REPEATERS JEE MAIN - 2026

(JEE MAIN ONE YEAR PROGRAMME)

PHYSICS

STUDY MATERIAL

Brilliant
STUDY CENTRE
PALA

Mutholy , Ph: 04822 - 206100, 206800

www.brilliantpala.org., email: admissions@brilliantpala.org

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Chapter 01

UNITS AND MEASUREMENTS

SYNOPSIS

1. Measurement of any physical quantity involves comparison with a certain basic, arbitrarily chosen internationally accepted reference standard called **unit**

2. Physical quantities that are independent of others are called fundamental quantities. Physical quantities that can be defined in terms of the base quantities are called derived quantities. The units for the fundamental or base quantities are called **fundamental or base units.** The units of all other physical quantities can be expressed as a combination of the base units. Such units obtained for the derived quantities are called **derived units**

3. A system of unit is a family of units of fundamental and derived physical quantities. The system of units which is at present internationally accepted for measurement is the "International system of units" abbreviated as SI.

   other system of units are

   a) C.G.S (Centimetre, Gram, Second)

   b) F.P.S (Foot, Pound, Second)

   c) M.K.S (Metre, Kilogram, Second)

SI base quantities and units

Base quantity	SI unit	
	Name	Symbol
Length	metre	m
Mass	kilogram	kg
Time	second	s
Electric current	ampere	A
Thermodynamic temperature	kelvin	K or θ
Amount of substance	mole	mol
Luminous intensity	candela	cd

Besides these seven base units (given above) there are two more units that are defined for plane angle and solid angle. The **unit for Plane angle is radian (rad)** and unit for the **solid angle is steradian (sr).**

4. Range of Lengths

1 fermi = 1f = 10^{-15} m; 1 angstrom = $1\mathring{A}$ = 10^{-10}m

1 astronomical unit = 1Au (distance of the sun from the earth) = 1.496 x 10^{11}m

1 light year = 1ly = 9.46 x 10^{15}m (distance that light travels with velocity of 3 x 10^{8} ms^{-1} in 1 year)

1 par sec = 3.26 light years = 3.08 x 10^{16} m

(Note that parsec is an abbreviation of parallactic second)

Dimensions of physical quantities

1. The dimensions of a physical quantity are the powers to which the base quantities are raised to represent that quantity.

2. The nature of a physical quantity is described by its dimensions

3. All the physical quantities represented by derived units can be expressed in terms of some combination of seven fundamental or base quantities.

4. Using the square brackets [ ] round a quantity means that we are dealing with the dimensions of the quantity

5. In mechanics all the physical quantities can be written in terms of dimensions [L], [M] and [T]

   eg: Force = mass x acceleration = mass x (length) /(time)^2

   ie, the dimensions of force are [M] [L]/[T]^2 = [MLT^{-2}]

   ie, force has one dimension in mass, one dimension in length and –2 dimensions in time. The dimensions in all other base quantities are zero.

   In this type of representation, the magnitudes are not considered.

6. The dimensional equations are the equations which represent the dimensions of a physical quantity in terms of the base quantities

   for eg: the dimensional eqn of volume [v] may be expressed as

   [v] = [$M^oL^3T^o$]

7. Only those physical quantities can be added or subtracted which have the same dimensions. ie velocity cannot be added to force

8. The arguments of special functions, such as the trigonometric, logarithmic and exponential functions must be dimensionless. A pure number, ratio of similar physical quantities has no dimensions

Dimensionless quantities

Angle, solid angle, trigonometrical ratios, relative density, relative permittivity, relative permeability, Poisson's ratio, strain, refractive index, mechanical equivalent of heat (Joules constant), π, angular displacement, emissivity, thermo-dynamic constant $\left(\gamma = \frac{C_p}{C_v}\right)$, limit of resolution of telescope (angle), Power factor $(\cos\phi)$, form factor, quality factor (Q), amplication factor (μ), and efficiency have no dimensions.

9. A dimensionally correct equation need not be actually a correct equation, but dimensionally wrong incorrect or inconsistent equation must be wrong.

10. Uses of dimensions

i) conversion of units

ii) To check the dimensional correctness of a given physical equation

iii) To establish the relation among various physical quantities

11. Limitations

If a physical quantity depends on more than three factors, the relation among them cannot be established because we can have only three eqns by establishing the powers of M,L and T.

12. Principles of Homogeneity of Dimensions

This principle states that the dimensions of all the terms in a physical expression should be same. for eg, in the physical expression $s = ut + 1/2\ at^2$, the dimensions of s, ut, $1/2at^2$ all are same. The physical quantities separated by the symbols

+, –, =, >, < etc have the same dimensions.

Least count

The smallest division on the scale of the measuring instrument is called its least count.

Significant figures

Significant figures indicate, the precision of the measurement which depends on the least count of the measuring instrument.

The reliable digits plus the first uncertain digit are known as the significant digits or significant figures.

1. A choice of change of different units does not change the number of significant digits or figure in a measurement
2. All the non zero digits are significant
3. All the zeros between two non - zero digits are significant, no matter where the decimal point is, if at all
4. If the number is less than 1, the zeros on the right of decimal point is significant but to the left of the first non zero digit are not significant
5. The trailing zeros in a number with a decimal point are significant
6. The terminal or trailing zeros in a number without a decimal point are not significant.

Rules for Arithmetic operations with significant figures

1. In multiplication or devision, the final result should retain as many significant figures as are there in the original number with the least significant figures.

2. In addition or subtraction, the final result should retain as many decimal places as are there in the number with the least decimal places.

Rounding off the uncertain digit

1. Preceding digit is raised by 1 if the insignificant digit to be dropped is more than 5, and is left unchanged if the latter is less than 5.

2. If the insignificant digit is 5 and if the preceding digit is even, the insignificant digit is simply dropped and if it is odd, the preceding digit is raised by 1.

Error

5. The result of every measurement by any measuring instrument is an approximate number, which contains some uncertainty. This uncertainty is called error

The accuracy of a measurement is a measure of how close the measured value is to the true value of quantity. Precision tells us to what resolution or limit the quantity is measured.

In general, the error in measurement can be broadly classified as (a) systematic errors and (b) random errors.

a) Systematic errors: are those error that tend to be in one direction either positive or negative. some of the sources are

i) Instrument errors (due to imperfect design or calibration, zero error)

ii) Imperfection in experimental technique or procedure (due to changes in external condition)

iii) personal errors

b) Random errors

These are those errors which are irregular and thus random in nature with respect to their sign or size. The causes of these errors are not known. The same person may get different readings for the same measurement on two occasions.

Types of errors

a) Absolute error

a = actural value

a_i = i^{th} observed value

absolute error, $\Delta a_i = a_i - a$

b) Relative or fractional error

The relative error in the ith reading is $= \frac{\Delta a_i}{a}$

ie $= \frac{\text{absolute error}}{\text{actual value}}$

c) Percentage error $= \frac{\Delta a_i}{a} \times 100$

Determination of the actual value

No instrument can give you the actual value because every instrument has a least count i.e., a certain precision. So arithmetic mean of all readings is assumed to be the actual value a.

Note: The arithmetic mean of all the absolute errors is taken as the final or mean absolute error of the value of the physical quantity a.

Combination of errors

a) Error of a sum or a difference

Rule: when two quantities are added or subtracted, the absolute error in the final result is the **sum of the absolute errors** in the individual quantities.

b) Error of a product or a quotient

Rule: When two quantities are multiplied or divided, the fractional error in the result is the sum of the **fractional error in the multipliers**

c) error due to the power of a measured quantity

if $Z = A^p B^q / C^r ; \Delta Z / Z = P(\Delta A / A) + q(\Delta B / B) + r(\Delta C / C)$

Rule: The fractional error in a physical quantity raised to the power is the power times the fractional error in the individual quantity

Eg: Find the fractional error in Z, If $Z = A^4 B^{1/3} / CD^{3/2}$

Ans: The fractional error in Z is,

$$\frac{\Delta Z}{Z} = 4\left(\frac{\Delta A}{A}\right) + \left(\frac{1}{3}\right)\left(\frac{\Delta B}{B}\right) + \left(\frac{\Delta C}{C}\right) + \frac{3}{2}\left(\frac{\Delta D}{D}\right)$$

SECTION - I
QUESTIONS

SINGLE CORRECT TYPE

1. Parsec is the unit of

1) Time

2) Distance

3) Frequency

4) Angular acceleration

2. An accurate measurement implies that

1) the spread of the reading are broad around the mean value

2) the spread of the readings are narrow around the mean value

3) the mean value of the readings is always lower than the true value

4) the closeness of the mean of the reading to the true value

3. Which of the following quantities has not been expressed in proper unit ?

a.	Torque	Newton metre
b.	Stress	Newton metre^{-2}
c.	Modulus of elasticity	Newton metre^{-2}
d.	Power	Newton metre second
e.	Surface tension	Newton metre^{-2}

1) a,b 2) a,c

3) d,e 4) b,c

4. The density of a material is SI unit is 128 kg m^{-3}. In certain units in which the unit of length is 25cm and the unit of mass is 50g, the numerical value of density of the material is :

1) 40 2) 16

3) 640 4) 410

5. A force is given by $F = at + bt^2$, where t is time. What are the dimension of a and b

1) MLT^{-3} and ML^2T^{-4}

2) MLT^{-3} and MLT^{-4}

3) MLT^{-3} and MLT^0

4) MLT^{-4} and MLT^1

6. The equation of a circle is given by $x^2 + y^2 = a^2$, where a is the radius. If the equation is modified to change the origin other than (0, 0), then find out the correct dimensions of A and B in a new equation :

$(x - At)^2 + \left(y - \frac{t}{B}\right)^2 = a^2$, The dimensions of t is given as $[T^{-1}]$

1) A = $[L^{-1}T]$, B = $[LT^{-1}]$

2) A = $[LT]$, B = $[L^{-1}T^{-1}]$

3) A = $[L^{-1}T^{-1}]$, B = $[LT^{-1}]$

4) A = $[L^{-1}T^{-1}]$, B = $[LT]$

7. Which of the following choices does not represent the same dimensions of the mentioned physical quantities?

1) Heat, potential energy and work

2) Electric flux, electric field and electric dipole moment

3) Pressure, stress and Young;s modulus

4) Potential difference, voltage and electromotive force of a galvanic cell

8. If E, M, J and G, respectively, denotes energy, mass, angular momentum and gravitational constant, EJ^2/M^5G^2 has the dimensions of

1) length 2) angle

3) mass 4) time

9. The dimensions of $(\mu_0\varepsilon_0)^{-(1/2)}$ are

1) $[L^{1/2}T^{1/2}]$

2) $[L^{1/2}T^{-1/2}]$

3) $[L^{-1}T]$

4) $[LT^{-1}]$

10. A student writes four different expressions for the displacement y in a periodic motion as a function of time t, a as amplitude, T as time period. Which of the following can be correct?

1) $y = aT\sin\frac{2\pi t}{T}$

2) y = a sin Vt

3) $y = \frac{a}{T}\sin\frac{t}{a}$

4) $y = \frac{a}{\sqrt{2}}\left[\sin\frac{2\pi t}{T} + \cos\frac{2\pi t}{T}\right]$

11. If the velocity (V), acceleration (A), and force (F) are taken as fundamental quantities instead of mass (M), length(L), and time (T), the dimensions of Young's modulus (Y) would be

1) FA^2V^{-4} 2) FA^2V^{-5}

3) FA^2V^{-3} 4) FA^2V^{-2}

12. The largest mass (m) that can be moved by a flowing river depends on velocity (v), density (ρ) of river water and acceleration due to gravity (g). The correct relation is

1) $m \propto \frac{\rho^2 v^4}{g^2}$ 2) $m \propto \frac{\rho v^6}{g^2}$

3) $m \propto \frac{\rho v^4}{g^3}$ 4) $m \propto \frac{\rho v^6}{g^3}$

13. From the point of view of significant figures, which of the following statements are correct

i) 10.2 cm + 8 cm = 18.2 cm

ii) 2.53 – 1.2 m = 1.33 m

iii) 4.2 m × 1.4 m = 5.88 m^2

iv) $3.6\,m \div 1.75\,s = 2.1\,m/s$

1) i only 2) i and iv

3) i and ii 4) iv only

14. The power in an electrical circuit for a current of 5 ± 0.4A and voltage 10 ± 0.2V is measured at 10% error. To measure the power at 5% error the current should be measured at an error of

1) 5% 2) 2%

3) 10% 4) 3%

15. The density of a sphere is measured by measurement its mass and diameter. If it is known that the maximum percentage errors in the measurement are 2% and 3%, what is the maximum percentage error in the measurement of density?

1) 8% 2) 10%

3) 11% 4) 5%

16. Two resistance are given as R_1=(10±0.5)Ω and R_2=(15±0.5)Ω. The percentage error in the measurement of equivalent resistance when they are connected in parallel is -

1) 2.33 2) 4.33

3) 5.33 4) 6.33

17. A public park, in the form of a square, has an area of $(100 \pm 0.2)m^2$. The side of park is:

1) $(10 \pm 0.01)m$ 2) $(10 \pm 0.1)m$

3) $(10 \pm 0.02)m$ 4) $(10 \pm 0.2)m$

18. A vernier callipers has 1mm marks on the main scale. It has 20 equal divisions on the vernier scale which match with 16 main scale divisions. For this vernier calipers, the least count is

1) 0.02 mm 2) 0.05 mm

3) 0.1 mm 4) 0.2 mm

19. Match correctly column I and column II

Column I		Column II	
A.	Linear mass density	P.	$[M^0L^0T^{-1}]$
B.	Velocity gradient	Q.	$[ML^{-1}T^{-2}]$
C.	Pressure	R.	$[ML^{-1}T^{-1}]$
D.	Coefficient of viscosity	S.	$[ML^{-1}T^0]$

1) A-P, B-Q, C-R, D-S

2) A-S, B-P, C-R, D-Q

3) A-S, B-Q, C-R, D-P

4) A-S, B-P, C-Q, D-R

20. The period of oscillation of a simple pendulum is $T = 2\pi\sqrt{L/g}$. Measured value of L is 10 cm known to 1mm accuracy and time for 100 oscillations of the pendulum is found to be 50s using a wrist watch of 1s resolution. What is the accuracy in the determination of g?

1) 2% 2) 3%

3) 4% 4) 5%

SECTION - II
QUESTIONS

NUMERICAL TYPE

21. In a new system of units, the unit of mass is 100 g, unit of length is 4 m and unit of time is 2 s. Find the numerical value of 10 J in this system.

22. The length of a wire is 2.17 cm and radius is 0.46 cm. Find number of significant digits in the value of volume of wire.

23. If the screw on a screw-gauge is given six rotations, it moves by 3 mm on the main scale. If there are 50 divisions on the circular scale, the least count of the screw gauge is $n \times 10^{-3}$ cm. Then value of n is:

24. To find the distance d over which a signal can be seen clearly in foggy conditions, a railways engineer uses dimensional analysis and assumes that the distance depends on the mass density ρ of the fog, intensity (power/area) S of light from the signal and its frequency 'f'. The engineer finds that d is proportional to $S^{1/n}$. The value of n is

25. The relative density of material is found by weighing the body first in air and then in water. If the weight in air is (10.0±0.1)gf and the weight of water is (5.0±0.1)gf, then the maximum permissible percentage error in relative density is

Chapter 02

MOTION IN A STRAIGHT LINE

SYNOPSIS

1. **Point Object** :- An object is said to be a point object if it changes its position by distances which are much greater than its size.

2. **State of rest** :- An object or particle is said to be in a state of rest if it does not change its position with time with respect to its surroundings

3. **State of motion** :- An object or particle is said to be in a state of motion if it changes its position with respect to its surroundings

4. **Motion in one dimension** :- It is that motion in which a particle or a body moves in one particular direction w.r.to a point of reference.

5. **Distance** :- It is the length of actual path traversed by a body during motion in a given interval of time. Distance is a scalar quantity. The distance travelled by a body can never be zero or negative.

6. **Displacement** :- Displacement of a body in a given time is defined as the change in position of the body in a particular direction.

   1) Displacement is a vector quantity

   2) The unit of displacement is that of length

   3) Displacement can be positive, zero or negative

   4) The value of displacement can never be greater than the distance travelled

   5) When a moving body returns to its starting point then its effective displacement is zero

7. **Speed** :- The speed of a particle or body is defined as the distance travelled by it in unit time

   Speed $= \dfrac{\text{distance}}{\text{time}}$ is a scalar quantity

8. **Uniform speed** :- A body is said to move with uniform speed, if it covers equal distances in equal intervals of time, howsoever small these intervals may be

9. **Variable speed** :- A body is said to be moving with a variable speed if it covers equal distances in unequal intervals of time or unequal distances in equal intervals of time, howsoever small these intervals may be.

10. Average speed :- When a body is moving with a variable speed, then the average speed of the body is defined as the ratio of total distance travelled by the body to the total time taken.

$$\text{Average speed} = \frac{\text{total distance travelled}}{\text{total time taken}}$$

11. Instantaneous speed :- When the body is moving with variable speed, then the speed of the body at a given instant of time is called its instantaneous speed.

12. Velocity :- Velocity of a particle or body is defined as the rate of change of displacement

1) Velocity is a vector quantity

2) Velocity of a body can be zero, negative or positive

3) Velocity can never be greater than the speed of the body

13. Uniform velocity :- A body is said to be moving with uniform velocity, if it undergoes equal displacements in equal intervals of time; howsoever these intervals may be.

14. Average velocity :- When a body is moving with a variable velocity, the average velocity of the body in a given time is defined as the ratio of the total displacement to the total time taken.

$$\text{Average Velocity} = \frac{\text{total displacement}}{\text{total time taken}}$$

15. Instantaneous Velocity :-

1) When a body is moving with a variable velocity the velocity of the body at a given instant of time is called instantaneous velocity.

2) If at an instant t, a body while moving covers a displacement $\overrightarrow{\Delta r}$ in a small interval of time Δt, so that $\Delta t \to 0$, then instantaneous velocity $= \underset{\Delta t \to 0}{Lt} \frac{\vec{\Delta r}}{dt} = \frac{dr}{dt}$

($\frac{dr}{dt}$ is the first derivative of displacement $\vec{r}$ w.r.t. time)

16. Acceleration :- Acceleration of a particle or body is defined as the rate of change of velocity.

$$\text{Acceleration} = \frac{\text{Change in velocity}}{\text{time taken}}$$

1) Acceleration is a vector quantity and its S.I.unit is m/s^2.

2) Acceleration can be positive negative or zero

3) Negative acceleration is called retardation or deceleration

17. Uniform acceleration :- A object is said to be moving with a uniform acceleration, if its velocity changes by equal amounts in equal intervals of time.

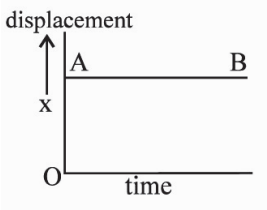
$$\text{Average acceleration} = \frac{\text{total change in velocity}}{\text{total time taken}}$$

18. Instantaneous acceleration : If at an instant 't' a body while moving with variable acceleration then the acceleration of the body at a given instant of time is called instantaneous acceleration.

instantaneous acceleration $\underset{\Delta t \to 0}{Lt} \frac{\vec{\Delta v}}{\Delta t} = \frac{d\vec{v}}{dt}$ ($\frac{dv}{dt}$ is the first derivative of velocity w.r. to time)

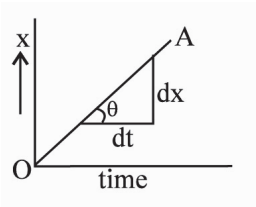
19. Displacement time graph :- A graph drawn with time along the x-axis and the displacement along the y-axis.

1)



For a stationary body, the time displacement graph AB, is a straight line parallel to the time axis

2)

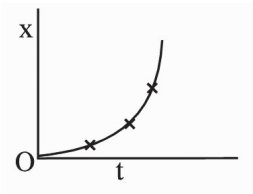


Uniform motion. Equal displacement take place at equal intervals of time.

Velocity = $\frac{dx}{dt}$ = slope of the straight line OA.

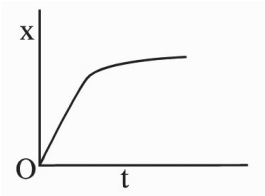
$V = \frac{dx}{dt} = \tan\theta$. Where θ is the angle made by the straight line OA with the time axis.

3)



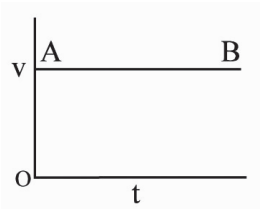
Body moving with constant acceleration. The graph is a curve which bends upwards.

4)

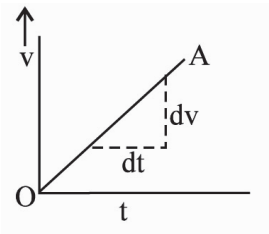


Body moving with constant deceleration

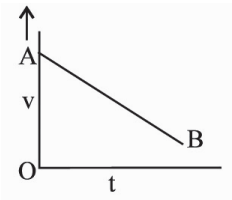
20. Velocity time graph :- A graph drawn with velocity along the y-axis and time along the x-axis.

1) 

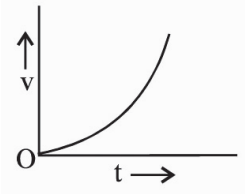
Body moving with constant velocity the velocity time graph is a straight line AB parallel to the time axis.

2) 

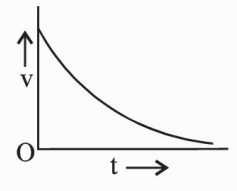
Body moving with constant acceleration and its initial velocity is zero. It is a straight line inclined to the time axis. The slope of the time OA gives the acceleration. The area under the v-t graph gives the displacement.

3) 

Body moves with constant retardation and its initial velocity is not zero the velocity time graph is an oblique. Straight line AB not passing through origin.

4) 

Body moving with increasing accelerations. The v-t graph is a curve which bend upwards.

5) 

Body moving with negative acceleration

21. Equations of motion

u = initial velocity of body

a = Uniform acceleration of the body

v = velocity after a time t

s = distance travelled by the body in time t

s_n = distance travelled by the body in the nth second

1) $V = u + at$

2) $U^2 = u^2 + 2as$

3) $S = ut + 1/2\ at^2$

4) $S_n = u + \frac{a}{2}(2n-1)$

22. Relative velocity

1) The relative velocity of one body w.r.t another body is the velocity with which one body moves w.r.t another body

2) The relative velocity of one body w.r.t. another body is defined as the time rate of change of relative position w.r.t. to another.

3) When two bodies A and B are in relative motion, the relative velocity of body A w.r.t. to body B can be obtained by imposing equal and opposite velocity of B on both A and B, so that B is brought to rest. The resultant of the two velocities of A gives the relative velocity of body A w.r.t body B.

   i.e., Relative velocity of A w.r.t B is $\vec{V}_{AB} = \vec{V}_A - \vec{V}_B$

   Relative velocity of B w.r.t A is $\vec{V}_{BA} = \vec{V}_B - \vec{V}_A$

4) When two bodies are moving along parallel straight lines in the same direction, the relative velocity of A w.r.t. B is

   $V_{AB} = V_A - V_B$ is the direction of $\vec{V}_A$

5) When two bodies are moving along parallel straight lines in opposite directions, the relative velocity of A w.r.t. B is

   $V_{AB} = V_A + V_B$ in the direction of $\vec{V}_A$

   Relative velocity of B w.r.t. A is $V_{AB} = V_B + V_A$ in the direction of $\vec{V}_B$

SECTION - I
QUESTIONS

SINGLE CORRECT TYPE

1. Distance travelled by the tip of minute hand of length 10cm in 100 sec is

1) $\frac{\pi}{180}$m 2) $\frac{\pi}{360}$m

3) $\frac{\pi}{1200}$m 4) $\frac{3\pi}{2160}$m

2. A particle moving in a straight line covers half the distance with speed of 3m/s. The other half of the distance covered in two equal time intervals with speed of 4.5m/s and 7.5 m/s respectively. The average speed of the particle during this motion is

1) 4.0 m/s 2) 5.0 m/s

3) 5.5 m/s 4) 4.8 m/s

3. On a 100km straight road, a car travels the first half at a uniform speed of 30 km h^{-1}. How fast must the car travel for the next half so that the average speed of 45 km h^{-1} is attained for the journey?

1) 45 km h^{-1} 2) 90 km h^{-1}

3) 70 km h^{-1} 4) 35 km h^{-1}|

4. A particle starts from rest, moves with constant acceleration for 15s. If it covers S_1 distance in first 5s then distance S_2 in next 10s, then find the relation between S_1 and S_2

1) $S_2 = 2S_1$ 2) $S_2 = 4S_1$

3) $S_2 = 6S_1$ 4) $S_2 = 8S_1$

5. A bullet fired into a fixed target loses half of its velocity after penetrating 3cm. How much further it will penetrate before coming to rest assuming that it faces constant resistance to motion?

1) 1.5 cm

2) 1.0 cm

3) 3.0 cm

4) 2.0 cm

6. A particle moving with uniform acceleration has velocity 6 ms^{-1} at a distance 5m from the initial position. After moving another 7m, the velocity becomes 8 ms^{-1}. The initial velocity and acceleration of the particle are

1) 6 ms^{-1}, 1 ms^{-2}

2) 4 ms^{-1}, 4 ms^{-2}

3) 4 ms^{-1}, 2 ms^{-2}

4) 2 ms^{-1}, 4 ms^{-2}

7. A car accelerates from rest at constant rate for first 10 seconds and covers a distance x. It covers a distance y in next 10 s at the same acceleration. Which of the following is true?

1) x = y

2) x = 3y

3) y = 2x

4) y = 3x

8. An automobile travelling with a speed of 60km h^{-1} can brake to stop within a distance of 20m. If the car is going twice as fast, that is, 120km h^{-1}, the stopping distance is

1) 29 m 2) 40 m

3) 80 m 4) 100 m

9. The acceleration a of a particle starting from rest varies with time according to the relation $a = \alpha t + \beta$. The velocity of the particle after time t is

1) $\frac{(\alpha t^2 + \beta)}{2}$

2) $\alpha t^2 + \frac{1}{2}\beta t$

3) $\frac{\alpha t^2}{2} + \beta$

4) $\frac{\alpha t^2}{2} + \beta t$

10. The position x of a particle with respect to time t along x-axis is given by $x = 9t^2 - t^3$ where x is in meters and t in second. What will be the position of this particle when it achieves maximum speed along the positive x-direction?

1) 54 m

2) 81 m

3) 24 m

4) 32 m

11. Which of the following statements regarding the freely falling body from rest are correct?

1) The body is non-uniformly accelerated

2) The body is not accelerated

3) The distance travelled by the body in the first second, first two seconds and first three seconds are in the ratio of 1:3:5.

4) The distance travelled by the body in the first second, first two seconds and first three seconds are in the ratio of 1:4:9.

12. A ball is thrown vertically upwards. The ball was observed at a height h twice with a time interval Δt. The initial velocity of the ball is

1) $\sqrt{8gh + (g\Delta t)^2}$

2) $\sqrt{2gh + \left(\frac{g\Delta t}{2}\right)^2}$

3) $\sqrt{8gh + (2g\Delta t)^2}$

4) $\sqrt{2gh}$

13. A particle is projected upwards. The time corresponding to height h while ascending and while descending are t_1 and t_2 respectively. The velocity of projection will be :

1) gt_1

2) gt_2

3) $g(t_1 + t_2)$

4) $\frac{g(t_1 + t_2)}{2}$

14. A parachutist after bailing out falls 50 m without friction. When parachute opens, it decelerates at 2 ms^{-2}, He reaches the ground with a speed of 3 ms^{-1}. At what height, did he bail out?

1) 293 m

2) 111 m

3) 91 m

4) 182 m

15. A body dropped from top of a tower falls through 60m during the last 2s of its fall. The height of tower is (g = 10 ms^{-1})

1) 95 m
2) 80 m
3) 90 m
4) 60 m

16. Water drops are falling in regular intervals of time from top of a tower of height 9m. If 4th drop begins to fall when 1st drop reaches the ground, find the positions of 3rd drops from top of the tower.

1) 1m
2) 2m
3) 3m
4) 4m

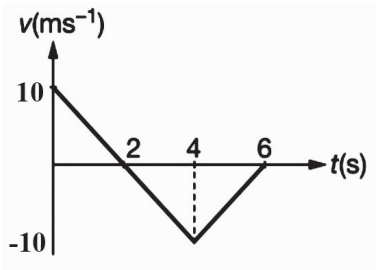
17. A man drops a ball from the roof of a tower of height 400m. At the same time, another ball is thrown upwards with a velocity 60ms^{-1} from the ground. Where would they meet each other? (from ground) (g = 10 ms^{-2})

1) 60m
2) 178m
3) 100m
4) 200m

18. A scooterist sees a bus 1 km ahead of him moving with a velocity 10 ms^{-1}. With what speed the scooterist should move so as to overtake the bus in 100 s?

1) 10 ms^{-1}
2) 20 ms^{-1}
3) 30 ms^{-1}
4) 40 ms^{-1}

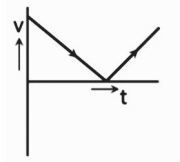
19. For the velocity-time graph shown in figure, in a time interval from t = 0 to t = 6s, match the following.

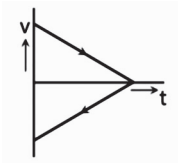


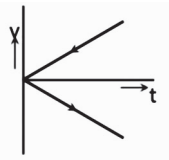
Column I		Column II	
A.	Change in velocity	p.	$-\frac{5}{3}$ SI unit
B.	Average acceleration	q.	-20 SI unit
C.	Total displacement	r.	-10 SI unit
D.	Acceleration at t = 3s	s.	-5 SI unit

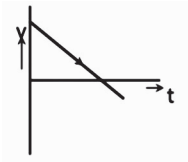
1) A - r ; B - p ; C - r ; D - s
2) A - p ; B - r ; C - r ; D - s
3) A - s ; B - p ; C - r ; D - r
4) A - s ; B - r ; C - p ; D - s

20. A ball is thrown vertically upwards. Which of the following graph represents velocity-time graph of the ball during its flight (Air resistance is neglected).

a) 

b) 

c) 

d) 

1) A
2) B
3) C
4) D

Statement Question

Read the following questions and give your answer using the following options (a, b, c and d):

a) Statement -I is true, Statement -II is true, Statement -II is correct explanation for Statement -I

b) Statement -I is true, Statement -II is true, Statement -II is not correct explanation for Statement -I

c) Statement -I is true, Statement -II is false

d) Statement -I is false, Statement -II is true.

21. **Statement I :** The instantaneous velocity does not depend on instantaneous position vector.

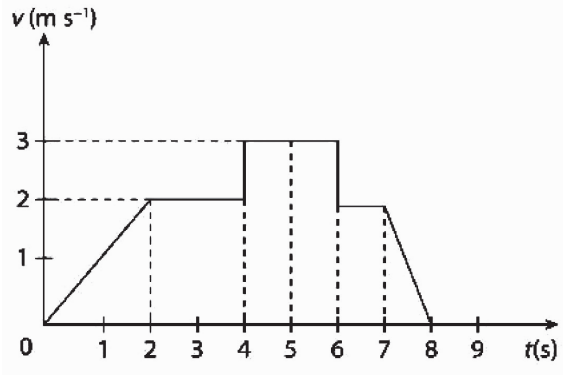
Statement II : The instantaneous velocity and average velocity of a particle are always same.

SECTION - II QUESTIONS

NUMERICAL TYPE

22. A passenger takes 2 minutes standing on a moving escalator to reach the top. If escalator is stationary he takes 3 minutes to walk up. Time taken to reach the top when he walk up on moving escalator is 12×10^{-n}. The n equal to

23. A particle starts from the origin at time t = 0 and moves along the positive x-axis. The graph of velocity with respect to time is shown in figure. The position of the particle at time t= 5 second (in m) is



24. Two balls are dropped from same height at 1 second interval of time. The separation between the two balls after 2s of the drop of the first ball is (Take g = 10 ms^{-2}) (in m)

25. A train of 150m length is going towards north direction at a speed of 10 ms^{-1}. A parrot flies at a speed of 5 ms^{-1} towards south direction parallel to a railway track. The time taken by the parrot to cross the train (in s) is

Chapter 03

MOTION IN A PLANE

SYNOPSIS

VECTORS

A vector is a quantity having both magnitude and direction.

- Representation of a vector

  $\vec{r} = r\hat{n}$ where $r = |\vec{r}|$ gives the magnitude and $\hat{n}$ is a unit vector that gives direction

- Unit vectors along the three coordinate axes are called orthogonal unit vectors. They are named $\hat{i}, \hat{j}, \hat{k}$ respectively

- Magnitude of a vector

  If a vector is represented as $\vec{r} = x\hat{i} + y\hat{j} + z\hat{k}$ its magnitude is given by $|\vec{r}| = \sqrt{x^2 + y^2 + z^2}$

- Types of vectors

  → Equal vectors - two vectors having equal magnitude and same direction

  → Parallel vectors - vectors along the same direction

  → Antiparallel vectors - vectors in opposite directions

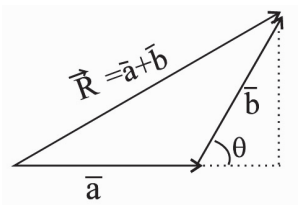
  → Collinear vectors - vectors along the same line

  → Zero vector - a vector having zero magnitude

  → Coplanar vectors - vectors over the same plane

VECTOR ADDITION

1. Triangle law of vector addition



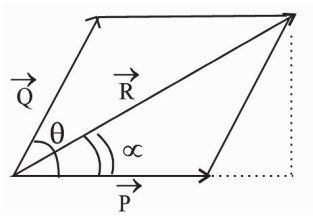
If $\vec{a}, \vec{b}$ are the consecutive sides of a triangle then the resultant is given by the closing side of the

triangle taken in the opposite order. Magnitude of the resultant is given by,

$$\left|\vec{R}\right| = \sqrt{a^2 + b^2 + 2ab\cos\theta}$$

2. Parallelogram law of vector addition

If $\vec{P}$ & $\vec{Q}$ represent the adjacent sides of a parallelogram, the resultant vector is given by the diagonal of the parallelogram drawn from the meeting point of tails of $\vec{P}$ and $\vec{Q}$



Magnitude of the resultant vector is given by, $\left|\vec{R}\right| = \sqrt{P^2\ Q^2 + 2PQ\cos\theta}$

Also, $\tan\alpha = \dfrac{Q\sin\theta}{P + Q\cos\theta}$

Special cases

1. If the vectors are along the same direction, $\theta = 0^0 \therefore \left|\vec{R}\right| = \left|\vec{P} + \vec{Q}\right|$

2. If the vectors are in opposite directions, $\theta = 180^0 \therefore \left|\vec{R}\right| = \left|\vec{P} - \vec{Q}\right|$

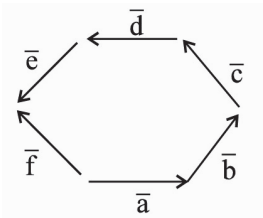
3. If the vectors are perpendicular to each other, $\theta = 90^0 \therefore \left|\vec{R}\right| = \sqrt{P^2 + Q^2}$

Note

The resultant of vectors $\vec{P}$ and $\vec{Q}$ always lies between $\left|\vec{P} - \vec{Q}\right|$ and $\left|\vec{P} + \vec{Q}\right|$

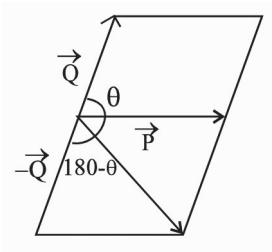
3. Polygon law of vector addition

If $\bar{a}, \bar{b}, \bar{c}, \bar{d}$ and $\bar{e}$ are the successive sides of a polygon, the resultant vector is given by the closing side of the polygon taken in the opposite order.



$$\bar{f} = \bar{a} + \bar{b} + \bar{c} + \bar{d} + \bar{e}$$

VECTOR SUBTRACTION



$$\left|\vec{P}-\vec{Q}\right| = \sqrt{P^2+Q^2-2PQ\cos\theta}$$

APPLICATIONS

1. Relative velocity

   If $\vec{V}_A$ and $\vec{V}_B$ are the velocities of bodies A and B travelling at an angle θ apart, relative velocity of A with respect to B is given by $\vec{V}_{AB} = \vec{V}_A - \vec{V}_B = \sqrt{V_A^2+V_B^2-2V_AV_B\cos\theta}$

2. Acceleration

   If $\vec{V}_i$ and $\vec{V}_f$ are the initial and final velocities, acceleration is given by $\vec{a} = \dfrac{\vec{V}_f - \vec{V}_i}{t}$

PRODUCT OF VECTORS

I. Dot product (Scalar product)

Dot product of vectors $\vec{A}$ and $\vec{B}$ is defined as

$\vec{A}\cdot\vec{B} = \left|\vec{A}\right|\left|\vec{B}\right|\cos\theta \quad \theta \rightarrow$ angle between $\vec{A}$ and $\vec{B}$

Note: If $\vec{A} = a_1\hat{i}+a_2\hat{j}+a_3\hat{k}$ and $\vec{B} = b_1\hat{i}+b_2\hat{j}+b_3\hat{k}$, then $\vec{A}\cdot\vec{B} = a_1b_1+a_2b_2+a_3b_3$

- Properties

1. It is commutative, $\vec{A}\cdot\vec{B} = \vec{B}\cdot\vec{A}$
2. It is distributive, $\vec{A}\cdot\left(\vec{B}+\vec{C}\right) = \vec{A}\cdot\vec{B}+\vec{A}\cdot\vec{C}$
3. Angle between the vectors $\vec{A}$ and $\vec{B}$, $\theta = \cos^{-1}\left[\dfrac{\vec{A}\cdot\vec{B}}{\left|\vec{A}\right|\left|\vec{B}\right|}\right]$
4. If two vectors are perpendicular, $\theta = 90^0 \therefore \vec{A}\cdot\vec{B} = 0$
5. $\vec{A}\cdot\vec{A} = A^2$
6. $\hat{i}.\hat{i}=1;\ \hat{j}.\hat{j}=1;\ \hat{k}.\hat{k}=1$ ie., identical unit vectors when taken dot product give one
7. $\hat{i}.\hat{j}=0;\ \hat{j}.\hat{k}=0;\ \hat{k}.\hat{i}=0$ ie., unlike unit vectors when taken dot product give zero.

Note: The common situations where the dot product is used are given below:

(i) Power = $\vec{F}\cdot\vec{V}$

(ii) Work = $\vec{F}\cdot\vec{d}$

(iii) Flux = $\vec{E}\cdot\vec{A}$ or $\vec{B}\cdot\vec{A}$

II. Cross product (Vector product)

Cross product of vectors $\vec{A}$ and $\vec{B}$ is defined as

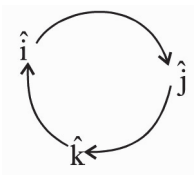
$\vec{A}\times\vec{B}=|\vec{A}||\vec{B}|\sin\theta\,\hat{n}$

When $\hat{n}$ represents the direction. Direction is given by right handed screw rule.

If a right handed screw is rotated from $\vec{A}$ to $\vec{B}$ the direction of tip of the screw gives the direction of $\vec{A}\times\vec{B}$

- Properties

1. It is not commutative, $\vec{A}\times\vec{B}\neq\vec{B}\times\vec{A}$
2. It is distributive , ie, $\vec{A}\times(\vec{B}+\vec{C})=\vec{A}\times\vec{B}+\vec{A}\times\vec{C}$
3. Angle between two vectors $\vec{A}$ and $\vec{B}$, $\theta=\sin^{-1}\left[\dfrac{|\vec{A}\times\vec{B}|}{|\vec{A}||\vec{B}|}\right]$
4. If two vectors are parallel, $\theta=0\ \therefore\vec{A}\times B=0$
5. $\vec{A}\times\vec{A}=0$
6. $\hat{i}\times\hat{i}=0;\ \hat{j}\times\hat{j}=0;\ \hat{k}\times\hat{k}=0$
7. $\hat{i}\times\hat{j}=\hat{k};\ \hat{j}\times\hat{k}=\hat{i};\ \hat{k}\times\hat{i}=\hat{j}$



Note: 1

The common situations where the cross product is used are listed below:

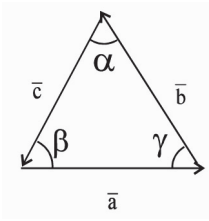
(i) Torque, $\vec{\tau}=\vec{r}\times\vec{F}$ (ii) Angular momentum, $\vec{L}=\vec{r}\times\vec{P}$ (iii) Linear velocity, $\vec{V}=\vec{\omega}\times\vec{r}$

Note : 2

If $\vec{A} = a_1\hat{i} + a_2\hat{j} + a_3\hat{k}$ and $\vec{B} = b_1\hat{i} + b_2\hat{j} + b_3\hat{k}$

$$\vec{A}\times\vec{B} = \begin{vmatrix} i & j & k \\ a_1 & a_2 & a_3 \\ b_1 & b_2 & b_3 \end{vmatrix} = (a_2b_3 - a_3b_2)\hat{i} - (a_1b_3 - a_3b_1)\hat{j} + (a_1b_2 - a_2b_1)\hat{k}$$

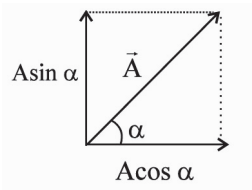
- **Lami's theorem**



In ΔABC with sides $\vec{a}, \vec{b}, \vec{c}$ $\frac{\sin\alpha}{a} = \frac{\sin\beta}{b} = \frac{\sin\gamma}{c}$

- **Resolution of a vector into components**

(i) Vector in a plane



The vector can be split up into two components, A cos α and A sin α

(ii) Vector in space $\vec{A} = A_x\hat{i} + A_y\hat{j} + A_2\hat{k}$

$\text{Cos}\,\alpha = \frac{A_x}{A} = 1$ $\alpha \rightarrow$ angle between the vector and the y-axis

$\text{Cos}\,\beta = \frac{A_y}{A} = m$ $\beta \rightarrow$ angle between the vector and the y-axis

$\text{Cos}\,\gamma = \frac{A_z}{A} = n$ $\gamma \rightarrow$ angle between the vector and the z-axis

l, m, n are called direction cosines. Also, $l^2 + m^2 + n^2 = \cos^2\alpha + \cos^2\beta + \cos^2\gamma = 1$

Note: 1

If a body is in equilibrium under a set of non-collinear forces, the minimum number of forces has to be three

Note: 2

(a) If $\vec{A}, \vec{B}$ are the adjacent sides of a parallelogram, area of the parallelogram is given by

Area = $\vec{A} \times \vec{B}$

(b) If diagonals $\vec{C}$ and $\vec{D}$ are given,

Area = $\frac{1}{2}\left(\vec{C} \times \vec{D}\right)$

PROJECTILES

I. OBLIQUE PROJECTILE

A body projected at a particular angle with an initial velocity u

Assumptions

1. Friction due to air is neglected
2. There is no horizontal force acting on the body

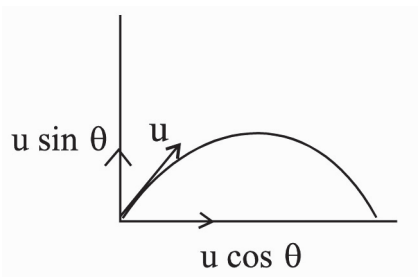
- Projectile motion is a two dimensional motion. The path taken by the body is parabolic and is called trajectory.
- Initial velocity u has two components; horizontal $u\cos\theta$ and vertical $u\sin\theta$
- As the body starts ascending, vertical component decreases; becomes zero at the topmost point; increases during the descent.
- Horizontal velocity remains $u\cos\theta$ throughout the motion.
- At the topmost point,

  a) velocity $= u\cos\theta$

  b) momentum = $mu\cos\theta$

  c) Kinetic energy $= \frac{1}{2}mu^2\cos^2\theta$

  d) Potential energy $= \frac{1}{2}mu^2\sin^2\theta$



Note :1

If $\theta = 45^0$, kinetic energy and potential energy at the topmost point are equal.

