earth.

→ Atmospheric pressure decrease with increase in altitude (b/c decrease in density of air)

Gauge Pressure is the difference in pressure b/n a System and Surrounding atmosphere

$$P_{gauge} = P_{system} - P_{atmosphere}$$

Gauge pressure is relative to atmospheric pressure
- positive for pressure above atmospheric pressure
- Negative for below it

Absolute Pressure is the total pressure

→ Cannot be negative Pa

$$P_{absolute} = P_{gauge} + P_{atmosphere}$$

→ Smallest absolute pressure is zero. Thus, Smallest possible gauge pressure is $P_{gauge} = -P_{atmosphere}$

Example

A Submerged wreck is located 18.3m beneath the Surface of the Ocean off the Coast of South florida. Determine

a) P_{gauge} b) P_{abs} (Note→density of sea water is 1025 kg/m³)

Solution

a) $P_{gauge} = \rho g h = (1025\ kg/m^3)(9.8\ m/s^2)(18.3m) = 1.83 \times 10^5 \frac{N}{m^2}$

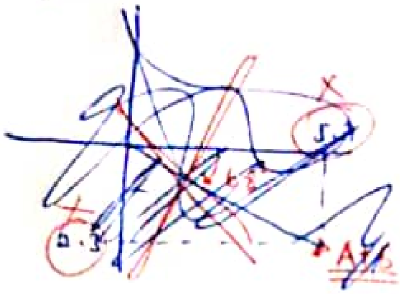
$$P_{gauge} = 1.83 \times 10^5 N/m^2 = 182\ kpa$$

b) $P_{abs} = P_{gauge} + P_{atm}$

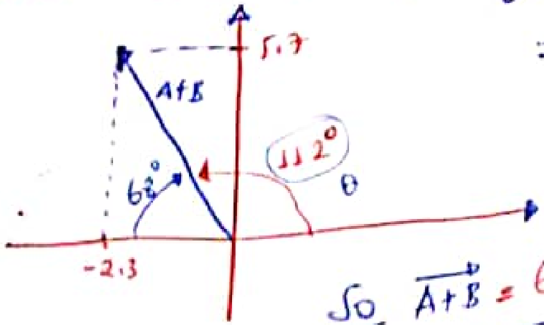
$= (1.83 \times 10^5 + 1.013 \times 10^5) N/m^2$

$= 2.84 \times 10^5 N/m^2$ = 284 kpa

Graph of A+B



$A+B = -2.3i + 5.7j$



$\theta = 180 - 68$
$= 112°$

So $\overrightarrow{A+B} = 6.16 \angle 112°$

③ if $A = 6i - 8j$, $B = -8i + 3j$ $C = 26i + 19j$
find a & b such that $aA + bB + C = 0$.

Soln

$aA = 6ai - 8aj$
$bB = -8bi + 3bj$
$C = 26i + 19j$

Given $aA + bB + C = 0i + 0j$

$(6a - 8b + 26)i + (-8a + 3b + 19)j = 0i + 0j$

So $6a - 8b + 26 = 0$ --- ①
$-8a + 3b + 19 = 0$ --- ②

$6a - 8b = -26$ --- divide by ②
$-8a + 3b = -19$

$(3a - 4b = -13) \times 3$
$(-8a + 3b = -19) \times 4$

$9a - 12b = -39$
$-32a + 12b = -76$

$\dfrac{-23a}{-23} = \dfrac{-115}{-23}$

$a = \dfrac{-115}{-23} = \dfrac{115}{23}$

$a = 5$

Put a into equation

$-8a + 3b = -19$
$-8(5) + 3b = -19$
$-40 + 3b = -19$
$3b = -19 + 40$
$3b = 21$
$b = \dfrac{21}{3}$
$b = 7$

So, The value of
$a = 5$ & $b = 7$

⑦

Example

A sample of an unknown materials weighs 300N in air & 200N when submerged in alcohol solution with a density of $0.7 \times 10^3 \, kg/m^3$. What is density of material?

Solution

Given

$W_{air} = 300N$

$W_{alcohol} = 200N$

$\rho_{alcohol} = 0.7 \times 10^3 \, kg/m^3$

$\rho_{material} = ?(\rho_o)$

$$F_{buoyant} = W_{air} - W_{alcohol} = 300 - 200 = 100N$$

$$\frac{W_{air}}{F_{buoyant}} = \frac{\rho_o}{\rho_{alcohol}} \Rightarrow \rho_o = \frac{W_{air} \times \rho_{alcohol}}{F_{buoyant}} = \frac{(0.7 \times 10^3) \times (300)}{100N}$$

$$\rho_o = 2.1 \times 10^3 \, kg/m^3$$

Moving Fluids & Bernoulli equation

→ If the flow is steady, then the velocity of the fluid particles at any point is a constant with time. The various layers of the fluid slide smoothly past each other. This is called **Stream line** or **laminar flow**.

→ Turbulent flow is the irregular movement of particles in a fluid and results in loss of energy due to internal friction b/w neighbouring layers of the fluid, called **Viscosity**.

* Factors affecting laminar flow are density, compressibility, temperature and viscosity.

Assumptions

* The fluid is non-viscous → there is no internal friction b/n adjacent layers
* The flow is steady → the velocity of fluid at each point remains constant
* The fluid is incompressible → density of fluid is constant
* The flow is irrotational → the fluid has no angular momentum about any point.

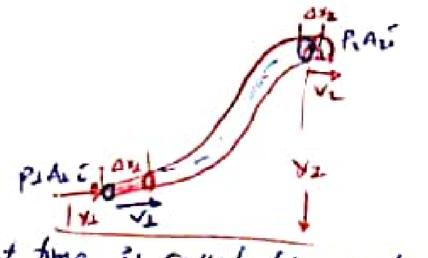
Equation of Continuity

Equation of continuity expresses conservation of mass for an incompressible fluid flowing in a tube. It says "the amount (either mass or volume) of fluid flowing through a cross section of tube in a given time interval must be the same for all cross-sectional or the product of the area and the fluid speed at all points along a tube is constant for an incompressible fluid.

$$AV = A_1 V_1 = A_2 V_2$$

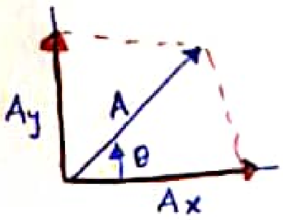
$$\boxed{\text{flow rate} = \frac{\text{Volume}}{\text{time}} = AV = \text{constant.}}$$

→ When cross sectional area is decreased then the flow rate increases



The product AV, which has the dimensions of volume per unit time is called **flow rate**

1.3.3 Components of Vector



$\cos\theta = \frac{A_x}{A} \rightarrow$ $\boxed{A_x = A\cos\theta}$ ... x component of A

$\sin\theta = \frac{A_y}{A} \rightarrow$ $\boxed{A_y = A\sin\theta}$ ... y component of A

Resultant → $\boxed{A = A_x + A_y}$

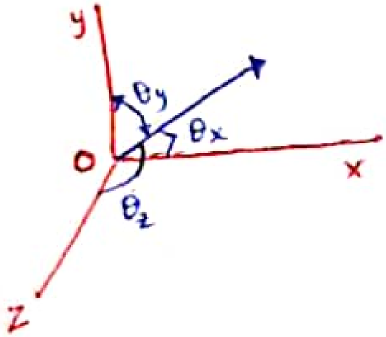
Magnitude of resultant → $\boxed{A = \sqrt{A_x^2 + A_y^2}}$

→ for 3 dimension

x, y, z

Resultant $R = R_x + R_y + R_z$

Magnitude $R = \sqrt{A_x^2 + R_y^2 + R_z^2}$



↗ direction of cosines ↗ direction angles

$\cos\theta_x = \frac{R_x}{R} \Rightarrow \theta_x = \cos^{-1}\left(\frac{R_x}{R}\right)$

$\cos\theta_y = \frac{R_y}{R} \Rightarrow \theta_y = \cos^{-1}\left(\frac{R_y}{R}\right)$

$\cos\theta_z = \frac{R_z}{R} \Rightarrow \theta_z = \cos^{-1}\left(\frac{R_z}{R}\right)$

1.4 Unit Vector

* A unit Vector is a vector that has magnitude of One and specified direction.
  - it is dimensionless
  - it is sole purpose is to point of given Vector in
  - it is usually denoted by with a "hat"

$\boxed{A = A\hat{u}}$

Any Vector Canbe expressed interms of Unit Vectors

2-dimension

$A = A_x\hat{i} + A_y\hat{j}$

3D

$A = A_x\hat{i} + A_y\hat{j} + A_z\hat{k}$

Addition Let $\vec{A} = A_x\hat{i} + A_y\hat{j} + A_z\hat{k}$

$\vec{B} = B_x\hat{i} + B_y\hat{j} + B_z\hat{k}$

$\vec{A} + \vec{B} = (A_x + B_x)\hat{i} + (A_y + B_y)\hat{j} + (A_z + B_z)\hat{k}$

Buoyant Force and Archimede's Principle

Pascal's principle - states that pressure applied to a confined fluid in a Container is transmitted equally to all regions of the fluid and to the walls of the Container.

- An important application of pascal's principle is the hydraulic press

hydraulic press

$$P_2 = F_2/A_2$$

$$P_1 = F_1/A_1$$

According to pascal's principle

$$P_1 = P_2$$

$$\hookrightarrow \boxed{\frac{F_1}{A_1} = \frac{F_2}{A_2}}$$

Example

A small piston of a hydraulic lift has an area of 0.20 m². A car weighing 1.2×10^4 N sits on a rack mounted on the large piston. The large piston has an area of 0.90 m². How large force must be applied to the small piston to support the car.

Given

$A_1 = 0.2\ m^2$

$A_2 = 0.9\ m^2$

$F_2 = 1.2 \times 10^4 N$

$F_1 = ?$

According to pascal's principle

$$\frac{F_1}{A_1} = \frac{F_2}{A_2}$$

So. $F_1 = F_2\left(\frac{A_1}{A_2}\right) = 1.2 \times 10^4 \left(\frac{0.2m^2}{0.9m^2}\right)$

$$F_1 = \underline{2.7 \times 10^4 N}$$

Archimede's Principle

Archimede's principle states anybody Completely or partially Submerged in a fluid is bouyed up by a force equal to the weight of the fluid displaced by the body

$$F_{bouyant} = W_{fluid} = \rho_{fluid} V_{\substack{displaced \\ fluid}}\, g$$

→ Any object which is partially or totally Submerged in a liquid has bouyant force acting on it wic is pushes the object up.

→ Pressure of the fluid is dependent on the depth of the fluid

So. pressure at the top of an object is less than pressure at the bottom of the object.

Finding a Unit Vector

Consider any Vector

$$\vec{r} = x\hat{i} + y\hat{j} + z\hat{k}$$

The Unit Vector $\hat{r}$ in the same direction is simply Vector $\vec{r}$ is divided by its magnitude r

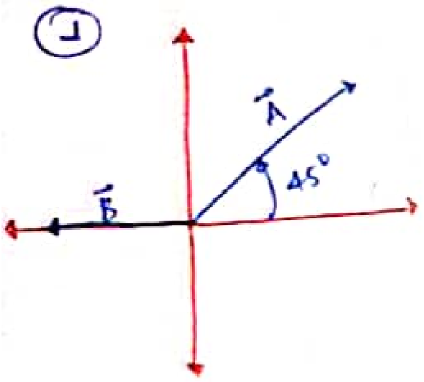
$$\hat{r} = \frac{\vec{r}}{r} = \frac{x\hat{i} + y\hat{j} + z\hat{k}}{\sqrt{x^2+y^2+z^2}} = \frac{x}{r}\hat{i} + \frac{y}{r}\hat{j} + \frac{z}{r}\hat{k}$$

r

Unit vector in the same direction

Chapter Review question/solution

(1)



find a) magnitude & direction $\vec{A}+\vec{B}$

b) magnitude and direction of $\vec{A}-\vec{B}$

Solution

$\vec{A} = A_x\hat{i} + A_y\hat{j}$ — $A_x = A\cos\theta$, $A_y = A\sin\theta$

Given

$A = 8$ unit, $\theta_1 = 45°$

$B = 8$ unit, $\theta_2 = 0°$

So $A_x = 8\cos 45° = 8 \times \frac{\sqrt{2}}{2} = 4\sqrt{2}$

$A_y = 8\sin 45° = 8 \cdot \frac{\sqrt{2}}{2} = 4\sqrt{2}$

$\vec{B} = B_x\hat{i} + B_y\hat{j}$

$B_x = B\cos\theta_2 = -8\cos 0° = -8 \times 1 = -8$

$B_y = B\sin\theta_2 = -8\sin 0° = -8 \times 0 = 0$

So Resultant

$A = A_x\hat{i} + A_y\hat{j} = 4\sqrt{2}\hat{i} + 4\sqrt{2}\hat{j}$

$B = B_x\hat{i} + B_y\hat{j} = -8\hat{i} + 0\hat{j} = -8\hat{i}$

So $\vec{A}+\vec{B} = (A_x + B_x)\hat{i} + (A_y + B_y)\hat{j}$

$= (4\sqrt{2} - 8)\hat{i} + 4\sqrt{2}\hat{j}$

$= (5.7 - 8)\hat{i} + 5.7\hat{j}$

$4\sqrt{2} = 5.656 \approx 5.7$

$$\boxed{A + B = -2.3\hat{i} + 5.7\hat{j}}$$

magnitude of $A+B = \sqrt{(-2.3)^2 + (5.7)^2} = \sqrt{37.78} = 6.16$

Direction of $A+B \Rightarrow \alpha = \tan^{-1}\left(\frac{5.7}{-2.3}\right) = -68°$

so $\theta = 180 - \alpha = 180 - 68° = 112°$

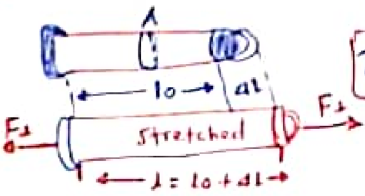
(6)

1. Tensile strain

Tensile stress = $\frac{\text{the ratio of the force magnitude}}{\text{cross-sectional area}} = \frac{F_\perp}{A}$

* The fractional change in length of an object under a tensile stress is called the tensile strain.

(a) A bar in tension



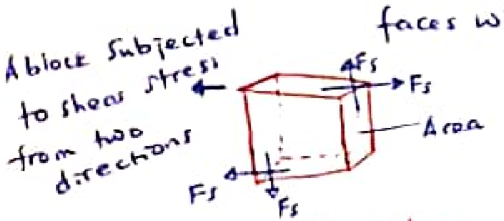
(b) Tensile strain

Tensile stress = $\frac{F_\perp}{A}$

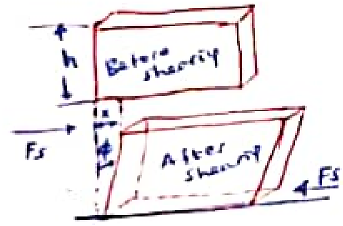
Tensile strain = $\frac{\Delta l}{l_0}$

2. Shear stress and strain

Shear stress - when an object is subjected to a force parallel to one of its faces while the opposite face is held fixed by another force.



(a) shear stress



(b) shear strain

Shear strain = $\frac{x}{h}$ = $\tan\phi$

→ Shear strain is defined as the ratio x/h, where x is the horizontal distance that the sheared face moves and h is the height of the object.

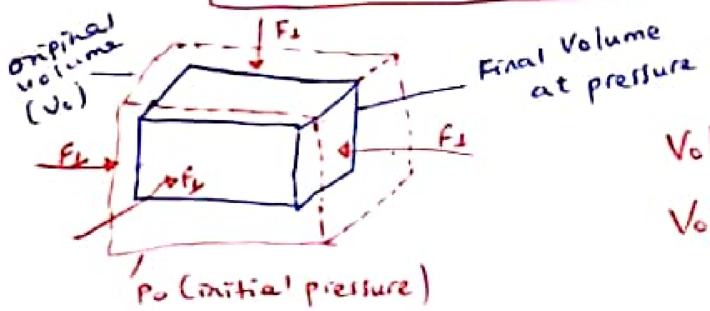
3. Volume stress and strain

Volume Stress is a stress which causes volume deformation on an object and defined as the ratio of change in the magnitude of applied force ΔF to the surface A

Volume Stress = $\frac{\Delta F}{A}$

Volume Strain is the fraction change in volume that is - the change in volume, ΔV divided by original volume, V_0

Volume Strain = $\frac{\Delta V}{V_0}$



Volume Stress = Δp

Volume Strain = $\frac{\Delta V}{V_0}$

A Lens is a part of transport thick glass which is bounded by two Spherical Surfaces. It is an optical device through which the rays of the light Converge or diverge before transmitting.

Convex lenses: Converging lenses thickest at their Center and Converge a beam of parallel light to real focus.

Concave lenses: diverging lenses thinnest at their Center and diverge a beam of parallel light from Virtual focus.

The distance from the focal point to the lens is called focal ~~lengt~~ length (f.)

The equation that relates Object and image distances for a lens is identical to the mirror equation

$$\frac{1}{S_o} + \frac{1}{S_i} = \frac{1}{f}$$

Magnification is defined as the ratio of image height (h_i) to Object height (h_o) or ratio of image distance (S_i) to object distance (S_o)

$$m = \frac{h_i}{h_o} = \frac{S_i}{S_o}$$

Generally the image formed by a Convex lens has the ff feature.

→ If an object is brought Close to the lensy the size of image keeps On increasing

→ As it goes more close to the lens, the image all the more enlarged.

The images formed will be diminished inverted images, Small sizes inverted images, enlarged inverted images, and enlarged erect images

So. in concave lens there is a possibility of agetting real as well as an inverted image.

CamScanner

4) Find a Unit Vector in the direction of resultant Vectors

$A = 2i - 3j + k$

$B = i + j + 2k$

$C = 3i - 2j + 4k$

Solution

$\vec{A} = 2i - 3j + k$

$|A| = \sqrt{2^2 + (-3)^2 + (1)^2}$

$= \sqrt{4 + 9 + 1} = \sqrt{14}$

$A_{un} = \frac{\vec{A}}{|A|}$

$\vec{A}_{\hat{u}} = \frac{2i - 3j + k}{\sqrt{14}} = \frac{2}{\sqrt{14}} i - \frac{3}{\sqrt{14}} j + \frac{1}{\sqrt{14}} k$

$\vec{B} = i + j + 2k \longrightarrow |B| = \sqrt{1^2 + 1^2 + 2^2}$

$|B| = \sqrt{1 + 1 + 4} = \sqrt{6}$

So $\vec{B}_{un} = \frac{\vec{B}}{|B|} = \frac{i + j + 2k}{\sqrt{6}}$

$\vec{B}_{un} = \frac{1}{\sqrt{6}} i + \frac{1}{\sqrt{6}} j + \frac{2}{\sqrt{6}} k$

$\vec{C} = 3i - 2j + 4k$

$\vec{C}_{un} = \frac{\vec{C}}{|C|}$

$|C| = \sqrt{3^2 + (-2)^2 + 4^2}$

$=$

Finish it

4) Find a Unit Vector in the direction of resultant Vectors

$A = 2i - 3j + k$

$B = i + j + 2k$

$C = 3i - 2j + 4k$

Solution

$\vec{A} = 2i - 3j + k$

$|A| = \sqrt{2^2 + (-3)^2 + (1)^2}$

$= \sqrt{4 + 9 + 1} = \sqrt{14}$

$A_{un} = \frac{\vec{A}}{|A|}$

$\vec{A}_{\hat{u}} = \frac{2i - 3j + k}{\sqrt{14}} = \frac{2}{\sqrt{14}} i - \frac{3}{\sqrt{14}} j + \frac{1}{\sqrt{14}} k$

$\vec{B} = i + j + 2k \longrightarrow |B| = \sqrt{1^2 + 1^2 + 2^2}$

$|B| = \sqrt{1 + 1 + 4} = \sqrt{6}$

So $\vec{B}_{un} = \frac{\vec{B}}{|B|} = \frac{i + j + 2k}{\sqrt{6}}$

$\vec{B}_{un} = \frac{1}{\sqrt{6}} i + \frac{1}{\sqrt{6}} j + \frac{2}{\sqrt{6}} k$

$\vec{C} = 3i - 2j + 4k$

$\vec{C}_{un} = \frac{\vec{C}}{|C|}$

$|C| = \sqrt{3^2 + (-2)^2 + 4^2}$

$=$

Finish it

CHAPTER - 3

FLUID MECHANICS

Fluid mechanics is the branch of physics concerned with the mechanics of fluids in motion (fluid dynamics) or at rest (fluid statics) & forces on them.

→ a fluid is a substance that continually deforms (flows) under an applied shear stress, or external force.

Fluids are a phase of matter include liquids and gases.

Properties of Bulk Matter

a solid may be thought of as having a definite shape and volume, it's possible to change its shape and volume by applying external forces.

→ A sufficiently large force will permanently deform or break an object, but otherwise, when the external forces are removed, the objects tends to return to its original shape and size is called elastic behaviour.

Elastic materials are materials that regain their original shape and size when the deforming force is removed.

Elastic deformation is a reversible deformation by a force applied within the elastic limit.

→ Beyond elastic limit, a force applied on an object causes permanent and irreversible deformation called plastic deformation.

Plastic materials do not regain their original shape and size when the deforming force is removed.

The elastic properties of solid materials are described in terms of stress & strain

Stress: is the force per unit area that is causing some deformation. It has SI unit N/m^2 called the pascal (pa), the same as unit of pressure

$$\text{Stress} = \frac{F}{A}$$

Strain: measures the amount of deformation by applied stress and defined as the change in configuration of a body divided by its initial configuration.