Note :2

During the motion of a projectile, total energy remains conserved. During the ascent, kinetic energy is converted to potential energy and during descent potential energy is converted back to kinetic energy

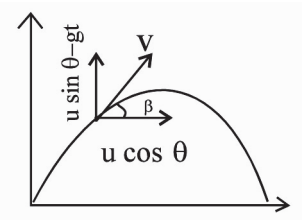
Note :3

For a projectile,

a) Velocity of projection = velocity of landing

b) Kinetic energy of projection = kinetic energy of landing

- Equation of trajectory of a projectile is $y = x\tan\theta - \frac{gx^2}{2u^2\cos^2\theta}$



- Velocity of the body at any instant $V = \sqrt{u^2 + g^2t^2 - 2ugt\sin\theta}$
- Angle made by the velocity vector with the horizontal is given by, $\tan\beta = \frac{u\sin\theta - gt}{u\cos\theta}$

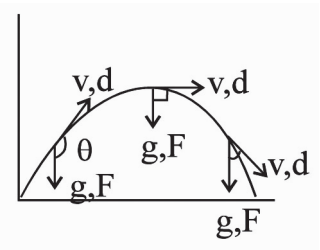
Note: In a projectile motion, θ is obtuse while the body ascends; 90^0 at the topmost point and it is acute while the body descends where θ is the angle between

i) displacement and acceleration

ii) displacement and force

iii) velocity and acceleration

iv) velocity and force



- For a projectile

1. Time of flight, $T = \frac{2u\sin\theta}{g}$

2. Maximum height attained $H_{max} = \frac{u^2\sin^2\theta}{2g}$

3. Horizontal range $R = \frac{u^2\sin 2\theta}{g}$

4. Maximum horizontal range $R_{max} = u^2/g$

Note:1

A projectile attains maximum range when projected at an angle 45°

Note: 2

R_{max} and H_{max} are related as $R_{max} = 4\ H_{max}$ (where $\theta = 45°$)

Note : 3

For two angles of projection, θ and (90 - θ)

1. $R_1 = R_2$; the ranges are equal

2. $\frac{T_1}{T_2} = \tan\theta$

3. $T_1 T_2 = \frac{2R}{g}$

4. $\frac{H_1}{H_2} = \tan^2\theta$

5. $R = 4\sqrt{H_1 H_2}$

- Change in momentum between

1. The point of landing and point of projection = -2 mu sin θ

2. The topmost point and point of projection = -mu sin θ

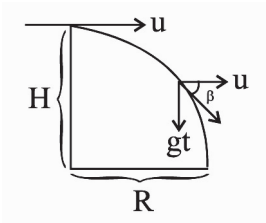
II HORIZONTAL PROJECTILE

A body projected with an initial horizontal velocity. Initial vertical velocity is zero

• For a horizontal projectile,

a) Time of flight $T = \sqrt{\frac{2H}{g}}$

b) Horizontal range $R = u\sqrt{\frac{2H}{g}}$



Note :1

Horizontal velocity remains constant throughout the motion; vertical velocity goes on increasing

Note :2

For a body thrown horizontally, time taken to reach the ground is independent of initial velocity of projection.

Velocity at any instant is given by $V = \sqrt{u^2 + g^2 t^2}$

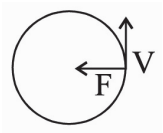
Angle made by the velocity vector with the horizontal is given by $\tan\beta = \frac{gt}{u}$

Equation of trajectory of the projectile is $y = \frac{gx^2}{2u^2}$

CIRCULAR MOTION

Uniform Circular Motion

The body executing circular motion has constant speed. But the velocity goes on changing continuously.



- Angular displacement - the angle swept by the radius vector. Unit is rad
- Angular velocity, $\omega = d\theta/dt$. Unit is rad/sec
- Angular acceleration $\alpha = \frac{d\omega}{dt} = \frac{d^2\theta}{dt^2}$. Unit is rad/s^2

Note : Linear velocity and angular velocity are related as $\vec{V} = \vec{\omega} \times \vec{r}$

- Change in velocity

  Change in velocity is given by $\left|\Delta\vec{V}\right| = \left|\vec{V}_2 - \vec{V}_1\right| = \sqrt{V_1^2 + V_2^2 - 2V_1V_2\,\text{Cos}\,\theta}$

  For uniform circular motion, $V_1 = V_2 = V \quad \therefore \Delta V = 2V\sin\left(\theta/2\right)$

- Time period (T) - the time taken by a body to complete one revolution.
- Frequency (υ) - number of revolutions per second
- Angular velocity $\omega = \dfrac{2\pi}{T} = 2\pi\upsilon$

Note: Linear acceleration and angular acceleration are related as $\vec{a} = \vec{\alpha} \times \vec{F}$

- Centripetal acceleration - acceleration acting on a body executing uniform circular motion $a_c = v^2/r = r\omega^2 = v\omega$
- Centripetal force is given by $F_c = ma_c$; $\quad F_c = \dfrac{mv^2}{r} = mr\omega^2 = mv\omega$
- Work done by a centripetal force $W = F.d = Fd\cos\theta = Fd\cos 90 = 0$

Centripetal force in different situations	
Situations	**Centripetal Force**
A particle tied to a string and whirled in a circle	Tension in the string
Vehicle taking a turn on a level road	Frictional force
Revolution of earth around sun	Gravitational force
Electron revolving around a nucleus in an atom	Coulomb force of attraction
A charged particle describing a circular path in a magnetic field	Lorentz force

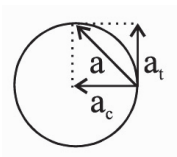
Note

Angular velocity, angular acceleration, angular momentum and torque are axial vectors.

Non-Uniform circular motion

In a non-uniform circular motion, both magnitude and direction of velocity continuously change. An additional acceleration called tangential acceleration also acts in this case.

The resultant acceleration is given by $a = \sqrt{a_c^2 + a_t^2}$



SECTION - I
QUESTIONS

SINGLE CORRECT TYPE

1. A unit vector of a vector $\vec{A}$

1) has magnitude equal to one unit

2) is in the same plane as that of $\vec{A}$

3) is having the same direction of $\vec{A}$

4) all of these

2. A vector is inclined at an angle 60° to the horizontal. If its rectangular component in the horizontal direction is 50N, then its magnitude in the vertical direction is

1) 25N

2) 75N

3) 87N

4) 100N

3. The minimum number of unequal vectors which can give zero resultant are

1) two

2) three

3) four

4) more than four

4. Two forces 3N and 2N are at an a angle θ such that the resultant is R. The first force is now increased to 6N and the resultant becomes 2R. The value of θ is

1) 30^0 2) 60^0

3) 90^0 4) 120^0

5. The angle between $\vec{P}$ and resultant of $\vec{P}+\vec{Q}$ and $\vec{P}-\vec{Q}$ is

1) 0^0

2) 30^0

3) 45^0

4) 60^0

6. Unit vector in the direction of the resultant of vectors $A=-3\hat{i}-2\hat{j}-3\hat{k}$ and $B=2\hat{i}+4\hat{j}+6\hat{k}$ is

1) $\frac{-3\hat{i}+2\hat{j}-3\hat{k}}{\sqrt{14}}$

2) $-\hat{i}+2\hat{j}+3\hat{k}$

3) $\frac{-\hat{i}+2\hat{j}+3\hat{k}}{\sqrt{14}}$

4) $-2\hat{i}-4\hat{j}+8\hat{k}$

7. A bird is flying towards north with a velocity 40 km/h and a train is moving with a velocity 40 km/h towards east. What is the velocity of the bird noted by a man in the train?

1) $40\sqrt{2}\,\text{km/h}\ \text{N}-\text{E}$

2) $40\sqrt{2}\,\text{km/h}\ \text{S}-\text{E}$

3) $40\sqrt{2}\ \text{km/h}\ \text{N}-\text{W}$

4) $40\sqrt{2}\ \text{km/h}\ \text{S}-\text{W}$

8. A man running at a speed of 5km h^{-1} finds that the rain falls vertically. When he stops running he finds that the rain is falling at an angle of 60^0 with the horizontal. The velocity of rain with respect to running man is

1) $\frac{5}{\sqrt{3}}\text{km h}^{-1}$

2) $\frac{5\sqrt{3}}{2}\text{km h}^{-1}$

3) $\frac{4\sqrt{3}}{5}\text{km h}^{-1}$

4) $5\sqrt{3}\ \text{kmh}^{-1}$

9. A boat which has a speed of 5 km/h in still water crosses a river of width 1km along the shortest possible path in 15 min. The velocity of the river water in Km per hour is

1) 1 2) 3

3) 4 4) $\sqrt{41}$

10. A bird is flying towards east with velocity 50km/h and a train is moving with a velocity 50 km/h towards south. What is the velocity of the bird with respect an observer in train

1) $50\sqrt{20}$ km/h north-east

2) $50\sqrt{20}$ km/h south-east

3) $50\sqrt{2}$ km/h south-west

4) $50\sqrt{2}$ km/h north-east

11. An arrow is short into air. Its range is 200 m and its time of flight is 5s. If g = 10 ms^{-2}, then horizontal component of velocity of the arrow is

1) 25.0 ms^{-1}

2) 31.25 ms^{-1}

3) 35 ms^{-1}

4) 40 ms^{-1}

12. A projectile is projected at 10 ms^{-1} by making an angle 60^0 to the horizontal. After some time, its velocity makes an angle of 30^0 to the horizontal. Its speed at this instant is

1) $\frac{10}{\sqrt{3}}$ 2) $10\sqrt{3}$

3) $\frac{5}{\sqrt{3}}$ 4) $5\sqrt{3}$

13. The height y and the distance x along the horizontal plane of a projectile on a certain planet (with no surrounding atmosphere) are given by $y=(8t-5t^2)$m and x= 6t m, where t is in seconds. Find the initial velocity of the projectile

1) 6ms^{-1}

2) 8 ms^{-1}

3) 10 ms^{-1}

4) Data is not sufficient

14. Two bodies are projected from ground with equal speeds 20 ms^{-1} from the same position in the same vertical plane to have equal range but at different angles above the horizontal. If one of the angles is 30^0, then the sum of their maximum heights is (g = 10 ms^{-2}).

1) 20m 2) 30m

3) 40m 4) zero

15. A projectile is given an initial velocity of $\left(\hat{i}+2\hat{j}\right)ms^{-1}$, where $\hat{i}$ is along the ground and $\hat{j}$ is along vertical. If g = 10 ms^{-1}, the equation of its trajectory is

1) $y = x - 5x^2$

2) $y = 2x - 5x^2$

3) $4y = 2x - 5x^2$

4) $4y = 2x - 25x^2$

16. The ceiling of a hall is 60m high. For maximum horizontal distance, the angle at which the ball may be thrown with a speed of $40ms^{-1}$ without hitting the ceiling of the hall is

1) 25^0 2) 30^0

3) 45^0 4) 60^0

17. An aeroplane is flying horizontally with a velocity of 600 km/h at a height of 1960 m. When it is vertically at a point *A* on the ground, a bomb is released from it. The bomb strikes the ground at point *B*. The distance *AB* is

1) 1200 m

2) 0.33km

3) 3.33 km

4) 33 km

18. Two tall buildings are 30 m apart. The speed with which a ball must be thrown horizontally from a window 150m above the ground in one building so that it enters a window 27.5m from the ground in the other building is

1) 2 m/s 2) 6 m/s

3) 4 m/s 4) 8 m/s

19. A particle is moving along a circular path with a constant speed of 10 m/s. What is the magnitude of the change in velocity of the particle when it moves through an angle of 60^0 around the centre of the circle?

1) $10\sqrt{3}\ m/s^{-2}$

2) 0

3) $10\sqrt{2}\ ms^{-1}$

4) $10ms^{-1}$

20. A particle moves in a circle of radius 30cm. Its linear speed is given by v = 2t, where t is in second and v is in ms^{-1}. Find out its radial and tangential acceleration at t = 3s, respectively

1) $110\ ms^{-2}$, $10\ ms^{-2}$

2) $120\ ms^{-2}$, $2\ ms^{-2}$

3) $100\ ms^{-2}$, $5\ ms^{-2}$

4) $220\ ms^{-2}$, $50\ ms^{-2}$

STATEMENT TYPE QUESTION

Read the following questions and give your answer using the following options

1) Statement -1 is true, Statement -2 is true, Statement - 2 is correct explanation for Statement - 1

2) Statement -1 is true, Statement -2 is true, Statement -2 is not correct explanation for Statement -1

3) Statement -1 is true, Statement -2 is false

4) Statement -1 is false, Statement -2 is true

21. **Statement -1 :** A body is thrown with a velocity u inclined to the horizontal at some angle. It moves along a parabolic path and falls to the ground. Linear momentum of the body, during its motion, will remain conserve.

Statement-2 : Throughout the motion of the body, a constant force acts on it.

SECTION - II
QUESTIONS

NUMERICAL TYPE

22. A ball is thrown with a velocity whose horizontal component is $12ms^{-1}$ from a point 15m above the ground and 6m away from a vertical wall 18.75m high in such a way so as just to clear the wall. At what time will it reach the ground) ($g= 10ms^{-2}$)

23. A ball rolls off the top of a stairway with a horizontal velocity of magnitude $1.8\ ms^{-1}$. The steps are 0.20 m high and 0.20m wide. Which step will the ball hit first? ($g = 10\ ms^{-2}$)

24. A ball is projected from the ground at angle θ with the horizontal. After 1s it is moving at angle 45^0 with the horizontal and after 2s if is moving horizontally. If the velocity of projection of the ball is $10\sqrt{n}\ m/s$ then the value of n is?

25. A particle is projected from the ground at an angle 30° with the horizontal with an initial speed $20\ ms^{-1}$. After how much time will the velocity vector of projectile be perpendicular to the initial velocity ? [in second]

Chapter 04

LAWS OF MOTION

SYNOPSIS

- **Inertia of rest** is the inability of body to change its state of rest by itself, while inertia of motion is the inability of the body to change its state of motion by itself.
- **Inertia of direction** is the inability of the body to change its direction of motion by itself.
- **Newton's first law** of motion gives the definition of force and the concept of inertia.
- The quantity of motion possessed by a body is called momentum. It is measured by the product of mass and velocity.
- **Newton's second law** says that the rate of change of momentum is directly proportional to the applied force.
- Force is an external effort in the form of push or pull which (i) one produces or tries to produce motion in a body at rest, or (ii) stops or tries to stop a moving body, or (iii) changes or tries to change the direction of motion of the body.
- Frictional force, tensional force, normal force, air resistance force, applied force and spring force are contact forces.
- Gravitational force, electrical force, weak force are action-at-a distance forces.
- The force between two static charges is called electrostatic force.
- The force between two magnetic poles is called magnetic force.
- If $\vec{F}_1, \vec{F}_2, \vec{F}_3$ ..... are the concurrent forces acting on the same point, then the point will be in equilibrium if $\vec{F}_1 + \vec{F}_2 + \vec{F}_3 + ... = 0$
- Impulse is the measure of the degree to which an external force produces a change in momentum of the body. The product of a large force acting on a body for a small interval is called impulse.
- Newton's third law of motion says that every action has equal and opposite reaction. Action and reaction act on different bodies and they are simultaneous.
- Action and reaction never cancel each other.
- The law of conservation of linear momentum is a logical consequence of Newton's second law.

- If *n* bullets each of mass *m* and velocity *v* are fired from a gun then the average force acting on the gun is *mnv*.
- Principle of conservation of momentum follows from Newton's first law of motion.
- Newton's third law contains law of conservation of momentum.
- In case of a uniform circular motion, the change in momentum with time is not zero, i.e. $\frac{\Delta\vec{p}}{\Delta t} \neq 0$

  but $\Delta p = 0$
- When the lift is at rest or in uniform motion, then the weight recorded by the spring balance is equal to the actual weight of the body.
- When the lift is accelerated up, then the weight recorded by the spring balance is more than the actual weight of the body.
- When the lift is accelerated down, the weight recorded by the spring balance is less than the actual weight of the body.
- For a lift falling freely, acceleration of the lift is *g* and hence the body will feel weightlessness.
- The spring balance will record an increase in weight for a moment, when the lift starts to move up with uniform velocity and then will record the actual weight of the boy.
- If no external force acts on a system of two or more bodies, then the total momentum of the system remains constant. This is known as the principle of conservation of momentum.
- Thrust on the rocket at any instant is equal to the product of the exhaust speed of the burnt gases and the rate of combustion of fuel at that instant.

  i.e. $F = -u\left(\frac{dM}{dt}\right)$

  -ve sign indicates that thrust on the rocket is in a direction opposite to the direction of escaping gas.

Friction

- Force of friction opposes relative motion of the point of contact withe respect to the surface.
- Force of friction acts parallel to the surface.
- The number of frictional forces acting on a body depends upon the number of contact surfaces. For every contact surface, there is a frictional force.
- Frictional forces are produced on account of intermolecular interactions between the two bodies or surfaces.

- Frictional force is a self adjusting force which increases with increasing applied force till the body is at rest but on the point of motion.
- For frictional force relative motion between two bodies or surfaces is not necessary. In fact, contact between two bodies or surfaces in necessary.

Type of frictional forces

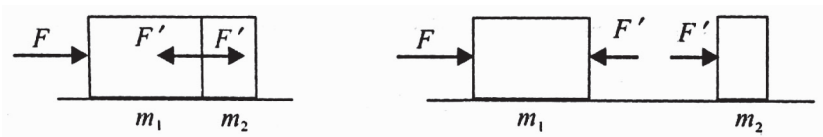
- Static friction: It is a self adjusting force with an upper limit called the limiting friction.
- Dynamic friction/kinetic friction.
- Sliding friction
- Rolling Friction
- Rolling friction < dynamic friction < sliding friction
- If $\mu_s =$ static coefficient of friction, R=N=normal relation, then static frictional force $<\mu_s R$ (body is at rest). Limiting friction $=\mu_s R$ (body is on point of motion).
- If μ_k =kinetic coefficient of friction, then kinetic frictional force = $\mu_k R$ (body is in motion).
- The limiting frictional force between two surfaces in contact with each other depends only on μ (nature of surfaces) and normal contact force R. It does not depend on their shape, size or surface area.

Tension

- Tension force always pulls a body.
- Tension can never push a body or rope.
- Tension across a massless pulley or frictionless pulley remains constant.
- Rope becomes slack when tension force becomes zero.
- When a rope is pulled by a force, the rope becomes tight or taut. This conveys the concept of tension.

Contact force-Motion of bodies in contact

(a) Two bodies in contact



A force F is applied on mass m_1 horizontally. Masses m_1 and m_2 are in contact. Contact force between m_1 and m_2 = F. Contact force is that force with which one body presses the other at the point of contact when the two bodies are placed on a frictionless surface.

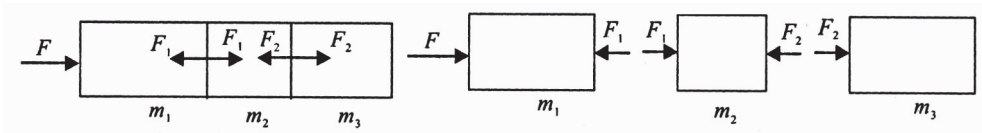
$\therefore$ Acceleration a $= \dfrac{\text{Force applied to system}}{\text{mass of system}}$

$$\therefore a = \frac{F}{(m_1 + m_2)}$$

$\therefore$ Contact force on m_1 and $m_1 a$ = $\dfrac{m_1 F}{(m_1 + m_2)}$

Contact force on $m_2 = m_2 a = \dfrac{m_2 F}{(m_1 + m_2)}$, or $F'' = m_2 a = \dfrac{m_2 F}{(m_1 + m_2)}$

(b) Three bodies in contact



Force applied on the system = F

Mass of the system = $m_1 + m_2 + m_3$

Acceleration of the system=a

$\therefore$ Acceleration of each mass(a)= $\dfrac{F}{(m_1 + m_2 + m_3)}$

Contact force between m_1 and $m_2 = F_1$

Contact force between m_2 and $m_3 = F_2$

For first body, $F - F_1 = m_1 a$

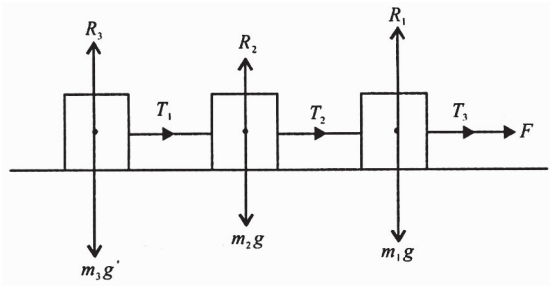
For second body, $f_1 - F_2 = m_2 a$

For third body, $F_2 = m_3 a$

$$\therefore F_1 = F - m_1 a = F - \frac{m_1 F}{(m_1 + m_2 + m_3)} = \frac{(m_2 + m_3) F}{(m_1 + m_2 + m_3)}$$

$$\therefore F_2 = m_3 a = \frac{m_3 F}{(m_1 + m_2 + m_3)}$$

(c) Motion of bodies connected by strings



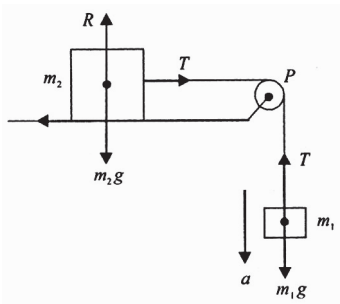
Acceleration in system=a

$$\therefore\ a = \frac{F}{(m_1 + m_2 + m_3)} \quad \text{Tension } T_1 = m_3 a = \frac{m_3 F}{(m_1 + m_2 + m_3)}$$

$$\text{Tension } T_2 = (m_2 + m_3)a = \frac{(m_2 + m_3)F}{(m_1 + m_2 + m_3)}$$

Tension $T_3 = F$

- Consider a body of mass m_2 which rests on a surface which is horizontal. Let a string passing over a pulley connect m_2 with mass m_1 as shown in figure.



a) without friction between m_2 and horizontal table,

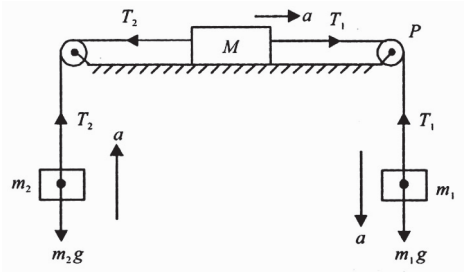
$$\text{Acceleration, } a = \frac{m_1 g}{(m_1 + m_2)}$$

$$\text{Tension, } T = \frac{m_1 m_2 g}{(m_1 + m_2)}$$

b) With friction between body m_2 and table,

$$\text{Acceleration, } a = \frac{(m_2 - \mu m_2)g}{(m_1 + m_2)} \quad ; \qquad \text{Tension, } T = \frac{m_1 m_2 (1 + \mu) g}{(m_1 + m_2)}$$

- Two masses are suspended as shown in figure.



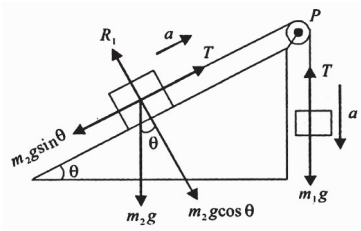
The block on horizontal table moves towards right with acceleration a.

$m_1g–T_1=m_1a$ ..... (i)

$T_2–m_2g=m_2a$ .....(ii)

$T_1–T_2=Ma$ .....(iii) we get, acceleration, $a=\frac{(m_1-m_2)g}{(m_1+m_2+M)}$

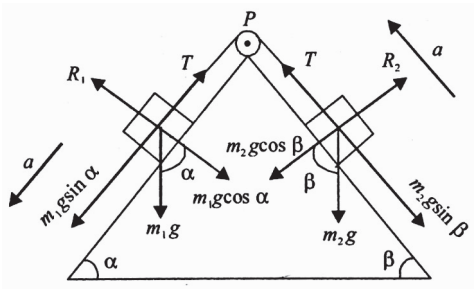
- Two masses are suspended over a pulley on an inclined plane as shown in the figure. The mass m_1 descends with an acceleration a. Mass m_2 is on inclined plane.



Without friction

Acceleration, $a=\frac{(m_1-m_2\sin\theta)}{(m_1+m_2)}g$; Tension, $T=\frac{m_1m_2(1+\sin\theta)g}{(m_1+m_2)}$

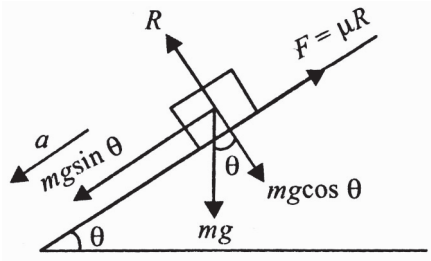
- Masses m_1 and m_2 are connected by a string passing over a pulley such that $m_1 > m_2$



Motion on an inclined plane

The inclined plane may be rough or smooth. A body may move down the plane or up the plane.

(i) Motion of a body down the rough plane:



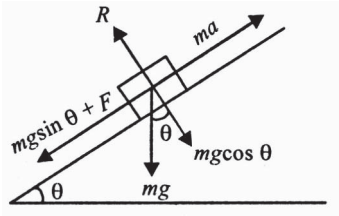
Normal reaction $R = mg\cos\theta$; $mg\sin\theta - \mu R = ma$

$\therefore mg\sin\theta - \mu mg\cos\theta = ma$ or $a = g(\sin\theta - \mu\cos\theta)$

Acceleration down the rough plane $= g(\sin\theta - \mu\cos\theta)$

(ii) Motion of a body down the smooth plane : $(\mu = 0)$; Acceleration of body = $g\sin\theta$

(iii) Motion of a body up the rough plane :

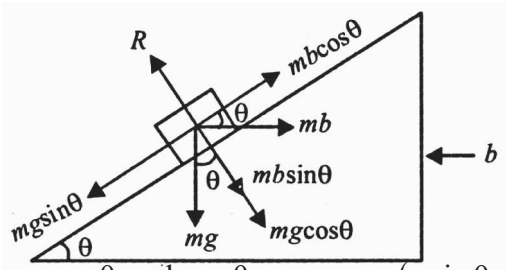


When the body moves up the plane, the force of friction $F = \mu R$ acts down the plane to oppose the motion.

$\therefore ma = mg\sin\theta + F = mg\sin\theta + \mu R$

$= mg\sin\theta + \mu mg\cos\theta = mg(\sin\theta + \mu\cos\theta)$ or acceleration $a = g(\sin\theta + \mu\cos\theta)$

v) Plane is given horizontal acceleration, plane is smooth



$mg\cos\theta - mb\cos\theta = ma$ $\therefore a = (g\sin\theta - b\cos\theta)$; If $a = 0, b = g\tan\theta$

SECTION - I
QUESTIONS

SINGLE CORRECT TYPE

1. A force of 5N gives a mass M_1 an acceleration equal to $8m/s^2$ and M_2, an acceleration equal to $24m/s^2$. What is the acceleration if both masses are combined together?

1) $16\ m/s^2$ 2) $6m/s^2$

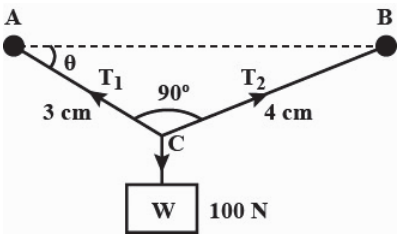
3) $12\ m/s^2$ 4) $4\ m/s^2$

2. If a bullet of mass 5gm moving with velocity 100m/sec, penetrates the wooden block up to 6cm. Then the average force imposed by the bullet on the block is

1) 8300N 2) 417 N

3) 830 N 4) zero

3. A and B are two nails on a horizontal line, AC, BC are two uniform strings from which a weight of 100N is suspended. The tension in (N) in AC is



1) 100 N

2) 80N

3) 60N

4) 50N

4. A light string passing over a smooth light pulley connects two blocks of masses m_1 and m_2 (vertically). If the acceleration of the system is $\frac{g}{8}$ then the ratio of the masses is

1) 8:1 2) 9 : 7

3) 4 : 3 4) 5 : 3

5. A person is standing in an elevator, in which situation he finds his weight less than actual when

1) The elevator moves upward with constant acceleration

2) The elevator moves downward with constant acceleration

3) The elevator moves upward with uniform velocity

4) The elevator moves downward with uniform velocity

6. A rocket has an initial mass of 20×10^3kg. If it is to blast off with an initial acceleration of $4ms^{-2}$, the initial thrust needed is ($g = 10ms^{-2}$)

1) 6×10^4N

2) 28×10^4N

3) 20×10^4N

4) 12×10^4N

7. A monkey of mass m kg slides down a light rope attached to a fixed spring balance with an acceleration a. The reading of spring balance is W kg.

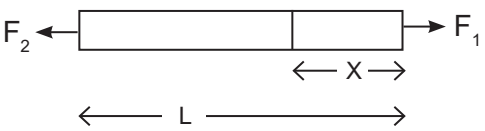
1) The tension in the rope is m(g - a)

2) $m = \frac{W}{g-a}$

3) The tension in the rope is W

4) All options are correct

8. The rod of length L and mass M is acted on by two unequal forces F_1 and $F_2 (F_2 < F_1)$ as shown in the following figure. The tension in the rod at a distance x from the end A is given by



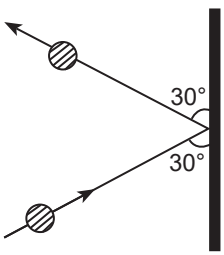
1) $F_1\left[1-\frac{x}{L}\right]+\frac{F_2 x}{L}$

2) $F_2\left[1-\frac{x}{L}\right]+F_1\left[\frac{x}{L}\right]$

3) $(F_1-F_2)\frac{x}{L}$

4) None of these

9. A 0.5kg ball moving with speed of 12m/s strikes a hard wall at an angle of 30^0 with the wall, it is reflected with the same speed and at the same angle. If the ball is in contact with the wall for 0.25 seconds, the average force acting on the wall is



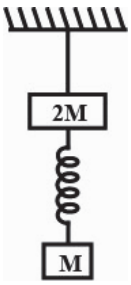
1) 24N

2) 12 N

3) 96N

4) 48 N

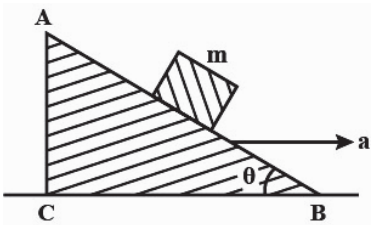
10. Two blocks are connected by a spring. The combination is suspended, at rest from a ceiling as shown. The string breaks suddenly. Immediately after the string breaks, what is the initial downward acceleration of the upper block of mass 2M.



1) 0 2) $\frac{3g}{2}$

3) g 4) 2g

11. A block of mass m is placed on a smooth inclined θ wedge ABC of inclination as shown in the figure. The wedge is given an acceleration 'a' towards the right. The relation between a and θ for the block to remain stationary on the wedge is



1) $a=\frac{g}{\operatorname{cosec}\theta}$ 2) $a=\frac{g}{\sin\theta}$

3) $a=g\tan\theta$ 4) $a=g\cos\theta$

12. A 5000kg rocket is set for vertical firing. The exhaust speed is $800 ms^{-1}$. To give an initial upward acceleration of $20\ ms^{-2}$, the amount of gas ejected per second to supply the needed thrust will be ($g = 10 ms^{-2}$)

1) 127-5 kg s^{-1} 2) 187. 5 kg s^{-1}

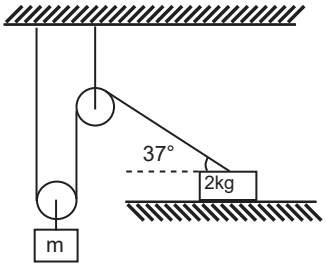
3) 185.5 kg s^{-1} 4) 137.5 kg s^{-1}

13. A block of mass 5kg is on a rough horizontal surface and is at rest. Now a force of 24N is imparted to it with negligible impulse. If the coefficient of kinetic friction if 0.4 and g = 9.8 m/s^2, then the acceleration of the block is

1) 0.26 m/s^2 2) 0.39 m/s^2

3) 0.69 m/s^2 4) 0.88 m/s^2

14. In the shown arrangement of ideal pulleys and string if 2kg block is just about to slide if coefficient of friction between 2kg block and surface is μ = 4/7, then value of m is



1) 4kg 2) 2kg

3) 1kg 4) 3kg

15. A 500kg horse pulls a cart of mass 1500kg along a level road with an acceleration of 1m/s^2. If coefficient of sliding friction is 0.2, then force exerted by earth on horse is (g=10m/s^2)

1) 3000N 2) 40000N

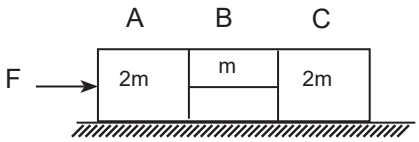
3) 5000N 4) $5000\sqrt{2}$N

16. The minimum force required to start pushing a body up along a rough (frictional coefficient μ) inclined plane is F_1 while the minimum force needed to prevent it from sliding down is F_2. If the inclined plane makes an angle θ from the horizontal such that tan θ=2μ, then the ratio $\frac{F_1}{F_2}$ is

1) 1 2) 2

3) 3 4) 4

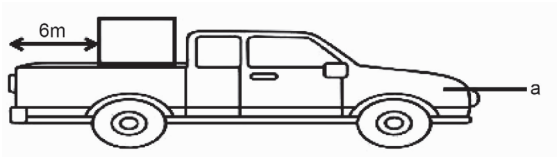
17. A system of three masses A, B and C shown in figure is pushed by a force F. All surfaces are smooth except between B and C. Static frictional coefficient between B and C is μ. Minimum value of F to prevent block B from down ward slipping is



1) $\frac{3mg}{2\mu}$ 2) $\frac{5mg}{2\mu}$

3) $\frac{5\mu mg}{2}$ 4) $\frac{3\mu\, mg}{2}$

18. A block of mass 2kg is placed on a truck as shown in figure. The coefficient of kinetic friction between the block and surface is 0.5. The truck starts from rest and moves with acceleration 8m/s^2. After how much time the block fall off the truck.



1) 4s 2) 3s

3) 2s 4) 1.5s s

19. A bend in a level road has a radius of 100m. Find the maximum speed which a car turning this bend may have without skidding (μ_3 = 0.8)

1) 25 m/s

2) 26 m/s

3) 28 m/s

4) None

STATEMENT TYPE QUESTIONS

1) Both statement I and statement II are true and statement II is the correct explanation of statement I

2) Both statement I and statement II are true but statement II is not the correct explanation of statement I

3) Statement I is true, Statement II is false

4) Statement I is false and statement II is true

20. **Statement I :** A block placed on a horizontal table is at rest, because reaction force cancel the action force on the block.

Statement II : Net force on the block is zero.

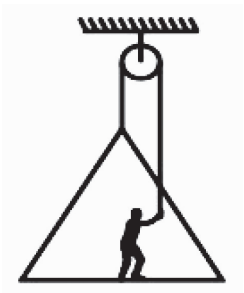
21. **Statement I :** It is easier to pull a heavy object than to push it on a level ground

Statement II : The magnitude of frictional force depends on the nature of the two surfaces in contact.

SECTION - II QUESTIONS

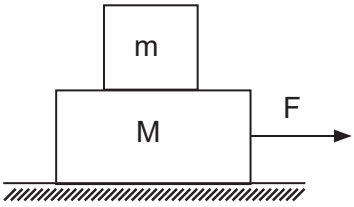
NUMERICAL TYPE

22. In the figure a painter of mass 100kg standing in a crate of mass 25kg pulls himself up with the crate with an acceleration. If the painter exerts an effective force of 450 N on the floor of the crate. Then the acceleration of the man is. [in m/s^2]

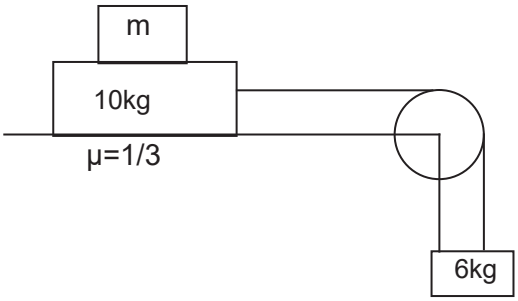


23. Two 100 g blocks hang at the ends of a light flexible cord passing over a small friction less pulley. A 40 g block rests on the block on right and removed after 2 second. The distance each block move, in the first second after the 40 g block is removed is $\frac{980}{x}$ cm. Find x

24. Two blocks (m = 0.5kg and M = 4.5 kg) are arranged on a horizontal frictionless table as shown in the figure. The coefficient of static friction between the two blocks is $\frac{3}{7}$. Then the maximum horizontal force that can be applied on the larger block so that the blocks move together is .....M(Round off to the nearest integer) [Take g as 9.8 ms^{-2}]



25. Consider the situation shown in the figure. The minimum value of m (in kg) so that block do not move is



Chapter 05

WORK ENERGY POWER

SYNOPSIS

Work is said to be done when a force F displaces its point of application. Workdone is measured as $W = \vec{F} \cdot \vec{S} = FS\cos\theta$.

Unit of work:- Joule (J) in SI and erg in CGS system. Gravitational unit of work is kg.m.

1kgm = 9.8 J

1 J = 10^7 ergs. Dimensions ML^2T^{-2}

If θ = 0 $\vec{F}$ and $\vec{S}$ are along the same direction. Work done W = FS is maximum.

If θ = 90^0, $\vec{F}$ and $\vec{S}$ are perpendicular to each other. Work done by the force is zero. ie,

$W = FS\cos\theta = 0$

If $\theta < 90^0, W = FS\cos\theta$, work done is positive: work is said to be done by the force

If $\theta > 90^0, W = FS\cos\theta$, work done is negative: work is said to be done against the force

Retarding force performs negative work. Accelerating force performs positive work.

Calculation of work:

(i) For constant force, $W = \vec{F} \cdot \vec{S}$

(ii) For uniformly varying force, W = Av. force × Displacement

(iii) For non-uniformly varying force and in general, $W = \int \vec{F} \cdot d\vec{s}$

The area under force - displacement graph gives the work done.

Energy of a body is the capacity of doing work. It is measured in terms of work. So the units and dimensions of energy are the same as those of work.

Mechanical energy exists in two forms:

(1) Kinetic energy - possessed by virtue of motion

$$KE = \frac{1}{2}mv^2 = \frac{P^2}{2m} \quad [P = mv]$$

Work - Energy Principle: $W = \Delta KE$ = Work done by all forces

(2) Potential energy is the energy possessed by virtue of position, or state of strain.

Gravitational PE = mgh. (by virtue of position)

Elastic PE (of a stretched spring or body) = $\frac{1}{2}kx^2$ - the energy possessed due to the state of strain where k is the force constant (or, spring constant), x is the stretching length or strain produced.

$$k = \frac{F}{x} = \frac{mg}{x}$$

For an elastic spring the stretching force F = +kx

Work done in stretching = $\frac{1}{2}kx^2$. This amount of work will be stored in the spring as its elastic PE.

Conservation of Mechanical Energy

Total energy is conserved in a mechanical system if the force acting is conservative.

ie; KE + PE = a constant.

Power is the rate of doing work $P = \frac{W}{t} = \frac{\vec{F}\cdot\vec{s}}{t} = \vec{F}\cdot\vec{v}$.

If F is varying $P_{inst} = \frac{dW}{dt}$

Unit: - Watt (W) = Joule/s. Dimension ML^2T^{-3}

Kilowatt (kW) = 10^3 W

Another commonly used unit of power is horse power (HP)

1 HP = 746 W

Kilo watt - hour (kWh) is the commonly used unit of energy. It is the energy consumed at the rate of 1 kJ/s in one hour.

$\therefore$ 1 kWh = 1000 x 60 x 60 J = 3.6 x 10^6 J

Energy in kWh = Power in kW x time in hour.

COLLISION

Elastic and inelastic collisions.

Elastic collision 1. Total linear momentum is conserved

2. Total KE is conserved

3. TE is conserved

4. Forces involved during collision are conservative

In the case of a linear elastic collision

$m_1u_1 + m_2u_2 = m_1v_1 + m_2v_2$

$$\frac{1}{2}m_1u_1^2 + \frac{1}{2}m_2u_2^2 = \frac{1}{2}m_1v_1^2 + \frac{1}{2}m_2v_2^2$$

Solving ,

$$v_1 = \frac{2m_2u_2}{m_1+m_2} + \frac{(m_1-m_2)u_1}{(m_1+m_2)} \text{.....}(1)$$

$$v_2 = \frac{2m_1u_1}{m_1+m_2} + \frac{(m_2-m_1)u_2}{(m_1+m_2)} \text{.....}(2)$$

$v_2 - v_1 = u_1 - u_2$ .....(3)

Relative velocity of separation = Relative velocity of approach

Special cases

(1) If $m_1 = m_2$ $v_1 = u_2$, $v_2 = u_1$ velocities interchange after collision

(2) If $m_1 >> m_2$ and $u_2 = 0$, then $v_1 = u_1$ and $v_2 = 2\,u_1$

(3) If $m_1 << m_2$ and $u_2 = 0$, then $v_1 = -u_1$ and $v_2 = 0$

Inelastic collision

(1) Total Linear momentum is conserved

(2) Total energy is conserved

(3) There is a loss of KE

(4) Some or all the forces involved during collision are non-conservative.

Coefficient of restitution

A ball moving with a velocity u_1 collides inelastically with another body moving with a velocity u_2 in the same direction and after collision if their velocities are v_1 and v_2 respectively, then,

$v_2 - v_1 = e(u_1 - u_2)$ where, e is the coefficient of restitution

$$e = \frac{v_2 - v_1}{u_1 - u_2} = \frac{\text{relative velocity of separation}}{\text{relative velocity of approach}} .....(4)$$

The values of e lies between 0 and 1.

When a ball falls on a hard floor from a height h_1 with a velocity u and rebounds with a velocity v to a height h_2 then, it can be shown that $e = \frac{v}{u} .....(5)$ and also, $e = \sqrt{\frac{h_2}{h_1}} .....(6)$

Conservation of energy

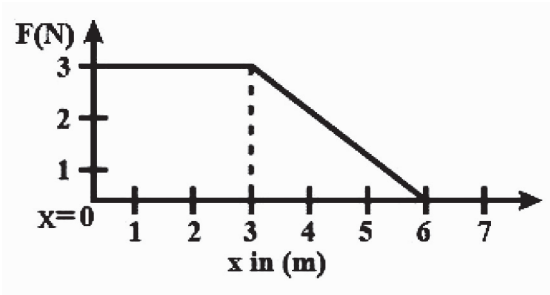
Total energy is conserved

When a mass m is fully converted into energy, the energy produced $E = mc^2$

SECTION - I
QUESTIONS

SINGLE CORRECT TYPE

1. A force F acting on an object varies with distance x as shown here. The force is in N and x is in m. The work done by the force in moving the object from x = 0 to x = 6m is ?



1) 18 J 2) 13.5 J
3) 4.5 J 4) 9J

2. A body of mass 3kg is under a force which causes a displacement in it, given $S = \frac{t^2}{3}$ (in m). The work done by the force in 2 seconds

1) 2J 2) 3.8J
3) 5.2J 4) 2.6J

3. If a body loses half of its velocity on penetrating 3cm in a wooden block, then how much will it penetrate more before coming to rest ?

1) 1 cm 2) 2 cm
3) 3 cm 4) 4 cm

4. Work required to raise a stone of mass 5 kg and relative density 3, lying at the bed of a lake through a height of 3m is

1) 25J 2) 40J
3) 75J 4) 100J

5. A block of mass 10kg, moving in x-direction with a constant speed of 10m/s, is subjected to a retarding force $F = 0.1x\ {}^{J}\!/_{m}$ during its travel from x = 20m to x = 30m. Its final K.E will be

1) 450J 2) 275J
3) 250J 4) 475J

6. A rod of mass M and length ℓ is lying on a horizontal surface. The work done in making to stand on one end is:

1) $Mg\ell$ 2) $Mg\frac{\ell}{2}$
3) $2Mg\ell$ 4) $Mg\frac{\ell}{4}$

7. A ball is thrown downward with a velocity υ_0 from a height of 10m. It collides the ground and loses 50% of its energy and rises back to the same height. Find the initial velocity ($g = 9.8ms^{-2}$)

1) $196ms^{-1}$ 2) $14ms^{-1}$
3) $28ms^{-1}$ 4) $7ms^{-1}$

8. A long spring is stretched by 2 cm, its potential energy is U. If the spring is stretched by 10 cm, the potential energy stored in it is

1) $\frac{U}{25}$ 2) $\frac{U}{5}$
3) 5U 4) 25U

9. A particle of mass 4m which is at rest explodes into three fragments. Two of the fragments each of mass m are found to move with a speed v in mutually perpendicular directions. The total kinetic energy released in explosion is

1) $2mv^2$ 2) $\frac{3}{2}mv^2$
3) mv^2 4) $3mv^2$

10. Three identical spherical balls A,B and C are placed on a table as shown in figure along straight line

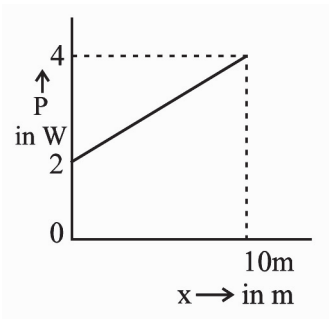
'B' and 'C' are rest initially. The ball 'A' hits 'B' with a speed of $10 m/s^{-1}$. Then after all collisions (assumed to be elastic) 'A' and 'B' comes to rest 'C' take off with a velocity of

1) $5 m/s^{-1}$
2) $10 m/s^{-1}$
3) $2.5 m/s^{-1}$
4) $7.5 m/s^{-1}$

11. A body of mass 5kg is taken up an inclined plane of length 10m and height 5m and then released to slide down to the bottom. If the coefficient of friction between the surface and the body is 0.1, the net work done against frictional force and gravitational force in the round trip is

1) 25J, 0
2) $50\sqrt{3}J, 0$
3) $0, 50\sqrt{3}J$
4) $50\sqrt{3}J, 50J$

12. A particle of mass $\frac{10}{7}kg$ is moving in the positive x-direction. Its initial position is x = 0 and initial velocity 1m/s. Then the velocity at x =10m is:

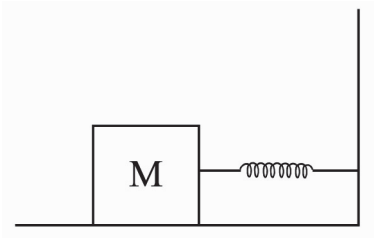


1) 4m/s
2) 2m/s
3) $3\sqrt{2}m/s$
4) $\frac{10}{\sqrt{2}}m/s$

13. A car of mass m starts moving so that its velocity varies according to the law $v = \beta\sqrt{s}$, where β is a constant, and s is the distance covered. The total work performed by all the forces which are acting on the car during the first t seconds after the beginning of motion is ?

1) $\frac{m\beta^4t^2}{8}$
2) $\frac{m\beta^2t^4}{8}$
3) $\frac{m\beta^4t^2}{4}$
4) $\frac{m\beta^2t^4}{4}$

14. The block of mass M moving on the frictionless horizontal surface collides with a spring of spring constant K and compresses it by length L. The maximum momentum of the block after collision is

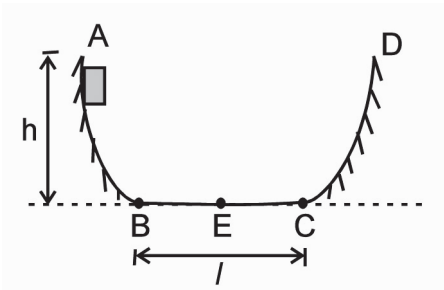


1) $\sqrt{MKL}$
2) $\frac{\sqrt{KL^2}}{2M}$
3) 0
4) $\frac{\sqrt{ML^2}}{K}$

15. A body of mass m dropped from a certain height strikes a light vertical fixed spring of stiffness K. The height of its fall before touching the spring, if the maximum compression of the spring is equal to $\frac{3mg}{K}$ is ?

1) $\frac{3mg}{2K}$
2) $\frac{2mg}{K}$
3) $\frac{3mg}{4K}$
4) $\frac{mg}{4K}$

16. A particle slides along a track with elevated ends and a flat central part as shown in figure. The flat part has a length l = 3m. The curved portion of the track are frictionless. For the flat part, the coefficient of kinetic friction μ_K = 0.2. The particle is released at point 'A', which is at height h = 1.5m above that flat part of the track, when will the particle finally come to rest



1) BE = 3m

2) BE = 2.7m

3) BE = 1.5m

4) BE = 0.8m

17. Power supplied to a particle of mass 2 kg varies with time as $P = \frac{3}{2}t^2$ watt (t is in seconds). If the velocity of the particle at t = 0 is zero, the velocity of the particle at t = 2 second will be

1) 1 m/s

2) 2 m/s

3) 3 m/s

4) $\frac{3}{2}$ m/s

18. A ball of mass 'm' moving with a speed 'u' undergoes a head on elastic collision with a ball of mass 'nm'at rest. The fraction of the incident energy transferred to heavier ball is

1) $\frac{n}{1+n}$
2) $\frac{n}{(1+n)^2}$
3) $\frac{4n}{(1+n)^2}$
4) $\frac{2n}{(1+n)^2}$

19. A body of mass m moving horizontally with a velocity v_0 strikes a pendulum of equal mass at rest. The two bodies stick together after collision. The height to which the pendulum rises is:

1) $\frac{v_0}{8g}$
2) $\frac{v_0^2}{4g}$
3) $\frac{v_0^2}{8g}$
4) $\frac{v_0^2}{2g}$

STATEMENT TYPE QUESTIONS

1) Both Statement-I and Statement-II are true and Statement-II is the correct explanation of Statement-I.

2) Both Statement-I and Statement-II are true but Statement-II is not the correct explanation of Statement-I.

3) Statement-I is true, Statement-II is false

4) Statement-I is false and Statement-II is true

20. **Statement I :** In a circular motion, work done by centripetal force is not zero always

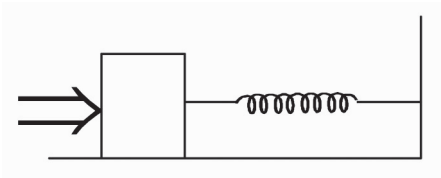
Statement II : If the speed of a particle increases or decreases in circular motion, net force acting on the particle does not remain towards centre

SECTION - II QUESTIONS

NUMERICAL TYPE

21. A light inextensible string goes over a smooth fixed pulley connects two blocks of masses 0.36 kg and 0.72 kg. Find the work done by the string on the block of 0.36 kg during the first second after the system is released from rest.

22. A block of mass 0.18 kg is attached to a spring of force constant 2 N m^{-1}. The coefficient of friction between the block and the floor is 0.1. Initially the block is at rest and the spring is un-stretched. An impulse is given to the block as shown in figure. The block slides a distance of 0.06m and comes to rest for the first time. The initial velocity of the block in ms^{-1} is V = N/10. Then N is



23. A man is riding on a cycle with velocity 7.2 km/hr up a hill having a slope 1 in 20. The total mass of the man and cycle is 100 kg. The power of the man is xW. What is x ? ($g = 9.8\ m/s^2$)

24. A force F = 20 + 10 y acts on a particle in y-direction where F is in newton and y in meter. Work done by this force to move the particle from y = 0 to y = 1m is (in J)

25. A spring of force constant 800N/m is stretched initially through 5cm. The work done in stretching it from 5cm to 15cm is: (in J)

Chapter 06

SYSTEM OF PARTICLES AND RIGID BODY ROTATION

SYNOPSIS

Rigid body

- Ideally a rigid body is a body with a perfectly definite and unchanging shape
- The distance between different pairs of such a body do not change
- No real body is truly rigid

Centre of Mass

- The centre of mass of a body is a point where the whole mass of the body is supposed to be concentrated
- Position vector of the centre of mass

$$\vec{r}_{cm} = \frac{m_1\vec{r}_1 + m_2\vec{r}_2 + ... + m_n\vec{r}_n}{m_1 + m_2 + ... + m_n}$$

- Co-ordinates of the centre of mass

$$X_{cm} = \frac{m_1x_1 + m_2x_2 + ... + m_nx_n}{m_1 + m_2 + ... + m_n}$$

$$Y_{cm} = \frac{m_1y_1 + m_2y_2 + ... + m_ny_n}{m_1 + m_2 + ... + m_n}$$

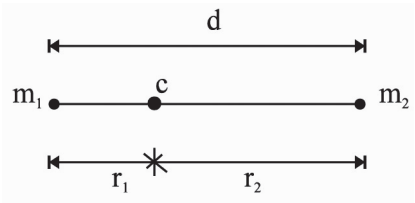
$$Z_{cm} = \frac{m_1z_1 + m_2z_2 + ... + m_nz_n}{m_1 + m_2 + ... + m_n}$$

- The sum of the moments of masses of all the particles of the body about the centre of mass is zero

$$\sum_{i=1}^{n} m_i r_i = 0$$

- Centre of mass of a continuous mass distribution $X_{cm} = \frac{\int Xdm}{\int dm}$, $Y_{cm} = \frac{\int Ydm}{\int dm}$, $Z_{cm} = \frac{\int Zdm}{\int dm}$

Centre of mass of two particle system

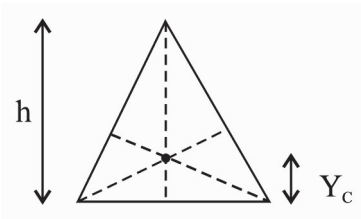


$$r_1 = \left[\frac{m_2}{m_1 + m_2}\right] d \quad ; \qquad r_2 = \left[\frac{m_1}{m_1 + m_2}\right] d$$

- The position of centre of mass of a body depends on the shape, size and distribution of mass within the body
- The centre of mass does not lie necessarily within the object
- In symmetrical bodies with homogeneous distribution of mass centre of mass coincides with the geometrical centre
- The centre of mass changes its position in translatory motion but remains unchanged in rotatory motion
- The centre of gravity has no relevance where there is no force of gravity, where as the centre of mass is independent of gravitational forces

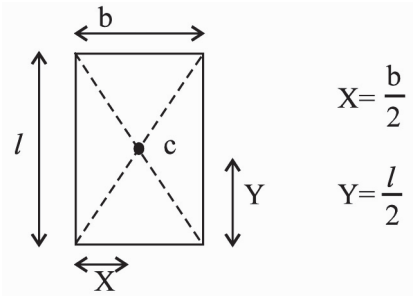
Centre of mass of some homogeneous bodies

A triangular plate



at the centroid

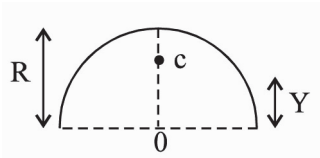
A rectangular plate



$$X = \frac{b}{2}$$

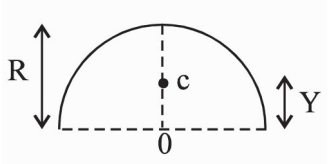
$$Y = \frac{l}{2}$$

A semi-circular ring



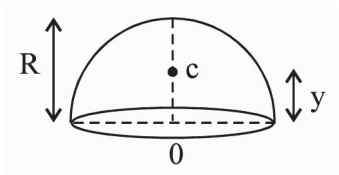
$$Y = \frac{2R}{\pi}$$

A semi-circular disc



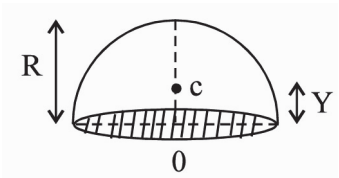
$$Y = \frac{4R}{3\pi}$$

A hemispherical shell



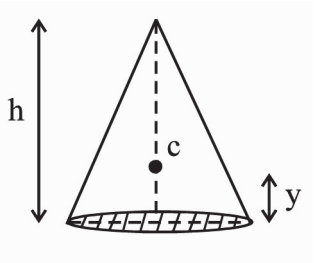
$$Y = \frac{R}{2}$$

A solid hemisphere



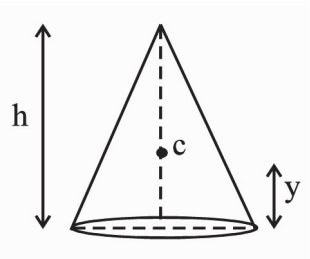
$$Y = \frac{3R}{8}$$

A circular Cone



$$Y = \frac{h}{4}$$

A circular Cone



$$Y = \frac{h}{3}$$

Motion of Centre of Mass

- Velocity of centre of mass

$$\vec{V}_{cm} = \frac{m_1\vec{V_1} + m_2\vec{V_2} + ... + m_n\vec{V_n}}{m_1 + m_2 + ... + m_n}$$

- Acceleration of centre of mass

$$\vec{a}_{cm} = \frac{m_1\vec{a_1} + m_2\vec{a_2} + ... + m_n\vec{a_n}}{m_1 + m_2 + ... + m_n}$$

- Total momentum of the system of particles

$$\vec{P} = M\vec{V}_{cm}$$

- The centre of mass of the system of particles moves as if all the mass of the system was concentrated at the centre of mass and all the external forces were applied at that point.

$$M\vec{a}_{cm} = \vec{F}_{ext}$$

- When no external force acts on a body its centre of mass will remain either at rest or move with a constant velocity.

Moment of Inertia

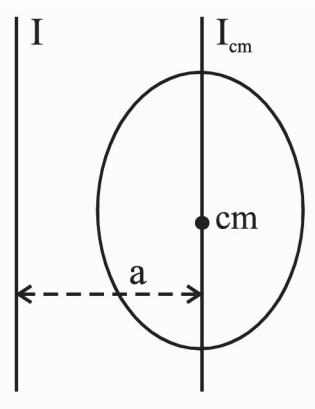
- Moment of inertia gives a measurement of the resistance of a body to a change in its rotational motion.
- Moment of inertia of a body about an axis depends on the mass as well as its distribution about that axis.
- For a single particle of mass m rotating about an axis at a distance r from the axis

  $I = mr^2$
- For a system of particles about an axis $I = \sum mr^2$
- For a rigid body rotating about an axis $I = \int r^2\, dm$
- Radius of gyration of a body about an axis may be defined as the distance from the axis to a mass point whose mass is equal to the mass of the whole body and whose moment of inertia is equal to the moment of inertia of the body about the axis.

Parallel Axes Theorem

The moment of inertia of a body about any axis is equal to the sum of the moment of inertia of the body about a parallel axis passing through its centre of mass and the product of its mass and the square of the distance between two parallel axes.

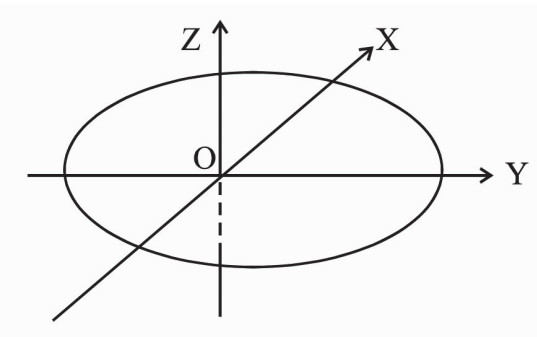
$$\boxed{I = I_{cm} + Ma^2}$$



Perpendicular Axes Theorem

Moment of inertia of a planar body (lamina) about an axis perpendicular to its plane is equal to the sum of its moments of inertia about two perpendicular axes concurrent with the perpendicular axis and lying in the plane of the lamina.

$$\boxed{I_Z = I_X + I_Y}$$



Moment of inertia of some regular shaped bodies about specific axes

Body		Axis	Moment of Inertia
Thin circular ring of radius R	a)	Passing through centre and perpendicular to the plane	MR^2
	b)	Diameter	$\frac{MR^2}{2}$
Circular disc of radius R	a)	Passing through centre and perpendicular to the plane	$\frac{MR^2}{2}$
	b)	Diameter	$\frac{MR^2}{4}$
Uniform thin rod of length L	a)	Passing through mid point and perpendicular to length	$\frac{ML^2}{12}$
	b)	Passing through one end and perpendicular to length	$\frac{ML^2}{3}$
Solid sphere of radiur R	a)	Diameter	$\frac{2}{5}MR^2$
Hollow sphere of radius R	a)	Diameter	$\frac{2}{3}MR^2$
Hollow cylinder of radius R and length L	a)	Axis of cylinder	MR^2
	b)	Passing through centre and perpendicular to length	$M\left[\frac{L^2}{12}+\frac{R^2}{4}\right]$
Solid cylinder of radius R and length L	a)	Axis of the cylinder	$\frac{MR^2}{2}$
	b)	Passing through centre and perpendicular to length	$M\left[\frac{L^2}{12}+\frac{R^2}{4}\right]$
Thin rectangular plate of length l and breadth b	a)	Axis passing through centre and perpendicular to its plane	$\frac{M}{12}\left[l^2+b^2\right]$
Thin square plate of side a	a)	Axis passing through centre and perpendicular to plane	$\frac{Ma^2}{6}$
Cone of radius R	a)	Axis joining vertex to the centre of the base	$\frac{3}{10}MR^2$

Torque

- Torque or moment of force is the rotational analogue of force
- Torque or the moment of force about a point is measured as the product of force and the perpendicular distance from the point to the line of action of the force

$\tau = rF\sin\theta$; $\vec{\tau} = \vec{r} \times \vec{F}$

- Torque is related to angular acceleration as $\tau = I \propto$

Angular Momentum

- Angular momentum is the rotational analogue of linear momentum
- Angular momentum $L = rp\sin\theta$

$\vec{L} = \vec{r} \times \vec{p}$

- Geometrical meaning of angular momentum $L = 2m\frac{dA}{dt}$
- Angular momentum of a rotating rigid body $L = I\omega$
- Relation between torque and angular momentum $\tau = \frac{dL}{dt}$

Kinematic Equations of Rotational Motion

$\omega_t = \omega_0 + \propto t$

$\theta = \omega_0 t + \frac{1}{2} \propto t^2$

$\omega_t^2 = \omega_0^2 + 2 \propto \theta$

Conservation of angular momentum

In the absence of an external torque, the angular momentum of the rotating system is conserved.

When I = 0 L = Iw = constant

$I_1\omega_1 = I_2\omega_2$

- Kinetic energy of a rotating rigid body $KE = \frac{1}{2}I\omega^2$

Analogy between translational motion and rotational motion

	Translational Motion		Rotational Motion
1.	Linear displacement $\vec{r}$	1.	Angular displacement $\vec{\theta}$
2.	Linear velocity $\vec{V} = \frac{d\vec{r}}{dt}$	2.	Angular velocity $\vec{\omega} = \frac{d\vec{\theta}}{dt}$
3.	Linear Acceleration $\vec{a} = \frac{d\vec{v}}{dt}$	3.	Angular acceleration $\vec{\propto} = \frac{d\vec{\omega}}{dt}$
4.	Time t	4.	Time t
5.	Mass m	5.	Moment of inertia I
6.	Linear momentum $\vec{p} = m\vec{v}$	6.	Angular momentum $\vec{L} = I\vec{\omega}$
7.	Linear impulse $\vec{F} \times \Delta t = \overrightarrow{\Delta p}$	7.	Angular impulse $\vec{\tau} \times \Delta t = \Delta\vec{L}$
8.	Force $\vec{F} = m\vec{a}$	8.	Torque $\vec{\tau} = I\vec{\propto}$
9.	$W = \vec{F} \cdot \vec{s}$		$W = \vec{\tau} \cdot \vec{\theta}$
10.	$KE = \frac{1}{2}mv^2$	10.	$KE = \frac{1}{2}I\omega^2$
11.	Power $P = \vec{F} \cdot \vec{v}$	11.	Power $P = \vec{\tau} \cdot \vec{\omega}$
12.	Kinematic equations $V = u + at$ $S = ut + 1/2\,at^2$ $V^2 - u^2 = 2as$ $S_n = U + \frac{a}{2}(2n-1)$	12.	Kinematics equations $w_t = w_0 + \propto t$ $\theta = \omega_0 t + 1/2 \propto t^2$ $\omega_t^2 - \omega_0^2 = 2 \propto \theta$ $\theta_n = \omega_0 + \frac{\propto}{2}(2n-1)$

SECTION - I
QUESTIONS

SINGLE CORRECT TYPE

1. Masses 8kg, 2kg, 4kg and 2kg are placed at the corners A, B, C and D respectively, of a square ABCD of diagonal 80cm. The distance of centre of mass from A will be

1) 20 cm
2) 30cm
3) 40 cm
4) 60 cm

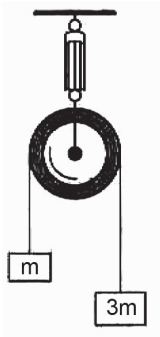
2. Consider a system of two particles having masses m_1 and m_2, if the particle of mass m_1 is pushed towards the centre of mass of the particles through a distance d, by what distance would be particle of mass m_2 move so as to keep the centre of mass of the particle at the original position ?

1) $\frac{m_1}{m_1+m_2}d$
2) $\frac{m_1}{m_2}d$
3) d
4) $\frac{m_2}{m_1}d$

3. Two bodies of different masses 2kg and 4kg are moving with velocities 20 m/s and 10m/s, respectively, towards each other due to mutual gravitational attraction. What is the velocity of their centre of mass?

1) 5 m/s
2) 6 m/s
3) 8 m/s
4) zero

4. If the system shown below is released, then the acceleration of the centre of mass of the system is

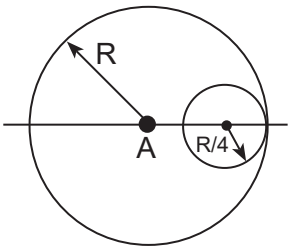


1) $\frac{g}{4}$
2) $\frac{g}{2}$
3) g
4) 2g

5. A man weighing 80kg is standing on a trolley weighing 320kg. The trolley is resting on frictionless horizontal rails. If the mas starts walking on the trolley along the rails at a speed of 1m/s. Then after 4s his displacement relative to ground will be :

1) 5m
2) 4.8m
3) 3.2m
4) 4m

6. The centre of mass of the shaded portion of the disc is (The mass is uniformly distributed in the shaded portion)



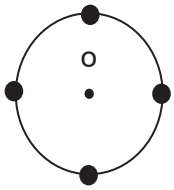
1) $\frac{R}{20}$ to the left of A
2) $\frac{R}{12}$ to the left of A
3) $\frac{R}{20}$ to the right of A
4) $\frac{R}{12}$ to the right of A

7. Three identical uniform rods each of length l are joined to form a rigid equilateral triangle. Its radius of gyration about an axis passing through a corner and perpendicular to the plane of the triangle is

1) $\sqrt{\frac{3}{2}}l$ 2) $\sqrt{3}l$

3) $\frac{l}{2\sqrt{2}}$ 4) $\frac{l}{\sqrt{2}}$

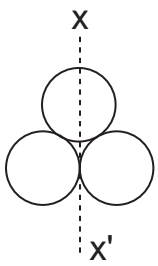
8. Four similar point masses (each of mass *m*) are placed on the circumference of a disk of mass *M* and radius *R*. The moment of inertia of the system about the normal axis through the centre *O* will be



1) $MR^2 + 4mR^2$ 2) $\frac{1}{2}MR^2 + 4mR^2$

3) $MR^2 + \frac{8}{5}mR^2$ 4) none of these

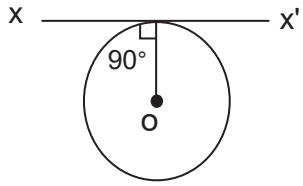
9. Three solid spheres of mass M and radius R are shown in the figure. The moment of inertia of the system about XX' axis will be



1) $\frac{7}{2}MR^2$ 2) $\frac{14}{5}MR^2$

3) $\frac{16}{5}MR^2$ 4) $\frac{21}{5}MR^2$

10. A thin wire of length *L* and uniform linear mass density ρ is bent into a circular loop and centre O as shown. The moment of inertia of the loop about the axis XX' is



1) $\frac{\rho L^3}{8\pi^2}$ 2) $\frac{\rho L^3}{16\pi^2}$

3) $\frac{5\rho L^3}{16\pi^2}$ 4) $\frac{3\rho L^3}{8\pi^2}$

11. The moment of inertia of a solid cylinder about its own axis is same as its moment of inertia about an axis passing through its centre of gravity and perpendicular to its length. The relation between its length *L* and radius *R* is

1) $L = \sqrt{2}R$ 2) $L = \sqrt{3}R$

3) L= 3R 4) L = R

12. A constant torque of 1000N m turns a which of moment of inertia 200kg m^2 about an axis through its centre. Its angular velocity after 3s is (in rad/s)

1) 1 2) 5

3) 15 4) 10

13. A rod of length 1m is standing vertically. When its outer end touches the ground without slipping, then the speed of other end will be

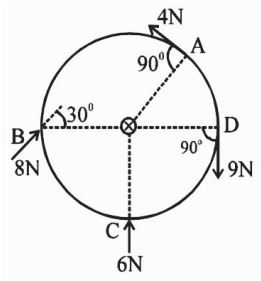
1) $\sqrt{19.6}\,m/s$

2) $\sqrt{29.4}\,m/s$

3) 4.9 m/s

4) 9.8 m/s

14. A wheel of radius 20cm has forces applied to it as shown in figure. The net torque on the wheel about its axis is



1) 5.4Nm anticlockwise

2) 1.8Nm clockwise

3) 2Nm clockwise

4) 3.4Nm anticlockwise

15. If the earthwere to suddenly contract to $\frac{1}{n}^{th}$ of its present radius without any change in its mass, then the duration of the new day will be nearly

1) $\frac{24}{n}h$ 2) 24 nh

3) $\frac{24}{n^2}h$ 4) $24n^2h$

16. A rope of negligible mass is round a hollow cylinder of mass 3 kg and radius 40cm free to rotate about its own stationary axis. The rope is pulled with a force of 30N. Assuming that there is no slipping, the angular acceleration of the rope are

1) 20 rad/s² and 8m/s²

2) 10 rad/s² and 5m/s²

3) 40 rad/s² and 20m/s²

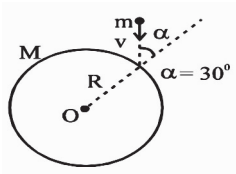
4) 25 rad/s² and 10m/s²

17. A wheel is rotating at 900 rpm about its axis. When power is cut-off, it comes to rest in 1 min. The angular retardation (in rad s^{-2}) is :

1) $\frac{\pi}{2}$ 2) $\frac{\pi}{4}$

3) $\frac{\pi}{6}$ 4) $\frac{\pi}{8}$

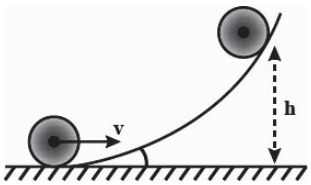
18. A circular disc of mass M and radius R can rotate freely about an axis passing through its centre and perpendicular to its plane. A bullet of mass m travelling with speed v hits the disc as shown and gets stuck to it. The angular velocity of the system if the disc was initially at rest (M=2m)



1) $\frac{V}{4R}$ 2) $\frac{V}{6R}$

3) $\frac{V}{R}$ 4) $\frac{3V}{2R}$

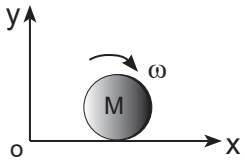
19. A disk of mass M and radius R rolls on a horizontal surface and then rolls up an inclined plane as shown in the figure. If the velocity of the disk is v, the height to which it can rise will be



1) $\frac{3v^2}{2g}$ 2) $\frac{3v^2}{4g}$

3) $\frac{v^2}{4g}$ 4) $\frac{v^2}{2g}$

20. A disk of mass *M* and radius *R* is rolling with angular speed ω on a horizontal plane as shown. The magnitude of angular momentum of the disk about the origin *O* is



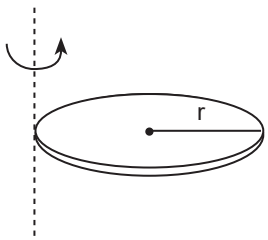
1) $\frac{1}{2}MR^2\omega$ 2) $MR^2\omega$

3) $\frac{3}{2}MR^2\omega$ 4) $2MR^2\omega$

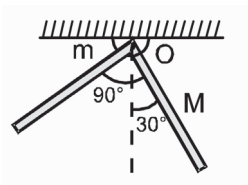
SECTION - II QUESTIONS

NUMERICAL TYPE

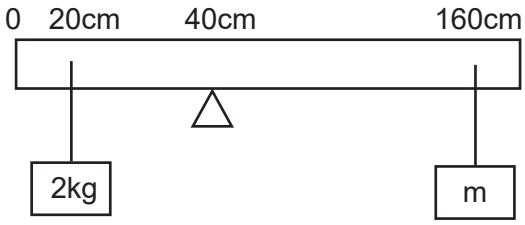
21. A solid sphere of radius R has moment of inertia I about its geometrical axis. f it is melted into a disc of radius r and thickness t. If it's moment of inertia about the tangential axis (which is perpendicular to plane of the disc), is also equal to I, then the value of r is equal to $\frac{2R}{\sqrt{K}}$ .Find K



22. Two uniform rods of equal length but different masses are rigidly joined to form an L-shaped body, which is then pivoted about O as shown. If in equilibrium the body is in the shown configuration, ratio M/m is $K^{1/2}$.Find K.

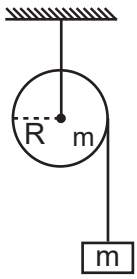


23. A uniform rod of length 200cm and mass 500g is balanced on a wedge placed at 40cm mark. A mass of 2kg is suspended from the rod at 20cm and another unknown mass 'm' is suspended from the rod at 160cm mark as shown in the figure. The value of 'm' such that the rod is in equilibrium is $\frac{1}{x}$kg where x is (g = 10m/s²)



24. A particle of mass 5 kg is moving with a uniform speed $3\sqrt{2}$ m/s in XOY plane along the line Y = X + 4. The magnitude of its angular momentum about the origin is (in Kg m² s⁻¹).

25. A mass ma is suspended by a massless string wound round a uniform cylinder of mass m and radius R. On releasing the mass from rest, it will fall with an acceleration, $a = \frac{2g}{x} m/s^2$ where 'x' is



Chapter 07

GRAVITATION

SYNOPSIS

Newton's Law of Gravitation

- The force between two masses m_1 and m_2 separated by a distance *r*

$$F = G\frac{m_1 m_2}{r^2}$$

- G is the universal gravitational constant.
- G = 6.67×10^{-11} Nm^2kg^{-2}
- Dimensional formula of G is $M^{-1}L^3T^{-2}$

Properties of Gravitational Force

- Always attractive.
- Independent of medium.
- Two body interaction. i.e., independent of the presence or absence of other bodies.
- Action reaction pair.
- Central force.
- Conservative force.
- Holds good over a wide range of distances.

Acceleration Due to Gravity (g)

- The uniform acceleration produced in a freely falling body due to the gravitational pull of earth.
- Acceleration due to gravity on the surface of earth,

$$g = \frac{GM}{R^2}$$

M – mass of earth, R - radius of earth

Variation of g

1. Due to the shape of earth

$$g \propto \frac{1}{R^2}$$

Since polar radius is less than equatorial radius, g is more at the poles than at the equator.

2. With latitude

$$g' = g - R\omega^2 \cos^2 \lambda$$

ω – angular velocity of earth, λ – latitude

3. With altitude

Acceleration due to gravity at a height h above the earth surface,

$$g' = \frac{g}{(1 + h/R)^2}$$

if h << R

$$g' = g\left(1 - \frac{2h}{R}\right)$$

4. With depth

Acceleration due to gravity at a depth d below the earth surface,

$$g' = g\left(1 - \frac{d}{R}\right)$$

Gravitational Field

- Gravitational field of a body is the space around the body where its gravitational influence is felt.

Intensity of Gravitational Field (I)

- Intensity of gravitational field at a point is the force experienced by a body of unit mass placed at that point.

Gravitational intensity at a point due to a point mass

- Gravitational intensity at a distance r from a point mass M,

$$I = \frac{GM}{r^2}$$

- Intensity of gravitational field at a point on the surface of earth,

$$I = \frac{GM}{R^2} = g$$

Gravitational Potential (V)

- Gravitational potential at a point is the work done in bringing unit mass from infinity to that point.
- It is also measured as the potential energy per unit mass at that point.

Gravitational potential at a point due to a point mass

- Gravitational potential at a distance r from a point mass M,

$$V = \frac{-GM}{r}$$

Intensity and Potential due to a Sphere

Body	Position of Point	Gravitational Intensity	Gravitational Potential
Solid sphere (Mass M and radius R)	r > R	$I = \frac{GM}{r^2}$	$V = \frac{-GM}{r}$
	r = R	$I = \frac{GM}{R^2}$	$V = \frac{-GM}{R}$
	r < R	$I = \frac{GMr}{R^3}$	$V = \frac{-GM\left(3R^2 - r^2\right)}{2R^3}$
	r = 0	I = 0	$V = \frac{-3GM}{2R}$
Hollow sphere (Mass M and radius R)	r > R	$I = \frac{GM}{r^2}$	$V = \frac{-GM}{r}$
	r = R	$I = \frac{GM}{R^2}$	$V = \frac{-GM}{R}$
	r < R	I = 0	$V = \frac{-GM}{R}$
	r = 0	I = 0	$V = \frac{-GM}{R}$

Gravitational Potential Energy

- Gravitational PE of a mass at a point = Gravitational Potential x Mass of body

$$U = \frac{-GMm}{r}$$

- Gravitational PE of a body of mass m on the surface of earth, $U = \frac{-GMm}{R} = -mgR$

Satellite

- Orbital velocity of a satellite, $v_0 = \sqrt{\frac{GM}{r}} = \sqrt{\frac{GM}{(R+h)}} = \sqrt{\frac{gR^2}{(R+h)}}$

- If the orbit is close to the earth (minimum orbit), $v_0 = \sqrt{\frac{GM}{R}} = \sqrt{gR} = 7.92\,kms^{-1}$

- The velocity corresponding to minimum orbit is called first cosmic velocity.

- Time period of a satellite, $T = 2\pi\sqrt{\frac{r^3}{GM}}$
- A satellite which revolves around the earth with the same angular speed in the same direction as that of earth is called ***geostationary satellite.***
- Time period of geostationary satellite is 24 hours.
- The orbit of geostationary satellite is called parking orbit.

Energy of Satellite

- Potential energy of the satellite, $PE = \frac{-GMm}{r}$
- Kinetic energy of the satellite, $KE = \frac{GMm}{2r}$
- Total energy of the satellite, $TE = \frac{-GMm}{2r}$
- Binding energy of the satellite, $BE = \frac{+GMm}{r}$

Escape Velocity

- The minimum velocity with which a body must be projected so that it may escape from the gravitational field of earth is called escape velocity from the earth.
- Escape velocity from the surface of earth,

$$v_e = \sqrt{\frac{2GM}{R}} = \sqrt{2gR} = 11.2\,kms^{-1}$$

- Escape velocity of a body from the surface of earth is called second cosmic velocity.
- If a body is projected with a velocity $v > v_e$, it will move in the interstellar space with,

$$v' = \sqrt{v^2 - v_e^2}$$

Kepler's Laws of Planetary Motion

First Law (Law of Orbits)

- Every planet revolves around the sun in an elliptical orbit with sun at one of the foci.

Second Law (Law of Area)

- The line joining the planet to the sun sweeps out equal areas in equal intervals of time i.e., the areal velocity of planet around the sun is constant.