Strain is unit less quantity.

$$\text{Strain} = \frac{\text{change in configuration}}{\text{initial configuration}}$$

There are 3 kinds of strains

1) Tensile strain
2) shear stress and strain
3) Volume stress and strain

* Measurement = $X_{best} \pm \delta x$

Where X_{best} = best estimate of measurement

δx = Uncertainity (error) in measurement.

1.2. Significant digits

→ If zero has a non-zero digit anywhere to its left, then zero is significant. Otherwise it is not.

Eg → 7.00 has 3 significant figures

→ 0.0007 has only 1 significant figures

→ 1.0007 has 5 sf

→ 300 - Not well defined, rather 3×10^2 → has 1 sf or 3.00×10^2 → has 3 sf

* When writing numbers, zeros used only to help in locating the decimal point are not significant.

Rules for significant figures

Rule 1 → When approximate numbers are multiplied/divided, the no of significant digits in the final answer is the same as the no of significant digits in the least accurate of factors

Ex: $X = \frac{45}{(3.22m) \times (2.005m)} = 6.97015 \frac{N}{m^2}$

→ Least significant factor is 45 has only two digits so the answer should be

$X = 7.0 \, N/m^2$

Rule 2 → When approximate no are added or substracted, the no of significant digits should equal the smallest no of decimal places of any term in the sum or difference

Ex: $9.65cm + 8.4cm - 2.89cm = 15.16cm$

⇒ It should be → 15.2 cm

In general to determine significant digits in a given number

1. All non-zero numbers are significant
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CHAPTER-REVIEW QUESTION

1. How would the period of a simple pendulum be affected if it were located on the moon instead of the earth?

Solution

The time period of simple pendulum is $T = 2\pi\sqrt{l/g}$. The time period is adversely proportional to acceleration due to gravity

Time period could increase by $\sqrt{6}$ when compared to earth

Hence, pendulum should swing slower and the frequency will also be on the lower side.

2. What effect would the temperature have on the time kept by a pendulum clock if the pendulum rod increase in length with an increase in temperature.

Solution

→ A major source of error in pendulum clocks is in thermal expansion. The pendulum rod changes in length slightly with changes in temperature, causing changes in the rate of the clock.

→ An increase in temperature causes the rod to expand, making the pendulum longer, so its period increases and the clock loses time.

3. What kind of graph would result if the period T were graphed as a function of the square root of the length l.

Solution

We are talking of a simple pendulum so period $T = 2\pi\sqrt{l/g}$

$$= \left(\frac{2\pi}{\sqrt{g}}\right)\sqrt{l}$$

$\left(\frac{2\pi}{\sqrt{g}}\right)$ is constant for a given location.

So

We can write $T = k\sqrt{l}$ where $k = \frac{2\pi}{\sqrt{g}}$ is constant.

→ Thus, The graph of the period T, as a function of the square root of the length l, would be a straight line with slope

$$k = \frac{2\pi}{\sqrt{g}}$$

1.3 Vectors: Composition and Resolution

Scalar:- is a quantity that is completely specified by a no and unit
- it has magnitude but not direction

Ex mass, time, Volume, Speed etc

Vector:- is a quantity that has both specified by a magnitude + direction

Ex displacement, Velocity, acceleration, momentum etc.

Vector Representation

A) **Algebraic Method**:- Vectors are represented algebraically by a letter (or symbol) with an arrow its head

Eg Velocity → $\vec{V}$, momentum → $\vec{P}$

Magnitude of a Vector is a positive Scalar & Written as either $|A|$ or A

B) **Geometric Method**

Eg. $\vec{A} + \vec{B}$ ⇒ it means beginning of Vector $\vec{A}$ to end of another Vector $\vec{B}$

⊛ A Vector changes if its magnitude or direction or if both magnitude and direction change.

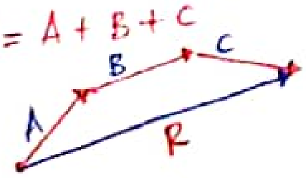
Vector Addition

- Graphical Method
- parallelogram Method

A) **Graphical method**: Can be added by joining their head to tail and the Vector drawn in any order their resultant Vector is the Vector drawn from the tail of the first Vector to head of the last Vector

* A single Vector that is obtained by adding two or more Vector is called resultant Vectors

Ex $R = A + B + C$



B) **Parallelogram method**

1) Cosine law: $R = \sqrt{A^2 + B^2 - 2AB\cos\theta}$

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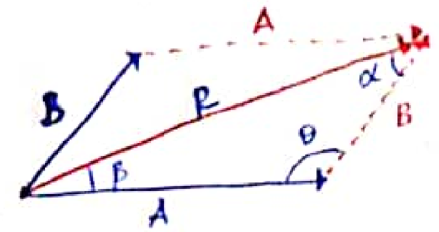

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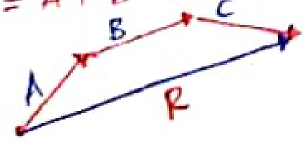

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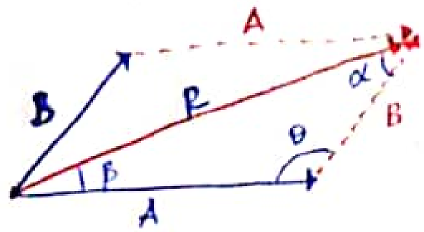

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To convert a quantity from one unit to another multiply by conversions factors

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Quantity	From	To	Operation
Length	inch (in)	m	(inch) × 0.0254
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	mile (mi)	m	(mile) × 1609.34
Mass	pound (lb)	kg	(pound) × 0.4536
	metric ton (t)	kg	(ton) × 1000
	Ounce	kg	(ounce) × 0.02835
Volume	Litre (l)	m^3	(litre) × 0.001
	gallon (gal)	m^3	(gallon) × 0.00379
Temperature	Fahrenheit (F)	K	$(F-32)\times\frac{5}{9} + 273.15$
	Celcius (C)	K	C + 273.15

Example: 1) 0.02 in → m

Solution 0.02 in = 0.02 × 0.0254 m = 0.000508 m = 5.08×10^{-4} m or 0.508 mm

2) Honda fit weights about 2,500 lb to kg

Soln 2,500 × 0.4536

= 1134.0 kg

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$$6x = \frac{\text{Smallest increment}}{2}$$

Example: Meter stick (scale device) → $6x = \frac{1\,mm}{2} = 0.5\,mm = 0.05\,cm$

⊛ Uncertainity in a digital measuring device is equal to smallest increment

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Example: A reading from digital balance (digital device) is 5.7513 kg therefore $6x = 0.0001$

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$$V = \lambda f$$

Types Of Waves

- Based on the need of material medium for its propagation < mechanical wave / Electromagnetic

1) Mechanical waves:- are waves produced by oscillation of particles of a mechanical medium and need medium for propagation

Ex. Water waves, Sound waves, wave in strings etc

All mechanical wave requires
- ✓ Some Source of disturbance
- ✓ a medium that can be disturbed and
- ✓ physical medium through which elements of medium can influence each other

2) Electromagnetic (EM) waves:- are produced by accelerated charged particles and can propagate through both material medium & Vacuum.

Ex. light, radio & TV waves, microwaves, X-rays etc

All EM wave in Vacuum propagate with Speed $c = 3 \times 10^8 \, m/s$

* Based on the way they are propagating < Transverse / longitudinal

1) Transverse Wave:- where particles of the disturbed medium oscillate perpendicular to the direction of wave motion.

Eg. water waves, waves on strings & all EM waves.

Sinusoidal graphs can represent this motion. 

2) Longitudinal Wave:- is a wave where particles of the disturbed medium Oscillate Parallel to the direction of wave motion.

Ex Sound wave

2) Refraction of wave

It is the change in direction of wave passing from one medium to another caused by its change in speed.

3) Diffraction of wave

- It is the spreading of waves around obstacles.
- Diffraction takes place with sound, with electromagnetic radiation, such as light, x-rays & gamma rays

4) Interference of wave

the net effect of combination of two or more wave trains moving on intersecting or coincident paths.

Interference also occurs between two wave trains moving in the same direction but having different wavelengths or frequencies.

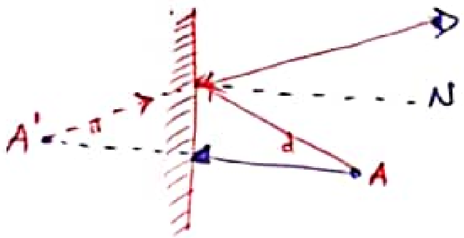
A pulsating frequency, called a beat, results when the wavelength are slightly different.

Image formation by thin lenses and mirrors

→ Images formed by plane mirrors

If the reflecting surface of the mirror is flat, we call this type of mirror as plane mirror.

→ Light always has regular reflection on plane mirrors.



* we have to see the rays coming from the object to see it. If the light first hits the mirror and then reflects with the same angle, the extensions of the reflected rays are focused at one point behind the mirror. We see the coming rays as if they are coming from behind of the mirror.

→ At point A' image of the point is formed and we call this image Virtual image which means not real.

The distance of image of the mirror = distance of object to the mirror

→ Images formed by lenses :- Lenses are commonly used to form images by refraction in optical instruments such as cameras, telescopes and microscopes.

A Lens is an optical system with two refracting surfaces.

The two types of lenses are

1) Convex lenses
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1.1 Physical Quantities and Measurement

Physical Quantity :- is a quantifiable or assignable property ascribed to a particular phenomenon or body

Measurement :- is act of comparing a physical quantity with certain standard.

1. physical quantities
   - A) Basic physical quantities :- We cannot be expressed in terms of any other physical quantity
     - Example :- Length, mass and time
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(*) Measurements of physical quantities are expressed in terms of Units
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2. SI Units : Basic and Derived Units

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	Quantity	Symbol	SI Unit	Dimensions
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5.4 Resonance

→ Resonance is the increase in amplitude of oscillation of an electric or mechanical system exposed to a periodic force whose increase is equal or very close to the natural undamped frequency of the system.

* The frequency at which the second body starts oscillating or vibrating at higher amplitude is called the resonant frequency of the body.

Example :- Swinging of a person sitting on a swing.

Doppler Effect

The doppler effect is observed whenever the source of waves is moving with respect to an observer.

It can be described as the effect produced by a moving source of waves in which there is an apparent upward shift in frequency for observers towards whom the source is approaching & an apparent downward shift in frequency for observers from whom the source is receding.

The Doppler effect can be observed for any type of wave; water wave, sound wave, light wave, etc.

Let f_0 = frequency heard by observer & f_s = frequency emitted by source

Let V_0, V and V_s respectively velocity of observer, sound wave & source

The observed frequency due to Doppler Effect is

$$f_0 = f_s \left(\frac{V \pm V_0}{V \mp V_s} \right)$$

"Upper" signs (i.e $+V_0$ & $-V_s$) refer to motion of one towards other

"Lowers" signs (i.e $-V_0$ & $+V_s$) refer to motion of one away from other.