Third Law (Law of period)

- The square of the time period of revolution of a planet around the sun is directly proportional to the cube of the semi major axis.

$$T^2 \propto a^3$$

SECTION - I
QUESTIONS

SINGLE CORRECT TYPE

1. Three particles each of mass m are situated at the vertices of an equilateral triangle of side a. The only forces acting on the particles are their mutual gravitational forces. It is intended that each particles moves along a circle while maintaining their original separation a. The time period of their circular motion is

1) $2\pi\sqrt{\frac{5a^3}{Gm}}$

2) $2\pi\sqrt{\frac{a^3}{Gm}}$

3) $2\pi\sqrt{\frac{a^3}{3Gm}}$

4) $2\pi\sqrt{\frac{2a^3}{Gm}}$

2. Two spheres of masses m and M are situated in air and the gravitational force between them is F. The space around the masses is now filled with a liquid of specific gravity 3. The gravitational force will now be

1) 3F 2) F

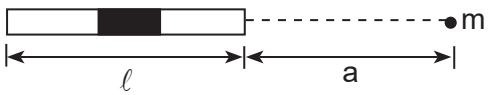
3) $\frac{F}{3}$ 4) $\frac{F}{9}$

3. A mass M is split into two parts, m and (M-m), which are then separated by a certain distance. What ratio of m/M maximizes the gravitational force between the two parts

1) 1/3 2) ½

3) 1/4 4) 1/5

4. A mass m is at a distance 'a' from one end of a uniform rod of length 'ℓ' and mass M. The gravitational force on the mass due to the rod is



1) $\frac{GMm}{(a+\ell)^2}$ 2) $\frac{GMm}{a(\ell+a)}$

3) $\frac{GMm}{a^2}$ 4) $\frac{GMm}{2(a+\ell)^2}$

5. A point mass m is placed inside a spherical shell of radius R and mass M at a distances $\left(\frac{R}{2}\right)$ from the centre of the shell. The gravitational force exerted by the shell on the point mass is

1) $\frac{GMm}{R^2}$ 2) $\frac{2GMm}{R^2}$

3) zero 4) $\frac{4GMm}{R^2}$

6. Acceleration due to gravity on moon is $1/6$ of the acceleration due to gravity on earth. If the ratio of densities of earth (ρ_e) and moon (ρ_m) is $\frac{\rho_e}{\rho_m}=\frac{5}{3}$ then radius of moon (R_m) in terms of (R_e) will be

1) $\frac{5}{18}R_e$ 2) $\frac{1}{6}R_e$

3) $\frac{7}{18}R_e$ 4) $\frac{1}{2\sqrt{3}}R_e$

7. The weight of a body at the surface of earth is 18N. The weight of the body at an altitude of 3200 km above the earth's surface is (given, radius of earth R_e=6400 km)

1) 9.8 N 2) 4.9 N

3) 19.6 N 4) 8 N

8. At what depth from the surface of earth the time period of a simple pendulum 0.5% more than that on the surface of the earth ? (Radius of earth is 6400 km)

1) 32 km 2) 64 km

3) 96 km 4) 128 km

9. Infinite number of bodies, each of mass 2 kg, are situated on x-axis at distance 1m, 2m, 4m, 8m ..... respectively, from the origin. The resulting gravitational potential due to this system at the origin will be:

1) –G 2) $\frac{-4}{3}G$

3) $\frac{-8}{3}G$ 4) –4G

10. If g is the acceleration due to gravity on the earth's surface, the gain in potential energy of the body at a height equal to two times the radius R of the earth will be:

1) 2 mgR 2) 3 mgR

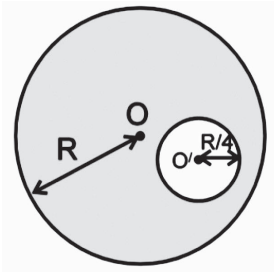
3) $\frac{1}{3}mgR$ 4) $\frac{2}{3}mgR$

11. An object is allowed to fall from a height R above the earth, where R is the radius of earth. Its velocity when it strikes the earth's surface, ignoring air resistance, will be:

1) $2\sqrt{gR}$ 2) $\sqrt{gR}$

3) $\sqrt{\frac{gR}{2}}$ 4) $\sqrt{2gR}$

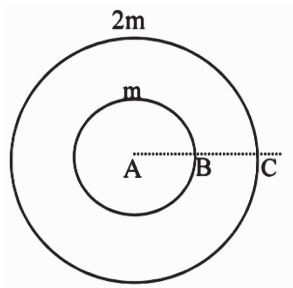
12. From a uniform solid sphere of mass M and radius R, a small portion of radius $\frac{R}{4}$ is removed symmetrically as shown. Let O and O' be the centres of the solid sphere and the removed sphere. Distance $OO' = \frac{R}{2}$. The gravitational potential at the point O' due to the remaining portion is



1) $\frac{-41}{32}\frac{GM}{R}$ 2) $\frac{-39}{34}\frac{GM}{R}$

3) $\frac{-49}{36}\frac{GM}{R}$ 4) $\frac{-41}{39}\frac{GM}{R}$

13. Two spherical shells having masses m and 2m as shown. Choose the incorrect options.



1) Between A and B gravitational field strength is zero

2) Between A and B gravitational potential is constant

3) There will be two points one lying between B and C and another lying between C and infinity where gravitational field strengths are same

4) There will be a point between B and C where gravitational potential will be zero

14. There are two planets. The ratio of radius of the two planets is K but ratio of acceleration due to gravity of both planets is g. What will be the ratio of their escape velocity

1) $(Kg)^{1/2}$

2) $(Kg)^{-1/2}$

3) $(Kg)^{2}$

4) $(Kg)^{-2}$

15. Escape velocity from the surface of the earth is V. An object is dropped from infinity to earth, which passes through a smooth tunnel from the surface of the earth to the centre. Velocity when it reaches the centre is:

1) $\sqrt{\frac{3}{2}}V$ 2) $\sqrt{\frac{4}{3}}V$

3) $\sqrt{3}V$ 4) $\sqrt{2}V$

16. A satellite of mass m is revolving in a circular orbit of radius 2R, around the earth of mass M. The work done to shift the satellite to an orbit of radius 3R is

1) $\frac{GMm}{2R}$

2) $\frac{GMm}{3R}$

3) $\frac{GMm}{9R}$

4) $\frac{GMm}{12R}$

17. A satellite is moving around the earth with speed 'v' in a circular orbit of radius 'r'. If the orbit radius is decreased by 1%, its speed will

1) Increase by 1%

2) Increase by 0.5%

3) Decrease by 1%

4) Decrease by 0.5%

18. If the distance of the earth from Sun is 1.5×10^{6} km. Then the distance of an imaginary planet from Sun, if its period of revolution is 2.83 years is

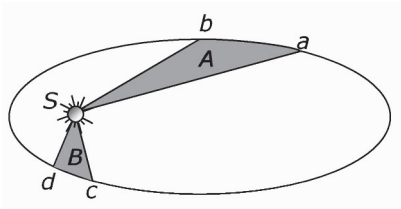
1) 6×10^{7} km

2) 6×10^{6} km

3) 3×10^{6} km

4) 3×10^{7} km

19. The figure shows the motion of a planet around the sun in an elliptical orbit with sun at the focus. The shaded areas A and B are also shown in the figure which can be assumed to be equal. If t_1 and t_2 represent the time for the planet to move from 'a' to 'b' and 'd' to 'c' respectively, then



1) $t_1 < t_2$

2) $t_1 > t_2$

3) $t_1 = t_2$

4) $t_1 \le t_2$

20. The minimum and maximum distances of a satellite from the centre of the earth are 2R and 4R respectively, where R is the radius of the earth and M is the mass of the earth. The minimum and maximum speeds of the satellite are respectively

1) $\sqrt{\frac{GM}{6R}}, \sqrt{\frac{2GM}{3R}}$

2) $\sqrt{\frac{GM}{3R}}, \sqrt{\frac{2GM}{3R}}$

3) $\sqrt{\frac{GM}{5R}}, \sqrt{\frac{6GM}{R}}$

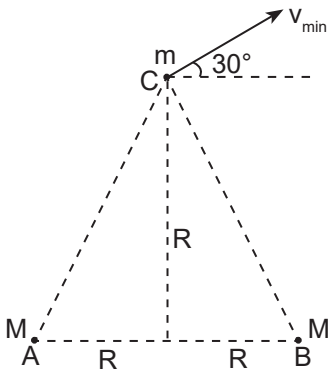
4) $\sqrt{\frac{GM}{6R}}, \sqrt{\frac{3GM}{2R}}$

SECTION - II
QUESTIONS

NUMERICAL TYPE

21. The gravitational field in a region is given by $\vec{E_g} = 5\hat{i} + 12\hat{j} N/Kg$, then the magnitude of the gravitational force acting on a particle of mass 2 Kg. placed at the origin, (in N) will be

22. The maximum speed should m be projected from point C in presence of two fixed masses M each at A and B as shown in the figure such that mass m should escape the gravitational attraction of A and B is $\sqrt{\frac{x\sqrt{2}GM}{R}}$. Then the value of x is



23. The escape velocity from earth is about 11 km per second. The escape velocity from a planet having twice the radius and same mean density as earth is in km/s

24. A geostationary satellite is orbiting the earth at a height of 6R above the surface of earth, R being radius of earth, its time period is T. The time period of another satellite at a height of 2.5R from the surface of earth is $\frac{T}{n\sqrt{2}}$ where n is

25. An artificial satellite is moving in a circular orbit around the earth with a speed equal to half the magnitude of the escape velocity from the earth. If the satellite is stopped suddenly in its orbit and allowed to fall freely on the earth, Find the speed (in km/s) with it hits the surface of earth
(g = m/sec^2 and R = 6400km)

Chapter 08

MECHANICAL PROPERTIES OF SOLIDS AND FLUIDS

SYNOPSIS

A. ELASTICITY

Elasticity is the property of the materials to regain the original state on the removal of the deforming forces. (Quartz is almost perfectly elastic)

Hooke's law

With in the limits of elasticity, stress is α strain. Then, $\frac{\text{stress}}{\text{strain}} = E$ is called Modulus of elasticity

Stress = F/A, Unit = N/m^2, Unit of E is also N/m^2

Since **strain** $\left(=\frac{\text{change in dimension}}{\text{orginal dimension}}\right)$ has no unit

When a wire (or body) is stretched by a force F, a restoring force equal to F but opposite in direction is developed in the wire. This restoring force/unit area is called tensile stress (=F/A, where A is the area of cross section of the wire)

The corresponding strain $\left(\frac{\Delta\ell}{\ell}\right)$ produced is called longitudinal strain or linear strain

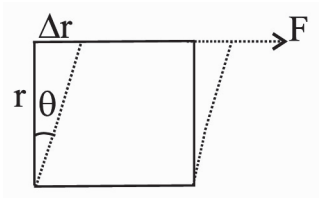
Then, $\frac{\text{tensile stress}}{\text{longitudinal strain}} = \frac{F/A}{\Delta\ell/\ell} = Y$ is called the **Young's modulus** of the material of the wire.

$$\therefore \mathbf{Y} = \frac{\mathbf{F}}{\mathbf{A}}\frac{\ell}{\Delta\ell}$$

The normal stress acting on a body of volume V producing volume change ΔV is usually taken as the pressure P and the modulus involved is called **Bulk modulus**

Then, Bulk modulus $B = \frac{\text{normal stress (or Pr)}}{\text{volume strain}} = \frac{F/A}{\Delta V / V}$ ie. $\mathbf{B} = \frac{\mathbf{F}}{\mathbf{A}}\frac{\mathbf{V}}{\Delta\mathbf{V}}$

If two equal an opposite forces are applied parallel to the cross sectional area of a body, there is relative displacement between the opposite faces of the body. The restoring force then, developed per unit area of the surface is called tangential stress or shearing stress.



The shearing stress can change only the shape of the body. The strain, thus produced is called the shearing strain and is the ratio of relative displacement Δr to the distance between the faces r

ie., $\frac{\Delta r}{r} = \theta$

The ratio of shearing stress to the corresponding shearing strain is called shear modulus or modulus of rigidity and is represented by G or n.

Then shear modulus $G = \frac{\text{Shearing stress}}{\text{Shearing strain}} = \frac{F/A}{\Delta r/r}$ ie., $\mathbf{G = \frac{F}{A}\frac{r}{\Delta r}}$

Thus Young's modulus $Y = \frac{F}{A}\frac{\ell}{\Delta \ell}$

Bulk modulus $B = \frac{F}{A}\frac{V}{\Delta V}$

Shear modulus $G = \frac{F}{A}\frac{r}{\Delta r}$

Gases and liquids have volume elasticity only. Then $B = \frac{F}{A}\frac{V}{\Delta V} = P\frac{V}{\Delta V} = E$

E is called modulus of elasticity of the liquid or the gas. Also $E = -P\frac{V}{\Delta V}$

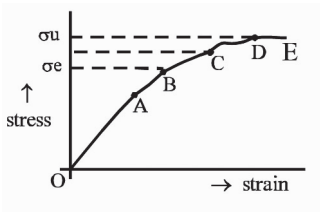
–ve sign indicates than as P increases V decreases.

Compressibility C is the reciprocal of Bulk modulus B ie; $C = \frac{1}{B} = \frac{1}{P}\frac{\Delta V}{V}$. It is the fractional change in volume per unit increase in pressure.

unit of C is $\frac{1}{Nm^{-2}}$ ie; $N^{-1}m^2$

Gases have isothermal elasticity E_I = P, and adiabatic elasticity $E_A = \gamma P$

Stretching a wire under increasing weights



σ_e - limiting stress B is elastic limit or yield point; σ_u - tensile strength or ultimate strength ; along OA - Hooke's law is obeyed

Poissons' ratio

When a wire is extended its diameter decreases. Then the Poissons' ratio

$$\sigma = \frac{\text{lateral strain}}{\text{longitudinal strain}} = \frac{\Delta r}{r} \Big/ \frac{\Delta l}{l}$$

Theoretical limits - 1 to $\frac{1}{2}$. Practical limits 0 to $\frac{1}{2}$

Work done in stretching

W = $\frac{1}{2}$ load × extension = $\frac{1}{2}Fx$; This is the PE stored in the stretched wire.

ie; $\mathbf{W} = \frac{1}{2}\mathbf{Fx}$ = PE stored

Work done /unit volume = Energy stored per unit volume = $\frac{1}{2}$ stress × strain = $\frac{1}{2}\frac{\text{stress}^2}{Y} = \frac{Y}{2}\text{strain}^2$

B. HYDROSTATICS

Density = Mass/Volume

Relative Density = $\frac{\text{Density of the substance}}{\text{Density of water (at } 4^0\text{C)}}$

Thrust = Normal force acting on a surface is Thrust. Unit $\rightarrow$ N

Pressure $= \frac{\text{Thrust}}{\text{area}}$. Unit - N/m^2, or Pascal (Pa). Dimensions - $ML^{-1}T^{-2}$

Pressure due to a fluid column of height h

$P = h\rho g$ Unit Nm^{-2} or Pa

Atmospheric Pressure P_0 is the pressure exerted by the earth's atmosphere. $P_0 = H\sigma g$ where H is the height of the atmosphere. σ is the average density of air

At sea level P_0 = 76 cm of Hg

ie, $P_0 = 0.76 \times 13.6 \times 10^3 \times 9.8 = 1.01325 \times 10^5$ Pa This is the standard atmospheric pressure.

$P_0 \cong 10^5$ Pa is called one atmosphere or one Bar.

Gauge Pressure : The pressure measured in excess of atmospheric pressure is the gauge pressure. If P is the actual pressure of a gas in a vessel and h is the manometer level difference $P = P_0 + h\rho g$. Here $P - P_0 = h\rho g$ is called gauge Pressure.

Pascal's Law : (1) Pr. applied at any point in a liquid is equally transmitted to all other points in the liquid in all direction.

(2) In a communicating column of liquid, pressure is same at all points in a horizontal plane.

Buoyancy : A body immersed fully or partially in a fluid experiences an upthrust called buoyancy. It is acting through the C.G of the displaced fluid - the centre of Buoyancy (C.B). For a floating body, *wt. of the floating body = wt. of the liquid displaced by it.* For the equilibrium of the floating body, centre of mass and centre of buoyancy must be along the same vertical line. For stable equilibrium CG lies below CB and for unstable equilibrium CG lies above CB.

Archimedis principle : When a body is fully immersed in a liquid, the body experiences a loss of wt. Then,

Apparent wt = wt in air – upthrust

Loss of wt = wt of displaced liquid = upthrust

R.D of a body $= \dfrac{\text{Wt. in air}}{\text{Loss of wt. in water}}$

R.D of a liquid $= \dfrac{\text{loss of wt. of a body in liquid}}{\text{loss of wt. of the body in water}}$

C. SURFACE TENSION

It is the property of a liquid surface to acquire minimum surface area. It is acting tangential to the surface and is perpendicular to any line imagined to be drawn on the surface. Surface tension . Unit N/m. Dimension MT^{-2}

Molecules on the surface of a liquid have greater P.E. Work has to be done in increasing the surface area. This work done will be stored in the surface in the form of P.E. Surface tension is numerically equal to work done to increase surface area by unity.

S.T = $\dfrac{\text{work}}{\text{area}}$ $\sigma = \dfrac{w}{A}$, Energy = Area × S.T

Cohesive force is the force between molecules of same substances.

Adhesive force is the force between molecules of diff.substances.

Angle of contact θ is the angle between the tangent to the liquid meniscus and the solid surface in liquid.

i) If $\theta < 90^\circ$, the liquid surface will be concave. Adhesive force > Cohesive force. Eg. water in glass

ii) If $\theta > 90^\circ$ the liquid surface will be convex, adhesive force < cohesive force; eg. Hg in glass

iii) If $\theta = 90^\circ$, the liquid surface will be horizontal adhesive force = $\frac{\text{cohesive force}}{\sqrt{2}}$

eg:- water in silver capillary

Applications :

1. Capillary rise:

$h = \frac{2T\cos\theta}{rdg}$; r is the radius of the capillary tube. If $\theta = 0$ $h = \frac{2T}{r\rho g}$ $h \propto \frac{1}{r}$ for a given liquid. graph between h and r is a rectangular hyperbola. ST in general decreases with increase of temp. ST = 0, at boiling point and also at critical temp. ST increases with temp for molten cadmium and copper.

2. Excess of Pressure:

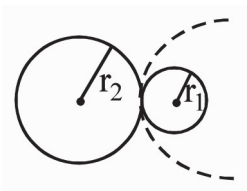
Pressure on the concave side of a surface is greater than that on the convex side. This pressure difference is called excess of pressure. The excess pressure inside a spherical bubble of radius r is given by

$$P = \frac{4T}{r}$$

A drop has only one surface, Therefore, the excess of pressure inside a spherical drop $P = \frac{2T}{r}$

For a cylindrical drop, the excess of pressure $P = \frac{T}{r}$

Radius of curvature of the interface of two bubbles of radii r_1 and r_2 ($r_1 < r_2$)



$$r = \frac{r_1 r_2}{r_2 - r_1}$$

In case of a thin liquid layer between two glass plates, the excess pressure over the concave surface.

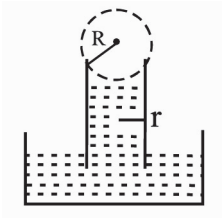
$P = \frac{2T}{d}$; d is the separation between the plates. So force required to separate the plates $F = \frac{2T}{d}A$.

Detergents decreases S.T.

Notes:

(1) In case of capillarity, the excess pressure is balanced by the hydrostatic pressure

ie, $\frac{2T}{R} = h\rho g$



Where R is the radius of curvature of the surface.

But $R = \frac{r}{\cos\theta}$ where θ is the angle of contact. r is the radius of capillary tube.

$\therefore \frac{2T\cos\theta}{r} = h\rho g$ or, $h = \frac{2T\cos\theta}{r\rho g}$

When $\theta = 0$ $R = r$

$\therefore \frac{2T}{r} = h\rho g$ $h = \frac{2T}{r\rho g}$

(2) In the case of capillaries of insufficient length $(l < h)$, there will be no overflow. At the upper end radius of the meniscus increases such that $hR = l\,r_1$ where, r_1 is the radius of curvature of the surface at the top.

D. VISCOSITY

Viscosity is the internal friction between successive layers of a fluid when it is in stream line motion or it is the property of fluid to oppose the relative motion between successive layers. The force developed is called Viscous force or Viscous drag, and is given by,

$$F = \eta A\frac{dv}{dx}, \; ; \quad \therefore \eta = \frac{F}{A\frac{dv}{dx}} \; ;$$

$\eta = F$ when A = 1, $\frac{dv}{dx} = 1$

η is called the coefficient of viscosity. Its unit is poiseuille (P*l*) in SI and poise in CGS system.

1 P*l* = 1 N/m^2/ unit velocity gradient = Nm^{-2}s or, kg m^{-1} s^{-1}

Dimensions ML^{-1}T^{-1}

1 Poise = 1 dyne / cm^2 / unit velocity gradient

1 P*l* = 10 poise (1 deca poise)

Stoke's formula :

When a spherical body of radius r and density d is moving down through a liquid of density ρ, its weight is acting in the downward direction. At the same time, the force due to buoyancy and the force due to viscosity are acting in the upward direction. When the down ward and upward forces become equal, the body attains a constant velocity called the terminal velocity v. At this condition,

wt. of the body = upthrust + viscos force

The viscos force is given by Stoke's formula as $F = 6\pi r\eta v$

$\therefore\ Vdg = V\rho g + 6\pi r\eta v$

Here $V = \frac{4}{3}\pi r^3$ the volume of the body.

Substituting and simplyfing, the terminal velocity $v = \frac{2}{9}\frac{r^2}{\eta}(d-\rho)g$

E. HYDRODYNAMICS

When a liquid is flowing through a pipe of varying area of cross section, the mass of liquid crossing each section, must be a constant in order to maintain continuous flow

ie; $a_1 v_1 \rho_1 = a_2 v_2 \rho_2$ Since the liquids are incompressible, $\rho_1 = \rho_2$; $a_1v_1 = a_2v_2$

Bernoulli's Theorem

Total energy of a small amount of liquid flowing from one point to another along a stream line is a constant. ie, Potential energy + Pressure energy + Kinetic energy = a constant.

For unit mass, $gh + \frac{P}{\rho} + \frac{1}{2}v^2 = \text{a constant}$ or $h + \frac{P}{\rho g} + \frac{v^2}{2g} = \text{a constant}$ h is gravitational head, $\frac{P}{\rho g}$ is the pressure head and $\frac{v^2}{2g}$ is the velocity head.

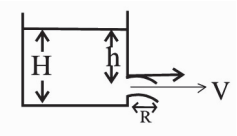
For horizontal flow h is constant, $\frac{P}{\rho g} + \frac{v^2}{2g} = \text{a constant}$ or $\frac{P}{\rho} + \frac{v^2}{2} = \text{a constant}$

As velocity increases pressure decreases.

Atomiser - Principle: As velocity increases pressure decreases

Velocity of Efflux is the velocity with which a liquid comes out of an orifice. This velocity is equal to velocity acquired by a body falling freely from a height equal to the height of liquid above the orifice

$v = \sqrt{2gh}$



Range R = $2\sqrt{h(H-h)}$; R is max. when h = H/2.

SECTION - I
QUESTIONS

SINGLE CORRECT TYPE

1. A body of mass 1 kg is fastened to one end of a steel wire of cross-sectional area 3×10^{-6} m^2 and is rotated in horizontal circle of radius 20cm with constant speed 2m/s. The elongation of the wire is ($Y = 2\times10^{11}$ N/m^2)

1) 0.33×10^{-5} m

2) 0.67×10^{-5} m

3) 2×10^{-5}m

4) 4×10^{-5} m

2. A thick rope of rubber of density 1.5×10^{3} kgm^{-3} and Young's modulus 5×10^{6} Nm^{-2}, 8 m in length is hung from the ceiling of a room, the increase in its length due to its own weight is

1) 9.6×10^{-2} m

2) 19.2×10^{-2} m

3) 9.6×10^{-3} m

4) 9.6 m

3. The length of an elastic string is 'a' meter when the longitudinal tension is 4N and b meter when the tension is 5N. The length of the string (in metre) when the longitudinal tension is 9N is

1) a - b

2) 5b - 4a

3) $2b-\frac{a}{2}$

4) 4a - 3b

4. A light spring extends 40 mm when stretched by a force of 10N and for tension upto this value, the extension is proportional to the stretching force. Two such springs are joined end-to-end and the double length spring is stretched 40 mm beyond its natural length. The total strain energy (in joule) stored in the double spring is

1) 0.05 2) 0.10

3) 0.80 4) 0.40

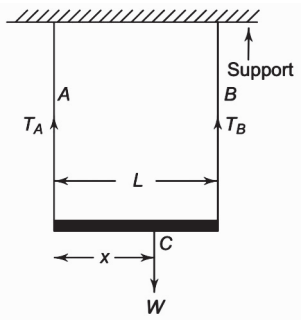
5. Figure shows a 80 cm square brass plate of thickness 0.5 cm. It is fixed at its bottom edge. What tangential force *F* must be exerted on the upper edge, so that the displacement *x* of this edge in the direction of force is 0.16 mm?

(The shear modulus of brass is 3.5×10^{10} Pa)

1) 2.8×10^{4} N 2) 3.8×10^{-4} N

3) 5×10^{5} N 4) 4×10^{-5} N

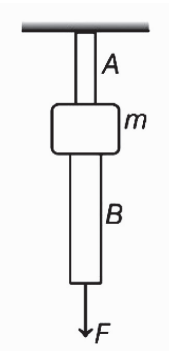
6. A light rod of length L is suspended from a support horizontally by means of two vertical wires A and B of equal length as shown in figure. The cross-sectional area of A is half that of B and the Young's modulus of A is twice that of B. A weight W is hung as shown. The value of x so that W produces equal stress in wires A and B is



1) $\frac{L}{3}$ 2) $\frac{L}{2}$

3) $\frac{2L}{3}$ 4) $\frac{3L}{4}$

7. The massless wires *A* and *B* shown in figure are made of the same material and have radii r_A and r_B, respectively. A block of mass *m* is connected between them. When the force *F* is *mg/3*, one of the wires breaks, then which of the following option is correct?



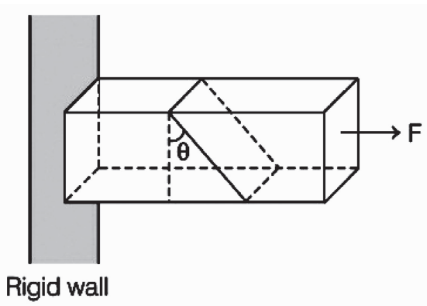
1) A wont break before *B* if $r_A > r_B$

2) A wont break before *B* if $r_A = r_B$

3) Either *A* or *B* will break if $r_A = 2\, r_B$

4) The length of *A* and *B* must be known to decide which wire will break

8. A uniform rectangular bar of area of cross-section A is fixed at one end and on other end force F is applied as shown in figure. Find the shear stress at a plane through the bar making an angle θ with the vertical as shown in figure.



1) $\frac{F}{2A}(\cos 2\theta)$ 2) $\frac{F}{2A}$

3) $\frac{F}{2A}(\sin 2\theta)$ 4) $\frac{F}{2A}\cos\theta$

9. A force *F* is required to break a wire of length *l* and radius *r*. What force is required to break a wire, of the same material, having twice the length and six times the radius?

1) *F*

2) 3*F*

3) 9*F*

4) 36 *F*

10. A U-tube contains water and methylated spirit separated by mercury. The mercury columns in the two arms are in level with 10.0 cm of water in one arm and 12.5 cm of spirit in the other. The specific gravity of spirit would be

1) 0.70

2) 0.80

3) 0.90

4) 0.60

11. A capillary tube of radius r is immersed in water and water rises in it to a height h. The mass of water in the capillary tube is 5g. Another capillary tube of radius 2r is immersed in water. The mass of water that will rise in this tube is

1) 2.5g

2) 5.0g

3) 10g

4) 20g

12. A cylindrical vessel is filled with equal amounts of weight of mercury and water. The overall height of the two layers is 29.2 cm, specific gravity of mercury is 13.6. Then the pressure of the liquid at the bottom of the vessel is

1) 29.2 cm of water

2) 29.2 / 13.6 cm of mercury

3) 4 cm of mercury

4) 15.6 cm of mercury

13. A body of density ρ is dropped from rest at a height *h* into a lake of density σ, where σ > ρ. Neglecting all dissipative forces, calculate the maximum depth to which the body sinks before returning to float on the surface.

1) $\frac{h}{\sigma-\rho}$ 2) $\frac{h\rho}{\sigma}$

3) $\frac{h\rho}{\sigma-\rho}$ 4) $\frac{h\sigma}{\sigma-\rho}$

14. A cubical block of wooden edge *l* and a density ρ floats in water of density 2ρ. The lower surface of cube just touches the free end of a massless spring of force constant *k* fixed at the bottom of the vessel. The weight ω put over the block so that it is completely immersed in water without wetting the weight is

1) $\ell(l\rho g+k)$

2) $\ell(l^2\rho g-k)$

3) $\ell\left(\frac{l\rho g}{2}+2k\right)$

4) $l\left(l^2\rho g+\frac{k}{2}\right)$

15. Two spherical soap bubbles formed in vacuum have diameters 3.0mm and 4.0mm. They coalesce to form a single spherical bubble. If the temperature remains unchanged, the diameter of the bubble so formed will be

1) 5.0 mm 2) 5.8 mm

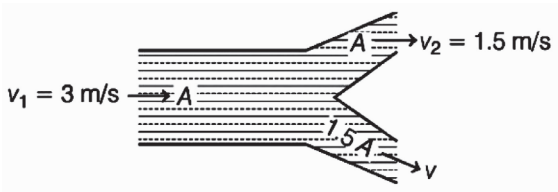
3) 6.2 mm 4) 7.0 mm

16. A water barrel having water upto a depth d is placed on a table of height h. A small hole is made on the wall of the barrel at its bottom. If the stream of water coming out of the hole falls on the ground at a horizontal distance 'R' from the barrel, then the value of d is

1) $\frac{4h^2}{R}$ 2) $\frac{2h^2}{R}$

3) $\frac{R^2}{4h}$ 4) $\frac{R^2}{2h}$

17. An incompressible liquid flows through a horizontal tube as shown in the figure. Then, the velocity of the fluid is



1) 3 m/s

2) 1.5 m/s

3) 1.0 m/s

4) 2.25 m/s

18. What is the ratio of surface energy of 1 small drop and 1 large drop if 1000 drops combine to form 1 large drop?

1) 100 : 1

2) 1000 : 1

3) 10 : 1

4) 1 : 100

STATEMENT TYPE QUESTIONS

Read the following questions and give your answer using the following options (a,b, c and d):

a) Statement I is true, Statement II is true, Statement II is correct explanation for Statement I

b) Statement I is true, Statement II is true, Statement II is not correct explanation for Statement I

c) Statement I is true, Statement II is false

d) Statement I is false, Statement II is true

19. **Statement I :** When height of a tube is less than liquid rise in the capillary tube,the liquid does not overflow

Statement II : Product of radius of meniscus and height of liquid in capillary tube always remains constant.

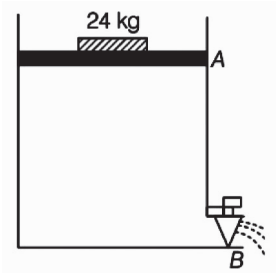
20. **Statement I :** The velocity of fall of a man jumping with a parachute first increases and then becomes constant.

Statement II : The constant velocity of fall of man is called terminal velocity.

SECTION - II QUESTIONS

NUMERICAL TYPE

21. Consider a water tank as shown in the figure. Its cross-sectional area is 0.4 m^2. The tank has an opening *B* near the bottom whose cross- sectional area is 1 cm^2. A load of 24 kg is applied on the water at the top when the height of the water level is 40 cm above the bottom, the velocity of water coming out the opening *B* is υ ms^{-1}. The value of υ, to the nearest integer, is..... (Take, g = 10 ms^{-2})



22. The largest average velocity (in ms^{-1}) of blood flow in artery of radius 2×10^{-3}, if the flow must remain laminar will be ..... (Take, viscosity of blood = 2.084×10^{-3} Pa-s and density of blood=1.04×10^{3} kgm^{-3}). (Take critical Reynold's number as 2000)

23. If a solid floats with $(1/4)^{th}$ its volume above the surface of water, then the density (in kgm^{-3}) of the solid will be .....

24. When a long glass capillary tube of radius 0.015 cm is dipped in a liquid, the liquid rises to a height of 15 cm within it. If the contact angle between the liquid and glass is close to 0^0, the surface tension of the liquid (in mN m^{-1}) to the nearest integer is (Take, $\rho_{(liquid)}$ = 900kgm^{-3}, g = 10ms^{-2})

25. A square plate of side 10 cm moves parallel to another plate with a velocity of 10 cms^{-1}. The gap between the plates is filled with water. If the viscous force is 200 dyne and viscosity of water is 0.01 poise, then their separation distance is found to be $x \times 10^{-2}$cm, then the value of *x* is .....

Chapter 09

HEAT AND THERMODYNAMICS

SYNOPSIS

Temperature : Temperature of a body is that physical quantity which indicates degree of hotness or coldness of the body.

Heat : Heat is a form of energy. The natural flow of heat is from higher temperature to lower temperature.

Different types of temperature scales

Name of scale	Symbol	Lower fixed point	Upper fixed point	No. of divisions on the scale
Celsius	^{0}C	0^{0}C	100^{0}C	100
Fahrenheit	^{0}F	32^{0}F	212^{0}F	180
Kelvin	K	273 K	373 K	100

Relationship between different scales $\frac{C}{100} = \frac{F-32}{180} = \frac{K-273}{100}$

At the following temperature different temperature scales have the same reading

– 40^{0}C = –40^{0}F

574.25^{0}F = 574.25K

Celsius scale and Kelvin scale cannot have the same reading.

The Celsius and Kelvin scale have different zero points but the same size degrees.

Therefore any temperature difference is the same on the Celsius and Kelvin scales.

If f reading correspond to faulty thermometer and t is the true value then

$$\frac{t - \text{LFP of true scale}}{(\text{UFP} - \text{LFP})\text{ of true scale}} = \frac{f - \text{LFP of faulty scale}}{(\text{UFP} - \text{LFP})\text{ of faulty scale}}$$

Thermometry

A branch of science which deals with the measurement of temperature. The linear variation in some physical properties of a substance with change in temperature is the basic principle of thermometry and this properties are defined as thermometric property which are:

1. Volume of liquid - liquid thermometers
2. Pressure of a gas - constant volume gas thermometers
3. Electrical resistance - resistance thermometers
4. Thermoemf - thermoelectric thermometer
5. Intensity of light - radiation pyrometer
6. Magnetic property - magnetic thermometer

If X is the thermometric property then the unknown temperature $t = \left(\frac{X_t - X_0}{X_{100} - X_0}\right) \times 100^0 C$

Thermal expansion in solids

The length, area and volume of a solid increases with increase in temperature as

$L_t = L_0(1 + \alpha\Delta T)$ $\alpha \rightarrow$ coefficient of linear expansion

$A_t = A_0(1 + \beta\Delta T)$ $\beta \rightarrow$ coefficient of superficial expansion

$V_t = V_0(1 + \gamma\Delta T)$ $\gamma \rightarrow$ coefficient of cubical expansion

$\alpha : \beta : \gamma = 1 : 2 : 3$

For anisotropic solids $\gamma = \alpha_X + \alpha_Y + \alpha_Z$ where α_x, α_y, and α_z represent coefficient of linear expansion along three mutually perpendicular directions.

For small change in temperature

$\Delta L = L\alpha\Delta T$, $\Delta A = A\beta\Delta T$, $\Delta V = V\gamma\Delta T$

Contraction on Heating

Some rubber like substances contract with rise in temperature because transverse vibration of atoms dominate over longitudinal vibrations which is responsible for expansion.

Effect of temperature on time period of pendulum

$$\frac{\Delta T}{T} = \frac{1}{2}\alpha\Delta t$$

If T = 1 sec Time loss/gain per day = $\frac{1}{2}\alpha\Delta t \text{ x } 86400 \sec.$

Thermal Stress in Rigid Fixed Rod

Thermal stress = $Y \propto \Delta t$

Thermal Expansion of Liquid

Since liquid can be heated only by heating the container along with the liquid the container also expands therefore apparent expansion of the liquid is not the real expansion. Thus a liquid has got 2 expansities.

$$\gamma_r = \frac{\text{Real increase in volume}}{\text{Initial Volume} \times \text{change in temp.}} = \frac{(\Delta V)_r}{V \times \Delta\theta}$$

$$\gamma_a = \frac{\text{Apparent increase in volume}}{\text{Initial Volume} \times \Delta\theta} = \frac{(\Delta V)_a}{V \times \Delta\theta}$$

$$\gamma_r = \gamma_{app} + \gamma_{vessel}$$

Anomalous Expansion of Water

In the case of water it expands on heating if its temperature is greater than 4°C. In the range 0°C to 4°C water contracts on heating and expands on cooling. This behaviour of water in the range of 0°C to 4°C is called anomalous expansion of water. Density of water is maximum a 4°C and volume minimum.

Variation of Density with Temperature

In the case of a substance it expands on heating therefore density decreases.

$$\rho = \frac{\rho_0}{1+\gamma\ \Delta\theta} = \rho_0 (1-\gamma\ \Delta\theta)$$

Expansion of Gases

At constant pressure $V_t = V_0 (1+\alpha t)$

α-Coefficient of volume expansion

At constant volume $P_t = P_0 (1+\beta t)$

β-Coefficient of pressure expansion

For an ideal gas $\alpha = \beta = \frac{1}{273}\ {}^0C^{-1}$

Specific Heat C

It is the amount of heat required to raise the temperature of unit mass of a substance through 1°C or 1K expressed in J/kg°C or J/KgK

Sp: heat capacity of water = 4200J/KgK or 4.2J/gmK = 1cal/gm°C

Thermal capacity

Amount of heat required to raise the temperature of a body by 1°C

H = mc J/°C

Water equivalent

The mass of water which has got the same thermal capacity as that of the substance

Water equivalent $= \frac{mc}{C_w}$

Dulong and petit law

Average molar sp:heat of all metals at room temperature is constant (except Be, B, C, Si)

Principle of mixtures

When two bodies at different temperature are placed in contact, heat will be transferred from a body at higher temperature to lower temperature until both reach a common temperature. Then

Heat lost by hot body = heat gained by cold body

Specific Heat of Gases (Molar Specific Heat)

Molar specific heat at constant volume C_V : The amount of heat required to raise the temperature of 1 mole of gas through 1°C or 1K keeping volume constant.

Molar specific heat at constant pressure C_p heat required to raise the temperature of 1 mole of gas through 1°C or 1K keeping pressure constant.

$C_P - C_V = R$ (Mayer's relation)

$$\frac{C_P}{C_V} = 1 + \frac{2}{f} = \gamma$$

f - degree of freedom

Latent heat

The Amount of heat required to change the state of unit mass of the substance

Latent heat of ice = 80 cal/g

Latent heat of steam = 536 cal/g

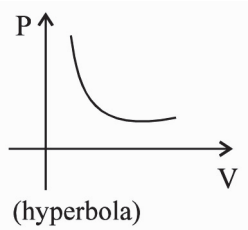
Solar constant : The amount of solar energy received in unit time by unit area of earth.

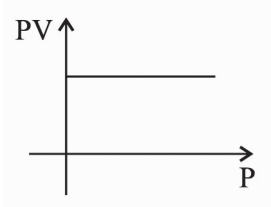
$S = 1400\ Wm^{-2}$

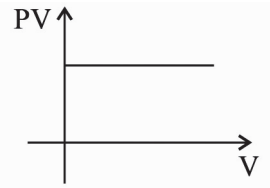
Kinetic theory of gases

Boyle's law

$V \propto \frac{1}{P}$ at constant temperature for a given mass of ideal gas



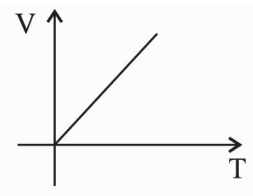




$P_1V_1 = P_2V_2$

Charle's Law

$V \propto T$ at constant pressure for a given mass of ideal gas



For an ideal gas

$P \propto T$ at constant volume (Gay-Lussac's Law)

Avagadro's hypothesis

Equal volume of all gases under the same pressure and temperature contain equal no. of molecules.

Ideal gas equation

PV = nRT

R = 8.31 J mol^{-1} k^{-1} = 1.98 cal mol^{-1} $^0C^{-1}$ = 2 cal mol^{-1} $^0C^{-1}$

$\frac{R}{N} = k$

N → Avagadro number

R → universal gas constant

k → Boltzman's constant

Kinetic theory of gases

Root mean square velocity $C_{rms} = \sqrt{\frac{C_1^2 + C_2^2 + ...C_n^2}{n}}$

$$C_{rms} = \sqrt{\frac{3RT}{M}}$$

Average speed $= C_{av} = \frac{C_1 + C_2 + ... + C_n}{n}$; $C_{av} = \sqrt{\frac{8RT}{\pi M}}$

Most probable speed $C_{mp} = \sqrt{\frac{2RT}{M}}$

Mean free path $\lambda = \frac{1}{\sqrt{2}\pi d^2 n}$; $\lambda \ \alpha \frac{T}{P}$

d → diameter of molecule

n → no. of molecules per unit volume

Pressure exerted by a gas

$$P = \frac{1}{3}\rho C_{rms}^2$$

KE of a gas : - KE is equally divided between degree of freedoms (Equipartition theorem)

KE of a molecule / degree of freedom = $\frac{1}{2}kT$

KE of one mole / degree of freedom = $\frac{1}{2}RT$

Total kinetic energy for one molecule = $\frac{n}{2}kT$

Total kinetic energy for one mole = $\frac{n}{2}RT$

where 'n' is the no. of degrees of freedom.

THERMODYNAMICS

Thermodynamics deals with processes involving heat, work and internal energy.

System: It is a portion of matter under consideration.

Surroundings: Anything outside the system which has got some bearing on the behaviour of the system.

1. Open system → can exchange matter and energy with surroundings

2. Closed system → can exchange only energy

3. Isolated system → cannot exchange matter and energy.

First law of thermodynamics

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

$\Delta Q \rightarrow$ heat absorbed or released

$\Delta U \rightarrow$ change in internal energy

$\Delta W \rightarrow$ work done

→ work done by the system is taken as positive

→ work done on the system is taken as negative

→ heat absorbed is taken as positive

→ heat released is taken as negative

Work done by a thermodynamic system

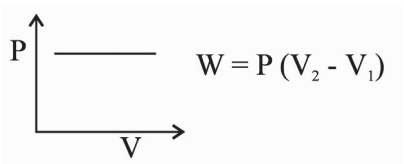
$$W = \int_{V_1}^{V_2} PdV$$

Thermodynamic Processes

Thermodynamic equilibrium → If the system is in mechanical equilibrium, thermal equilibrium and chemical equilibrium it is said to be in thermodynamic equilibrium.

Quasistatic Process → A process in which all the states through which the system passes can be considered as thermodynamic equilibrium is known as a quasistatic process.

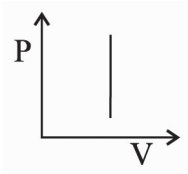
Isobaric Process - Constant Pressure



$W = P(V_2 - V_1)$

Isochoric Process - Constant Volume

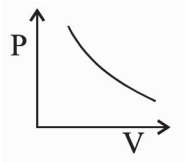
Work Done = 0



Isothermal Process - Constant Temperature

$\Delta U = 0$; $\Delta Q = W$

PV = constant

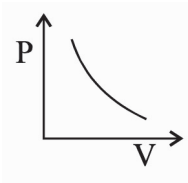


$$W = 2.303nRT\log(V_2/V_1) = 2.303nRT\log(P_1/P_2)$$

Isothermal bulkmodulus of elasticity = P

Adiabatic Process → No heat exchange between system and surroundings.

$\Delta Q = 0,\ \Delta U = -W$



Equation of state

PV^{γ} = constant

$TV^{\gamma-1}$ = constant

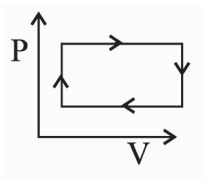
$T^{\gamma}P^{1-\gamma}$ = constant

Work done = $W = \dfrac{nR}{\gamma - 1}(T_1 - T_2)$

→ The slope of adiabatic is γ times that of isothermal.

→ Adiabatic bulkmodulus of elasticity = γP

Cyclic Process



$\Delta U = 0;\ \Delta Q = W$

Work done in cyclic process is the area of cyclic loop.

Critical temperature: Temperature below which the gas can be liquified by the mere application of pressure alone.

Critical Pressure: The minimum pressure that should be applied to the gas at its critical temperature in order to liquify it.

Critical Volume: Volume at critical temperature and pressure.

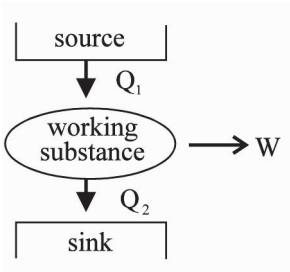
Triple point → It is a point on the P - T plane at which the solid, liquid and vapour states of a substance co exist in equilibrium.

Second law of thermodynamics

Kelvin statement: It is impossible to get a continuous supply of work from a body by cooling it to a temperature lower than its surroundings.

Clausius statement: It is impossible for a self acting machine to transfer heat from a body at a lower temperature to a body at a higher temperature.

Carnot's heat engine

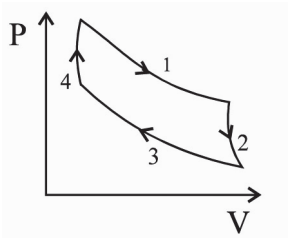


$$W = Q_1 - Q_2$$

$$\eta = \frac{W}{Q_1} = 1 - \frac{Q_2}{Q_1}$$

$$\eta = 1 - \frac{T_2}{T_1}$$

Carnot's cycle:



1. Isothermal expansion
2. Adiabatic expansion
3. Isothermal compression
4. Adiabatic compression

Refrigerator

Coefficient of performance $\beta = \frac{Q_2}{W} = \frac{T_2}{T_1 - T_2}$

Heat Transfer

There are three modes of heat transfer

1. Conduction 2. Convection 3. Radiation

Conduction

In conduction heat flows from a region of high temperature to a region of low temperature with out the transport of matter. Heat imparted to any part at a body sets the molecules of that part in to more energetic vibrations. These molecules transmit the vibrations to their neighbours and heat travels along the body from molecules to molecules.

Convection :

Heat flows along with the transport of matter. It is possible only in fluids. Trade winds, Land breeze and sea breeze and monsoon are due to convection.

Radiation :

In radiation heat does not require any material medium. It travels in the form of electromagnetic radiation

Law of heat conduction

$$\frac{\Delta Q}{\Delta t} = kA\left(\frac{\Delta T}{\Delta x}\right)$$

A $\rightarrow$ cross sectional area of the slab

$\Delta x \rightarrow$ thickness of slab

$\Delta T \rightarrow$ difference in temperature between ends

$\frac{\Delta Q}{\Delta t} \rightarrow$ rate of heat flow

$k \rightarrow$ thermal conductivity

$\frac{\Delta T}{\Delta x} \rightarrow$ temperature gradient

Thermal conductance $= \frac{KA}{l}$;

Thermal resistance $= \frac{l}{KA}$

If two conductors are connected in series equivalent thermal resistance $R = R_1 + R_2$

Connected in parallel $\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2}$

Properties of heat radiations

→ Radiant heat travels with the speed of light

→ It travels along a straight line

→ It can be reflected as well as refracted like light rays

→ Intensity of heat radiations decreases in inverse square proportionality with distance

→ It shows the phenomenon of interference, diffraction and polarisation

Perfectly black body : A body which absorbs all radiation incident on it.

Absorptive power (a) : The ratio of radiant energy absorbed to the total energy incident on it.

$a \le 1$

a = 1 for perfectly black body

Emissive power : Energy emitted per unit area per unit time by a body

Kirchoff's law :

$\frac{\text{emissive power}}{\text{absorptive power}} = \text{constant} \Rightarrow$ a good emitter is a good absorber

Stefan's law

Radiant energy emitted by a black body per unit area per second is proportional to fourth power of absolute temperature T.

$E \propto T^4 \; ; E = \sigma T^4$

$\sigma = 5.68 \times 10^{-8} \; Wm^{-2}K^{-4}$

Stefan - Boltzman law

Net radiant energy lost from a black body per unit area per unit time, $E \propto \left(T^4 - T_0^4\right), T_0 \rightarrow$, temp of surroundings

Wien's displacement law

The wavelength of maximum spectral intensity is inversely proportional to the absolute temperature of the body

$\lambda_m \propto \frac{1}{T}; \lambda_m T = b$ Wien's constant

b = 0.29 cm K

Newton's law of cooling

When the temperature difference between the body and its surroundings is not very large, then the rate of cooling is directly proportional to the temperature difference.

$$\frac{\theta_1 - \theta_2}{t} \propto \left(\frac{\theta_1 + \theta_2}{2}\right) - \theta_0$$

$\theta_1 \rightarrow$ initial temperature of body

$\theta_2 \rightarrow$ final temperature of the body

t $\rightarrow$ time taken to cool from θ_1 to θ_2

$\theta_0 \rightarrow$ temperature of surroundings

SECTION - I
QUESTIONS

SINGLE CORRECT TYPE

1. An iron piece is heated from 30^0C to 90^0C. Find the change in its temperature on the Fahrenheit and the Kelvin scale.

1) 108 and 60

2) 60 and 108

3) 100 and 50

4) 50 and 40

2. On an X temperature scale, water freezes at -125.0^0 X and boils at 375.0^0 X. On a Y temperature scale, water freezes at -70.0^0Y and boils at -30.0^0Y. The value of temperature on X-scale equal to the temperature of 50.0^0Y on Y-scale is

1) 455.0^0X

2) -125.0^0X

3) 1375.0^0X

4) 1500.0^0X

3. An isosceles triangle is formed with a rod of length ℓ_1 and coefficient of linear expansion α_1 for the base and two thin rods each of length ℓ_2 and coefficient of linear expansion α_2 for the two pieces. If the distance between the apex and the midpoint of the base remain unchanged as the temperature is varied, then $\frac{\ell_1}{\ell_2} =$

1) $2\frac{\alpha_2}{\alpha_1}$ 2) $2\sqrt{\frac{\alpha_2}{\alpha_1}}$

3) $\sqrt{\frac{\alpha_1}{\alpha_2}}$ 4) $4\sqrt{\frac{\alpha_1}{\alpha_2}}$

4. A glass flask of volume 1 litre at 0^0C is filled, level full of mercury at this temperature. The flask and mercury are now heated to 100^0C. How much mercury will spill out, if coefficient of volume expansion of mercury is 1.82×10^{-4}/°C and linear expansion of glass is 0.1×10^{-4}/°C respectively?

1) 21.2 cc 2) 15.2 cc

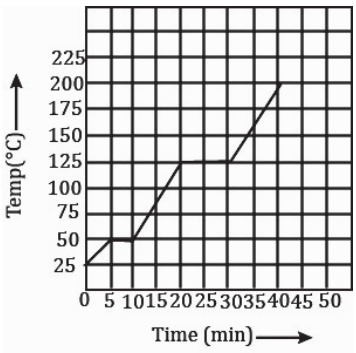
3) 1.52 cc 4) 2.12 cc

5. Two liquids are at temperature 20^0C and 40^0C. When same mass of both of them is mixed, the temperature of the mixture is 32^0C. What is the ratio of their specific heat:

1) $\frac{1}{3}$ 2) $\frac{2}{3}$

3) $\frac{1}{5}$ 4) $\frac{2}{5}$

6. The graph shown in the figure represent change in the temperature of 5kg of a substance as it absorbs heat at a constant rate of 63 kJ min^{-1}. The latent heat of vaporization of the substance is:



1) 630 kJ kg^{-1}

2) 126 kJ kg^{-1}

3) 84 kJ kg^{-1}

4) 12.6 kJ kg^{-1}

7. 10 kg of ice at -10^{0}C is mixed with 40 kg of water at 45^{0}C. The final temperature of mixture is:

(specific heat of ice = 2100 J/kg -k)

1) 19^{0}C 2) 17^{0}C

3) 15^{0}C 4) 13^{0}C

8. 5g of ice at 0^{0}C is kept in a calorimeter of water equivalent 5g. How much heat should be supplied to the apparatus to evaporate the water thus formed? (Neglect loss of heat)

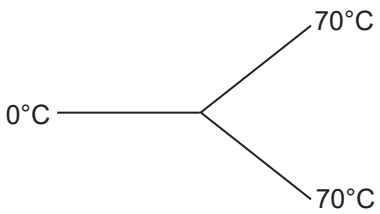
1) 4100 cal

2) 7200 cal

3) 13600 cal

4) 8200 cal

9. Three rods of same material and of equal cross sectional area and length have been connected together as shown in the figure.



The temperature of the junction of the rods approximately is

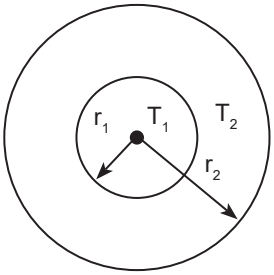
1) 35^{0}C

2) 47^{0}C

3) 51^{0}C

4) 57^{0}C

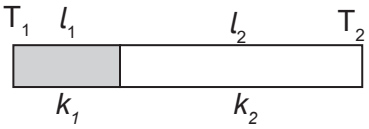
10. The figure shows a system of two concentric spheres of radii r_1 and r_2 and kept at temperature T_1 and T_2 respectively. The radial rate of flow of heat in a substance between the two concentric spheres is proportional to:



1) $(r_2 - r_1)/r_1r_2$ 2) $\text{In}\left(\frac{r_2}{r_1}\right)$

3) $\frac{r_1r_2}{(r_2 - r_1)}$ 4) $(r_2 - r_1)$

11. One end of a thermally insulated rod is kept at a temperature T_1 and the other at T_2. The rod is composed of two sections of lengths l_1 and l_2 and thermal conductivities k_1 and k_2 respectively. The temperature at the interface of the two sections is



1) $(k_2l_2T_1 + k_1l_1 T_2) / (k_1l_1 + k_2l_2)$

2) $(k_2l_2T_1 + k_1l_1T_2)/(k_2l_1 + k_1l_2)$

3) $(k_1l_2T_1 + k_2l_1T_2)/ (k_1l_2 + k_2l_1)$

4) $(k_1l_1T_1 + k_2l_2T_2)/(k_1l_1 + k_2l_2)$

12. Hot water cools from 60^{0}C to 50^{0}C in the first 10 minutes and to 42^{0}C in the next 10 minutes. The temperature of the surroundings is:

1) 25^{0}C 2) 10^{0}C

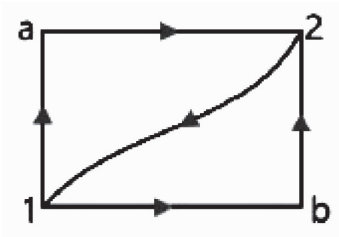
3) 15^{0}C 4) 20^{0}C

13. The power radiated by a black body is P and it radiates maximum energy at wavelength λ_0. If the temperature of the blackbody is now changed so that it radiates maximum energy at wavelength $\frac{3}{4}\lambda_0$, the power radiated by it becomes nP. The value of *n* is

1) $\frac{256}{81}$ 2) $\frac{4}{3}$

3) $\frac{3}{4}$ 4) $\frac{81}{256}$

14. When a system is taken from state 1 to 2 along the path 1a2 it absorbes 50 cal of heat and work done is 20 cal. Along the path 1b2, Q=36 cal. What is the work done along 1b2?



1) 56 cal 2) 66 cal

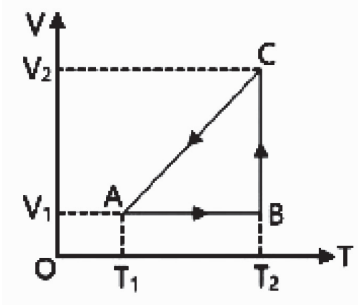
3) 16 cal 4) 6 cal

15. The ratio of work done by an ideal diatomic gas to the heat supplied to the gas in an isobaric process is

1) $\frac{5}{7}$ 2) $\frac{3}{5}$

3) $\frac{2}{7}$ 4) $\frac{5}{3}$

16. A cyclic process for 1 mole of an ideal gas is shown in figure in the V-T, diagram. The work done in AB, BC and CA respectively



1) $0, RT_2 \ln\left(\frac{V_1}{V_2}\right), R(T_1 - T_2)$

2) $R(T_1 - T_2), 0, RT \ln\frac{V_1}{V_2}$

3) $0, RT_2 \ln\left(\frac{v_2}{v_1}\right), R(T_1 - T_2)$

4) $0, RT_2 \ln\left(\frac{V_2}{V_1}\right), R(T_2 - T_1)$

17. For diatomic gas the relation between pressure of a gas and temperature T is given by $P \propto T^C$. Then value of C will be: (For adiabatic process)

1) $\frac{7}{5}$ 2) $\frac{2}{7}$

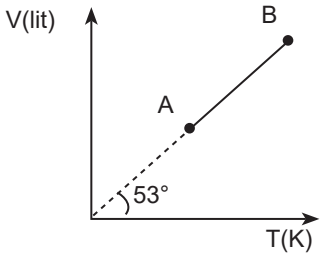
3) $\frac{5}{7}$ 4) $\frac{7}{2}$

18. A Carnot engine having efficiency $1/10$ as heat engine, is used as a refrigerator. If the work done on the system is 10J, the amount of heat rejected to the surrounding is

1) 99J 2) 90J

3) 1J 4) 100J

19. V-T curve for 2 moles of a gas is straight line as shown in the graph here. Find the pressure of gas at A.



1) 125 N/m^2 2) 1.25×10^4 N/m^2

3) 225 N/m^2 4) 2.25×10^4 N/m^2

20. A vessel of volume 8 litre contains an ideal gas at 300K and 2 atm pressure. The gas is allowed to leak till pressure becomes 125 kpa. Calculate amount of moles which leak out, if temperature remains constant-

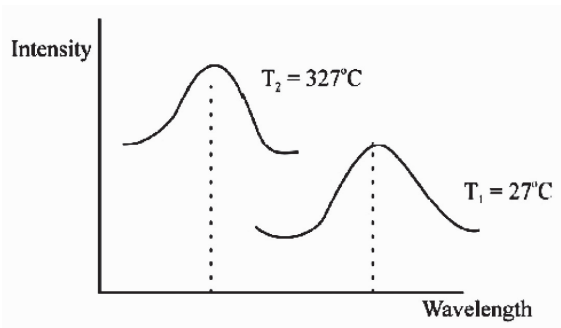
1) 0.4 moles 2) 0.24 moles

3) 0.34 moles 4) 0.14 moles

SECTION - II QUESTIONS

NUMERICAL TYPE

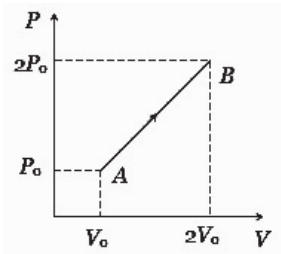
21. The spectrum of black body at two temperature 27^{0}C and 327^{0}C is shown. If A_1 and A_2 are the areas under the two curves respectively and λ_1 and λ_2 are wavelengths corresponding to maximum emission then A_2/A_1 is equal to



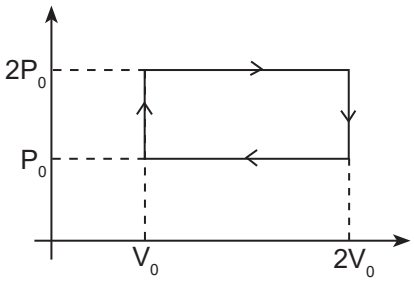
22. The density of upper atmosphere is very low of the order of 10^{14}m^{-3}. Assuming the average diameter of air molecule as $\sqrt{\frac{35}{\pi}}A^0$, the approximate mean free path of air molecules is (in km)

23. A vessel contains 28gm of N_2 and 32 gm of O_2 at temperature T = 1800K and pressure 2atm. Find the pressure if N_2 dissociates 30% and O_2 dissociates 50% if temperature remains constant. (in atm)

24. The PV diagram of 2g of helium gas for a certain process A → B is shown. The heat given to the gas during the process A → B is nP_0V_0, then the value of n is



25. The P-V diagram shown here represents the thermodynamic cycle of an engine, operating with an ideal monoatomic gas. The amount of heat extracted from the source in a single cycle is $\frac{n}{2}P_0V_0$. The value of n is



Chapter 10

OSCILLATIONS

SYNOPSIS

1. Periodic Motion

Motion that repeats in regular intervals of time

Eg: Revolution of Earth around the sun

2. Oscillatory or vibratory motion

A periodic to and fro motion about a mean position

Eg: Motion of pendulum of a clock

3. Simple Harmonic Motion (S.H.M)

It is an oscillatory motion in which the restoring force (F) acts on the body at any position (x) from the mean position,

$$F \alpha -x$$

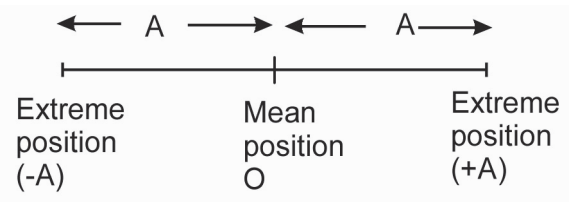
$$F = -kx$$

Where k is force constant and its unit is N/m

4. Terms related with oscillatory motion

(i) Amplitude (A)

Maximum displacement from the mean position



(ii) Time period (T)

Time taken for one complete oscillation. SI unit, seconds(s)

(iii) Frequency (υ)

No of oscillations in unit time $\upsilon = \frac{1}{T}$ SI unit: s^{-1} or Hertz (Hz)

(iv) Angular frequency (ω)

$\omega = 2\pi\upsilon = \frac{2\pi}{T}$ SI unit: rad/s

(v) Phase

It represents the state of vibration of an oscillating body

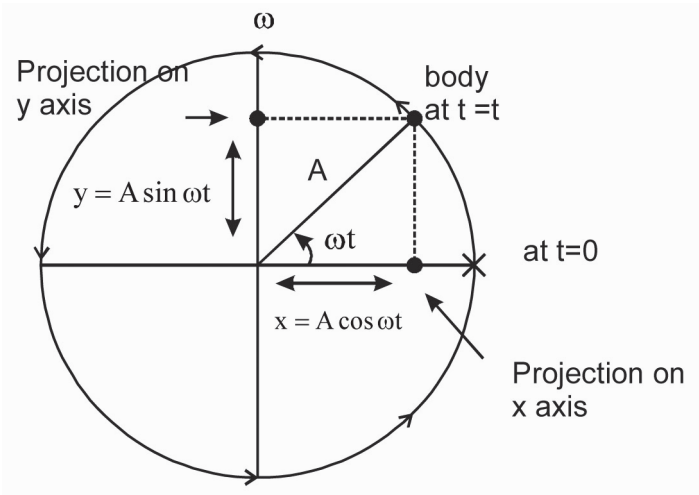
It is represented as the argument of sine or cosine function

Eg: in $Y = A\sin(\omega t + \phi_0), (\omega t + \phi_0)$ is the phase

Initial phase or epoch is the phase of the particle at t = 0

5. Uniform circular motion and simple harmonic motion

- Uniform circular motion is a periodic motion. But it is not simple harmonic
- Projection of a body in uniform circular motion about any one of the diameter of the circle is an example for SHM



(i) Displacement in SHM

Here, displacement can be written as

- $\boxed{Y = A\sin\omega t}$: If the particle starts from the mean position. or,
- $\boxed{x = A\cos\omega t}$: If the partice starts from the extreme position.

In general, position of the body in SHM from the mean position is

- $\boxed{Y = A\sin(\omega t \pm \phi_0)}$

Y - displacement from the mean position at a time t

A - Amplitude $(\omega t \pm \phi_0)$ - Phase at time t

ϕ_0 - Initial phase (Phase at t = 0) or epoch

(ii) Velocity in SHM

If $Y = A\sin\omega t$

$$V = \frac{dY}{dt}$$

$$\boxed{V = A\omega\cos\omega t}$$

or

$$\boxed{V = \omega\sqrt{A^2 - Y^2}}$$ Note: V-Y graph is an ellipse

(iii) Acceleration in SHM

If $V = A\omega\cos\omega t$

$$a = \frac{dV}{dt}$$

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

or

$$\boxed{a = -\omega^2 Y}$$

Note: a-Y graph is a straight line with slope $-\omega^2$

(iv) Force in SHM

Since, F = ma

$$\therefore \boxed{F = -m\omega^2 A\sin\omega t}$$

or

$$\boxed{F = -m\omega^2 Y}$$

Since $-kY = -m\omega^2 y$

$k = m\omega^2$

(v) Energy in SHM

(i) Potential Energy (U)

Since F = -kY

$$\therefore \boxed{U = \frac{1}{2}m\omega^2 Y}$$

(ii) Kinetic Energy (K)

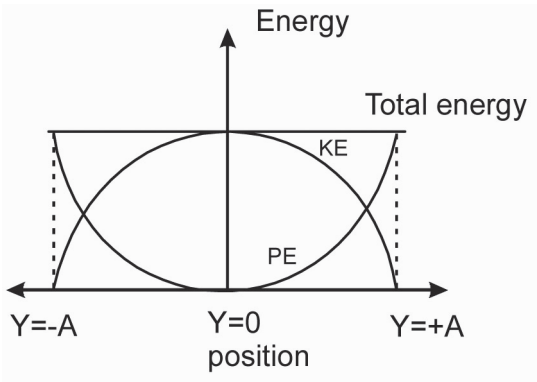
$$K = \frac{1}{2}mv^2 \quad v = \omega\sqrt{A^2 - Y^2}$$

$$\boxed{K = \frac{1}{2}m\omega^2\left(A^2 - Y^2\right)}$$

(iii) Total Energy (TE)

TE = U + K

$$\boxed{TE = \frac{1}{2}m\omega^2 A^2}$$



Quantity	Left extreme (Y = -A)	Mean (Y = 0)	Right extreme (Y = +A)
Displacement	-A (maximum)	0 (minimum)	+A (maximum)
Velocity	0 (minimum)	$A\omega$ (maximum)	0 (minimum)
Acceleration	$\omega^2 A$ (maximum)	0 (minimum)	$-\omega^2 A$ (maximum)
PE	$\frac{1}{2}m\omega^2 A^2$	0 (minimum)	$\frac{1}{2}m\omega^2 A^2$ (maximum)
KE	0 (minimum)	$\frac{1}{2}m\omega^2 A^2$ (maximum)	0 (minimum)
TE	$\frac{1}{2}m\omega^2 A^2$ (constant)	$\frac{1}{2}m\omega^2 A^2$ (constant)	$\frac{1}{2}m\omega^2 A^2$ (constant)

- At $Y = \pm\frac{A}{2}$, $U = \frac{TE}{4}$, $K = \frac{3}{4}TE$

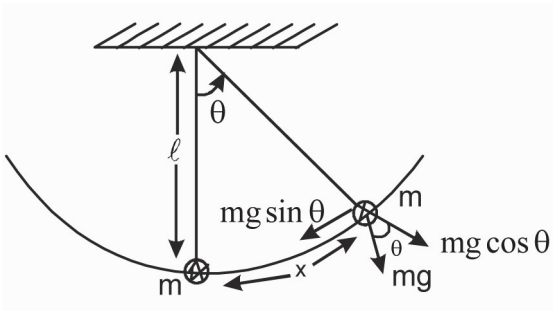
- At $y = \frac{\pm A}{\sqrt{2}}$, $U = K = \frac{TE}{2}$

6. Differential Equation of SHM

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

Where, $\omega^2 = \frac{k}{m}$

7. Simple Pendulum and its time period



Restoring force $F = -mg\sin\theta$

for small θ, $\sin\theta \approx \theta$, $\theta = \frac{x}{\ell}$

$F = -mg\theta$

$F = -mg\frac{x}{\ell}$ ------(1)

$\therefore F\alpha - x(SHM)$

In SHM $F = -m\omega^2 x$ -----(2)

(1) = (2)

$\omega = \sqrt{\frac{g}{\ell}}$

$$\boxed{T = 2\pi\sqrt{\frac{\ell}{g}}}$$

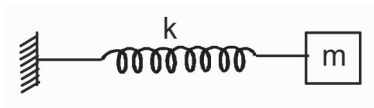
$$T \propto \sqrt{\ell}$$

- Graph between T^2 and ℓ is a straight line with slope $\frac{4\pi^2}{g}$
- $T \propto \frac{1}{\sqrt{g}}$
- T is independent of m

Second's Pendulum: Its a simple pendulum with time period two seconds. On the surface of the earth, $\left(g \approx 10\,m/s^2\right)$

$$T = 2\pi\sqrt{\frac{\ell}{g}}; \qquad 2 = 2\pi\sqrt{\frac{\ell}{10}}; \qquad \therefore \ell \approx 1m$$

8. Spring pendulum



Here restoring force, $F = -kx$ .....(1)

$$F\alpha - x\,(SHM)$$

In SHM $F = -m\omega^2 x$ -----(2)

(1) = (2)

$$\omega = \sqrt{\frac{k}{m}}$$

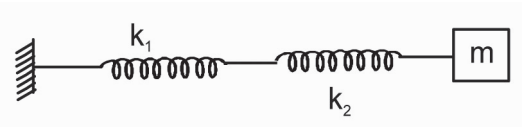
$$\boxed{T = 2\pi\sqrt{\frac{m}{k}}}$$

Here,

- $T \propto \sqrt{m}$
- $T \propto \frac{1}{\sqrt{k}}$
- T is independent of g

9. Combination of springs

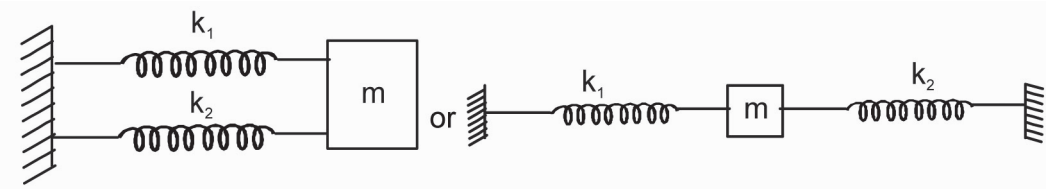
(i) Series combination



$$\frac{1}{K_{eff}} = \frac{1}{K_1} + \frac{1}{K_2}$$

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

(ii) Parallel combination



$$K_{eff} = K_1 + K_2$$

$$\therefore \; T = 2\pi\sqrt{\frac{m}{K_{eff}}}$$

SECTION - I
QUESTIONS

SINGLE CORRECT TYPE

1. The equation of a particle of mass 1g is $\frac{d^2x}{dt^2}+\pi^2x=0$ where x is displacement (in m) from mean position. The frequency of oscillation is (in Hz)

1) $\frac{1}{2}$

2) 2

3) $5\sqrt{10}$

4) $\frac{1}{5\sqrt{10}}$

2. Which of the following equations does not represent a simple harmonic motion

1) y = a sin ωt

2) y = a cos ωt

3) y = a sin ωt + b cos ωt

4) y = a tan ωt

3. A particle executes simple harmonic motion with a time period of 16s. At time t = 2s, the particle crosses the mean position while at t = 4s, its velocity is $4ms^{-1}$. The amplitude of motion in metre is

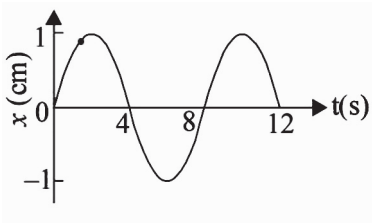
1) $\sqrt{2}\pi$

2) $16\sqrt{2}\pi$

3) $24\sqrt{2}\pi$

4) $32\sqrt{2}/\pi$

4. The x-t graph of a particle undergoing simple harmonic motion is shown below. The acceleration of the particle at t = 4/3 s is



1) $\frac{\sqrt{3}}{32}\pi^2 cm/s^2$

2) $\frac{-\pi^2}{32} cm/s^2$

3) $\frac{\pi^2}{32} cm/s^2$

4) $-\frac{\sqrt{3}}{32}\pi^2 cm/s^2$

5. A body performs SHM with an amplitude A. At a distance $A/\sqrt{2}$ from the mean position, the correct relation between KE and PE is

1) $KE=\frac{PE}{2}$ 2) $KE=\sqrt{2}PE$

3) KE = PE 4) $KE=\frac{PE}{\sqrt{2}}$

6. A horizontal spring block of mass M executes simple harmonic motion with an amplitude A. When the block is passing through its equilibrium position an object of mass m is put on it and the two move together. Find new amplitude of vibration.

1) $A\sqrt{\frac{M}{M+m}}$ 2) A

3) $\sqrt{\frac{M+m}{M}}$ 4) $\sqrt{\frac{(M+m)^2}{M}}A$

7. For a simple harmonic motion, match the column I and column II.

Column I		Column II	
a.	Velocity-time graph	p.	Straight line
b.	Acceleration-velocity graph	q.	Circle
c.	Acceleration-displacement graph	r.	Ellipse
d.	Acceleration-time graph	s.	Sinusoidal curve

1) a-s; b-r; c-p; d-s

2) a-r; b-s; c-p; d-q

3) a-s; b-p; c-r; d-q

4) a-s; b-q; c-p; d-s

8. A spring of spring constant 150 N/m is divided into 5 equal parts, 3 of them are connected in parallel with a block of mass 5kg. Then time period of oscillation of the system is:

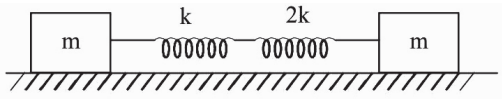
1) $\frac{5}{\sqrt{2}}$ second

2) $\frac{2}{3\sqrt{5}}$ second

3) $5\sqrt{2}$ second

4) $\frac{3\sqrt{2}}{5}$ second

9. A system is shown in the figure. The time period for small oscillations of the two blocks will be



1) $2\pi\sqrt{\frac{3m}{k}}$

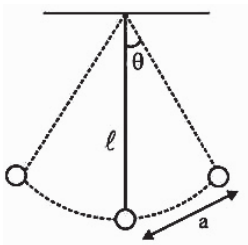
2) $2\pi\sqrt{\frac{3m}{2k}}$

3) $2\pi\sqrt{\frac{3m}{4k}}$

4) $2\pi\sqrt{\frac{3m}{8k}}$

10. In each of the following questions, a statement of Assertion (A) is given followed by a corresponding statement of Reason (R) just below it. Of the statements mark the correct answer as

Statement I : The motion of a simple pendulum is simple harmonic only for $a << \ell$.



Statement II : Motion of a simple pendulum is SHM for small angular displacement.

1) Statement -I is True, Statement - II is True; Statement - II is a correct explanation for Statement - I

2) Statement - I is True, Statement - II is True; Statement - II is NOT a correct explanation for Statement - I

3) Statement - I is True, Statement - II is False

4) Statement - I is False, Statement - II is True

11. The frequency of a simple pendulum is n oscillations per minute while that of another is (n + 1) oscillations per minute. The ratio of length of first pendulum to the length of second is

1) $\frac{n}{n+1}$

2) $\left(n+\frac{1}{n}\right)^2$

3) $\left(\frac{n+1}{n}\right)^2$

4) $\left(\frac{n}{n+1}\right)^2$

12. **Statement -1 :** When a girl sitting on a swing stands up, the periodic time of the swing will increase

Statement -2 : In standing position of the girl, the length of the swing will decrease

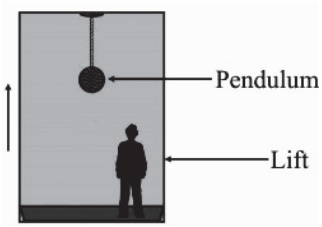
1) Statement -1 is True, Statement - 2 is True; Statement - 2 is a correct explanation for Statement - 1

2) Statement - 1 is True, Statement - 2 is True; Statement - 2 is NOT a correct explanation for Statement - 1

3) Statement - 1 is True, Statement - 2 is False

4) Statement - 1 is False, Statement - 2 is True

13. A man measures the period of a simple pendulum inside a stationary lift and finds it to be T s. If the lift accelerates upwards with an acceleration g/4, then the period of the pendulum will be



1) T

2) $\frac{T}{4}$

3) $\frac{2T}{\sqrt{5}}$

4) $2T\sqrt{5}$

14. The string of a simple pendulum is replaced by a uniform rod of length L and Mass M while the bob has a mass m. It is allowed to make small oscillations. Its time period is

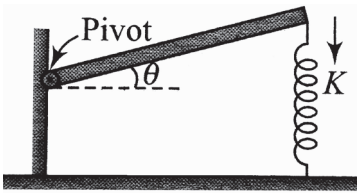
1) $2\pi\sqrt{\left(\frac{2M}{3m}\right)\frac{L}{g}}$

2) $2\pi\sqrt{\frac{2(M+3m)L}{3(M+2m)g}}$

3) $2\pi\sqrt{\frac{(M+m)}{(M+3m)}\frac{L}{g}}$

4) $2\pi\sqrt{\frac{(2m+M)}{3(M+2m)}\frac{L}{g}}$

15. A horizontal rod of mass m and length L is pivoted at one end. The rod's other end is supported by a spring of force constant k. The rod is displaced by a small angle θ from its horizontal equilibrium position and released. The angular frequency of the subsequent simple harmonic motion is



1) $\sqrt{\frac{3k}{m}}$

2) $\sqrt{\frac{k}{3m}}$

3) $\sqrt{\frac{3k}{m}+\frac{3g}{2L}}$

4) $\sqrt{\frac{k}{m}}$

16. A uniform disc of radius 5 cm and mass 200g is fixed at its centre to a metal wire, the other end of which is fixed with a clamp. The hanging disc is rotated about the wire through an angle and is released. If the disc makes torsional oscillations with time period 0.2s find torsional constant of wire

1) 25 kg m^2/s^2

2) 2.5 kg m^2/s^2

3) 0.25 kg m^2/s^2

4) 250 kg m^2/s^2

17. A moving particle of mass m has one - dimensional potential energy $U(x) = ax^2 + bx^4$, where 'a' and 'b' are positive constants. The angular frequency of small oscillations about the minima of the potential energy is equal to

1) $\pi\sqrt{\frac{a}{2b}}$

2) $2\sqrt{\frac{a}{m}}$

3) $\sqrt{\frac{2a}{m}}$

4) $\sqrt{\frac{a}{2m}}$

18. A particle is performing S.H.M. with acceleration $a = 8\pi^2 - 4\pi^2 x$ where x is coordinate of the particle w.r.t. the origin. The parameters are in S.I. units. The particle is at rest at x = –2 at t = 0

1) coordinate of the particle w.r.t. origin at any time t is $2 - 4\cos 2\pi t$

2) coordinate of the particle w.r.t. origin at any time t is $-2 + 4\sin 2\pi t$

3) coordinate of the particle w.r.t. origin at any time t is $-4 + 2\cos 2\pi t$

4) the coordinate cannot be found because mass of the particle is not given

19. The displacement of a simple harmonic motion is given by:

$$y = 5\sin\left(\omega t + \frac{\pi}{6}\right) + \sqrt{3}\sin\left[\omega t + \frac{2\pi}{3}\right].$$

Then resultant displacement is given by:

1) $2\sqrt{7}$ m

2) 4 m

3) $\frac{5}{\sqrt{2}}$ m

4) 9 m

20. A pendulum of length 'ℓ' is suspended from the roof of a lift. When the lift is stationary, T is the time period. When the lift moves with an acceleration 'a' time period becomes $\left(\frac{4T}{5}\right)$. What will be the value of 'a'?

1) $\frac{9g}{16}$ upwards

2) $\frac{9g}{16}$ downwards

3) $\frac{3g}{5}$ upwards

4) $\frac{3g}{5}$ downwards

SECTION - II
QUESTIONS

NUMERICAL TYPE

21. A particle of mass 10 grams is executing simple harmonic motion with an amplitude of 1.0 m and periodic time of $(\pi/5)$ seconds. The maximum value of the force acting on the particle is

22. A mass m attached to a spring oscillates with a period of 3s. If the mass is increased by 1 kg the period increases by 1s. Then find 7m.

23. A particle performs S.H.M. with time period T. The time taken by the particle to move from half the amplitude to the maximum displacement is T/n. Find n

24. A body of mass 36gram makes SHM with a time period 12 second and amplitude 13cm. At t = 0, displacement is 13cm. Force acting on the body in Dyne at t = 2 s is $\left[\pi^2 = 10\right]$

25. In a certain oscillatory system (particle is performing SHM), the amplitude of motion is 5m and the time period is 4s. The minimum time taken by the particle for passing between points, which are at distances of 4m and 3m from the centre and on the same side of it is t. Find 90t.

Chapter 11

WAVES

SYNOPSIS

When a disturbance is made in an elastic medium the particles of the medium are disturbed successively and put into SHM. At any instant the disturbed particles are in different states of SHM. A line joining all the disturbed particles at an instant will form a wave.

The length of a full wave is called wave length $(\lambda)\lambda$ is defined as the distance between two successive particles on a wave having the same state of vibration.

λ is also defined as the distance moved by the wave in the time taken for one SHM, called the time period (T).

Two particles on a wave separated by λ distance have a difference of one SHM, equivalent to a phase difference of (2π) radians or 360°.

ie, if the distance between two particles on a wave is λ. they have a phase difference of (2π) radians.

A transverse wave is produced by alternate crest and trough. Distance between successive crests or successive troughs is λ.

Distance from a crest to next trough $= \lambda/2$

Any vibrating body is a source of sound. The sound energy produced by the source moves in any medium in the form of a longitudinal wave and it will be a progressive wave. To move, a sound wave requires a material medium and sound wave does not move in vacuum.

If ν is the frequency of the source and λ is the wave length, velocity of the sound wave is given by $\boxed{V = \nu \times \lambda}$

Depending upon the frequency of the source sound produced is divided into three groups namely.

1. Infrasonic sound
2. Audible sound
3. Ultrasonic sound

If ν of the source is in the range, 0 - 20 Hz. Sound is called infrasonic and it cannot be heard.

If ν of the source is in the range 20 - 20000 Hz, sound is called audible sound and it can be heard

If ν of the source is larger than 20000 Hz, sound is ultrasonic and it cannot be heard.

In the same medium all the sound wave move with same velocity, but ν and λ are different.

If ν is minimum λ is maximum and vice versa

Factors affecting velocity of sound wave in a medium

1. Bulk modulus (B) or Elasticity

As elasticity of a medium increases velocity of wave in the medium increases and vice versa

2. Density (ρ)

As density of medium increases velocity of wave in the medium decreases and vice versa

Velocity of a sound wave in a medium of bulk modulus (B) and density (ρ) is given by

$$\boxed{v = \sqrt{\frac{B}{\rho}}}$$

According to Newton a sound wave moves through a medium isothermally. Then elasticity of the medium is isothermal = Pressure (P) of the medium

Then $v = \sqrt{\frac{P}{\rho}}$, called Newton's equation. But v calculated from Newtons eqn. is not the same as in experiment. Therefore Newton's eqn. is wrong, means sound wave is not moving isothermally in a medium.

According to Laplace a sound wave moves through a medium adiabatically. Then elasticity of the medium is adiabatic $= \gamma \times P$, where $\gamma = \frac{C_P}{C_V} > 1$

Then $v = \sqrt{\frac{E(\text{adiabatic})}{\rho}} = \sqrt{\frac{\gamma P}{\rho}}$, called Laplace's eqn. v calculated from Laplace's eqn. is the same as in expt.

$\therefore$ Laplace's eqn is correct, means sound wave moves through a medium adiabatically.

3. Pressure (P)

$$v = \sqrt{\frac{\gamma P}{\rho}}$$

As the pressure P changes, density ρ proportionately changes. Then $\left(\frac{P}{\rho}\right)$ will be a constant. For a medium γ is a constant. Therefore v is a constant. It means at all pressures of a medium, velocity of the wave is same or velocity is independent of pressure of the medium.

4. Temperature (T)

As temperature of the medium increases, velocity of the wave in the medium increases and vice versa.

$\boxed{v \propto \sqrt{T}}$ where T is the absolute temperature.

5. Humidity $v = \sqrt{\frac{\gamma\rho}{\rho}}$

As humidity in air increases density of air decrease and velocity of wave in air increases and vice versa.

$PV = nRT$

For 1 mole of medium

n = 1

$\therefore$ PV = RT, where V, is the molar volume = 22.4 liters, same for all gases.

If molar mass = M and molar volume = V

density $(\rho) = \frac{M}{V}$

$$V = \sqrt{\frac{\gamma P}{\rho}} = \sqrt{\frac{\gamma P}{M/V}} = \sqrt{\frac{\gamma(PV)}{M}}$$

$$\boxed{\because V = \sqrt{\frac{\gamma RT}{M}}}$$

Progressive wave

A progressive wave moving in the positive x direction is represented by the equation

$y = A\sin(kx - \omega t + \phi)$

Intensity of a Wave

$\boxed{I \propto A^2}$ $A \rightarrow$ Amplitude

I also depends upon the distance (d) between source and listener. As d increases I decreases and vice versa.