Characteristics of Waves

The characteristics of waves are important in determining the size of waves, the speed at which they travel, how they break on shore and much more.

Examples

① Reflection of Waves :-

Whenever a travelling wave reaches a boundary, part or all of the wave bounces back. This phenomenon (rebounding of wave from a surface) is called reflection

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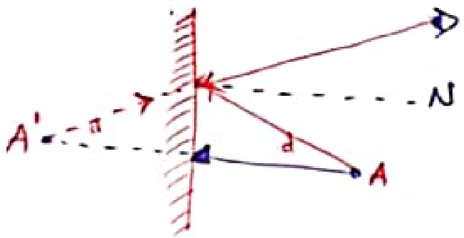

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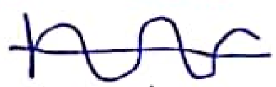
Sinusoidal graphs can represent this motion. 

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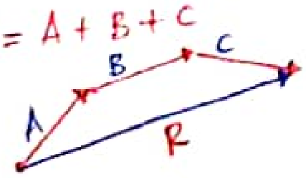

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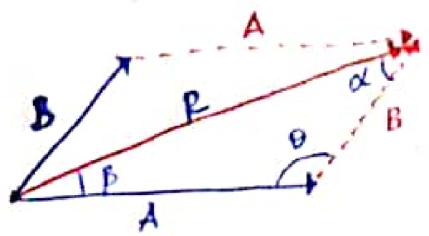

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$\left(\frac{2\pi}{\sqrt{g}}\right)$ is constant for a given location.

So

We can write ~~T = 2π~~ $T = k\sqrt{l}$ where $k = \frac{2\pi}{\sqrt{g}}$ is constant.

→ Thus, The graph of the period T, as a function of the square root of the length l, would be a straight line with slope

$$k = \frac{2\pi}{\sqrt{g}}$$

A Lens is a part of transport thick glass which is bounded by two spherical surfaces. It is an optical device through which the rays of the light converge or diverge before transmitting.

Convex lenses: Converging lenses thickest at their center and converge a beam of parallel light to real focus.

Concave lenses: diverging lenses thinnest at their center and diverge a beam of parallel light from virtual focus.

- The distance from the focal point to the lens is called focal length (f.)

- The equation that relates object and image distances for a lens is identical to the mirror equation

$$\frac{1}{S_o} + \frac{1}{S_i} = \frac{1}{f}$$

Magnification is defined as the ratio of image height (h_i) to object height (h_o) or ratio of image distance (S_i) to object distance (S_o)

$$m = \frac{h_i}{h_o} = \frac{S_i}{S_o}$$

Generally the image formed by a convex lens has the ff feature.

→ If an object is brought close to the lens, the size of image keeps on increasing

→ As it goes more close to the lens, the image all the more enlarged.

- The images formed will be diminished inverted images, small sizes inverted images, enlarged inverted images, and enlarged erect images so in concave lens there is a possibility of getting real as well as an inverted image.

4) Find a Unit Vector in the direction of resultant Vectors

$A = 2i - 3j + k$

$B = i + j + 2k$

$C = 3i - 2j + 4k$

Solution

$\vec{A} = 2i - 3j + k$

$|A| = \sqrt{2^2 + (-3)^2 + (1)^2}$

$= \sqrt{4 + 9 + 1} = \sqrt{14}$

$A_{un} = \frac{\vec{A}}{|A|}$

$\vec{A}_{\hat{u}} = \frac{2i - 3j + k}{\sqrt{14}} = \frac{2}{\sqrt{14}} i - \frac{3}{\sqrt{14}} j + \frac{1}{\sqrt{14}} k$

$\vec{B} = i + j + 2k \longrightarrow |B| = \sqrt{1^2 + 1^2 + 2^2}$

$|B| = \sqrt{1 + 1 + 4} = \sqrt{6}$

So $\vec{B}_{un} = \frac{\vec{B}}{|B|} = \frac{i + j + 2k}{\sqrt{6}}$

$\vec{B}_{un} = \frac{1}{\sqrt{6}} i + \frac{1}{\sqrt{6}} j + \frac{2}{\sqrt{6}} k$

$\vec{C} = 3i - 2j + 4k$

$\vec{C}_{un} = \frac{\vec{C}}{|C|}$

$|C| = \sqrt{3^2 + (-2)^2 + 4^2}$

$=$

Finish it

CHAPTER - 3

FLUID MECHANICS

Fluid mechanics is the branch of physics concerned with the mechanics of fluids in motion (fluid dynamics) or at rest (fluid statics) & forces on them.

→ a fluid is a substance that continually deforms (flows) under an applied shear stress, or external force.

Fluids are a phase of matter include liquids and gases.

Properties of Bulk Matter

a solid may be thought of as having a definite shape and volume, it's possible to change its shape and volume by applying external forces.

→ A sufficiently large force will permanently deform or break an object, but otherwise, when the external forces are removed, the objects tends to return to its original shape and size is called elastic behaviour.

Elastic materials are materials that regain their original shape and size when the deforming force is removed.

Elastic deformation is a reversible deformation by a force applied within the elastic limit.

→ Beyond elastic limit, a force applied on an object causes permanent and irreversible deformation called plastic deformation.

Plastic materials do not regain their original shape and size when the deforming force is removed.

The elastic properties of solid materials are described in terms of stress & strain

Stress: is the force per unit area that is causing some deformation. It has SI unit N/m^2 called the pascal (pa), the same as unit of pressure

$$\text{Stress} = \frac{F}{A}$$

Strain: measures the amount of deformation by applied stress and defined as the change in configuration of a body divided by its initial configuration.

strain is unit less quantity.

$$\text{Strain} = \frac{\text{change in configuration}}{\text{initial configuration}}$$

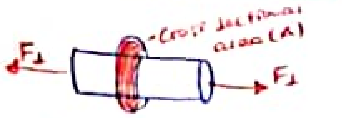
There are 3 kinds of strains

1) Tensile strain
2) shear stress and strain
3) Volume stress and strain

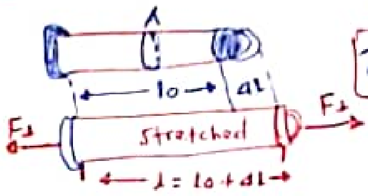
1. Tensile strain

Tensile stress = $\frac{\text{the ratio of the force magnitude}}{\text{cross-sectional area}} = \frac{F_\perp}{A}$

- The fractional change in length of an object under a tensile stress is called the tensile strain.



(a) A bar in tension



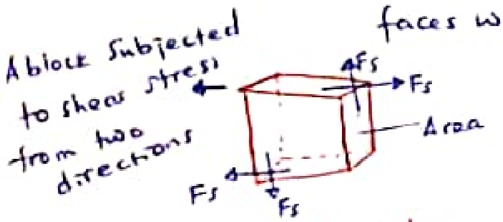
(b) Tensile strain

Tensile stress = $\frac{F_\perp}{A}$

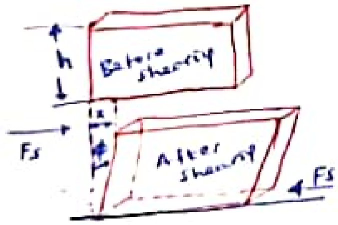
Tensile strain = $\frac{\Delta l}{l_0}$

2. Shear stress and strain

Shear stress - when an object is subjected to a force parallel to one of its faces while the opposite face is held fixed by another force.



(a) shear stress



(b) shear strain

shear strain = $\frac{X}{h}$

$= \tan \phi$

→ Shear strain is defined as the ratio x/h, where x is the horizontal distance that the sheared face moves and h is the height of the object.

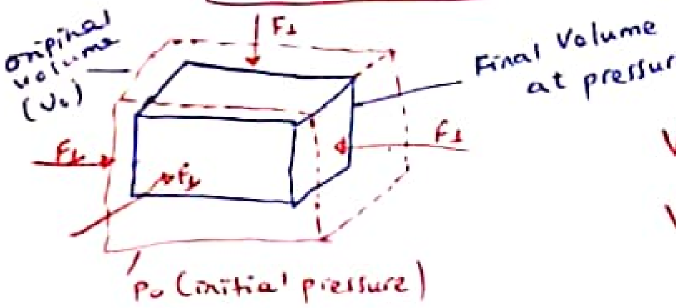
3. Volume stress and strain

Volume Stress is a stress which causes volume deformation on an object and defined as the ratio of change in the magnitude of applied force ΔF to the surface A

Volume Stress = $\frac{\Delta F}{A}$

Volume Strain is the fraction change in volume that is - the change in volume, ΔV divided by original volume, V_0

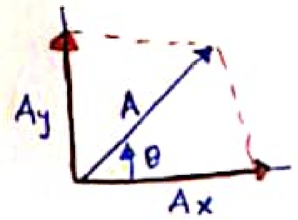
Volume Strain = $\frac{\Delta V}{V_0}$



Volume Stress = Δp

Volume Strain = $\frac{\Delta V}{V_0}$

1.3.3 Components of Vector



$\cos\theta = \frac{A_x}{A} \rightarrow \boxed{A_x = A\cos\theta}$ .. x component of A

$\sin\theta = \frac{A_y}{A} \rightarrow \boxed{A_y = A\sin\theta}$ .. y component of A

Resultant → $\boxed{A = A_x + A_y}$

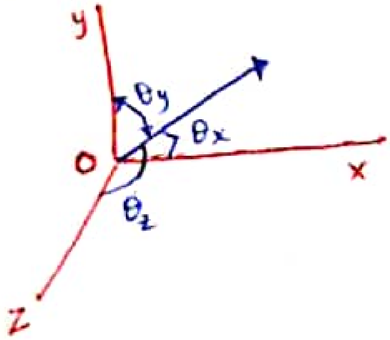
Magnitude of resultant → $\boxed{A = \sqrt{A_x^2 + A_y^2}}$

→ for 3 dimension

x, y, z

Resultant $R = R_x + R_y + R_z$

Magnitude $R = \sqrt{R_x^2 + R_y^2 + R_z^2}$



direction cosines ↗ ; direction angles ↗

$\cos\theta_x = \frac{R_x}{R} \Rightarrow \theta_x = \cos^{-1}\left(\frac{R_x}{R}\right)$

$\cos\theta_y = \frac{R_y}{R} \Rightarrow \theta_y = \cos^{-1}\left(\frac{R_y}{R}\right)$

$\cos\theta_z = \frac{R_z}{R} \Rightarrow \theta_z = \cos^{-1}\left(\frac{R_z}{R}\right)$

1.4 Unit Vector

* A unit Vector is a vector that has magnitude of One and is to point a given Vector in specified direction.
  - it is dimensionless
  - it is sole purpose is to point a given Vector in specified direction.
  - it is usually denoted ~~by~~ with a "hat"