$\therefore I \propto 1/d^2$

The SI unit of intensity is w/m^2. However as human ear respond to sound intensities over a wide range, ie from 10^{-12} W/m^2 to 1 W/m^2. So instead of specifying intensity of sound in W/m^2, we use a logarithmic scale of intensity called sound level defined as

$$SL = 10\log\left[\frac{I}{I_0}\right];\ \text{unit dB}$$

Where I_0 is the threshold of human ear. ie 10^{-12} W/m^2

Superposition of waves

When two waves are produced simultaneously in the same medium they superpose each other producing a resultant wave.

If A_1 and A_2 are the amplitudes and ϕ is the phase difference of the two superposing waves, the resultant amplitude A of the resultant wave is given by

$$A = \sqrt{A_1^2 + A_2^2 + 2A_1A_2\cos\phi}$$

If ϕ = 0, A = A_1 + A_2, the maximum amplitude

$$\boxed{\text{ie., } A_{max} = A_1 + A_2}$$

If ϕ = 180, A = A_1 – A_2, the minimum amplitude

$$\boxed{\text{ie., } A_{min} = A_1 - A_2}$$

Resultant intensity is given by

$$I = I_1 + I_2 + 2\sqrt{I_1I_2}\cos\phi$$

$$I_{max} = \left(\sqrt{I_1} + \sqrt{I_2}\right)^2; \qquad I_{min} = \left(\sqrt{I_1} - \sqrt{I_2}\right)^2$$

Beats

When two vibrating bodies having nearly equal frequencies υ_1 and υ_2 are put into vibration together the intensity of the resultant sound increases to a maximum called waxing, decreases to a minimum called waning. The variation in intensity between maximum and minimum produces beats.

Number of beats/second = $|\upsilon_1 - \upsilon_2|$.

Beat frequency

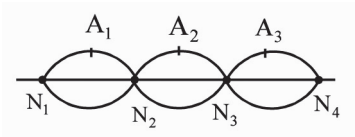
The time interval between successive maximum or successive minimum $= \left|\frac{1}{\upsilon_1 - \upsilon_2}\right|$.

Time interval between a maximum and next minimum $= \frac{1}{2} \times \frac{1}{|\upsilon_1 - \upsilon_2|}$

Stationary or Standing wave

When two similar waves are simultaneously produced along the same line in opposite directions they superpose each other producing a resultant wave. The resultant wave does not move in the medium and hence it is called a stationary wave.

The amplitude of particles on a stationary wave varies from zero at a point called node to a maximum at a point called antinode.



Distance between successive nodes or antinodes = $\frac{\lambda}{2}$.

Distance from a node to the next antinode = $\frac{\lambda}{4}$.

Usually a stationary wave is produced by superposing a progressive wave and its own reflected wave. If progressive wave is represented by

$y_1 = A\sin(kx - \omega t)$ its reflected wave is $y = +A\sin(kx + \omega t)$

Then stationary wave is represented by the equation, $y = y_1 + y_2$.

$y = (2A\sin kx)\cos\omega t$

Where $(2A\sin kx)$ is the amplitude of the stationary wave.

Since amplitude of each superposing wave is A, maximum amplitude at an antinode

$= A_1 + A_2 = A + A = 2A$.

Vibration of a stretched wire

Fundamental vibration or 1st mode

AB is a stretched wire of length l *m*, tension T newton and mass per unit length or linear density μ.

When it is put into vibration as shown, it produces a sound. The velocity of the sound wave is given by $v = \sqrt{\frac{T}{\mu}}$.

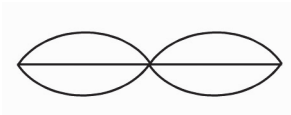
The whole length of the wire vibrates in one segment. Then A and B are successive nodes.

Therefore, $AB = l = \frac{\lambda}{2}$ $\lambda = 2l$ $v = \upsilon\lambda$ or $\upsilon = \frac{v}{\lambda}$

$\boxed{\upsilon = \frac{v}{2l}}$ Frequency υ is called the fundamental frequency or 1st Harmonic.

or $\boxed{\upsilon = \frac{1}{2l}\sqrt{\frac{T}{\mu}}}$

2nd mode

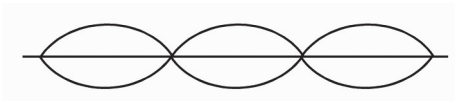


There are two segments in the wire. The frequency of vibration is given by, $\upsilon_1 = 2 \times \upsilon$

υ_1 is called the 1st overtone or 2nd harmonic.

$\therefore$ **1st overtone = 2nd harmonic**

3rd mode



There are three segments in the wire.

The frequency of vibration is given by $\nu_2 = 3 \times \nu$.

$\therefore$ **2nd overtone = 3rd harmonic**

[NB: The number of segments in the wire give the number of mode of vibration.

nth overtone = (n + 1) harmonic

In a stretched wire all the harmonics can be heard and hence the quality of sound is rich.

$$\upsilon = \frac{1}{2l}\sqrt{\frac{T}{\mu}}$$

From the above equation the three laws of transverse vibration of a string are concluded.

1. $\upsilon \propto \frac{1}{l}$, when T and m are constants.

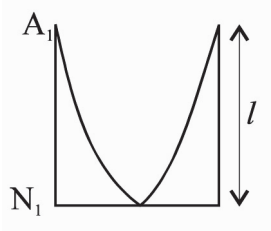
2. $\upsilon \propto \sqrt{T}$, when *l* and m are constants.

3. $\upsilon \propto \frac{1}{\sqrt{\mu}}$, when *l* and T are constants.

VIBRATION OF AIR COLUMNS

The air inside an empty pipe is called air column. The length of air column is equal to the length of empty pipe. When the air column in a pipe is put into vibration a stationary wave is formed inside the pipe, with a node at the closed end and an antinode at the open end of the pipe

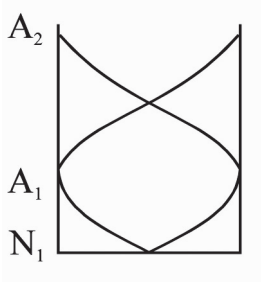
Closed Pipe: Ist Mode



$$\ell = \lambda/4; \lambda = 4\ell; v = \nu\lambda; \text{or } \upsilon = \frac{v}{\lambda} \quad \boxed{\therefore \upsilon = \frac{v}{4\ell}}$$

ν is called the 1st harmonic or fundamental frequency

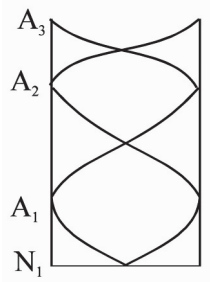
2nd mode



Frequency of vibration is $\upsilon_1 = 3 \times \nu$

ie 1st overtone = 3rd Harmonic

3rd mode



Frequency of vibration is,

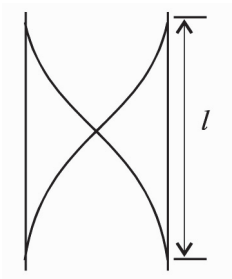
$\upsilon_2 = 5 \times \nu$

ie 2nd overtone = 5th Harmonic

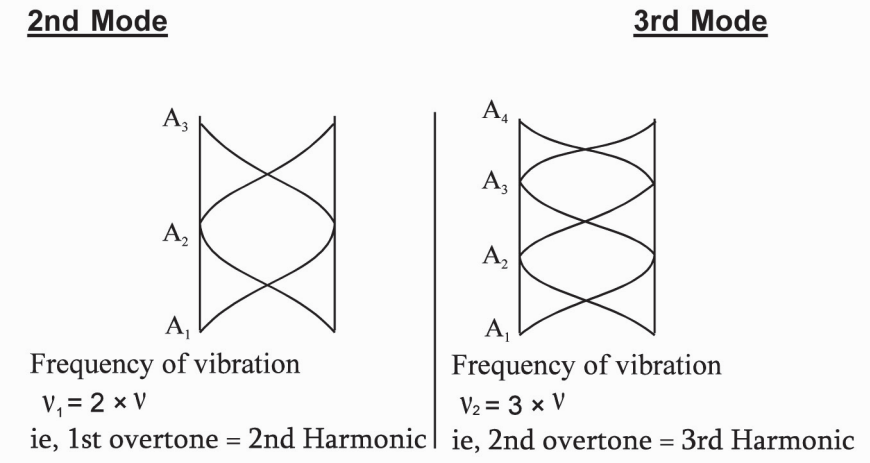
n^{th} overtone is equal to (2n+1) harmonic

In a closed pipe only the odd multiples of harmonics can be heard, no even multiples are heard. Therefore quality of sound is poor

Open pipe: Ist mode



$\ell = \lambda/2$; $\lambda = 2\ell$; $\nu = v/\lambda$ $\boxed{\therefore \nu = \frac{v}{2\ell}}$. ν is called 1st Harmonic or fundamental frequency

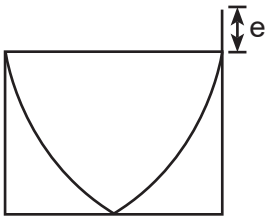


[NB : Number of nodes inside the pipe gives the number of mode of vibration.

n^{th} overtone = (n + 1) harmonic

In an open pipe all the harmonics can be heard and hence the quality of sound is rich]

End correction (e)



When the air column in a pipe is put into vibration the antinode is forming not exactly at the open end, but a little above the open end. The distance of antinode from the open end is called end correction given by [e = 0.3 × d], where d is the diameter of the tube.

Resonance Experiment

When the two vibration bodies vibrate with same frequency, resonance takes place and at resonance intensity of sound will be maximum.

In resonance experiment the frequency of the tunning fork and the frequency of vibrating air column are same, when resonance taken place.

Let ν be the frequency of the tunning fork. If ℓ_1 and ℓ_2 are the 1st and 2nd resonating lengths of air columns, the wave length of the wave forming inside the tube is given by

$\lambda = 2(\ell_2 - \ell_1)$. Where $\lambda/2 =$ distance between successive antinodes.

Then velocity of sound wave is given by

$v = \nu \times \lambda$

i.e. $\boxed{u = \nu \times 2(\ell_2 - \ell_1)}$

The end correction at the open end of pipe is given by

$$\boxed{e = \frac{\ell_2 - 3\ell_1}{2}}$$

SECTION - I
QUESTIONS

SINGLE CORRECT TYPE

1. A simple harmonic wave is represented as

$$y = 5\sin\frac{\pi}{2}(100t - 2x)$$

x, y are in metres, t in seconds

The ratio of wave velocity to maximum particle velocity will be

1) $1:2\pi$ 2) $1:3\pi$

3) $1:4\pi$ 4) $1:5\pi$

2. Two waves traveling in a medium in the x-direction are represented by y_1=Asin(αt-βx) and $y_2 = A\cos\left(\beta x + \alpha t - \frac{\pi}{4}\right)$, where y_1 and y_2 are the displacements of the particles of the medium, t is time, and α and β are constants. The two waves have different

1) speeds

2) directions of propagation

3) wavelengths

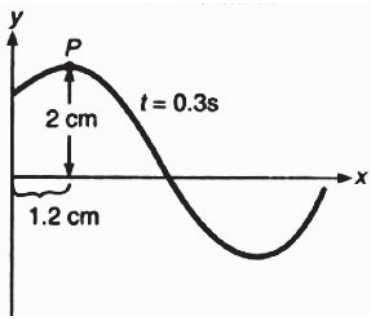
4) frequencies

3. Equal volume of helium and argon are mixed. The ratio of speed of sound through helium and through the mixture under same conditions is : (molecular weight of Argon is 40g)

1) $\sqrt{\frac{2}{11}}$ 2) $11\sqrt{2}$

3) $\frac{11}{\sqrt{2}}$ 4) $\sqrt{\frac{11}{2}}$

4. Figure shows a snap shot of a sinusoidal travelling wave taken at t = 0.3s. The wavelength is 7.5 cm and the amplitude is 2 cm. If the crest P was at x = 0 at t = 0, then the equation of travelling wave is



1) 2 cos (0.84 x- 3.36t)

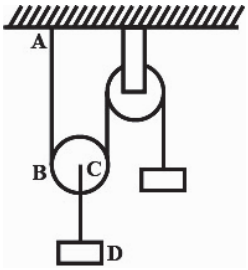
2) 2 cos (0.84x + 3.36t)

3) 2 sin (0.84 x - 3.36 t)

4) 2 sin (0.84 x + 3.36 t)

5. Both the strings shown in figure are made of same material and have same cross section. The pulleys are light. The wave speed of transverse wave in the string AB is V_1 and in CD is V_2

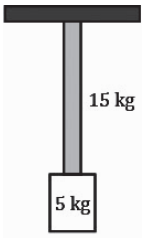
Then $\frac{V_1}{V_2}$ is



1) 1 2) 2

3) $\sqrt{2}$ 4) $\frac{1}{\sqrt{2}}$

6. A uniform rope of length 10m and mass 15 kg hangs vertically from a rigid support. A block of mass 5 kg is attached to the free end of the rope. A transverse pulse of wavelength 0.08 m is produced at lower end of the rope. The wavelength of the pulse when it reaches the top of the rope will be



1) 0.08 m

2) 0.04 m

3) 0.16 m

4) 0m

7. Two waves

X1 = A sin (wt - 0.1 x) and

X2 = A sin (wt - 0.1 x - $\frac{\phi}{2}$)

Super imposes. Resultant amplitude of combined wave is

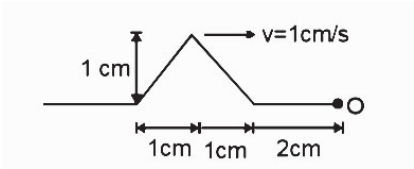
1) $2A\cos\left(\frac{\phi}{4}\right)$

2) $A\sqrt{2\cos\left(\frac{\phi}{4}\right)}$

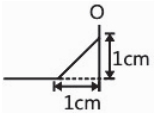
3) $2A\cos\frac{\phi}{2}$

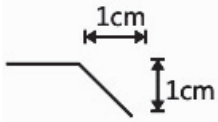
4) $A\sqrt{2(1+\cos\frac{\phi}{4})}$

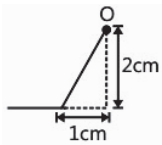
8. A wave pulse on a string has the dimension shown in figure. The wave speed is V = 1 cm/s. If point o is a free end. The shape of wave at time t = 3s is



1)

2) 

3) 

4) 

9. The equation of a wave on a string of linear mass density 0.04 kg/m is given by

$$y = 0.02\sin\left(2\pi\left(\frac{t}{0.04} - \frac{x}{0.5}\right)\right)$$

x, y are in metres and t is in second. Then tension in the string is

1) 6.25N

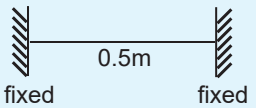
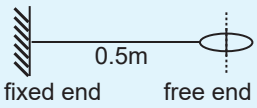
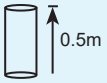
2) 4.0N

3) 12.5N

4) 0.5N

10. In each of four situation of column 1 a stretched string or an organ pipe is given along with required data. In case of strings the tension in the string is T = 102.4 N mass per unit length is 1g/m. Speed of sound in air is 320 m/s. The frequencies of resonance are given in column II

Match the following

Column I		Column II	
i.		a.	320Hz
ii.		b.	480Hz
iii.		c.	640Hz
iv.		d.	800Hz

1) i - a, c ii-d iii-a iv - c

2) i - a, c ii-b, d iii - a, c iv - b, d

3) i -c ii - b iii-a iv - c

4) i - a, c ii - d iii - a iv - d

11. Stationary waves are produced in 10m long stretched string fixed at both ends. If the string vibrates in 5 segments and wave velocity 20m/s then the frequency is

1) 10Hz 2) 5Hz

3) 4Hz 4) 2Hz

12. The length of a sonometer wire between two fixed end is 1.10 m. Where should the two bridges be placed to divide the wire into three segments whose fundamental frequencies are in the ratio 1 : 2: 3

1) 0.6 m and 0.9 m

2) 0.2 m and 0.4 m

3) 0.6 m and 0.8 m

4) 0.3 ma and 0.6 m

13. An underwater sonar source operating at a frequency of 60kHz directs its beam towards the surface. If velocity of sound air is 330m/s, wavelength and frequency of the waves in air are:

1) 5.5 mm, 60kHz

2) 3.30m, 60kHz

3) 5.5 mm, 30kHz

4) 5.5mm, 80 kHz

14. A source of sound is in the shape of a long narrow cylinder radiating sound waves normal to the axis of the cylinder. Two points P and Q are at perpendicular distances of 9m and 25m from the axis. The ratio of the amplitudes of the waves at P and Q is

1) 5:3

2) $\sqrt{5}:\sqrt{3}$

3) 3:5

4) 25:9

15. Two open pipes of length 25 cm and 25.5cm produced 0.1 beat/second. The velocity of sound will be:-

1) 255cm/s

2) 250cm/s

3) 350cm/s

4) None of these

16. A closed organ pipe of radius r_1 and an open organ pipe of radius r_2 and having same length L resonate when excited with a given tuning fork. Closed organ pipe resonates in its fundamental mode where as open organ pipe resonates in its first overtone, then:-

1) $r_2 - r_1 = L$

2) $r_2 - r_1 = L/2$

3) $r_2 - 2r_1 = 2.5\ L$

4) $2r_2 - r_1 = 2.5\ L$

17. The maximum length of a closed pipe that would produce a just audible sound is (V_{sound} = 336m/s) :

1) 4.2cm

2) 4.2m

3) 4.2mm

4) 1.0cm

18. A tuning fork is used to produce resonance in a glass tube. At room temperature 30°C two successive resonance are produced at 15cm and 48cm of column length. If the frequency of the tuning fork is 500Hz, velocity of sound at 0°C is:

1) 33000 ms^{-1} 2) 330 ms^{-1}

3) 312 ms^{-1} 4) 348 ms^{-1}

Assertion - Reason Type Question

19. 1) Both assertion and reason are true and reason is correct explanation of assertion

2) Both assertion and reason are correct but reason is not the correct explanation of assertion

3) Assertion is incorrect but reason is correct

4) Assertion is correct and reason is incorrect

Assertion : Two longitudinal waves in same medium given by equations, y_1=2asin(wt-kx)and y_2 = a sin (2 wt - 2 kx) will have equal intensity.

Reason : Intensity of waves of given frequency in same medium is proportional to square of amplitude only.

20. Two sound waves represented by y_1=4sin200πt and y_2 = 3sin208πt super impose each other. The beat frequency and ratio of maximum to minimum intensity are

1) 8 and $\frac{7}{1}$

2) 4 and $\frac{49}{1}$

3) 4 and $\frac{4}{3}$

4) 8 and $\frac{16}{9}$

SECTION - II
QUESTIONS

NUMERICAL TYPE

21. A uniform string of length 20 m is suspended from a rigid support. A short wave pulse is introduced at its lowest end. It starts moving up the string. The time taken to reach the support is $\sqrt{n}\,\text{sec}$. Then value of n is _____

22. A wire of linear mass density 9×10^{-3} kg/m is stretched between two rigid supports under tension of 360N. The wire resonates at frequency 210Hz. The next higher frequency at which same wire resonate is 280Hz. The number of loops produced in the Ist case will be

23. The speed of sound in hydrogen is X × 332 m/s at NTP if density of hydrogen is $\frac{1}{4}$th of that of air. Find value of X if speed of sound in air is 332 m/s at NTP

24. A tuning fork A produces 4 beats/sec with another fork B of frequency 256Hz. When A is slightly filed, the beat frequency increases. Then the original frequency of A is

25. A tuning fork of frequency 200 Hz is in unison with a sonometer wire. The number of beats are heard in 30s if the tension is increased by 1% is 10 n. Then n is equal to

Chapter 12

ELECTROSTATICS AND CAPACITANCE

SYNOPSIS

Electrostatics is the branch of physics which deals with electric charges at rest. There are two types of charges +ve and –ve. Like charges repel and unlike charges attract. Unit of charge is coulomb (C) in SI. In C.G.S the unit is stat coulomb or electrostatic unit of charge (esu of charge)

Electrification by friction

When two substances are rubbed together, electrons are transferred from one body to the other. The transfer of electrons takes place from the material in which electrons are held less tightly to the nucleus to the materials where electrons are held more tightly. The substance which loses electrons become +ve and the one which gains electrons become –vely charged

Properties of charges

1. Quantization
2. Additive property
3. Charge conservation
4. Speed independence

Difference between mass and charge

1. Charge can be +ve, –ve or zero, but mass is always +ve
2. Charge is quantized. Mass is not strictly quantized
3. Charge is independent of speed. Mass increases with speed as

$$m = \frac{m_0}{\sqrt{1-\frac{v^2}{c^2}}}$$

m_0– rest mass

m – mass when moving with a velocity v

c – velocity of light

Similarities between gravitational and electrostatic field

Both are

1. Central forces
2. Conservative
3. Inverse square law forces
4. Long range forces
5. Two body interaction

Difference

Electrostatic force	Gravitational force
1. May be attractive or repulsive	Always attractive
2. Affected by the medium	Not affected by the medium
3. Of strong magnitude	Of weak magnitude

Note that the electrostatic force between the electron and proton is 10^{38} times as large as the gravitational force between them for equal distance of separation

Coulomb's law

The force of attraction or repulsion between two charges q_1 and q_2 is directly proportional to the product of the charges and inversely proportional to the square of the distance between them

$$F \propto \frac{q_1 q_2}{r^2} \quad F = \frac{1}{4\pi\epsilon_0}\frac{q_1 q_2}{r^2}$$

ϵ_0 is the absolute permittivity of free space (air or vacuum) $\frac{1}{4\pi\epsilon_0} = 9\times10^9\,Nm^2C^{-2}$

When the charges are kept in a medium other than air or vacuum, $F = \frac{1}{4\pi\epsilon_0\epsilon_r}\frac{q_1 q_2}{r^2}$

ϵ_r is the relative permittivity or dielectric constant of the medium. $\epsilon_0\epsilon_r = \epsilon$ is the absolute permittivity of the medium

$$\frac{F_{air}}{F_{medium}} = \epsilon_r$$

The force between two charges will be reduced to zero if a metal plate is introduced between them. For metals $\epsilon_r = \infty$

$$\epsilon_0 = 8.854\times10^{-12}\,C^2N^{-1}m^{-2}$$

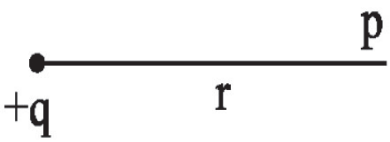
Principle of superposition

When a number of charges are interacting, the total force on a given charge is the vector sum of the individual forces exerted on the given charge by all the other charges.

Electric field

The space surrounding a charge where another charge experiences a force is known as an electric field. The intensity of the electric field $(\vec{E})$ at a point is the force experienced by a unit +ve charge (+1C) placed at that point. The magnitude of the intensity of the electric field at a point P due to a point charge is given by

$$E = \frac{1}{4\pi\epsilon_0}\frac{q}{r^2}$$



where r is the distance of the point from the point charge. The force experienced by a charge of q coulomb placed in an electric field strength $\vec{E}$ is given by

$$\vec{F} = q\vec{E}$$

Acceleration of a charged particle in an electric field $\vec{a} = \frac{q\vec{E}}{m}$

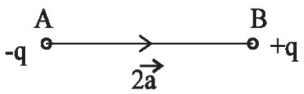
Unit of $\vec{E}$ is NC^{-1} or Vm^{-1}

$[E] = [I^{-1} MLT^{-3}]$

Properties of Electrostatic field lines

1. Electric field lines start from a +ve charge and ends on a –ve charge
2. Electric field lines do not intersect each other
3. The tangent at any point on the electric field line gives the direction of the electric field at that point
4. The number of lines of force passing normally through unit area taken around a point gives the intensity of the electric field at that point. It is also known as the electric flux density.
5. In a uniform electric field electric lines are parallel and equidistant from each other
6. Lines of force always start normal to a surface and end normal to a surface

Electric dipole



Two equal and opposite charges separated by a small vector distance form an electric dipole. The length of the dipole is a vector quantity. Its direction is from the –ve to the +ve charge. The length AB of the dipole is represented by $2\vec{a}$.

Electric dipole moment $\vec{p}$

It is the product of one of the charges and the distance between the charges.

(length of the dipole is $2\vec{a}$)

$$\vec{p} = q \times 2\vec{a}$$

It is a vector quantity. Its direction is from –ve to +ve charge

Intensity of the electric field at a point on the axial line

$$E = \frac{1}{4\pi\epsilon_0} \frac{2Pr}{(r^2 - a^2)^2}$$

If a<< r(ie short dipole)

$$E = \frac{1}{4\pi\epsilon_0} \frac{2P}{r^3}$$

Intensity of the electric field at a point on the equatorial line

$$E = \frac{P}{4\pi\epsilon_0 (r^2 + a^2)^{3/2}}; \text{If } a << r, E = \frac{1}{4\pi\epsilon_0}\frac{P}{r^3}$$

For a short dipole $E_{axial} = 2\ E_{equatorial}$

The direction of the electric field is antiparallel to the direction of the length of the dipole

Null point

A null point in an electric field is the point where the resultant field is zero

a) when two like charge are separated by a distance the null point will be:

(1) on the line joining the charges

(2) in between the charges

(3) nearer to the smaller charge

Also, $\frac{q_1}{r_1^2} = \frac{q_2}{r_2^2}$ where r_1 and r_2 are the distance of the null point from q_1 and q_2

If $q_1 = q_2$ null point will be at the centre

(b) When two unlike charge are separated by a distance the null point will be

(1) on the line joining the charges

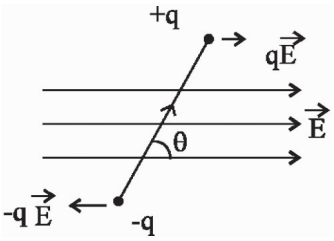
(2) outside the charges

(3) nearer to the smaller charge

Also, $\frac{q_1}{r_1^2} = \frac{q^2}{r_2^2}$ where r_1 and r_2 are the distance of the null point from the charges. If $q_1 = q_2$ there

will be no null point.

Torque acting on an electric dipole placed in a uniform electric field



Torque $\tau = PE\sin\theta$ ie $\vec{\tau} = \vec{p} \times \vec{E}$

(i) When the dipole is in stable equilibrium, $\theta = 0^\circ$, $\tau = PE \sin 0 = 0$

(ii) When the dipole is perpendicular to the field, $\tau = PE \sin 90 = PE$

This is the maximum torque.

(iii) When the dipole is in unstable equilibrium

θ = 180°, τ = PE sin 180° = 0

In stable equilibrium, $\vec{E}$ is parallel to $\vec{P}$

In unstable equilibrium, $\vec{E}$ is antiparallel to $\vec{P}$

Work done in rotating a dipole from θ_1 to θ_2 in a uniform electric field. (Potential energy of an electric dipole placed in a uniform electric field)

W= pE $(\cos\theta_1 - \cos\theta_2)$

θ_1 - initial

θ_2 - final

If θ_1 = 90° and $\theta_2 = \theta$, W = –pE cos θ

Electric potential : V at a point in an electricfield is the amount of work done in bringing a unit +ve charge (+1C) from infinity to that point against the direction of the field

$V = -\int_{\infty}^{r} \vec{E}.d\vec{r}$ V is a scalar quantity $V = \frac{W}{q}$. Unit of V is JC^{-1} (volt)

$[V] = I^{-1} ML^2 T^{-3}$

Potential difference between two points in an electric field is the amount of work done to bring a unit +ve charge from one point to the other against the direction of the field

$dV = V_B - V_A$

Equipotential surface is the surface over which the electric potential remains the same

On an equipotential surface the p.d between any two points is zero. Hence no work is done in moving a test charge on an equipotential surface

The electric field (ie, electric lines) are perpendicular to an equipotential surface

Potential gradient is the rate of change of potential w.r.t distance, ie $\frac{dv}{dr}$. It is a vector quantity

Electric field $E = \frac{-dv}{dr}$

In a constant electric field E × r = V

Unit of electric field is Vm^{-1}

Unit of potential gradient also is Vm^{-1}

Potential at a point due to a point charge is

$$V = \frac{1}{4\pi\epsilon_0}\frac{q}{r}$$

Potential due to a large number of charges q_1, q_2, ... is,

$$V = \frac{1}{4\pi\epsilon_0}\frac{q_1}{r_1} + \frac{1}{4\pi\epsilon_0}\frac{q_2}{r} + ...$$

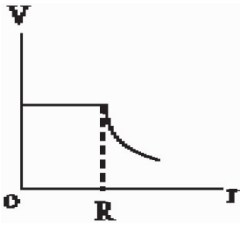
Potential due to a uniformly charged conducting spherical shell (or a conducting solid sphere) of radius R:

1. Potential at any point outside the shell at a distance r from the centre

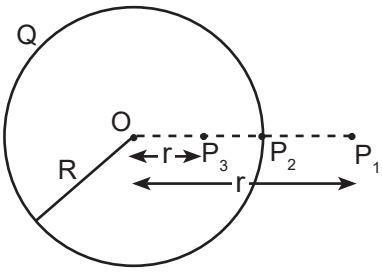
$$V = \frac{1}{4\pi\epsilon_0}\frac{q}{r}$$

2. On the surface of the shell, $V = \frac{1}{4\pi\epsilon_0}\frac{q}{R}$

3. Inside the shell, $V = \frac{1}{4\pi\epsilon_0}\frac{q}{R}$



Electric potential due to non-conducting charged solid sphere



Outside point P_1 (r > R)

$$V_{P_1} = \frac{Q}{4\pi\epsilon_0 r}$$

On the surface point P_2(r=R)

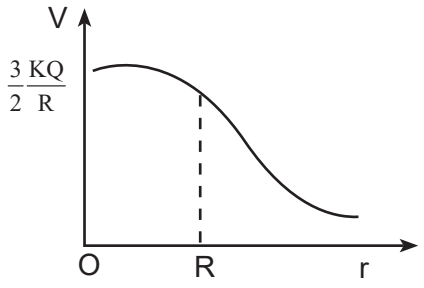
$$V_{P_2} = \frac{Q}{4\pi\epsilon_0 R}$$

Inside point P_3 (r < R)

$$V_{P_3} = \frac{Q}{4\pi\epsilon_0}\left[\frac{3R^2 - r^2}{2R^3}\right]$$

At centre O (r = 0)

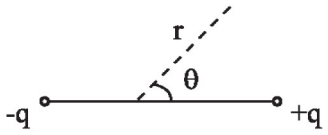
$$V_0 = \frac{3}{2}\frac{Q}{4\pi\epsilon_0 R}$$



Electric potential due to an electric dipole (short dipole)

1. At any point,

$$V = \frac{1}{4\pi\epsilon_0}\frac{p\cos\theta}{r^2}$$

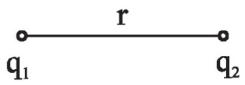


2. $V_{axial} = \frac{1}{4\pi\epsilon_0}\frac{p}{r^2}$

3. $V_{equitorial} = 0$

Potential energy of a system of two charges

$$U = \frac{1}{4\pi\epsilon_0}\frac{q_1 q_2}{r}$$

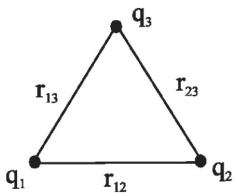


Potential energy = Potential × charge

Potential energy of system of three charges

$U = U_{12} + U_{23} + U_{13}$

$$= \frac{1}{4\pi\varepsilon_0}\left[\frac{q_1q_2}{r_{12}} + \frac{q_2q_3}{r_{23}} + \frac{q_1q_3}{r_{13}}\right]$$



Electric flux (ϕ) through an area (surface) in an electric field is the number of lines of force passing normally through the area. Flux through an area $d\vec{s}$ is given by $d\phi = Eds\cos\theta$ ie, $d\phi = Eds\cos\theta$

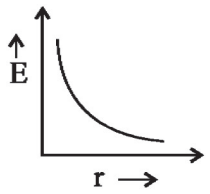
Flux is a scalar quantity. Note that the direction of area is normal to the area taken

Gauss's theorem : The total electric flux through any closed surface enclosing a charge is equal to $\frac{1}{\epsilon_0}$ times the total charge enclosed by the surface

$$\phi = \oint \vec{E}\cdot d\vec{s} = \frac{1}{\epsilon_0}.q$$

Applications

1. Electric field due to a point charge = $\frac{1}{4\pi\epsilon_0}\frac{q}{r^2}$

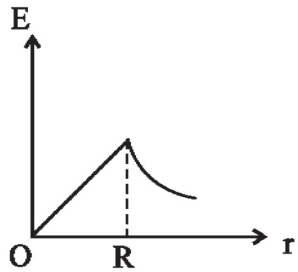


2. Electric field due to an infinitely long line charge, $E = \frac{\lambda}{2\pi\epsilon_0 r}$

3. Electric field due to an infinite thin plane sheet of charge, $E = \frac{\sigma}{2\epsilon_0}$

4. Electric field due to two infinite parallel sheets of charge with equal but opposite charge densities,
   (i) outside the sheets = 0
   (ii) in between the sheets = $\frac{\sigma}{\epsilon_0}$

5. Electric field due to a charged nonconducting solid sphere of radius R:



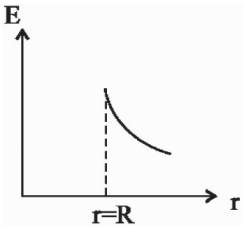
   (i) outside the sphere (r > R) $E = \frac{1}{4\pi\epsilon_0}\frac{q}{r^2}$

   (ii) on the sphere (r = R) $E = \frac{1}{4\pi\epsilon_0}\frac{q}{R^2}$

   (iii) inside the sphere (r < R) $E = \frac{1}{4\pi\epsilon_0}\frac{q}{R^3}r$

6. Electricfield due to a charged conducting shell (or conducting sphere) of radius R
   (i) outside the shell (r > r), $E = \frac{1}{4\pi\epsilon_0}\frac{q}{r^2}$
   (ii) on the sphere (r = R), $E = \frac{1}{4\pi\epsilon_0}\frac{q}{R^2}$

(iii) inside the sphere (r < R) E = 0



Electrostatic shielding is the vanishing of the electric field inside a conducting cavity

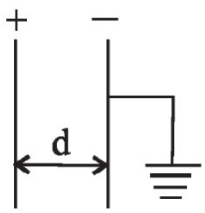
Capacitor or condenser

It is a device for storing large amount of electric charges. Charge stored in a capacitor, q = CV

C – capacitance or capacity

$C = \frac{q}{V}$ ∴ unit is CV^{-1} (Farad)

Parallel plate capacitor



(i) Air capacitor, Capacitance $C = \frac{\epsilon_0 A}{d}$

$E = \frac{\sigma}{\epsilon_0}$

V = E × d

(ii) Capacitor with a dielectric,

$C' = \frac{\epsilon_0 KA}{d}$

ie C' = C × K K is the dielectric constant

$E' = \frac{\sigma}{\epsilon_0 K}$ For metals K = ∞

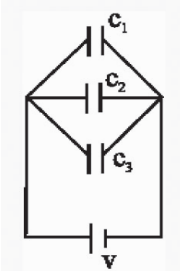
For vacuum K =1

$V' = E' \times d$ For Air K = 1.00059

≃ 1

Combination of capacitors

(i) Parallel

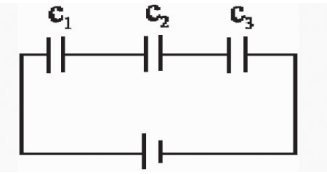


Potential difference across all the condensers will be the same, but charge will be different

$q_1 = C_1V$, $q_2 = C_2V$, $q_3 = C_3V$

Effective capacitance, $C_{eff} = C_1 + C_2 + C_3$

(ii) Series



Potential difference on different capacitors will be different, but the charge will be the same

$$V_1 = \frac{q}{C_1},\ V_2 = \frac{q}{C_2},\ V_3 = \frac{q}{C_3}$$

The effective capacitance C_{eff} is

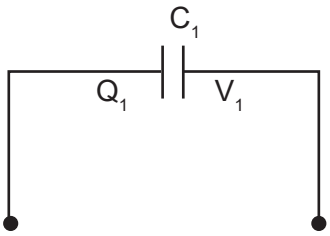
$$\frac{1}{C_{eff}} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}$$

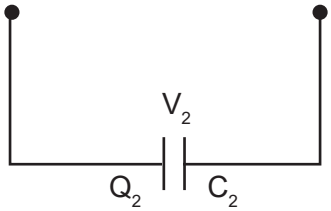
Energy of a charged capacitor is the amount of work done in charging the capacitor

$$U = \frac{1}{2}CV^2 \qquad U = \frac{1}{2}QV \qquad U = \frac{Q^2}{2C}$$

CAPACITORS

Two capacitors of capacitance C_1 and C_2, initially charged to V_1 and V_2 with respective initial charge Q_1 and Q_2





When these capacitors are joined they will attain a common potential $V = \frac{C_1V_1 + C_2V_2}{C_1 + C_2}$

Molecule as a dipole

If the +ve charge centre doesn't coincide with the –ve charge centre, the molecule will have a dipole moment. Such molecules are called polar molecules.

In non-polar molecules, the +ve and –ve charge centers coincide

Motion of a charged particle in an electric field

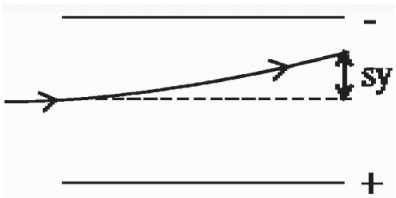
(i) A charged particle moving along the direction of the electric field

A +ve charged particle will move along the direction of the field with an acceleration of $\frac{qE}{m}$

A –ve charged particle will move more along the direction of the field with a deceleration of qE/m

Velocity after t seconds v = u + at

(ii) A charged particle entering perpendicular to a uniform electric field



The path of the charged particle inside the electric field is a parabola. Let t be the time spent by the particle inside the field. Initial velocity v_x is in the X – direction. Velocity acquired in the Y-direction is v_y. S_y is the displacement in the Y-direction. S_x is displacement in the X-direction within the field. Then

$$V_y = U_y + at \text{ But } u_y = 0 \therefore V_y = at$$

$$S_y = U_r + \frac{1}{2}at^2 \text{ But } u_y = 0 \therefore S_y = \frac{1}{2}at^2$$

$$S_x = V_x t$$

SECTION - I
QUESTIONS

SINGLE CORRECT TYPE

1. Three charges 4 q, Q and q are in a straight line in the positions $0, \ell/2$ and ℓ respectively. Resultant force at q will be zero if Q is equal to

1) -q
2) -2q
3) -q/2
4) 4q

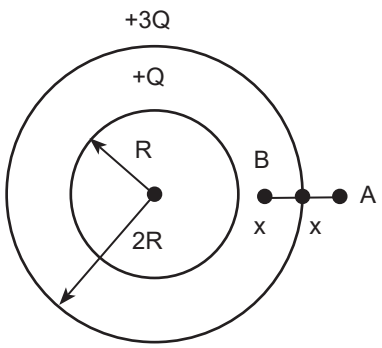
2. A charge q is placed at the centroid of an equilateral triangle. Three charges equal to Q are placed at the vertices of the triangle. The system of four charges will be in equilibrium if q is equal to

1) $-Q\sqrt{3}$
2) $-Q/3$
3) $-Q/\sqrt{3}$
4) $Q/\sqrt{3}$

3. The charges 9e and 3e are placed at a distance r. The distance of the point where the electric field intensity will be zero is

1) $\frac{r}{\sqrt{3}+1}$ from 3e charge
2) $\frac{r}{\sqrt{3}+1}$ from 9e charge
3) $\frac{r}{\sqrt{3}-1}$ from 3e charge
4) $\frac{r}{\sqrt{3}-1}$ from 9e charge

4. Two concentric conducting thin shells of radius R and 2R carry charges +Q and +3Q respectively. The magnitude of electric field at points A and B at a distance x outside and inside from the surface of outer sphere is same. Then the value of x is



1) $\frac{R}{3}$
2) $\frac{2R}{3}$
3) $\frac{R}{4}$
4) $\frac{R}{2}$

5. Two identical small bodies each of mass m and charge q are suspended from two strings each of length *l* from a fixed point. This whole system is taken into an artificial satellite. Then the tension in strings is

1) $\frac{kq^2}{l^2}+2mg$
2) $\frac{kq^2}{4l^2}+2mg$
3) $\frac{kq^2}{l^2}$
4) $\frac{kq^2}{4l^2}$

6. Five identical charges +q are placed at five corner of a regular hexagon of side a. Find the magnitude of electric field at centre

1) $\frac{q}{4\pi\varepsilon_0 a^2}$
2) $\frac{q}{2\pi\varepsilon_0 a^2}$
3) $\frac{5q}{4\pi\varepsilon_0 a^2}$
4) $\frac{5q}{2\pi\varepsilon_0 a^2}$

7. A uniform horizontal electric field E is established in the space between two large vertical parallel plates. A small conducting sphere of mass m is suspended in the field from a string of length L. If the sphere is given charge +q, then the period of oscillation of the pendulum is

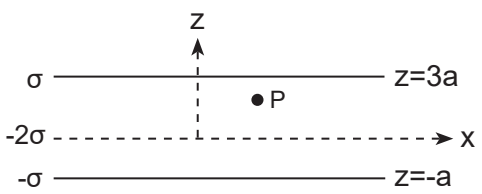
1) $2\pi\sqrt{L/g}$

2) $2\pi\sqrt{\dfrac{L}{g+qE/m}}$

3) $2\pi\sqrt{\dfrac{L}{g-qE/m}}$

4) $2\pi\sqrt{\dfrac{L}{\sqrt{g^2+(qE/m)^2}}}$

8. Three infinitely long charge sheets are placed as shown in figure. The electric field at point P is



1) $\dfrac{2\sigma}{\varepsilon_0}\hat{k}$

2) $-\dfrac{2\sigma}{\varepsilon_0}\hat{k}$

3) $\dfrac{4\sigma}{\varepsilon_0}\hat{k}$

4) $-\dfrac{4\sigma}{\varepsilon_0}\hat{k}$

9. A point charge of +6μC is placed at a distance 20 cm directly above the centre of a square of side 40 cm. The magnitude of the flux through the square is

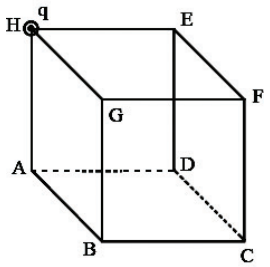
1) ε_0

2) $\dfrac{1}{\varepsilon_0}$

3) $\varepsilon_0 \times 10^{-6}$

4) $\dfrac{1}{\varepsilon_0}\times 10^{-6}$

10. A small spherically symmetric charge q is placed at one vertex of a cube as shown. The flux through the faces ABCD and HGFE are, respectively



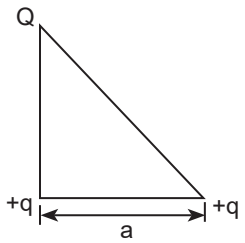
1) $\dfrac{q}{24\varepsilon_0}, \dfrac{q}{24\varepsilon_0}$

2) $0, \dfrac{q}{8\varepsilon_0}$

3) $\dfrac{q}{8\varepsilon_0}, 0$

4) $\dfrac{q}{24\varepsilon_0}, 0$

11. Three charges Q, +q and +q are placed at the vertices of a right angled isosceles triangle as shown in figure. The net electrostatic energy of the configuration is zero if Q is equal to



1) $\frac{-q}{1+\sqrt{2}}$ 2) $\frac{-2q}{2+\sqrt{2}}$

3) -2q 4) +q

12. An external agency carries -5C of charge from infinity to a point in an electrostatic field and performs 100 Joules of work. The potential at the given point is

1) +10V 2) -10V

3) +20 V 4) -20 V

13. A point charge q is placed at a distance of r from the centre of an uncharged conducting sphere of radius R (<r). The potential at any point on the sphere is

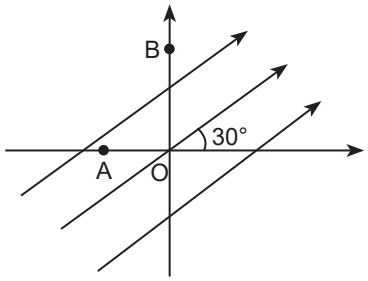
1) zero

2) $\frac{1}{4\pi\varepsilon_0}.\frac{q}{r}$

3) $\frac{1}{4\pi\varepsilon_0}.\frac{qR}{r^2}$

4) $\frac{1}{4\pi\varepsilon_0}.\frac{qr^2}{R}$

14. A uniform electric field of 100V/m is directed at 30° with the positive x-axis as shown in figure. Find the potential difference V_B - V_A if OA = 2m and OB = 4m



1) $100\left(2-\sqrt{3}\right)$

2) $-100\left(2+\sqrt{3}\right)$

3) $-200\sqrt{3}$

4) $-100\sqrt{3}$

15. Two short dipoles, each of dipole moment p, are placed at origin. The dipole moment of one dipole is along x-axis, while that of other is along y-axis. The magnitude of electric field at a point (a,0) is given by

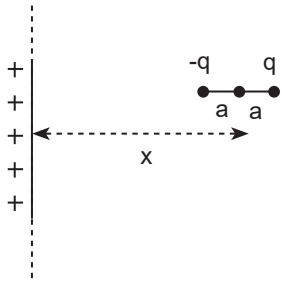
1) $\left(\frac{1}{4\pi\varepsilon_0}\right)\frac{2p}{a^3}$

2) $\left(\frac{1}{4\pi\varepsilon_0}\right)\frac{p}{a^3}$

3) $\left(\frac{1}{4\pi\varepsilon_0}\right)\frac{\sqrt{5}P}{a^3}$

4) zero

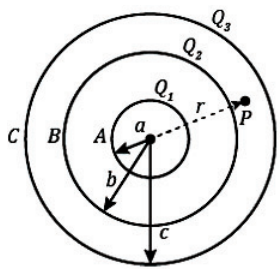
16. An electric dipole is placed at distance x from an infinitely long rod of linear charge density λ. What is net force acting on dipole ?