$\boxed{A = A\hat{u}}$

Any Vector Canbe expressed interms of Unit Vectors

2-dimension

$A = A_x\hat{i} + A_y\hat{j}$

3D

$A = A_x\hat{i} + A_y\hat{j} + A_z k$

Addition Let $\vec{A} = A_x\hat{i} + A_y\hat{j} + A_z k$

$\vec{B} = B_x\hat{i} + B_y\hat{j} + B_z k$

$\vec{A} + \vec{B} = (A_x + B_x)\hat{i} + (A_y + B_y)\hat{j} + (A_z + B_z)k$

Finding a Unit Vector

Consider any Vector

$$\vec{r} = x\hat{i} + y\hat{j} + z\hat{k}$$

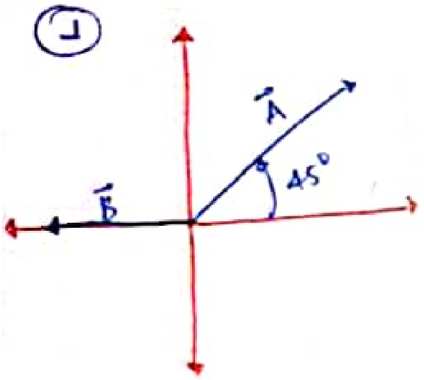
The Unit Vector $\hat{r}$ in the same direction is simply vector $\vec{r}$ is divided by its magnitude r

$$\hat{r} = \frac{\vec{r}}{r} = \frac{x\hat{i} + y\hat{j} + z\hat{k}}{\sqrt{x^2+y^2+z^2}} = \frac{x}{r}\hat{i} + \frac{y}{r}\hat{j} + \frac{z}{r}\hat{k}$$

Unit vector in the same direction ($\hat{r}$); $\sqrt{x^2+y^2+z^2} = r$

Chapter Review question/solution/

(1)



find a) magnitude & direction $\vec{A}+\vec{B}$
b) magnitude and direction of $\vec{A}-\vec{B}$

Solution

$\vec{A} = A_x\hat{i} + A_y\hat{j}$ — $A_x = A\cos\theta$, $A_y = A\sin\theta$

Given
$A = 8$ unit, $\theta_1 = 45°$
$B = 8$ unit, $\theta_2 = 0°$

So $A_x = 8\cos 45° = 8 \times \frac{\sqrt{2}}{2} = 4\sqrt{2}$

$A_y = 8\sin 45° = 8 \cdot \frac{\sqrt{2}}{2} = 4\sqrt{2}$

$\vec{B} = B_x\hat{i} + B_y\hat{j}$

$B_x = B\cos\theta_2 = -8\cos 0° = -8 \times 1 = -8$

$B_y = B\sin\theta_2 = -8\sin 0° = -8 \times 0 = 0$

So Resultant

$A = A_x\hat{i} + A_y\hat{j} = 4\sqrt{2}\hat{i} + 4\sqrt{2}\hat{j}$

$B = B_x\hat{i} + B_y\hat{j} = -8\hat{i} + 0\hat{j} = -8\hat{i}$

So $\vec{A}+\vec{B} = (A_x + B_x)\hat{i} + (A_y + B_y)\hat{j}$

$= (4\sqrt{2} - 8)\hat{i} + 4\sqrt{2}\hat{j}$

$= (5.7 - 8)\hat{i} + 5.7\hat{j}$

$4\sqrt{2} = 5.656 \approx 5.7$

$$A + B = -2.3\hat{i} + 5.7\hat{j}$$

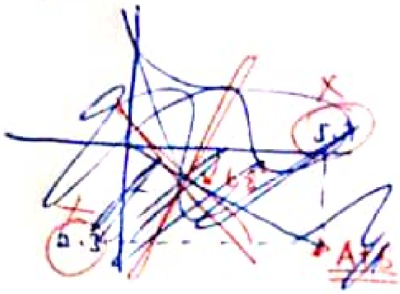
magnitude of $A+B = \sqrt{(-2.3)^2 + (5.7)^2} = \sqrt{37.98} = 6.16$

Direction of $A+B \Rightarrow \alpha = \tan^{-1}\left(\frac{5.7}{-2.3}\right) = -68°$

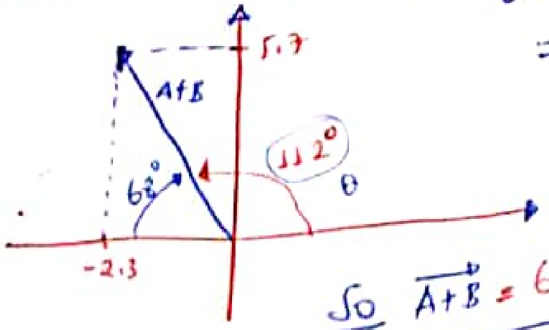
so $\theta = 180 - \alpha = 180 - 68° = 112°$

(6)

Graph of A+B



$A+B = -2.3i + 5.7j$



$\theta = 180 - 68$

$= \underline{112°}$

So $\overrightarrow{A+B} = 6.16 \angle 112°$

(3) if $A = 6i - 8j$, $B = -8i + 3j$, $C = 26i + 19j$
find a & b such that $aA + bB + C = 0$.

Soln

$aA = 6ai - 8aj$

$bB = -8bi + 3bj$

$C = 26i + 19j$

Given $aA + bB + C = 0i + 0j$

$(6a - 8b + 26)i + (-8a + 3b + 19)j = 0i + 0j$

So

$6a - 8b + 26 = 0$ --- (1)

$-8a + 3b + 19 = 0$ --- (2)

$6a - 8b = -26$ --- divide by (2)

$-8a + 3b = -19$

$(3a - 4b = -13) \times 3$

$(-8a + 3b = -19) \times 4$

$9a - 12b = -39$

$-32a + 12b = -76$

$-23a = -115$

$\frac{-23a}{-23} = \frac{-115}{-23}$

$a = \frac{-115}{-23} = \frac{115}{23}$

$a = 5$

Put a into equation

$-8a + 3b = -19$

$-8(5) + 3b = -19$

$-40 + 3b = -19$

$3b = -19 + 40$

$3b = 21$

$b = \frac{21}{3}$

$b = 7$

So, The value of

$a = 5$ & $b = 7$

(7)

Example

A sample of an unknown materials weighs 300N in air & 200N when submerged in alcohol sol^n with a density of $0.7 \times 10^3 kg/m^3$. What is density of material?

Solution

Given

$W_{air} = 300N$

$W_{alcohol} = 200N$

$\rho_{alcohol} = 0.7 \times 10^3 kg/m^3$

$\rho_{material} = ?(\rho_o)$

$$F_{buoyant} = W_{air} - W_{alcohol}$$
$$= 300 - 200$$
$$= 100N$$

$$\frac{W_{air}}{F_{buoyant}} = \frac{\rho_o}{\rho_{alcohol}} \Rightarrow \rho_o = \frac{W_{air} \times \rho_{alcohol}}{F_{buoyant}}$$

$$= \frac{(0.7 \times 10^3) \times (300)}{100N}$$

$$\rho_o = 2.1 \times 10^3 kg/m^3$$

Moving Fluids & Bernoulli equation

→ If the flow is steady, then the velocity of the fluid particles at any point is a constant with time. The various layers of the fluid slide smoothly past each other. This is called **Streamline** or **laminar flow**.

→ Turbulent flow is the irregular movement of particles in a fluid and results in loss of energy due to internal friction b/w neighbouring layers of the fluid, called **Viscosity**.

* Factors affecting laminar flow are density, compressibility, temperature and viscosity.

Assumptions

* The fluid is non-viscous → there is no internal friction b/w adjacent layers
* The flow is steady → the velocity of fluid at each point remains constant
* The fluid is incompressible → density of fluid is constant
* The flow is irrotational → the fluid has no angular momentum about any point.

Equation of Continuity

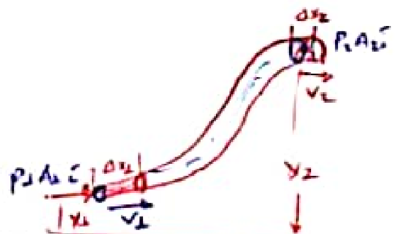
Equation of continuity expresses conservation of mass for an incompressible fluid flowing in a tube. It says "the amount (either mass or volume) of fluid flowing through a cross section of tube in a given time interval must be the same for all cross-sections"

or the product of the area and the fluid speed at all points along a tube is constant for an incompressible fluid.

$$AV = A_1V_1 = A_2V_2$$

$$\text{flow rate} = \frac{\text{Volume}}{\text{time}} = AV = \text{constant}$$

→ When cross sectional area is decreased then the flow rate increases



The product AV, which has the dimensions of volume per unit time is called **flow rate**

Atmospheric Pressure is the pressure due to weight of atmosphere exerted on the surface of Earth.

→ Atmospheric pressure decrease with increase in altitude (b/c decrease in density of air)

Gauge Pressure is the difference in pressure b/n a system and surrounding atmosphere

$$P_{gauge} = P_{system} - P_{atmosphere}$$

Gauge pressure is relative to atmospheric pressure < positive for pressure above atmospheric pressure; Negative for below it

Absolute Pressure is the total pressure

→ Cannot be negative Pa

$$P_{absolute} = P_{gauge} + P_{atmosphere}$$

→ Smallest absolute pressure is zero. Thus, smallest possible gauge pressure is $P_{gauge} = -P_{atmosphere}$

Example

A submerged wreck is located 18.3m beneath the surface of the Ocean off the coast of South florida. Determine

a) P_{gauge} b) P_{abs} (Note: density of sea water is $1025\ kg/m^3$)

Solution

a) $P_{gauge} = \rho g h = (1025\ kg/m^3)(9.8\ m/s^2)(18.3m) = 1.83 \times 10^5 \frac{N}{m^2}$

$$P_{gauge} = 1.83 \times 10^5\ N/m^2 = 182\ kpa$$

b) $P_{abs} = P_{gauge} + P_{atm}$

$= (1.83 \times 10^5 + 1.013 \times 10^5)\ N/m^2$

$= 2.84 \times 10^5\ N/m^2$ = ~~284~~ 284 kpa

Density and pressure in Static fluids

Density (ρ) is the quantity of mass (m) per Unit Volume (V) of a body with SI unit kg/m^3 and given by $\boxed{\rho = \frac{m}{V}}$

Specific gravity (SG) is the ratio of density of a substance to the density of another Substance w/c is taken as Standard.