1) $\frac{\lambda aq}{4\pi\varepsilon_0 x^2}$ 2) $\frac{\lambda aq}{\pi\varepsilon_0 x^2}$

3) $\frac{\lambda aq}{2\pi\varepsilon_0 x^2}$ 4) Zero

17. Three concentric spherical conductors are arranged as shown in figure. The potential at point P will be



1) $\frac{1}{4\pi\varepsilon_0}\left[\frac{Q_1}{r}+\frac{Q_2}{r}+\frac{Q_3}{r}\right]$

2) $\frac{1}{4\pi\varepsilon_0}\left[\frac{Q_1+Q_2}{r}+\frac{Q_3}{c}\right]$

3) $\frac{1}{4\pi\varepsilon_0}\left[\frac{Q_1}{a}+\frac{Q_2}{b}+\frac{Q_3}{c}\right]$

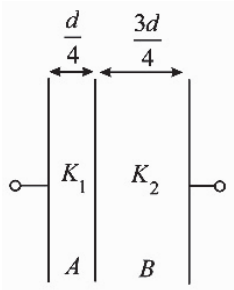
4) $\frac{1}{4\pi\varepsilon_0 c}\times[Q_1+Q_2+Q_3]$

18. In a region, if electric field is defined as $\vec{E}=\left(\hat{i}+2\hat{j}+\hat{k}\right)v/m$ then the potential difference between two pointes A(0,0,0) and B (2,3,4) in that region, is

1) 6V 2) 12 V

3) 8V 4) 9V

19. Two medium of dielectric constant K_1 and K_2 are introduced according to given figure. If $\frac{K_1}{K_2}=3$ then calculate ratio of capacity of part A and part B. (Area of each plate is A)



1) 1 : 9

2) 4 : 1

3) 9 : 1

4) 1 : 4

20. The plates of a parallel plate capacitor are charged up to 100 volt. A 2mm, thick dielectric plate is inserted between the plates, then to maintain the same potential difference, the distance between the capacitor plate is increased by 1.6mm. The dielectric constant of the plate is:-

1) 5

2) 1.25

3) 4

4) 2.5

SECTION - II
QUESTIONS

NUMERICAL TYPE

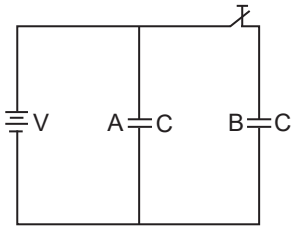
21. A solid sphere of radius R has a charge Q distributed in its volume with charge density $\rho = kr^a$, where k and a are positive constants and r is the distance from its centre. If the electric field at r = R/2 is 1/8 times that at r = R, the value of a is

22. Two identically charged spheres are suspended by strings of equal length. The strings make an angle of 2θ with each other. When suspended in a liquid of density 900 kg/m^3, the angle remains the same. What is the dielectric constant of the liquid if the density of the material of the sphere is 1200 kg/m^3?

23. Three concentric spherical metallic shells A, B and C of radii a,b and c (a<b<c) have surface charge densities σ, -σ and σ respectively. A and C are at the same potential. If a = 7cm and b = 17 cm, then the value of c-(a+b) in cm is

24. Three capacitors of capacitance 6μF each are available. The minimum and maximum capacitance, which may be obtained are.....

25. The figure shows two identical parallel plate capacitors connected to a battery with the switch S closed. The switch is now opened and the free space between the plates of the capacitors is filled with a dielectric of dielectric constant (or relative permittivity) 3. The ratio of the total electrostatic energy stored in both capacitors before and after the introduction of the dielectric is $n\times10^{-2}$. Then n = ...



Chapter 13

CURRENT ELECTRICITY

SYNOPSIS

Electric current through a conductor is defined as the time rate of flow of charge through any cross section of a conductor. If q is the charge flowing in time t, then current $I = \frac{q}{t}$. (for steady current)

Unit of current is Ampere. Current is a scalar quantity.

- If the rate of flow of charge varies with time, then the current at any time is given by $I = \frac{dq}{dt}$

Electromotive force

To maintain a steady current, we need a closed circuit with a source. The work done per unit charge by the source in taking a positive charge from lower to higher potential energy is called *electromotive force or emf* of the source.

OR

It is the p.d between the two terminals of a source in open circuit. SI unit of e.m.f is volt. (V)

Ohm's law

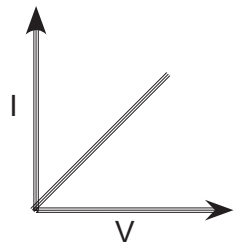
At constant temperature, the electric current flowing through a conductor is directly proportional to the potential difference across the two ends of the conductor.

ie $V \alpha I$

V = IR. Where the constant of proportionality R is called the resistance of the conductor.

* Resistance is the opposition to the current flow in a conductor. $R = \frac{V}{I}$ Its unit is V/A or ohm. Ω.

Conductors which obey Ohm's law are known as ohmic conductors. Eg: Silver, Copper, Aluminium



V - I characteristic of ohmic conductor.

Factors affecting the resistance

The resistance of a conductor depends on its

i) length ii) area of cross section,

iii) nature of the material and, iv) temperature.

Law of resistance - The resistance of a conductor is directly proportional to its length (*l*) and inversely proportional to its area of cross section (A)

$$R \alpha \ell, R \alpha \frac{1}{A} \quad \therefore R \alpha \frac{\ell}{A}$$

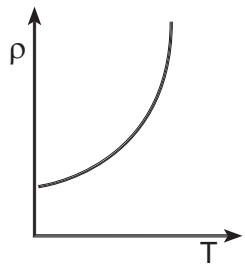
$R = \frac{\rho \ell}{A}$ Where ρ is a constant known as resistivity or specific resistance.

$\rho = \frac{RA}{\ell}$ Its unit is ohm metre (Ωm).

If $l = 1$ and A = 1, then ρ = R

Resistivity of the material of a conductor is defined as the resistance of the conductor of unit length and of unit area of cross section.

- Resistivity depends on the nature of the material $\rho = \frac{1}{n}$; n is the no. of free electrons per unit volume)
- Resistivity increases with the increase in temperature of the conductor.



- Resistivity is independent of geometrical dimensions (ie length, area, shape etc.)
- Substances having low resistivity are conductors of electricity.
- Substances having high resistivity are insulators.

Conductance

The reciprocal of resistance is called conductance. It is denoted by G. $G = \frac{1}{R} = \frac{A}{\rho \ell}$ SI unit is Ω^{-1} or mho

Conductivity

Conductivity a material is its ability to conduct electric current. Conductivity is the reciprocal of resistivity. $\sigma = \frac{1}{\rho}$. Its unit is $\Omega^{-1} m^{-1}$ or mho m^{-1}.

Temperature dependance of Resistance

For a conductor, $R \alpha \frac{1}{\tau}$ where $R \rightarrow$ Resistance, $\tau \rightarrow$ Relaxation time

When a metallic conductor is heated, vibration of atoms increases and collision increases. This reduces the relaxation time t and increases the value of resistance R.

If R_0 be the resistance of a conductor at 0°C and R_t at t°C then $R_t = R_0(1+\alpha t)$

Where α is called temperature coefficient of resistance of the material

$$\alpha = \frac{R_t - R_0}{R_0 t} = \frac{\text{change in resistance / degree rise in temperature}}{\text{resistance at } 0^\circ\text{ C}}$$

Thus the *temperature coefficient of resistance* can be defined as the ratio of the change in resistance per unit rise of temperature to the resistance at 0°C. (It's unit is K^{-1})

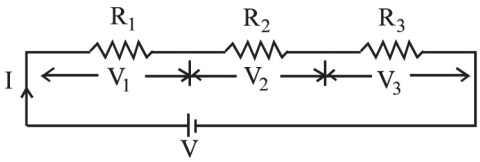
If R_1 and R_2 are resistances at t_1 and t_2°C, $\alpha = \frac{R_2 - R_1}{R_1 t_2 - R_2 t_1}$

- For metals α is +ve. Thus metals (conductors) has positive temperature coefficient of resistance.
- For semiconductors α is -ve. (negative temperature coefficient of resistance)
- Due to high resistance and low temperature coefficient of resistance, the alloys like constantan, manganin and nichrome are used as standard resistances.

Combination of resistances

i) Resistance in series

The resistors are said to be in series if the current through each one must be same and equal to main current.



Let three resistances R_1, R_2 and R_3 are connected in series to a source of potential V. Since they are in series combination the current through them is same. Let I be the current through the circuit. Let V_1, V_2 and V_3 be the potential difference across the resistances R_1, R_2 and R_3 respectively.

$V = V_1 + V_2 + V_3$

But $V_1 = IR_1$, $V_2 = IR_2$ and $V_3 = IR_3$

$\therefore\ V = IR_1 + IR_2 + IR_3 = I(R_1 + R_2 + R_3)$

If R_s is the equivalent resistance of their series combination, then $V = IR_s$ $\therefore IR_s = I(R_1 + R_2 + R_3)$

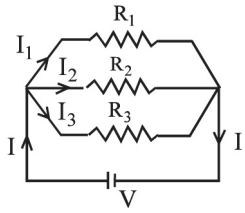
$\mathbf{R_s = R_1 + R_2 + R_3}$

ii) Resistances in parallel

The resistances are said to be in parallel if the p.d across each resistor is the same.

Let three resistance R_1, R_2 & R_3 are connected in parallel to a source of potential difference V. Since they are in parallel, potential difference across each resistor is same. Let I_1 be the current through R_1, I_2 through R_2 and I_3 through R_3 respectively. Let I be the total current then, $I = I_1 + I_2 + I_3$

from Ohm's law, $I_1 = \frac{V}{R_1}, I_2 = \frac{V}{R_2}\ \alpha\ I_3 = \frac{V}{R_3}$



If R_p is the equivalent resistance of the parallel combination,

$$I = \frac{V}{R_P} \qquad \therefore \frac{V}{R_P} = \frac{V}{R_1} + \frac{V}{R_2} + \frac{V}{R_3}$$

$$\therefore \frac{1}{R_P} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

Potentiometer

It is used for measuring potential difference accurately, comparing e.m.f's of two cells, measuring internal resistance of a cell etc. A potentiometer consists of a uniform resistance wire of 10m length, stretched on a wooden board.

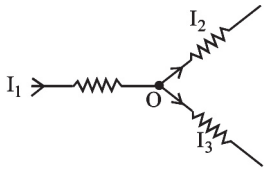
KIRCHOFF'S LAWS & ITS APPLICATION

Kirchoff's laws

First law (Point rule, Junction rule)

The algebraic sum of the current meeting at any junction in a closed circuit is zero.

Consider a circuit as shown below



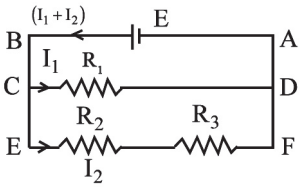
Three currents are meeting at O. Incomming current I_1 is taken as +ve and outgoing currents I_2 & I_3 are taken as -ve.

Then according to this rule, $I_1 - I_2 - I_3 = 0$ ie, $\sum I = 0$

Second law

The algebraic sum of the product of current and resistance in any closed loop is equal to the total e.m.f in that loop.

Consider a circuit,



Here anticlock wise currents are taken as positive and clockwise current are taken as negative.

Now consider loop ABCDA, $I_1R_1 = E$

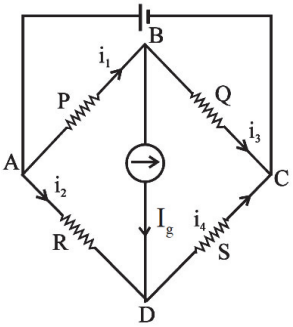
then ABEFA, $I_2R_3 + I_2R_2 = E$ or in general $\sum IR = \sum E$

Wheatstone's Bridge Network

Wheastone's Bridge is an arrangement of four resistance used for measuring one unknown resistance in terms of the other three known resistances.

Wheatstone's Network

P,Q,R and S are four resistors connected to form a loop ABCD. A cell is connected between A and C. A sensitive galvanometer of resistance G is connected between B and D. The current flowing through each branch of the circuit is shown in the diagram.



Applying Kirchhoff's rule to the mesh ABDA. $-i_1P - i_gG + i_2R=0$

For the loop BCDB, $-i_3Q + i_4S + i_gG = 0$

Now the four resistances are so adjusted so that the galvanometer current i_g is zero. Now the network is said to balanced.

Then, $i_1 = i_3$ and $i_2 = i_4$

so $i_1P = i_2 R$ .....(1) and

$i_3Q = i_4S$ .....(2)

$(1) \div (2)$ we get $\frac{i_1P}{i_3Q} = \frac{i_2R}{i_4S}$ $\frac{P}{Q} = \frac{R}{S}$

This is Wheatstone's Principle.

Flow of electric charges in a Metallic Conductor

In conductors, valence electrons can move about in whole conductor and are known as free electrons. When an external field is applied, these free electrons moves in a definite direction constituting an electric current. Thus electrons are current carriers in conductors.

- Since conduction is due to free electrons, these electrons are also called conduction electrons.

Drift Velocity

Drift velocity is defined as the average velocity with which free electrons in a conductor get drifted in a direction opposite to the direction of the applied electric field. [It is in the order of 10^{-5}m/s]

- Consider a conductor connected to a cell which provides an electric field in the conductor.

The electrons experiences a force $\vec{F} = -e\vec{E}$ $[\because F = qE \text{ here}, q = e]$

but F = m.a $\therefore \vec{a} = \frac{-e\vec{E}}{m}$

ie, In the presence of an external field, each electron experiences an acceleration $\frac{eE}{m}$ opposite to the field direction. This acceleration remains for a very short time (τ), called relaxation time. The small interval of time between two successive collisions between electrons and ions in the lattice is called relaxation time.

Now drift velocity

$$\vec{V}_d = u + \vec{a}t = O + \frac{-e\vec{E}}{m}\tau \quad V_d = \frac{-e\vec{E}}{m}\tau$$

- In the absence of electric field, the motion of electrons in the conductor is randomly distributed and there is no overall drift.

Mobility

Mobility of a charge carrier is defined as the drift velocity of the charge carrier per unit electric field. $\mu = \frac{V_d}{E}$. [It's unit is $m^2V^{-1}S^{-1}$]. Mobility is positive for both free electrons and holes*.

If m_e and m_h are electron and hole mobilities then $\mu_e = \frac{e\tau_e}{m_e}$ and $\mu_h = \frac{e\tau_h}{m_h}$

* Holes - Vacancy of an electron which acts like positive charge.

The electrical conductivity (σ) for a semiconductor containing electrons and holes can be represented as $\sigma = ne\mu_e + pe\mu_n$

Relation between drift velocity and electric current

Let V be the potential difference applied across the ends of a conductor with length ℓ and area of cross section 'A'.

Electric field produced across the conductor $E = \frac{V}{\ell}$

Let n be the number of free electrons per unit volume.

The total no. of electrons in the conductor = n × volume of the conductor = n × Aℓ

Now total charge in the conductor, Q=(n.A/)e

let 't' be the time taken by the charge to cross the conductor, $t = \frac{\ell}{V_d}$ where $V_d \rightarrow$ drift velocity $\ell \rightarrow$ length of the conductor (distance)

From the definition of electric current $I = \frac{Q}{t}$

$I = \frac{nA(e)}{\ell / V_d} = nAV_d e$ $I \alpha V_d$ (e, A & n are constants) $\therefore V_d = \frac{I}{nAe}$

Relation between mobility and electric current

Electric current $I = nAeV_d$ but $V_d = \mu_e E$

$\therefore I = nAe.\mu_e E$ or $\mu_e = \frac{I}{nAeE}$

Cell

Cell is a device which provides the necessary potential difference to maintain a continuous flow of current in an electric circuit. [Its symbol is ⊣⊢]

emf

EMF of a cell in the potential difference between the terminals of a cell when no current is drawn from it.

Potential difference

Potential difference is the difference of potentials between any two points in a closed circuit.

Comparison of emf & p.d

	emf	p.d
1	emf of a cell is the potential difference between the terminals of a cell when no current is drawn from it	Potential difference is the difference of potentials between any two points in a closed circuit.
2	is independent of resistance of the circuit	but pd is directly proportional to resistance
3	term emf is related with a cell	p.d is measured between any two points

Internal resistance of a cell

The electrical resistance offered by the electrolyte and the electrodes of a cell to the flow of current is called internal resistance.

Internal resistance of a cell depends on the

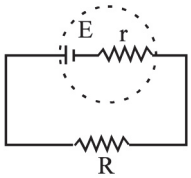
i) Separation between the electrodes

ii) Conductivity

iii) Area of the plates

iv) nature of the electrodes

Consider a cell with emf E and internal resistance 'r' is connected with a resistance R as shown



Then E = I(R + r) or $I = \frac{E}{R+r}$ (circuit equation)

E = IR + Ir = V + Ir V = E – Ir

This is the relation between pd, internal resistance and emf of a cell.

Grouping of cells

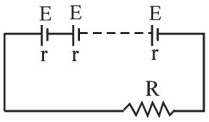
i) Cells in series

When cells are connected in series,

1) Total emf of series combination is equal to the sum of the individual emfs of the various cells.

2) The current in each cell is the same and is equal to the main current through the arrangement.

3) Total internal resistance of series combination is equal to the sum of the individual internal resistances.



Let n cells of emf E and internal resistance (r) are connected in series with R. Then total emf = nE

Then total resistance = R + nr

Current $I = \frac{nE}{nr + R}$

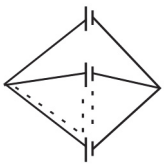
ii) Cells in parallel

When (n) identical cells are connected in parallel,

1) Total emf of the parallel combination is the same as that of a single cell.

2) The reciprocal of total internal resistance of the parallel combination is equal to the sum of the reciprocal of the resistances of the individual cells.

3) The main current is divided equally among the cells.



Total internal resistance R^1

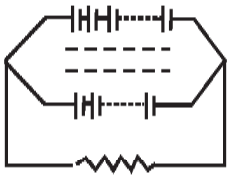
$\frac{1}{R^1} = \frac{1}{r} + \frac{1}{r} + ...n \text{ times}$ $\therefore R^1 = \frac{r}{n}$

$\therefore$ Total resistance $= \left(R + \frac{r}{n}\right)$

$\therefore$ Current $I = \frac{E}{R + \frac{r}{n}}$

iii) Mixed grouping

Let n cells of emf E and internal resistance r are connected in series and m' such combination is connected in parallel.



Total emf = nE

Internal resistance each row = nr

Total internal resistance = $\frac{nr}{m}$

$\therefore$ Total resistance = $R + \frac{nr}{m}$

$\therefore$ Current $I = \frac{nE}{R + \frac{nr}{m}}$

THERMAL & CHEMICAL EFFECTS OF ELECTRIC CURRENT

I. JOULES HEATING EFFECT

* Heat produced across resistance according to $H = I^2Rt = \frac{V^2}{R}t = VIt$ in Joules

  I = current, R = resistance, t = time, V = applied voltage

* In calories heat equation is

$$H = \frac{I^2Rt}{4.2}\,Cal = \frac{I^2Rt}{J}$$

J = The mechanical equivalent of heat

= 4.2 J/Cal

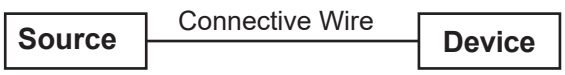
* In this effect heat energy is produced due to the collisions of free electrons with the ions or atoms of the conductor.
* Joules heating effect is irreversible.
* Heating effect produced by ac and dc are the same.

II. ELECTRIC POWER

* Electric power is the rate at which work is done by the source of emf. Its equations are

$$P = VI = I^2R = \frac{V^2}{R}$$

* Electricity is always transferred as power from source to device.



$P = VI$	$P = I^2R$	$P = \frac{V^2}{R}$
(Power delivered)	(Power loss)	(Power used)

So power is transferred with minimum current and maximum voltage.

* Unit of power - Watt or Ampere volt

  Horse power 1HP = 746 W

* In series combination of resistors, the power consumed $P \alpha R$
* In series combination of appliances, the effective power consumed P is $\frac{1}{P} = \frac{1}{P_1} + \frac{1}{P_2} + \frac{1}{P_3} + ...$
* In parallel combination of resistors, the power consumed $P \alpha \frac{1}{R}$
* In domestic supply, the appliances are connected in parallel and the effective power consumed is

  $P = P_1 + P_2 + P_3 + ...$

SECTION - I
QUESTIONS

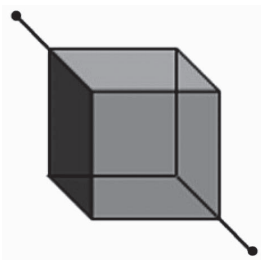
SINGLE CORRECT TYPE

1. An insulating pipe of cross-section area 'A' contains an electrolyte which has two types of ions : their charges being -e and +2e. A potential difference applied between the ends of the pipe results in the drifting of the two types of ions, having drift speed = v (-ve ion) and v/4 (+ve ion). Both ions have the same number per unit volume = n. The current flowing through the pipe is

1) $\frac{neAv}{2}$ 2) $\frac{neAv}{4}$

3) $\frac{5ne}{2}$ 4) $\frac{3neA}{2}$

2. Twelve wires of equal length and same cross-section are connected in the form of a cube. If the resistance of each of the wires is R, then the effective resistance between the two diagonal ends would be



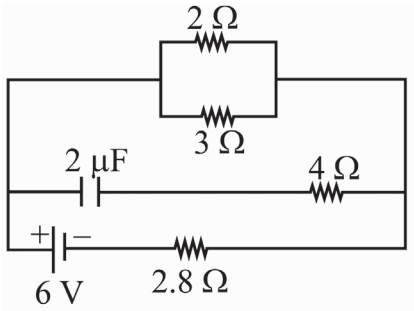
1) 2R

2) 12 R

3) $\frac{5}{6}R$

4) 8 R

3. In the figure shown, the capacity of the condenser C is 2μF . The current in 2Ω resistor is



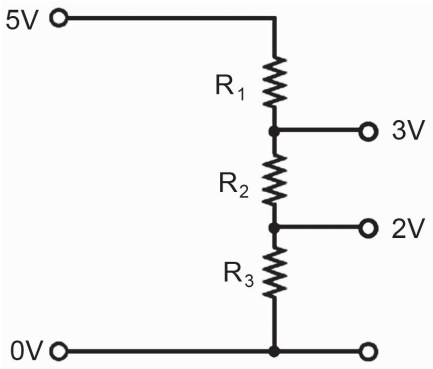
1) 9 A

2) 0.9 A

3) $\frac{1}{9}A$

4) $\frac{1}{0.9}A$

4. A potential divider is used to give outputs of 2V and 3V from a 5V source, as shown in figure. Which combination of resistances, R_1, R_2 and R_3 gives the correct voltages ?



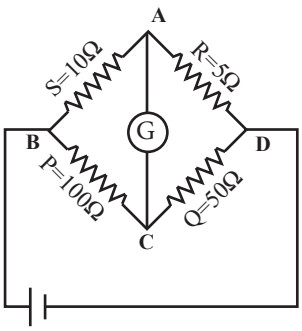
1) 1kΩ, 1kΩ, 2kΩ

2) 2kΩ, 1kΩ, 2kΩ

3) 3kΩ, 2kΩ, 2kΩ

4) 3kΩ, 2kΩ, 3kΩ

5. Figure shows a balanced Wheatstone's bridge



A) If P is slightly increased, the current in the galvanometer flows from C to A

B) If P is slightly increased, the current in the galvanometer flows from A to C

C) If Q is slightly increased, the current in the galvanometer flows from C to A

D) If Q is slightly increased, the current in the galvanometer flows from A to C

Choose the correct statements from the above options.

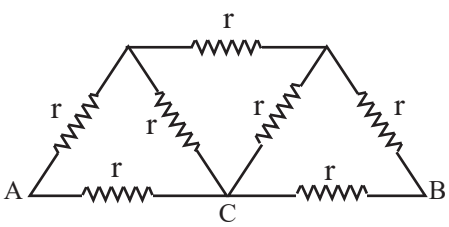
1) A and C

2) A and D

3) B and C

4) B and B

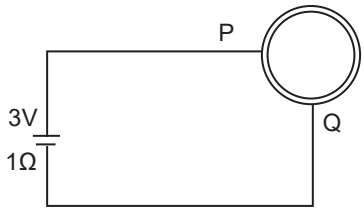
6. In the circuit shown, the value of each resistance is r, then equivalent resistance of circuit between points *A* and *B* will be



1) (4/3) r 2) 3r/2

3) r/3 4) 8r/7

7. A wire of resistance 10Ω is bent to form a circle. P and Q are points on the circumference of the circle dividing it into a quadrant and are connected to a Battery of 3 V and internal resistance 1Ω as shown in the figure. The currents in the two parts of the circle are



1) $\frac{6}{23}$ A and $\frac{18}{23}$ A

2) $\frac{5}{26}$ A and $\frac{13}{26}$ A

3) $\frac{4}{25}$ A and $\frac{12}{25}$ A

4) $\frac{3}{25}$ A and $\frac{9}{25}$ A

8. Two wires of resistance R_1 and R_2 have temperature coefficient of resistance α_1 and α_2, respectively. These are joined in series. The effective temperature coefficient of resistance is

1) $\frac{\alpha_1+\alpha_2}{2}$

2) $\sqrt{\alpha_1\alpha_2}$

3) $\frac{\alpha_1R_1+\alpha_2R_2}{R_1+R_2}$

4) $\frac{\sqrt{R_1R_2\alpha_1\alpha_2}}{\sqrt{R_1^2+R_2^2}}$

9. Two cells of equal *e.m.f.* and of internal resistances r_1 and r_2 ($r_1 > r_2$) are connected in series. On connecting this combination to an external resistance R, it is observed that the potential difference across the first cell becomes zero. The value of *R* will be

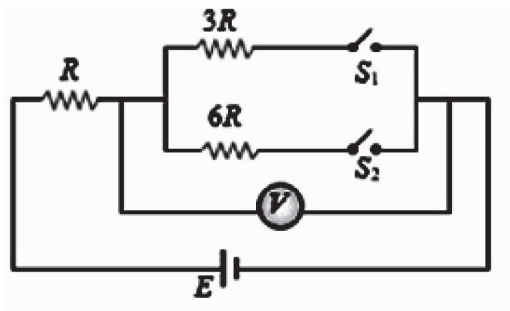
1) $r_1 + r_2$

2) $r_1 - r_2$

3) $\frac{r_1 + r_2}{2}$

4) $\frac{r_1 - r_2}{2}$

10. In the circuit shown in figure reading of voltmeter is V_1 when only S_1 is closed, reading of voltmeter is V_2 when only S_2 is closed and reading of voltmeter is V_3 when both S_1 and S_2 are closed. Then



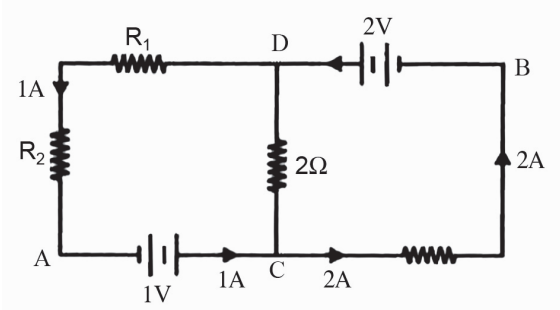
1) $V_3 > V_2 > V_1$

2) $V_2 > V_1 > V_3$

3) $V_3 > V_1 > V_2$

4) $V_1 > V_2 > V_3$

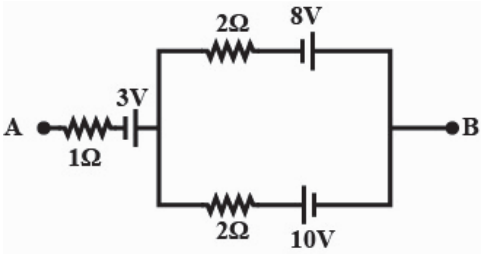
11. In the circuit shown in the figure, if the potential at point A is taken to be zero, the potential at point B is:



1) -2V 2) +1V

3) -1V 4) +2V

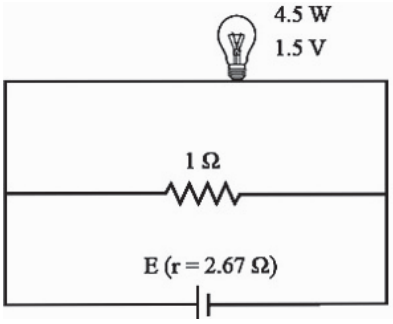
12. The net emf and internal resistance across AB of three batteries as shown in figure is :



1) 2V, 1Ω 2) 2V, 2Ω

3) 2V, 1.5Ω 4) 4V, 2Ω

13. A torch bulb rated as 4.5 W, 1.5 V is connected as shown in the figure. The e.m.f. of the cell needed to make the bulb glow at full intensity is



1) 4.5 V 2) 1.5 V

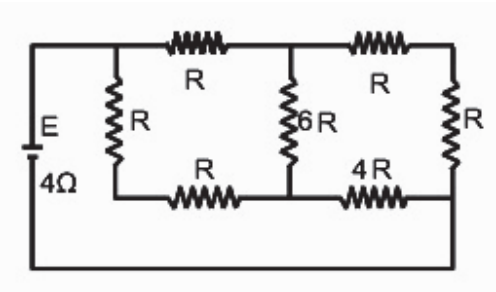
3) 2.67 V 4) 13.5 V

14. Two bulbs of 500 watt and 200 watt are manufactured to operate on 220 volt line. The ratio of heat produced in 500 W and 200 W, in two cases, when firstly they are joined in parallel and secondly in series, will be

1) $\frac{5}{2},\frac{2}{5}$ 2) $\frac{5}{2},\frac{5}{2}$

3) $\frac{2}{5},\frac{5}{2}$ 4) $\frac{2}{5},\frac{2}{5}$

15. A battery of internal resistance 4Ω is connected to the network of resistances as shown in figure. In order that the maximum power can be delivered to the network, the value of R in Ω should be



1) 2 2) 3

3) 4 4) 1

16. Two identical batteries, each of e.m.f. 2 *volt* and internal resistance 1.0 ohm are available to produce heat in an external resistance R = 0.5 *ohm* by passing a current through it. The maximum Joulean power that can be developed across R using these batteries is

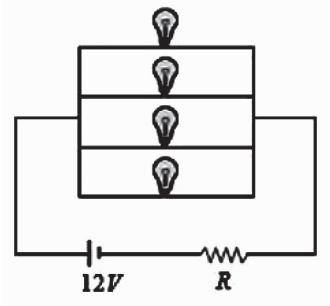
1) 1.28 *watt*

2) 2.0 *watt*

3) $\frac{8}{9}$ watt

4) 3.2 *watt*

17. Four identical electrical lamps are labelled 1.5*V*, 0.5*A* which describes the condition necessary for them to operate at normal brightness. A 12*V* battery of negligible internal resistance is connected to lamps as shown, then select the incorrect option.



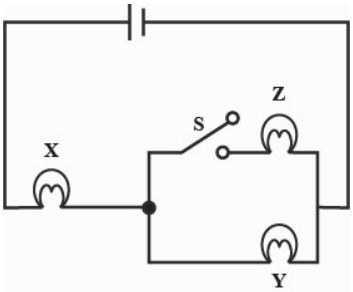
1) The value of *R* for normal brightness of each lamp is (3/4)Ω

2) The value of *R* for normal brightness of each lamp is (21/4)Ω

3) Total power dissipated in circuit when all lamps are normally bright is 24*W*

4) Power dissipated in *R* is 21*W* when all lamps are normally bright

18. If X, Y and Z in figure are identical lamps, which of the following changes to the brightness of the lamps occur when switch S is closed?



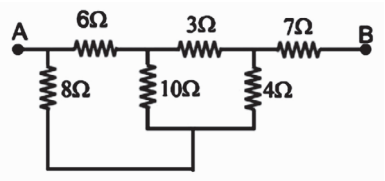
1) X stays the same, Y decreases

2) X-increases, Y-decreases

3) X increases, Y-stays the same

4) X decreases, Y increases

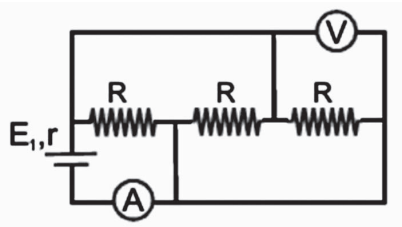
19. The equivalent resistance between the points A and B is



1) $\frac{36}{7}\Omega$ 2) 10Ω

3) $\frac{85}{7}\Omega$ 4) None of these

20. In the circuit shown in figure, ammeter and voltmeter are ideal. If E = 4V, R = 9Ω and r = 1Ω, then readings of ammeter and voltmeter are



1) 1A, 3V 2) 2A, 3V

3) 3A, 4V 4) 4A, 4V

SECTION - II QUESTIONS

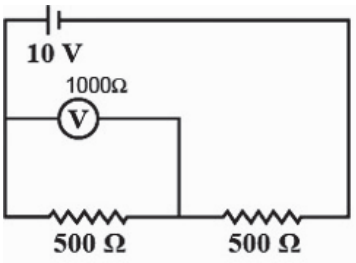
NUMERICAL TYPE

21. Water boils in an electric kettle in 15 minutes after switching on. If the length of the heating wire is decreased to 2/3 of its initial value, then the same amount of water will boil with the same supply voltage in _____ minutes

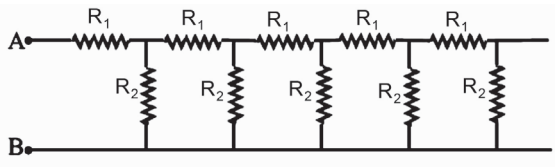
22. In a meter bridge, the gaps are closed by resistances 2 and 3 ohm. The value of shunt to be added to 3 ohm resistor to shift the balancing point by 22.5 cm is _____Ω.

23. The resistance of the series combination of two resistance is *S*. When they are joined in parallel the total resistance is *P*. If *S* = *nP*, then the minimum possible value of *n* is

24. A voltmeter of resistance 1000Ω is connected across a resistance of 500Ω in the given circuit. Then the reading of voltmeter is _____ volts



25. Consider an infinite ladder of network of resistors shown in the figure. A voltage is applied between points A and B. If the voltage is halved after each section, then the ratio of $\frac{R_2}{R_1}$ is _____



Chapter 14

MOVING CHARGES AND MAGNETISM

SYNOPSIS

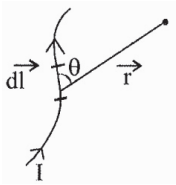
Hans Christian Oersted observed that when a compass needle is placed near a straight wire carrying current, the compass needle aligns so that it is tangent to a circle drawn around the wire. His discovery provided the first link between electricity and magnetism.

Biot - Savart's Law

According to this law, the magnetic field due to a current element of length dl carrying a current I at a point at distance 'r' from it is given by

$$dB = \frac{\mu_0}{4\pi}\frac{Idl\sin\theta}{r^2}$$

In vector form $\overrightarrow{dB} = \frac{\mu_0}{4\pi}\frac{I\left(\overrightarrow{dl}\times\hat{r}\right)}{r^2}$



Where, θ the angle between the direction of the current and the line joining the current element to the point.

μ_0 - permeability of the free space ($\mu_0 = 4\pi \times 10^{-7}\ TA^{-1}\ m$). The direction of magnetic field is along $\overrightarrow{dl}\times\vec{r}$

- When $\theta = 0$, dB = 0 i.e. the magnetic field along the axis of a current carrying conductor is zero
- When $\theta = 90^0$ $dB = \frac{\mu_0}{4\pi}\frac{Idl}{r^2}$ i.e. magnetic field is maximum in a plane perpendicular to the current element and passing through its axis.

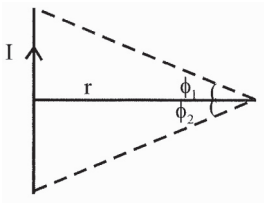
Comparison of Biot - Savart's law and Coulomb's law

- Magnetic field is produced by a vector source, the current element $I\vec{dl}$. But electrostatic field is produced by a scalar source, the electric charge.

- Both are long range, since both obey inverse square law. The principle of superposition applies to both fields.
- The electrostatic field is along the displacement vector joining the source and the field point. The magnetic field is perpendicular to the displacement vector
- There is an angle dependence in the Biot-Savart law which is not present in the coulomb's law
- Permeability μ_0 and permittivity ε_0 are related as $\mu_0\varepsilon_0 = \frac{1}{c^2}$

Magnetic field due to a current carrying conductor

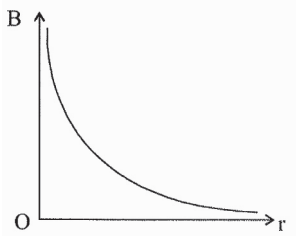
The magnetic field at a point at perpendicular distance 'r' from a straight conductor carrying current I is given by.



$$B = \frac{\mu_0 I}{4\pi r}[\sin\phi_1 + \sin\phi_2]$$

In case of the straight conductor of infinite length $\left(\phi_1 = \phi_2 = \frac{\pi}{2}\right)$

$$B = \frac{\mu_0}{4\pi}\frac{2I}{r} = \frac{\mu_0 I}{2\pi r} \quad \therefore B \propto \frac{1}{r}$$



At one end of a straight infinite conductor $\left(\phi_1 = 0, \phi_2 = \frac{\pi}{2}\right)$ $\quad B = \frac{\mu_0 I}{4\pi r}$

Right hand thumb rule : If the linear conductor is grasped in the palm of the right hand with thumb pointing along the direction of the current, then the curl fingers will point in the direction of lines of force.