→ The density of pure water at 4°c = 1.0×10^3 kg/m³ - taken as standard

- The SG is dimentionless quantity and the same in any s/m of measurement

Examples The density of aluminum is 2.7×10^3 kg/m³

∴ the SG of Al is $SG = \frac{2.7 \times 10^3 \, kg/m^3}{1.0 \times 10^3 \, kg/m^3} = \underline{2.7}$

Exampl A solid sphere made of wood has a radius of 0.1m. The mass of sphere is 1.0 kg. Determine a) density b) SG

Solution: The Volume of Sphere wood is $V = \frac{4}{3}\pi r^3$

Given

r = 0.1m

m = 1 kg

$= \frac{4}{3}\pi (0.1)^3 = \underline{4.18 \times 10^{-3} \, m^3}$

So a) density → $\rho = \frac{m}{V} = \frac{1 \, kg}{4.18 \times 10^{-3} m^3} = \underline{239 \, kg/m^3}$

b) SG → $SG = \frac{\text{density of wood}}{\text{density of water}} = \frac{239 \, kg/m^3}{1 \times 10^3 \, kg/m^3}$

$SG = \underline{0.239}$

Pressure: is the ratio of force acting perpendicular to surface Area (A) on w/c the force acts.

- SI Unit N/m², called pascal (pa)
- Another pressure Unit is atmosphere (atm) equal to 101.3 kpa w/c is average pressure, exerted by the Earth's atm at sea level

$\boxed{P = \frac{F_\perp}{A}}$

→ pressure produced by the column of fluid of height h and density ρ is given by $\boxed{P_{fluid} = \rho g h}$

Note that

- All points at same level in a fluid have same pressure
- Fluid pressure increase with increase in the depth of fluid.
- Fluid pressure does not depend on the shape of container

Elasticity Moduli:

The stress will be proportional to the strain if the stress is sufficiently small. In this regard, the proportionality constant known as elastic modulus depends on the material being deformed and on the nature of deformation.

$$\text{Stress} = \text{elastic modulus} \times \text{strain}$$

There are 3 types of elastic modulus

1. **Young's Modulus:** is the ratio of tensile stress to tensile strain.

   It measures the resistance of a solid to a change in its length and typically used to characterize a rod or wire stressed under either tension or compression.

$$Y = \frac{\text{tensile stress}}{\text{tensile strain}} = \frac{F_\perp/A}{\Delta l/l_0}$$

Y - has unit of force per unit area

$$Y \Rightarrow F/A = N/m^2$$

2. **Shear Modulus:** it is the measure of the resistance to motion of the planes within a solid parallel to each other.

   A material having large shear modulus is difficult to bend.

$$S = \frac{\text{Shear Stress}}{\text{Shear strain}} = \frac{\Delta F/A}{X/h}$$

Its SI units pascal

3. **Bulk Modulus:** it is measures the resistance of solids or liquids to changes in their volume

   A material having a large bulk modulus doesn't compress easily.

$$B = \frac{\text{Volume stress}}{\text{Volume strain}} = \frac{-\Delta F/A}{\Delta V/V_0} = \frac{-\Delta P}{\Delta V/V_0}$$

- a negative sign is included in this defining equation, so that B is always positive
- An increase in pressure (+ve ΔP) causes a decrease in volume negative (ΔV) and vice versa.

- Strain Energy is the energy stored in a stretched wire.

  If x is due to applied force F,

$$\text{Strain Energy} = \frac{1}{2} k x^2$$

Example

Suppose that the tension in the Cable is 940N as the actor reaches the lowest Point. What diameter should a 10 m long steel wire have if we do not it to stretch more than 0.5 cm under these conditions?

Solution

From definition of Young modulus

$F = 940N$

$l_o = 10m$

$\Delta l = 0.5cm = 0.005m$

$d = ?$

$$Y = \frac{F/A}{\Delta l/l_o} \longrightarrow \boxed{A = \frac{F l_o}{Y \Delta l}}$$

Since we are asked diameter we can get it from Area

Also $Y = 20 \times 10^{10} N/m^2$ -- for steel wire

So

$$A = \frac{(940N)(10m)}{(20 \times 10^{10} N/m^2)(0.005m)}$$

$$\boxed{A = 9.4 \times 10^{-6} m^2}$$

Because of radius of wire $\longrightarrow A = \pi r^2$

$$r = \sqrt{\frac{A}{\pi}} = \sqrt{\frac{9.4 \times 10^{-6} m^2}{\pi}} = 1.7 \times 10^{-3} m = 1.7mm$$

So. $\boxed{d = 2r = 2(1.7mm) = 3.4mm}$

Activity

A solid brass sphere is initially surrounded by air, and the air pressure exerted on it is $1.0 \times 10^5 N/m^2$. The sphere is lowered into the ocean to depth where the pressure is $2.0 \times 10^7 N/m^2$. The Volume of sphere in air is $0.50 m^3$. By how much does this Volume change once the sphere is submer

Solution

From definition of bulk modulus

$$B = \frac{-\Delta P}{\Delta V/V_i} \longrightarrow \Delta V = -\frac{V_i \Delta P}{B}$$

Given

$P_i = 1.0 \times 10^5 N/m^2$

$P_f = 2.0 \times 10^7 N/m^2$

$V_i = 0.5 m^3$

$\Delta V = ?$

$B = 6.1 \times 10^{10} N/m^2$ for Brass

So, $\Delta P = P_f - P_i \approx P_f = 2.0 \times 10^7 N/m^2$

B/c final pressure so much greater than initial pressure

$$\Delta V = -\frac{(0.5m^3)(2.0 \times 10^7 N/m^2)}{6.1 \times 10^{10} N/m^2}$$

$\boxed{\Delta V = -1.6 \times 10^{-4} m^3}$ → -ve sign indicat decrease in volume

5) Lead has a greater density than iron, and both are denser than water. Is the bouyant force on a lead object greater than, less than or equal to the bouyant force on an iron object of the same Volume?

Soln The bouyant force of a liquid on an object is equal to the weight of liquid displaced by it.

⇒ Since the lead object and iron object have the same Volume, both of them displace the same amount of water. Hence bouyant force is the same.

6. when an object is immersed on a liquid at rest, why is the net force on an object in the horizontal direction is equal to zero?

Solution The pressure is the same on points that are at the same level but on opposite sides, so net force along horizontal equals to zero.

7. When water freezes, it expands by about 9.0%. what pressure increase would occur inside your automobile engine block if the water in it froze? (The bulk modulus of ice is $2\times10^9\ N/m^2$)

Solution

$$B = \frac{\Delta P}{\Delta V/V} \longrightarrow \Delta p = B \times \frac{\Delta V}{V_i}$$

Given

$\Delta V = 9\%\ V$

$\Delta V = 0.09V$

$V_i = 1V$

$$= (2\times10^9\ N/m^2) \times \left(\frac{0.09V}{1V}\right)$$

$$\Delta p = 0.18\times10^9\ N/m^2$$

$$\Delta p = 1.8\times10^{10}\ N/m^2$$

8. A 40cm tall glass is filled with water to a depth of 30cm

A. What is the gauge pressure at the bottom of glass?

B. what is the absolute pressure at the bottom of glass?

Solution

Given $h = 30cm = 0.3m$ $\quad \rho_{water} = 1\times10^3\ kg/m^3$

$g = 9.81\ m/s^2$

a) $P_{gauge} = \rho g h = (1000)(9.81)(0.3)$

$= 2.9\times10^3\ pa$

b) $P_{absolute} = P_{gauge} + P_{atm}$

$= 2.9\times10^3\ pa + 1.01\times10^5\ pa$

$P_{absolute} = 1.04\times10^5\ pa$

9) calculate the absolute pressure at an ocean depth of 1.0×10^3 m. Assume that the density of the water is 1.025×10^3 kg/m³ and that $P_{atm} = 1.01 \times 10^5$ Pa

Solution

Given

$h = 1.0 \times 10^3$ m

$\rho = 1.025 \times 10^3$ kg/m³

P_{atm} or $P_o = 1.01 \times 10^5$ pa

$P_{absolute} = ?$

Soln

$P_{abs} = P_{gauge} + P_{atm}$

$= \rho g h + P_{atm}$

$= (1.025 \times 10^3 \, kg/m^3)(9.81 \, m/s^2)(1 \times 10^3 \, m) + 1.01 \times 10^5$ pa

$P_{absolute} = 1.01 \times 10^7$ pa

END OF CH-3

CHAPTER - 4
HEAT AND THERMODYNAMICS

Thermodynamics is a science of the r/ship b/n heat, work, temperature & energy.
↳ deals with the transfer of energy from one system to another / from one form to other)

Heat is defined as the flow of energy from one object to another. This flow of energy is caused by a difference in T°. Heat can flow → if they are in thermal contact.

Two objects are in thermal equilibrium if they are in close contact that allows either allows to gain energy from other, but nevertheless no energy transferred.

Experimentally, if object A is in thermal equilibrium with object B, and object B is in thermal equilibrium with object C, then, object A is in thermal equilibrium with object C. → This is called the Zeroth law of thermodynamics.

* Thermometers measure temperature according to well-defined scales of measurement
  ↳ The three most common T°-scales are Fahrenheit, Celsius and Kelvin.
  → Temperature scales are created by identifying two reproducible temperatures
  ↳ The freezing and boiling T° of water at standard atmospheric pressure used.

  * Freezing point of water is 0°c and boiling point is 100°c. [degree Celsius]
  * Freezing point of water is 32°F and boiling point is 212°F (degree Frenheit)

* $T_F = \frac{9}{5} T_C + 32$ $\qquad$ $T_K = \frac{5}{9}(T_F - 32) + 273.15$
* $T_C = \frac{5}{9}(T_F - 32)$ $\qquad$ $T_F = \frac{9}{5}(T_K - 273.15) + 32$
* $T_K = T_C + 273.15$

Thermal Expansion

Thermal expansion is the change is size or volume of a given system as its temperature changes. Example: Expansion of alcohol, expansion of hot air

→ Linear thermal expansion

The increase in length Δl of a solid is proportional to its initial length, l_0 and the change in its temperature ΔT. the proportionality constant is called the Coefficient of linear expansion α.

$$\boxed{\Delta l = \alpha l_0 \Delta T} \rightarrow l = l_0(1 + \alpha \Delta T) \qquad \alpha = \frac{l_0}{\Delta l}\Delta T$$

→ Areal Expansion

$$\Delta A = \beta A_0 \Delta T \Rightarrow A = A_0(1 + \beta \Delta T) \rightarrow \boxed{\beta = 2\alpha}$$

↳ it has units K^{-1} Coefficient and $(c^{\circ})^{-1}$

→ Volume Expansion

3. A 30 kg hammer strikes a steel spike 2.30 cm in diameter spike 2.30 cm in diameter while moving with a speed of 20m/s. The hammer rebounds with speed 10m/s after 0.11s. What is the average strain in the spike during impact?

$$\boxed{\Delta p = F \cdot \Delta t = m(V_f - V_i)}$$

Impulse = Δp

Given

$m = 30\,kg$

$\Delta t = 0.11\,s$

$V_i = 20\,m/s$

$V_f = -10\,m/s$ (rebounds)

Strain = ?

Solution

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

$$F \cdot \Delta t = m(V_f - V_i)$$

$$F \times 0.11 = 30(-10-20)$$

$$F = \frac{-900}{0.11} = \underline{8.18 \times 10^3\,N}$$

$$Stress = \frac{8.18 \times 10^3\,N}{\pi \times \left(\frac{2.3}{2} \times 10^{-2}\right)^2}$$

$$A = \pi\left(\frac{d}{2}\right)^2 = \pi\left(\frac{2.3}{2} \times 10^{-2}\right)^2$$

$$\boxed{Stress = 1.97 \times 10^7\,N/m^2}$$

$$Strain = \frac{Stress}{Y} = \frac{1.97 \times 10^7}{2 \times 10^{11}} = \underline{9.85 \times 10^{-5}}$$

4. If the shear stress in steel exceeds about $4 \times 10^8\,N/m^2$, the steel reptures. Determine the shearing force necessary to

a) a shear a steel bolt 1cm in a diameter

b) punch a 1cm diameter hole in a steel plate 0.5cm thick

Solution

a) $Stress = \frac{F}{A} \rightarrow$ $\boxed{\text{Force applied} = \text{Stress} \times \text{Area}}$

$$F = 4 \times 10^8\,N/m^2 \times \pi r^2$$

$$r = \frac{d}{2} = \frac{1}{2} = 0.5\,cm$$

$$r = \underline{5 \times 10^{-3}\,m}$$

$$= 4 \times 10^8\,N/m^2 \times \pi(5 \times 10^{-3})^2$$

$$= \underline{3.14 \times 10^4\,N}$$

b) The Area over which shear stress occur is equal to the circumference of the hole times its thickness

Thus, $A = (2\pi r)t = 2\pi(5 \times 10^{-3}m)(5 \times 10^{-3}m) = \underline{1.57 \times 10^{-4}\,m^2}$

So $F = A \times stress$

$$= (1.57 \times 10^{-4}\,m^2)(4 \times 10^8\,N/m^2)$$

$$\underline{F = 6.28 \times 10^4\,N}$$

Chapter Questions and problems

1. A 200kg load is hung on a wire having a length of 4.00 m, cross-sectional area $0.2 \times 10^{-4} m^2$ and Young Modulus $8 \times 10^{10} N/m^2$ what is increase in length?

Given

$l_0 = 4 m$

$A = 0.2 \times 10^{-4} m^2$

$Y = 8 \times 10^{10} N/m^2$

$m = 200 kg$

$\Delta l = ?$

From Young Modulus

$$Y = \frac{F_1/A}{\Delta l / l_0} = \frac{F_1 l_0}{A \Delta l} \qquad F_1 = mg$$

So.

$$\boxed{\Delta l = \frac{F_1 l_0}{A Y} = \frac{mg\, l_0}{A Y_0}}$$

$$\Delta l = \frac{200 kg (9.8 m/s^2)(4m)}{0.2 \times 10^{-4} m^2 \times 8 \times 10^{10} N/m} \approx 4.91 mm$$

Answer

$\Delta l = 4.91$ mm

2. A steel wire of diameter 1mm can support a tension of 0.2kN. A steel cable to support a tension of 20kN should have diameter of what order of magnitude?

Given

$d_1 = 1mm$

$F_1 = 0.2kN$

$F_2 = 20kN$

$d_2 = ?$

From Young modulus

$$Y = \frac{F l_0}{\Delta l A} \longrightarrow \boxed{A = \frac{F l_0}{\Delta l Y}}$$

Let A_1 - Cross-Sectional Area of Steel wire

A_2 - " " " of steel Cable

$$A_1 = \frac{F_1 l_0}{Y \Delta l} \qquad A_2 = \frac{F_2 l_0}{Y \Delta l} \longrightarrow \text{So, } \frac{A_2}{A_1} = \frac{\frac{F_2 l_0}{Y \Delta l}}{\frac{F_1 l_0}{Y \Delta l}} = \frac{F_2}{F_1}$$

$$\boxed{\frac{A_2}{A_1} = \frac{F_2}{F_1}}$$

$$A_1 = \frac{\pi d_1^2}{4} \qquad A_2 = \frac{\pi d_2^2}{4}$$

$$\frac{\frac{\pi d_2^2}{4}}{\frac{\pi d_1^2}{4}} = \frac{F_2}{F_1} \longrightarrow \frac{d_2^2}{d_1^2} = \frac{F_2}{F_1}$$

$$d_2^2 = d_1^2 \times \frac{F_2}{F_1}$$

$$d_2^2 = (1 \times 10^{-3} m)^2 \times \frac{20kN}{0.2kN} = 10^{-6} \times 100 = 10^{-4}$$

$$d_2 = \sqrt{10^{-4} m^2} = 10^{-2} m$$

$$d_2 = 10mm$$

Bernoulli's Equation

* The sum of pressure, kinetic energy per unit volume, and gravitational potential energy per unit volume has the same value at all points along a streamline.

This is called Bernoulli's Equation

$$P_1 + \frac{1}{2}\rho V_1^2 + \rho g h_1 = P_2 + \frac{1}{2}\rho V_2^2 + \rho g h_2$$

ρ - density
V - Velocity
P - Pressure

Example

Water circulates throughout a house in a hot water heating system. If the water is pumped at a speed of 0.50 m/s through a 4 cm diameter pipe in basement under pressure of 3.03×10^5 pa. What will be velocity and pressure in a 2.6 cm diameter pipe on the 2nd floor 5 m above?

Given

$V_1 = 0.5\ m/s$ $\quad V_2 = ?$

$h_1 = 0m$ (basement) $\quad h_2 = 5m$

$d_1 = 4cm = 0.04m$ $\quad d_2 = 2.6cm = 0.026m$

$A_1 = \pi r_1^2 = \pi (d_1/2)^2$ $\quad A_2 = \pi (d_2/2)^2 = 1.69 \times 10^{-4}\pi$

$= 0.0004\pi$

$P_1 = 3.03 \times 10^5\ pa$ $\quad P_2 = ?$

Solution

from Equation of Continuity

$$A_1 V_1 = A_2 V_2$$

$$V_2 = \frac{A_1 V_1}{A_2} = \frac{(0.0004\pi)(0.5)}{1.69 \times 10^{-4}\pi} = 1.183\ m/s$$

from Bernoulli's Equation

$$P_2 = P_1 + \frac{1}{2}\rho V_1^2 + \rho g h_1 - \frac{1}{2}\rho V_2^2 - \rho g h_2$$

$$= P_1 + \frac{1}{2}\rho (V_1^2 - V_2^2) + \rho g (h_1 - h_2)$$

$$= 3.03 \times 10^5 + \frac{1}{2}(1.0 \times 10^3)[0.5^2 - 1.183^2] + (1 \times 10^3)(9.8)[0 - 5]$$

$$P_2 = 1.84 \times 10^5\ pa$$

CHAPTER-5

Simple Harmonic Motion

5.1.1 Periodic and Oscillatory Motion

When a body repeats its path of motion back and forth about the equilibrium or mean position, the motion is said to be periodic.

Types of Oscillatory motion

There are two types of oscillatory motion < Linear oscillation & Circular oscillation

Example of linear oscillation

1. Oscillation of mass spring system
2. Oscillation of fluid column in U-tube
3. Oscillation of floating cylinder
4. Oscillation of body dropped in a tunnel along earth diameter.
5. Oscillation of strings of musical instruments.

Example of Circular Motion

1. Oscillation of simple pendulum
2. Oscillation of solid sphere in a cylinder
3. Oscillation of circular ring suspended on a nail
4. Oscillation of balance wheel of a clock
5. Rotation of earth around the sun

Oscillatory System

Oscillatory are the basic blocks of waves. Oscillatory systems are of two types mechanical and non-mechanical systems.

Mechanical Oscillatory Systems:- in this type of a system a body itself changes its position. For mechanical oscillation two things are especially responsible, inertia and restoring force.

Non-mechanical Oscillatory Systems:- the body itself doesn't change its position but its physical property varies periodically.

Period → (T):- is the time required to complete one full cycle of vibration ~~and~~ or oscillation.

Frequency → (f):- The frequency is the number of complete oscillations or cycles per unit time.

The frequency of wave is given by $f = \frac{1}{T}$

The first law of thermodynamics

The 1st law of thermodynamics states that "The change in internal energy of a system is equal to the sum of the heat flow into the system and the work done on the s/m."

In equation $\Delta U = Q + W$

ΔU - change in internal energy

$W = P\Delta V$ - Work done on the s/m
- P - pressure
- ΔV - Volume

The first law of different thermodynamic s/ms

Isolated System:- is a system which does not exchange heat with its surroundings and no work is done on the external environment.

$\Delta U = 0$ or $U =$ Constant — The internal energy of an isolated system is constant.

Cyclic process:- Engines operate in cycles, in which the system, example, a gas-periodically returns to its initial state.

Since, the system returns to its initial state, the change in internal energy in one complete cycle is zero.

$\Delta U = 0 \longrightarrow$ so, $Q = W$

Isochoric process:- In a constant volume process, the volume of the system stays constant.

Consequently, $W = 0 \longrightarrow \Delta U = Q$

→ All the heating entering the system goes into increasing internal energy

Adiabatic process:- The system does not exchange heat with its surroundings, $Q = 0 \longrightarrow \Delta U = W$

Isothermal process:- It is a process which involves no change in temperature of the system.

If the process occurs at constant temperature then there is no change in the internal energy of the system so ΔU.

The 1st law for isothermal

$\Delta U = Q + W \longrightarrow 0 = Q + W$

$Q = -W$

For ideal gas in isothermal process

$$W = nRT \ln\left(\frac{V_f}{V_i}\right)$$

Isobaric Process:- the expansion or compression occurs at constant pressure. Any work done by the system will result in an increase in volum

The work done on pressure - volume graph is equal to area under PV graph

For isobaric $W = P\Delta V = P(V_f - V_i)$

1st law of isobaric process $\longrightarrow \Delta U = Q + W$ or $\Delta U = Q - P\Delta V$

$= Q - P(V_f - V_i)$

Example - 1

5000J of heat are added to two moles of an ideal monatomic gas, initially at a temperature of 500k. while the gas performs 7500J of work. What is the final temperature of the gas?

Solution

$\Delta U = Q + W$

$= 5000 - 7500$

$= -2500J$

from equation $\Delta U = nC\Delta T \rightarrow \Delta U = \frac{3}{2} nR\Delta T$

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

$-2500 = \frac{3}{2}(2)(8.31)\Delta T$

$\Delta T = -100K$

$\Delta T = T_f - T_i$

$-100k = T_f - 500k$

$T_f = 400k$

Example - 2

2000J of heat leaves the System and 2500J of work is done On the System.

What is the change in internal energy of the s/m.?

Soln

$Q = -2000J$

$W = 2500J$

$\Delta U = Q + W$

$= -2000J + 2500J$

$\Delta U = 500J$

Activity 1 A 1 mol Sample of an ideal gas is kept at 0.0°c during an expansion from 3.0L to 10L

a) How much work is done on the gas during expansion?

Solution

$W = nRT \ln\left(\frac{V_f}{V_i}\right)$

$= (1\,mol)(8.31J/mol\,k)(273k)\ln\left(\frac{10}{3}\right)$

$= 2.73 \times 10^3 J$

b) How much energy transferred by heat occurs with the Sorroundings in this process

$\Delta U = Q + W$

$\Delta U = 0$

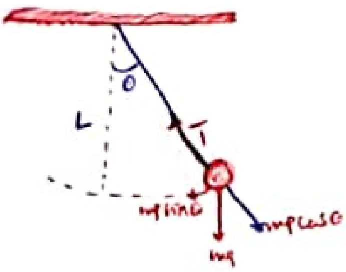
So

$Q = W$

$Q = W = 2.73 \times 10^3 J$

The Simple pendulum

A simple pendulum is another mechanical System that exhibits periodic motion.



The force of gravity is the only force that acts on the pendulum.

The pendulum bob moves along a circular arc, rather than back and forth in a straight line.

Hooke's law ⟶ $T = 2\pi\sqrt{L/g}$

L - length
g - gravity
T - period

* Period of simple pendulum does not depend on mass but only length & free fall acceleration.

Eg. A rock swings in a circle constant speed on the end on a string, making 50 revolutions in 30 sec. What is frequency and period for this motion

Soln

$$f = \frac{50\,rev}{30\,sec} = 1.67\,rev/sec = 1.67\,Hz$$

$$T = \frac{1}{f} = \frac{1}{1.67} = 2\,sec$$

Energy of Simple Harmonic Oscillator

In the absence of friction, the total energy of a block-spring System is constant and equal to the sum of kinetic and potential energies.

$$PE = \frac{1}{2}kx^2 \qquad KE = \frac{1}{2}mv^2$$

Total energy of the oscillator performing SHM is $E = \frac{1}{2}kA^2$

* Energy of SHM is constant & proportional to square of Amplitude.

Wave and Its charectristics

* Wave is a disturbance from normal or equilibrium Conditions that travels, or Propagates, carrying energy and momentum through space without the transport of matter

* Pulse is a simple disturbance travelling into a medium.

Wave supplies energy to the particles in a medium to set them in motion.

Terminologies in Wave

Crests/Thoughts: are positions in a wave with maximum displacements above/below the equilibrium position.

Amplitude (A) :- is the maximum displacement from equilibrium position

Displacement (y) :- is position of a wave from equilibrium position at any time.

Xample 1

How much heat energy is required to change a 40g ice cube from a solid at $-10°c$ to steam at $110°c$.

Solution

To raise the temperature of the ice to 0°c we need

$$\Delta Q_{ice} = m_{ice} C_{ice} \Delta T = 0.04\,kg \left(0.49 \frac{kcal}{kg.°c}\right) 10°c$$

$$= \underline{0.196\,kcal}$$

To melt the ice we need

$$\Delta Q_{ice} = m_{ice} L_{ice} = 0.04\,kg \left(80\,kcal/kg\right) = \underline{3.2\,kcal}$$

To raise the temperature of 100°c we need

$$\Delta Q_{ice} = m_{water} C_{water} \Delta T = 0.04\,kg \left(1 \frac{kcal}{kg°c}\right) 100°c = \underline{4\,kcal}$$

To raise the temperature of the system to 110°c we need

$$\Delta Q_{ice} = m_{system} C_{system} \Delta T = 0.4\,kg (0.48\,kcal/(kg°c)] 10°c = \underline{0.192\,kcal}$$

To boil the water need

$$\Delta Q_L = m_{water} L_{water} = 0.04\,kg \left(540\,k \frac{cal}{kg}\right) = \underline{21.6\,kcal}$$

Therefore total heat energy required is

$$\Delta Q = (0.96 + 3.2 + 4 + 21.6 + 0.192)\,kcal = \underline{29.188\,kcal}$$

Ex2 If 90g of molten lead at 327.3°c is poured into a 300g casting form made of iron and initially at 20°c. What is the final temperature of the system? Assume no energy lost to env't.

Soln The melting point of lead is 327.3°c. Assume the final temperature of the system is T.

- The amount of energy released by the lead as it solidifies is

$$\Delta Q_L = m_{lead} L_{lead} = 0.09\,kg\,(2.45 \times 10^4\,J/kg) = \underline{2205\,J}$$

- The amount of energy released as it cools is

$$\Delta Q = m_{lead} C_{lead} \Delta T = 0.09\,(128)(327.3 - T) = (11.52)(327.3 - T)$$

The energy is absorbed by the iron, for the iron

$$2205 + (11.52)(327.3 - T) = m_{iron} C_{iron} \Delta T = 0.3\,(448)(T - 20)$$

$$5975.5 - (11.52)T = 134T - 2688$$

$$8663.5 = 145.52T$$

$$T = 59.5°c$$

The Concept of Heat, Work and Internal energy

Heat. Symbol Q and unit joule (J) is spontaneous flow of energy into or out of a system caused by a d/ce in temperature b/n system and surroundings.

Work. Symbol W and Unit joule (J), is a non-spontaneous energy transfer into or out of a system due to force acting through a displacement.

Work takes many forms, moving a piston or stirring or running an electrical current through resistance.

Work is the non-spontaneous transfer of energy. Heat is microscopic form of energy transfer. involving large no of particles.

A system cannot possess heat or work. these two are energies that flow into or out of a system.

Heat transfer obeys the law of conservation of energy (if no heat is lost to surroundings)

$$Q \text{ lost by hotter object} = Q \text{ gained by cooler object}$$

Internal Energy. Symbol U, is defined as the energy associated with the random, disordered motion of the microscopic components-atoms and molecules.

Specific Heat and Latent Heat

Specific heats:-

Heat flowing into or out of a body (or system) changes the temperature of the body (or system) except during phase changes the temperature remains constant.

→ The quantity of heat Q required to change the temperature of the body of mass m by ΔT is proportional to both mass & ΔT

Mathematically $Q \sim m\Delta T \longrightarrow$ $\boxed{Q = mc\Delta T}$

c - heat capacity (or specific heat)

c - the amount of heat required to raise temperature of unit mass of any substance through a unit degree.

SI unit is $J/kg \cdot K$ or $J/kg \cdot {}^\circ C$

The amount of heat required to change the temperature of n moles of a substance is $Q = nc\Delta T$

Latent heats:-

Latent heat is the heat required per unit mass of a substance to produce a phase change at constant temperature.

→ the latent heat, Q_L, required to change the phase of "m" mass of a body at constant temperature is

$$Q_L = \pm mL$$

L - specific latent heat required to change a phase of 1kg of a substance at a constant temperature.

Types of latent heats

two types

1) Latent heat of fusion (L_f) is the heat absorbed or released when matter melts changing phase from solid to liquid form at constant temperature.

2) latent heat of vaporization (L_v) is the heat absorbed or released when matter vaporize changing phase from liquid to gas phase at constant temperature

Displacement, Velocity and acceleration in SHM

- Displacement → $X = A \sin \omega t$
- Velocity $= \omega A \cos(\omega t)$
- Acceleration $= -\omega^2 A \sin(\omega t) = -\omega^2 x$

* Maximum Velocity occurs at equilibrium position with $\boxed{V_{max} = \omega A}$

* Maximum acceleration occurs at $X = \pm A$; $\boxed{a_{max} = \omega^2 A}$

Example

An object oscillates with SHM along x-axis. its position Varies with time according to equation $X = (4.00)\text{m} \cos(\pi t + \frac{\pi}{4})$ where t is in seconds and angles in radians.

a) Determine A, f, and T of motion

b) Calculate $\vec{V}$, & $\vec{a}$ at any time.

c) Using results of part b, determine position, Velocity & $\vec{a}$ at $t = 1s$

d) determine maximum Speed and maximum acceleration of object.

Solution

Given

$X = (4.00)\text{m} \cos(\pi t + \frac{\pi}{4})$ (A, ω, ϕ) with the general eqn of Simple HM

$X(t) = A \cos(\omega t + \phi)$

a) $A = 4\text{m}$, $\omega = \pi \text{rad}/s$ → $f = \frac{\omega}{2\pi} = \frac{\pi \text{rad/s}}{2\pi} = 0.5 \text{ Hz}$

$T = \frac{1}{f} = \frac{1}{0.5} = 2 \text{ sec}$

b) $\vec{V} = \frac{dx}{dt} = \frac{d(4\text{m}\cos(\pi t + \frac{\pi}{4}))}{dt} = -(4\pi)\text{m/s} \sin(\pi t + \frac{\pi}{4})$ //

$a = \frac{dv}{dt} = -(4\pi)^2 \text{m/s}^2 \cos(\pi t + \frac{\pi}{4})$ //

c) at $t = 1 \text{sec}$

$x(t) = 4\cos(\pi t + \frac{\pi}{4}) = 4\cos(\pi(1) + \frac{\pi}{4})$

$= 4\cos 5\pi/4 = -2.83 \text{ m}$

$V(t) = -4\pi \sin(\pi(1) + \frac{\pi}{4})$

$= -4\pi \sin \frac{5\pi}{4} = 8.89 \text{ m/s}$

$a(t) = -(4\pi)^2 \cos(\pi(1) + \pi/4) = 27.9 \text{ m/s}^2$

d) $V_{max} = \omega A = 12.56 \text{ m/s}$

$a_{max} = \omega^2 A = 39.4 \text{ m/s}^2$ //

Amplitude (A) is the maximum displacement of the oscillatory from the equilibrium position.

Example: On average a human heart is found to beat 75 times in a minute. Calculate its frequency and period.

$$\Rightarrow f = \frac{75}{1\,\text{minute}} = \frac{75}{60\,s} = 1.25/s = \underline{\underline{1.25\,Hz}}$$

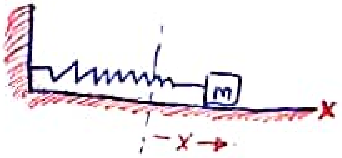
$$T = \frac{1}{f} = \frac{1}{1.25/s} = \underline{\underline{0.8\,\text{sec}}}$$

→ Simple harmonic motion is a special type of oscillatory motion caused by a restoring force which obeys Hooke's law.

In SHM acceleration

a) is always directly proportional in size but opposite in direction to its displacement (x).

A block of mass m, attached to one end of a spring, of constant k and oscillating in a horizontal frictionless floor, is example of SHM.



$$\boxed{F_s = -kx}$$

The minus (−) sign shows the force is always acting opposite to the displacement and always tries to restore the block back to its equilibrium position.

Newton's 2nd law $F_s = ma$

$$ma = -kx \longrightarrow a = -\left(\frac{k}{m}\right)x = \underline{\underline{-\omega^2 x}}$$

* k is constant of proportionality called the spring constant or stiffness factor and ω is angular frequency of oscillator.

Characteristics of SHM

1) The amplitude A is constant
2) The frequency and period are independent of Amplitude
3. The fluctuating quantity can be expressed interms of sinusoidal function of a single frequency.

For SHM to occur

- there must be a stable equilibrium position
- there must be no dissipation of energy
- the acceleration is proportional to displacement & opposite in direction.