- The conventional sign for a magnetic field coming out of the plane normal to it is a dot. ie. $\odot$
- The magnetic field perpendicular to the and pointing into the plane, normal to it is denoted by $\otimes$
- The magnetic induction at the centre of a square loop of wire of side a carrying a current I is

$$B = \frac{2\sqrt{2}\,\mu_0 I}{\pi a}$$

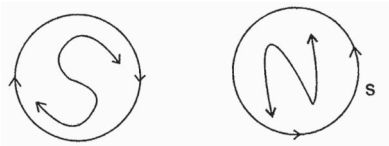
Magnetic field due to a current carrying circular coil

- For a coil of radius a consisting of N turns and carrying current I, the magnetic field at a point on the axis at a distance d from the centre is :

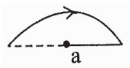
$$B=\frac{\mu_0}{4\pi}\frac{2\pi NIa^2}{(a^2+d^2)^{3/2}}=\frac{\mu_0 NIa^2}{2(a^2+d^2)^{3/2}};\ B=\frac{\mu_0}{4\pi}\frac{2M}{(a^2+d^2)^{3/2}}$$

Where M = NIA is the magnetic moment of the loop of wire which acts as a magnetic dipole. and A = πa^2 is the area of the coil.

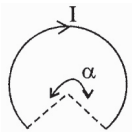
- at the centre of the coil $B_0=\frac{\mu_0 NI}{2a}$
- at d = a, $B=\frac{B_0}{\sqrt{8}}$
- The current carrying loop behaves as a small magnetic dipole placed along the axis. One face of the loop acts as north pole while the other face acts as south pole.
- The face in which the current is flowing in clockwise direction behaves as south pole while the face through which the current is flowing in anticlockwise direction behaves as south pole.



At the centre of a semi circle $B=\frac{\mu_0 I}{4a}$



At the centre of the arc of a circle of angle a, $B=\frac{\mu_0 I\alpha}{4\pi a}$ (α in radian)



Right hand thumb rule : Curl the fingers of the right hand around the circular wire with the fingers pointing in the direction of the current, then the thumb gives the direction of the magnetic field.

- Ampere's circuital law states that the line integral of magnetic field around any closed path is equal to μ_0 times the current enclosed by the path.

$$\oint \vec{B}.\vec{d\ell}=\mu_0 I_{enclosed}$$

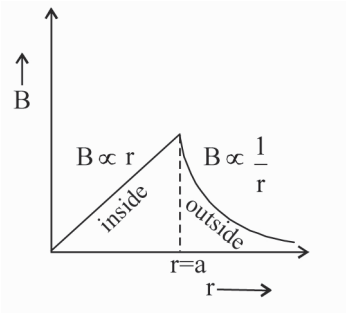
This law holds for steady current which do not fluctuate with time.

Field due to a long straight wire of radius 'a' carrying steady current I.

At a point outside the wire (r > a) $B=\frac{\mu_0 I}{2\pi r}$ or $B \propto \frac{I}{r}$

On the surface of the wire (r = a) $B=\frac{\mu_0 I}{2\pi a}$

At a point inside the wire (r < a) $B=\frac{\mu_0 Ir}{2\pi a^2}$ or $B\propto r$



Field due to a solenoid

If a solenoid of n turns per unit length carries a current I, then field $B=\frac{\mu_0 nI}{2}[\cos\theta_1-\cos\theta_2]$,

where θ_1 and θ_2 are the angle made by the ends of the solenoid with its axis at point.

- Magnetic field at a point well inside the solenoid, $B=\mu_0 nI$
- Field at one end of the solenoid, $B_{end}=\frac{\mu_0 nI}{2}=\frac{B}{2}$
- A solenoid acts as a magnetic dipole
- Direction of magnetic field can be found out by right hand thumb rule

Field due to a toroid

The magnetic field produced in toroid will be same at all points and at any point it will act along the tangent to the ring. $B=\mu_0 ni$

For any point inside the empty space surrounded by the toroid and outside the toroid magnetic field is zero.

Toroid produces magnetic field without any magnetic poles

- Force on a charge 'q' in an electric field E is F = qE

The acceleration of the charge is $a=\frac{qE}{m}$

- Force on a charge 'q' in a uniform magnetic field B with velocity v is, $\vec{F}=q\left(\vec{v}\times\vec{B}\right)$

or F = qvB sin θ

Then magnetic force is perpendicular to the velocity $\vec{v}$ and the work done by the magnetic force is zero. Therefore magnetic force cannot change the speed of charged particle even if the field is non-uniform.

Flemings left hand rule : If the forefinger, central finger and thumb are stretched at right angles to each other, then central finger represents the direction of current, fore finger represents field and thumb represents force.

Lorentz Force : The total force experienced by a charge moving inside the electric and magnetic field is called lorentz force. It is given by

$$\vec{F} = q\left[\vec{E} + \left(\vec{v} \times \vec{B}\right)\right]$$

Motion of a charge in a magnetic field

- The charge does not experience any force, if it is at rest or if it moves along the direction of magnetic field.
- If velocity and magnetic field are perpendicular, the force on the charge make it to move along a circular path. If r is the radius of the circular path, then

$$\frac{mv^2}{r} = qvB \qquad \therefore v = \frac{qBr}{m} \text{ or } r = \frac{mv}{qB} = \frac{P}{qB} = \frac{\sqrt{2mE}}{qB}$$

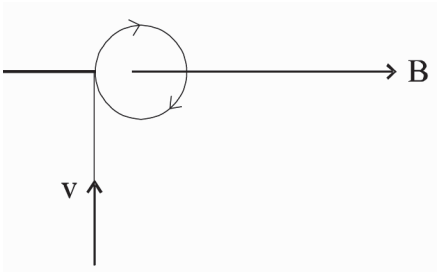
Where, P - momentum, E = kinetic energy

If the charge accelerated through a potential difference V then E = qV

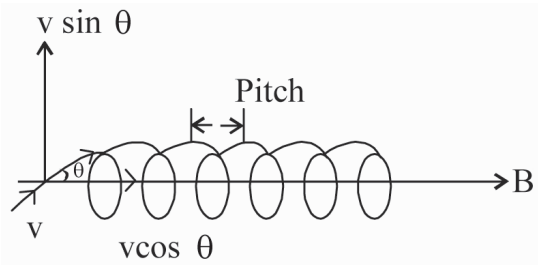
$$\therefore r = \frac{\sqrt{2mqV}}{qB}$$

Time period of revolution $T = \frac{2\pi r}{v} = \frac{2\pi m}{qB}$

Time period is independent of velocity and radius of the path



If $\vec{v}$ and $\vec{B}$ makes an angle 'θ', then due to the perpendicular component of velocity $v\sin\theta$ the charge moves along a circular path of radius, $r=\frac{mv\sin\theta}{qB}$. The parallel component of velocity $v\cos\theta$ makes the charge to moves along the direction of the magnetic field. Then the charge moves along a helical path. The pitch of the helix is, pitch = $\frac{2\pi mv\cos\theta}{qB}$

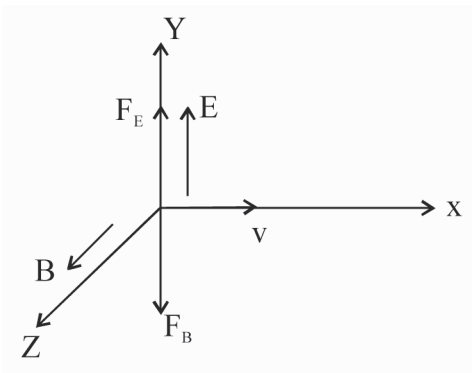


Velocity selector

If the electric field, magnetic field and velocity of the particle are mutually perpendicular as shown in figure.

$F_E = qE\hat{j}, F_B = q\vec{v}\times\vec{B} = -qvB\hat{j}$

total force $F = q(E - vB)\hat{j}$



If the total force on the charge is zero then qE = qvB or $v=\frac{E}{B}$.

Therefore only particles with speed $\frac{E}{B}$ pass undeflected through the region of crossed fields.

This method was used by J.J. Thomson to measure (e/m) of an electron.

Magnetic force on a current carrying conductor

A conductor of length 'ℓ' carrying current I placed in a uniform magnetic field B experiences a force $\vec{F} = I\left(\vec{\ell} \times \vec{B}\right)$ or $F = I\ell B \sin\theta$

Thus force is perpendicular to both the field and conductor. Force is maximum, when the magnetic field acts at right angles to the length of the conductor and the force is zero, when the length of the conductor is parallel to the magnetic field.

Force between two infinitely long parallel current carrying conductors

Force per unit length of the conductor is

$F = \frac{\mu_0}{4\pi}\frac{2I_1I_2}{r}$ where I_1 and I_2 are the currents through the conductors and r is the separation between conductors.

- The force is attractive, if currents are in the same direction and repulsive if currents are in opposite directions.
- When a coil of area A having N turns and carrying current I, is suspended in a magnetic field of strength B then the torque acts on the coil is

  t = NIAB sin θ = MB sin θ

  Where M = NIA - magnetic moment of the coil.

  θ - angle between the direction of $\vec{B}$ and normal to the plane of the coil.

  In vector form $\vec{\tau} = \vec{M} \times \vec{B}$

  If makes $\vec{B}$ an angle with the plane of the coil $\tau = NIAB\cos\theta = MB\cos\alpha$

Moving coil galvanometer : It is a device used to measure small electric current. A current carrying loop or coil experience a torque in a uniform magnetic field. This is the principle of moving coil galvanometer.

The radial field is perpendicular to the plane of the coil. Thus torque acts on the coil is τ = NIAB

If ϕ is the angle of rotation of the coil, the restoring torque $\tau = k\phi$ where k- tortional constant of the spring. In equilibrium $k\phi$ = NIAB

or $\phi = \frac{NAB}{k} I$ or $I = \frac{k}{NAB}\phi = G\phi$

Where $G = \frac{k}{NAB} =$ galvanometer constant

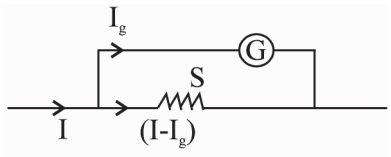
Current sensitivity : $\frac{\phi}{I} = \frac{NAB}{k} (\text{rad } A^{-1})$

Voltage sensitivity $\frac{\phi}{V} = \frac{NAB}{kR} (\text{rad } V^{-1})$, Where R - Resistance of the coil.

Ammeter

A Galvanometer of resistance G can be converted into an ammeter of range I, by connecting a small resistance S called shunt parallel to the galvanometer, which is given by

$$S = \frac{I_g G}{I - I_g}$$



Since $I_g G = (I - I_g)S$

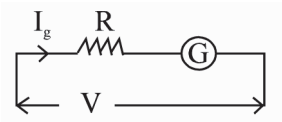
Where, Ig - current through galvanometer

Resistance of the ammeter is $R_A = \frac{GS}{G+S}$

Ammeter is a low resistance device and always connected in series to the circuit.

Voltmeter

A Galvanometer can be converted into a voltmeter read up to V by connecting a large resistance 'R' in series to the galvanometer and $R = \frac{V}{I_g} - G$



Resistance of voltmeter $R_V = R + G$

It is a high resistance device and always connected in parallel to the circuit.

Magnetic dipole moment of a revolving electron

Let T be the time period of revolution, r be the orbital radius of the electron and v the orbital speed, then $T = \frac{2\pi r}{v}$ and current $I = \frac{e}{T} = \frac{ev}{2\pi r}$

The orbital magnetic moment $\mu_\ell = IA = I\pi r^2 = \frac{evr}{2}$

or $\mu_\ell = IA = \frac{e}{2m} mvr = \frac{e}{2m} L, L = mvr$, angular momentum of the electron

$\frac{\mu_\ell}{L} = \frac{e}{2m}$ is called gyromagnetic ratio

According to Bobr hypothesis L = $\frac{nh}{2\pi}, n = 1, 2, 3.....$

$\therefore \mu_L = \frac{enh}{4\pi m}$

Its minimum value is $(\mu_\ell)_{min} = \frac{eh}{4\pi m} = 9.27 \times 10^{-24} Am^2$ and is called the Bohr magneton.

Electron has an intrinsic magnetic moment due to the spin motion of electron and is known as spin magnetic moment $\mu_s = \frac{e}{2m} S$, Where S - spin angular momentum

SECTION - I
QUESTIONS

SINGLE CORRECT TYPE

1. A particle of mass m, charge Q and kinetic energy T enters a transverse uniform magnetic field of induction $\vec{B}$. After 3 seconds the kinetic energy of the particle will be:

1) 4T

2) 3T

3) 2T

4) T

2. An electron and a proton with equal momentum enter perpendicularly into a uniform magnetic field, then

1) the path of proton shall be more curved than that of electron

2) the path of proton shall be less curved than that of electron

3) both are equally curved

4) path of both will be straight line

3. A charged particle of charge 5mC and mass 5g is moving with a constant speed 5 m/s in a uniform magnetic field on a curve $x^2 + y^2 = 25$. Where x and y are in meter. The value of magnetic field required will be

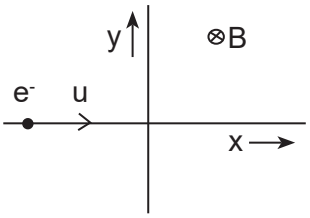
1) 0.5 Tesla

2) 1 T along z-axis

3) 5 kT along the x-axis

4) 1 kT along any line in the x-y plane

4. An electron travelling with a speed u along the positive x-axis enters into a region of magnetic field where $B = -B_0\hat{k}(x > 0)$. It comes out of the region with speed v then



1) v = u at y >0 2) v = u at y < 0

3) v > u at y>0 4) v > u at y < 0

5. An ionized gas contains both positive and negative ions. If it is subjected simultaneously to an electric field along the +x direction and a magnetic field along the +z direction then:

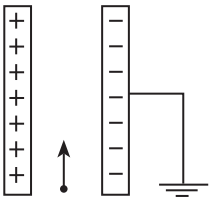
1) positive ions deflect towards +y direction and negative ions towards -y direction

2) all ions deflect towards +ve y-direction

3) all ions deflect towards -y direction

4) positive ions deflect towards -y direction and negative ions towards +y direction

6. A potential difference of 600V is applied across the plates of a parallel plate capacitor. The separation between the plates is 3mm. An electron is projected vertically, parallel to the plates, with a velocity of 2×10^6 m/s moves undeflected between the plates. The magnitude and direction of magnetic field in the region between the capacitor plate is:



1) 1T, into the plane of paper

2) 1T, out of the plane of paper

3) 0.1T, into the plane of paper

4) 0.1 T, out of plane of paper

7. A particle of charge q and mass m starts moving from the origin under the action of an electric field $\vec{E} = E_0\hat{i}$ and $\vec{B} = B_0\hat{i}$ with velocity $\vec{V} = V_0\hat{j}$. The speed of particle will become $2V_0$ after a time.

1) $t = \frac{2mV_0}{qE}$

2) $t = \frac{2Bq}{mV_0}$

3) $t = \frac{\sqrt{3}\,Bq}{mV_0}$

4) $t = \frac{\sqrt{3}\,mV_0}{q\,E_0}$

8. Two long parallel wires carry currents i_1 and i_2 such that $i_1 > i_2$. When the currents are in the same direction the magnetic field at a point midway between the wires is 6×10^{-6} T. If the direction of i_2 is reversed, the field becomes 3×10^{-5} T. The ratio i_1 / i_2 is

1) 1/2 2) 2

3) 2/3 4) 3/2

9. A metallic wire bent to form a hexagon of side 'a' carries a current I. The magnitude of the magnetic field at the centre of the hexagon is:

1) $\frac{\mu_0}{4\pi}\frac{\sqrt{3}I}{4a}$

2) $\frac{\mu_0}{4\pi}\frac{4\sqrt{3}\,I}{a}$

3) $\frac{\mu_0}{4\pi}\frac{\sqrt{3}I}{2a}$

4) $\frac{\mu_0}{4\pi}\frac{2\sqrt{3}I}{a}$

10. A long straight wire along the x-axis carries a current i in the negative z direction. The magnetic vector field $\vec{B}$ at a point having coordinates (x,y) on the z= 0 plane is

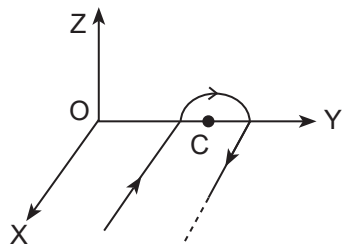
1) $\frac{\mu_0 I\left(y\hat{i} - x\hat{j}\right)}{2\pi\left(x^2+y^2\right)}$

2) $\frac{\mu_0 I\left(x\hat{i} + y\hat{j}\right)}{2\pi\left(x^2+y^2\right)}$

3) $\frac{\mu_0 I\left(x\hat{j} - y\hat{i}\right)}{2\pi\left(x^2+y^2\right)}$

4) $\frac{\mu_0 I\left(x\hat{i} - y\hat{j}\right)}{2\pi\left(x^2+y^2\right)}$

11. A long wire bent as shown in figure carries current I. If the radius of the semicircular portion is 'a', the magnetic field at centre 'C' is:



1) $\frac{\mu_0 I}{2\pi a}\left[\pi\hat{i} + 2\hat{k}\right]$

2) $\frac{\mu_0 I}{4\pi a}\left[\pi\hat{i} + 2\hat{k}\right]$

3) $\frac{-\mu_0 I}{4\pi a}\left[\pi\hat{i} + 2\hat{k}\right]$

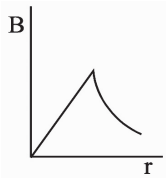
4) $\frac{\mu_0 I}{4\pi a}\left[\pi\hat{i} - 2\hat{k}\right]$

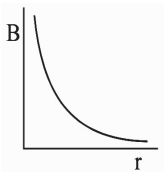
12. A long, straight wire of radius a carries a current distributed uniformly over its cross-section. The ratio of the magnetic fields due to the wire at distance $\frac{a}{2}$ and 2a, respectively from the axis of the wire is

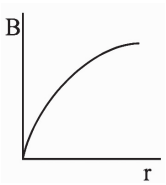
1) $\frac{2}{3}$ 2) 1

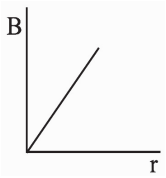
3) $\frac{1}{2}$ 4) 2

13. A long straight wire of circular cross section (radius a) carries a steady current I. The current I is uniformly distributed across the cross-section. The variation of the magnetic induction B with distance r from the centre of the wire for r < a is as shown in:

1) 

2) 

3) 

4) 

14. A long solenoid with 10 turn/cm and a radius of 7cm carries a current of 20mA. A current of 6A exist in a straight conductor located along the central axis of the solenoid. At what radial distance from the axis will be direction of magnetic field be at 45° to the axial direction?

1) 4.8 cm

2) 8.1 cm

3) 9.9 cm

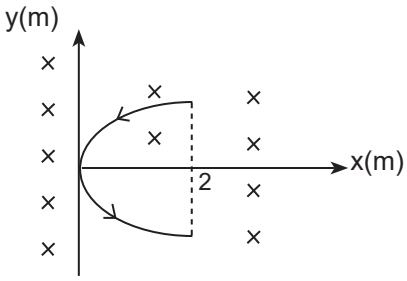
4) 10.6 cm

15. A current of 10 A is flowing in a wire of length 1.5 m. A force of 15 N acts on it when it is placed in a uniform magnetic field of 2T. The angle between the magnetic field and direction of current is

1) 30° 2) 45°

3) 60° 4) 90°

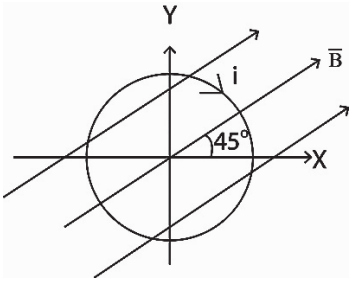
16. A conducting wire bent in the form of a parabola $y^2 = 2x$ carries a current I = 2A as shown in figure. This wire is placed in a uniform magnetic field $\vec{B} = -4\hat{k}T$. The magnetic force on the wire (in newton).



1) $32\hat{i}$ 2) $16\hat{i}$

3) $-32\hat{i}$ 4) $-16\hat{i}$

17. A circular loop of radius 20cm is placed in a uniform magnetic field $\vec{B} = 2T$ in X-Y plane, the loop carries a current 1A in the direction shown in figure. The magnitude of torque acting on the loop is nearly



1) 0.25 N-m
2) $\frac{0.25}{\sqrt{2}} N-m$
3) 0.75 N-m
4) $\frac{0.75}{\sqrt{2}} N-m$

18. A metallic wire is folded to form a square loop of side 'a'. It carries a current I and is kept perpendicular to a uniform magnetic field B. If the shape of the loop is changed to a circle without changing the length of the wire and the current, the work done in doing so is:

1) $IBa^2(\pi+2)$
2) $IBa^2(\pi-2)$
3) $IBa^2\left(\frac{4}{\pi}-1\right)$
4) $IBa^2\left(1-\frac{4}{\pi}\right)$

19. A galvanometer 30 divisions and a sensitivity of 16μA per division. It can be converted into a voltmeter to read 3V by connecting a resistance (approximately)

1) 6kΩ in series
2) 66kΩ in parallel
3) 66kΩ in series
4) 6kΩ in parallel

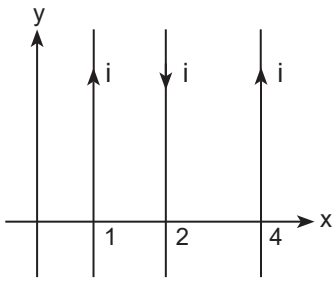
20. A galvanometer has a resistance of 20Ω and reads full scale when 0.2V is applied across it. To convert it into a 10A ammeter, the galvanometer coil should have a

1) 0.01Ω resistor connected across it
2) 0.02Ω resistor connected across it
3) 200Ω resistor connected in series with it
4) 2000Ω resistor connected in series with it

SECTION - II QUESTIONS

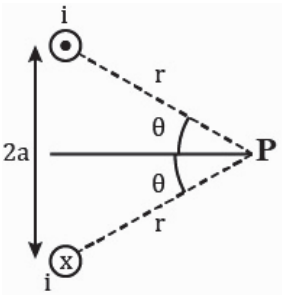
NUMERICAL TYPE

21. Equal currents of 1A flow through each of the wires parallel to the y-axis located at x = 1m, x = 2m, x = 4m ..... The currents in the adjacent wires are in opposite directions. The magnitude of the magnetic field at the origin is x × 10^{-7} T . Value of x is:



22. Velocity and acceleration vectors of a charged particle moving in a magnetic field at an instant are $\vec{v} = 3\hat{i} + 4\hat{j}$ and $\vec{a} = 2\hat{i} + x\hat{j}$. The value of $|x|$ is:

23. Two long parallel wires situated at a distance 2a carry equal current 'i' in opposite directions as shown in figure. The value of magnetic field at a point P situated at equal distances from both the wires will be : $\frac{\mu_0 ia}{\pi r^x}$, when value of x is



24. A circular arc of wire of radius of curvature r subtends an angle of $\frac{\pi}{4}$ radian at its centre. If i current is flowing in it then the magnetic induction at its centre is $\frac{\mu_0 i}{yr}$. Find y.

25. An α particle travels at an angle of 30° to a magnetic field 0.8T with a velocity of 10m/s. The magnitude of force is $x \times 10^{-14}$ N. Find *x*.

Chapter 15

MAGNETISM AND MATTER

SYNOPSIS

Magnetic Field Lines

Form continuous closed loops

Tangent to the field line at a given point represents the direction of the net magnetic field B at that point

Bar Magnet

2 equal and opposite magnetic poles separated by small distance

A Magnetic dipole :- Consist of a pair of magnetic poles of equal and opposite strength separated by small distance.

Magnetic moment of a bar magnet :- is defined as a vector quantity having magnitude equal to the product of pole strength (m) with effective length (l) and it is directed along the axis of the magnet from south pole to north pole ie $M = m\ell$

It is an axial vector

Its S.I. unit is Am^2

- A bar magnet attracts certain magnetic substances. The attracting power of the magnet is maximum at two points near the ends called poles
- Pole Strength : The attracting power of a bar magnet at its poles called pole strength
- The pole strength of north pole and south pole of a bar magnet is conventionally represented by +m and -m respectively
- The pole strength is a scalar quantity its unit is A.m.
- The pole strength of a bar magnet is directly proportional to its area of cross section. ie $m \alpha A$
- The attracting power of a bar magnet at its centre point is zero. So it is called neutral point
- Magnetic poles are always exist in pairs ie monopole does not exist in magnetism. So Gauss law in magnetism given as $\oint \bar{B}.d\bar{s} = 0$
- Effective length or magnetic length:- It is distance between two poles along the axis of a bar magnet. As poles are not exactly at the ends, the effective length (l) is less than the geometrical length (l_0) of the bar magnet. ie $l = 0.84\ l_0$
- Inverse square law:- The magnetic force between two isolated magnetic poles of strength m_1 and m_2 lying at a distance 'r' is directly proportional to product of poles strength and inversely proportional to the square of distance between their centers.

$$\text{ie } F \alpha \frac{m_1 m}{r^2} \text{ or } F = k\frac{m_1 m_2}{r^2}$$

where $K \rightarrow \frac{\mu_0}{4\pi}(SI)$, $K \rightarrow 1(c.g.s)$

- If a magnet is cut into two equal parts along the length then pole strength is reduced to half and length remains unchanged. New magnet moment $M^1 = m^1 \times l = \frac{m}{2} \times \ell = \frac{M}{2}$
- If a magnet is cut into two equal parts perpendicular to its length, then pole strength remains unchanged and length reduced to half. The new magnetic dipole moment $M^1 = m \times \ell / 2 = \frac{M}{2}$
- The magnetic dipole moment of a magnet is equal to product of pole strength and distance between poles. ie M = m × l
- As magnetic moment is a vector, in case of two magnets having magnetic moments M_1 and M_2 with angle θ between them, the resulting magnetic moment

$$M = \left[M_1^2 + M_2^2 + 2M_1M_2\text{Cos}\theta\right]^{1/2} \text{ with direction}$$

$$\tan\phi = \left[\frac{M_2\text{Sin}\theta}{M_1 + M_2\cos\theta}\right]$$

- Magnetic dipole in magnetic field

Torque on magnetic dipole

(a) Bar Magnet $\tau = MB\sin\theta$ $\rightarrow \theta = 90 \Rightarrow \tau = MB(\max i)$, $\rightarrow \theta = 0 \text{ or } 180 \Rightarrow \tau = 0(\min i)$

In vector form $\vec{\tau} = \overline{M} \times \overline{B}$

(b) Coil or loop $\tau = \overline{M} \times \overline{B}, \tau = NI(\overline{A} \times \overline{B})$

$\tau = BINA\sin\theta$ $\rightarrow \theta = 90 \Rightarrow \tau = BINA(\max i)$, $\rightarrow \theta = 0 \text{ or } 180 \Rightarrow \tau = 0(\min i)$

Dipole in uniform magnetic field
- $F_{net} = 0$ (not translatory motion)
- τ – may or may not be zero (decided by θ)

Dipole in non uniform magnetic field
- $F_{net} \neq 0$ (not translatory motion)
- τ – may or may not be zero (decided by θ)

- Work done in rotating a magnetic dipole $\int_{\theta_1}^{\theta_2} \tau . d\theta = \int_{\theta_1}^{\theta_2} MB \sin\theta \, d\theta = MB(\cos\theta_1 - \cos\theta_2)$

  If the magnetic dipole is rotated from field direction, Then work done

  (1) in one - rotation $(\theta_1 = 0, \theta_2 = 360)$

  W = MB (cos 0 - cos 360) = 0

  (2) in 3/4 rotation $(\theta_1 = 0, \theta_2 = 270)$

  W = MB (cos 0 - cos 270) = MB

  (3) in half rotation $(\theta_1 = 0, \theta_2 = 180)$

  W = MB (cos 0 - cos 180) = 2 MB.

  (4) in 1/4 rotation $(\theta_1 = 0, \theta_2 = 90)$

  W = MB (cos 0 - cos 90) = MB.

- Work done to rotate a dipole in a magnetic field is stored in the form of potential energy of magnetic dipole.
- Potential energy of magnetic dipole - defined as work done in rotating the dipole from a direction perpendicular to the given direction

  ie $U = W_\theta - W_{90} = MB(1 - \cos\theta) - MB = -MB\cos\theta$

  In vector form $U = -\vec{M}.\vec{B}$
- When M and B are parallel $(\theta = 0)$, the dipole has minimum potential energy and it is in stable equilibrium

  U = –MB (minimum)

  When M and B are antiparallel $(\theta = 180)$ the dipole has maximum P.E. and it is in unstable equilibrium, U = + MB (maxi)

- When M and $\overline{B}$ are perpendicular to each other $(\theta = 90)$, the dipole has potential energy U = 0

  and in this situation maximum torque acts on it hence no equilibrium.

  Magnetism & Gauss's Law
- The net magnetic flux through any closed surface is zero

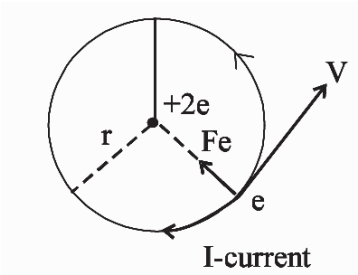
  $\oint \vec{B}.\overrightarrow{ds} = 0$
- Atomic Magnetism:

  Bohr's Postulates

  (i) $\frac{mv^2}{r} = \frac{kze^2}{r^2}$ (ii) $L = MrV = n \times \frac{h}{2\pi}$ where $n = 1, 2, 3.....$

Basic elements of atomic magnetism

(a) Orbital current



$$1 = ef = \frac{e}{T} = \frac{ev}{2\pi r} = \frac{ew}{2\pi}$$

(b) Magnetic Induction at nucleus position, $BN = \frac{\mu_0 I}{2r} = \frac{\mu_0 ef}{2r} = \frac{\mu_0 e}{2Tr} = \frac{\mu_0 ev}{4\pi r^2} = \frac{\mu_0 ew}{4\pi r}$

(c) Magnetic moment of circular orbit, $M = IA = ef \times \pi r^2 = \frac{\pi r^2 e}{T} = \frac{evr}{2} = \frac{ewr^2}{2}$

- Relation between magnetic moment and angular momentum of orbital electron

  $M = \frac{eVr}{2} \times \frac{m}{m} = \frac{eL}{2m}$; In vector form $\vec{M} = \frac{-e\vec{L}}{2m}$

  So for electron its $\vec{M}$ and $\vec{L}$ both are antiparallel axial vectors.

  Bohr Magneton (μ_B) - Bohr magneton can be defined as the magnetic moment of orbital electron which revolves in first orbit of the hydrogen atom.

$$\mu_B = \frac{eh}{4\pi m} = \frac{1.6 \times 10^{-19} \times 6.6 \times 10^{-34}}{4 \times 3.14 \times 9.1 \times 10^{-31}} = 0.923 \times 10^{-23} Am^2$$

- Time period of oscillation of suspended magnet . $T = 2\pi\sqrt{\frac{I}{MB_H}}$ Where M = magnetic moment of bar magnet.

  I - Moment inertia of bar magnet about its geometric axis.
- Magnetic field due to a bar magnet

  (i) At axial position $B_a = \frac{\mu_0}{4\pi} \times \frac{2Mr}{(r^2 - \ell^2)} = \frac{\mu_0}{4\pi} \times \frac{2M}{r^3}$

  (i) At equatorial position $B_e = \frac{\mu_0}{4\pi} \times \frac{M}{(r^2 + \ell^2)^{3/2}} \approx \frac{\mu_0}{4\pi} \times \frac{M}{r^3}$

Magnetic Materials

- Magnetic field or magnetic intensity $(\vec{H})$ – Field in which a material is placed for magnetisation, called as magnetising field.

  $$(\vec{H}) = \frac{B_0}{\mu_0} = \frac{\text{Magnetic field}}{\text{Permeability of free space}}$$
- Its S.I. unit is A/m
- Intensity of magnetisation $(\vec{I})$

  When a magnetic material is placed in magnetising field then induced dipole moment / unit volume of that material is known as intensity of magnetisation $\vec{I} - = \frac{\vec{m}}{v}$

  S.I. unit is Ampere / Meter
- **Magnetic Susceptibility** $(\chi_m) = \frac{I}{H}$ (It is a scalar with no units and dimensions)
- Physically it represent the way with which a magnetic material can be magnetised
- Magnetic Permeability $(\mu) = \frac{B_m}{H} = \frac{\text{Total magnetic field inside the material}}{\text{Magneti sin g field}}$

  its unit is TmA^{-1} or NA^{-2}
- Relative permeability $\mu_r = \frac{\mu}{\mu_0}$

  It has no units and dimensions

  Relation between permeability and susceptibility

  We know $B_m = B_0 + B_i = \mu_0 H + \mu_0 I$

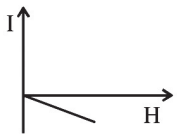
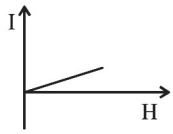
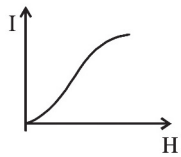
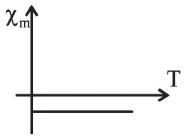
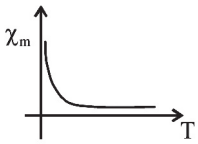
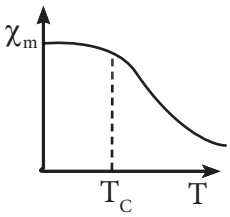
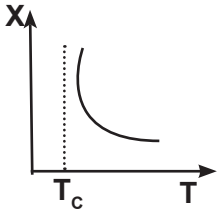
  $$B_m = \mu_0 (H + 1)$$

  $$\frac{B_m}{H} = \mu_0 \left(1 + \frac{I}{H}\right) = \mu_0 (1 + \chi_m);$$

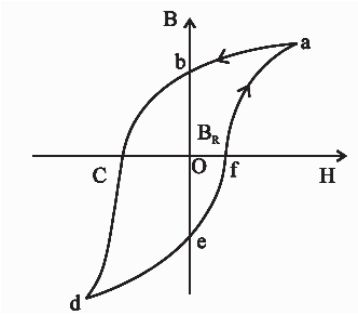
  $$\mu = \mu_0 (1 + \chi_m);\ \mu_r = (1 + \chi_m)$$

Classification of magnetic materials

On the basis of magnetic properties of the materials materials ae divided into three classes.

Properties	Diamagnetic	Paramagnetic	Ferromagnetic
Cause of magnetism	Orbital motion of electrons	Spin motion of electrons	Formation of domains
Substance placed in uniform magnetic field	Poor magnetisation in opposite direction. Here $B_m < B_0$ $I \rightarrow$ small, negative varies linearly with field	Poor magnetisation in same direction. Here $B_m > B_0$ I-small, positive varies linearly with field.	Strong magnetisation in same direction. Here $B_m >> B_0$ I-very large, positive & varies non-linearly with field.
I - H Curve			
$\chi_m - T$	$\chi_m \rightarrow$ small, negative and temperature independent $\chi_m \alpha\, T^0$	$\chi_m \alpha \frac{1}{T}$	$\chi_m \alpha \frac{1}{T - T_C} (T > T_C)$
$\chi_m - T$, curve  $1 > \mu r > 0$	 $2 > \mu r > 1$	 $\mu r >>> 1$, Ni	
Ex: Bi, Cu, Ag, Pb, H_2O Hg, H_2, He, Ne, Au Zn, Sb, NaCl Diamond	Na, K, Mg, Mn Sn, Al, O_2	Fe_3O_4, Gd, Alnico, etc	Iron, Cobalt, Nickel, CrO_2, Gadolinium etc.

Magnetic Hysteresis



The lagging of intensity of magnetisation (or magnetic Induction) behind the magnetising field, when a magnetic specimen is taken through a cycle of magnetisation, is called hysterisis.

Residual Magnetism (Ob) = B_K = retentivity = remanence - The value of Intensity of magnetisation of the magnetic material, when the magnetising field is reduced to zero is called retentivity.

Coercivity (oc) = The value of reverse magnetising field which has to be applied to the magnetic material so as to reduce the residual magnetisation to zero is called its coercivity.

SECTION - I
QUESTIONS

SINGLE CORRECT TYPE

1. The effective length of a magnet is 31.4 cm and its pole strength is 0.5Am. The magnetic moment, if it is bent in the form of a semi circle will be

1) 0.1 Am^2 2) 0.01 Am^2

3) 0.2 Am^2 4) 1.2 Am^2

2. Two similar bar magnets P and Q, each of magnetic moment M, are taken. If P is cut along its axial line and Q is cut along its equatorial line, all the four pieces obtained have

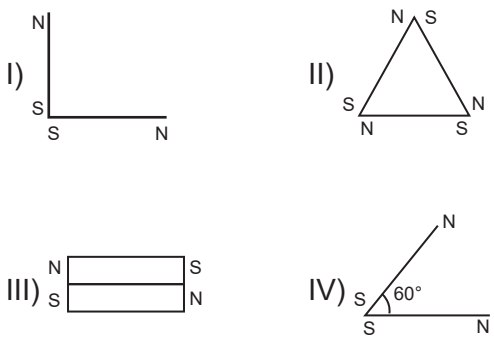
1) equal pole strength

2) magnetic moment $\frac{M}{4}$

3) magnetic moment $\frac{M}{2}$

4) magnetic moment m

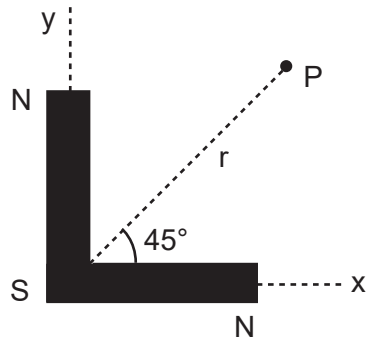
3. Figure shows different combinations of some magnets, each of magnetic moment M. Which combination has largest magnetic moment ?



1) I 2) II

3) III 4) IV

4. Two small identical bar magnets each of magnetic dipole moment M are placed as shown in the figure. Magnetic field in a distant point P is



1) $\frac{\mu_0}{4\pi}, \frac{2M}{r^3}$ 2) $\frac{\mu_0}{4\pi}\frac{2\sqrt{2}M}{r^3}$

3) $\frac{\mu_0}{4\pi}\frac{M}{r^3}$ 4) $\frac{\mu_0}{\pi}.\frac{M}{r^3}$

5. Two identical short bar magnets, each having magnetic moment of $10Am^2$, are arranged such that their axial lines are perpendicular to each other and their centres be along the same straight line in a horizontal plane. If the distance between their centres is 0.2m, the resultant magnetic induction at a point midway between them is:

1) $\sqrt{2}\times10^{-7}T$ 2) $\sqrt{5}\times10^{-7}T$

3) $\sqrt{2}\times10^{-3}T$ 4) $\sqrt{5}\times10^{-3}T$

6. A magnetic needle lying parallel to a magnetic field requires 'W' units of work to turn it through 45°, the torque needed to maintain in this position will be

1) $\sqrt{3}W$ 2) W

3) $\frac{\sqrt{3}}{2}W$ 4) $\frac{W}{\sqrt{2}-1}$

7. A short bar magnet of magnetic moment 0.32 J/T is placed in uniform field of 0.15T. If the magnet is free to rotate in the plane of the field. The P.E. of the magnet in stable equilibrium position.

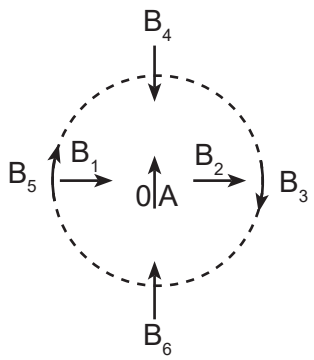
1) -4.8×10^{-2} J

2) -2.4×10^{-2} J

3) 4.8×10^{-2} J

4) 2.4×10^{-2} J

8. Figure shows a small magnetised needle 'A' placed at a point 'O'. The arrow shows the direction of its magnetic moment. The other arrows show different positions and orientations of the magnetic moment of another identical magnetised needle is:



Which configuration corresponds to the highest potential energy among all the configurations shown

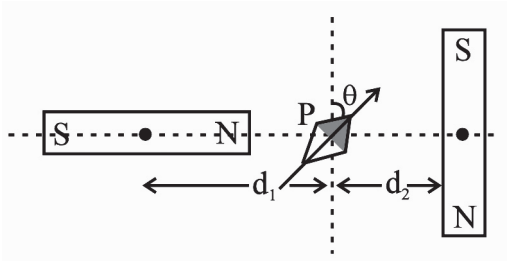
1) AB_6

2) AB_1

3) AB_4

4) AB_2

9. Two magnets A and B are identical and these are arranged as shown in the figure. Their length is negligible in comparison to the separation between them. A magnetic needle is placed between the magnets at point P which gets deflected through an angle of θ under the influence of magnets. The ratio of distance d_1 and d_2 will be:



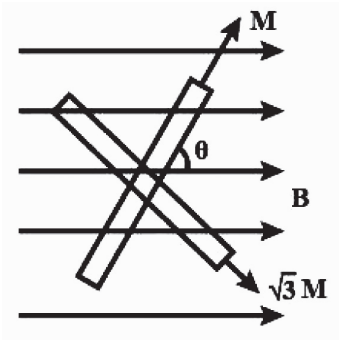
1) $(2\tan\theta)^{1/3}$

2) $(2\tan\theta)^{-1/3}$

3) $(2\cot\theta)^{1/3}$

4) $(2\cot\theta)^{-1/3}$

10. M and $\sqrt{3}m$ are the magnetic dipole moments of the two magnets, which are joined to form a cross figure. The inclination of the system with the field, if their combination is suspended freely in a uniform external field B is



1) θ = 30°

2) θ = 45°

3) θ = 60°

4) θ = 15°

11. The length of a magnet is large compared to its width and breadth. The time period of its oscillation in a vibration magnetometer is 2s. The magnet is cut along its length into three equal parts and these parts are then placed on each other with their like poles together. The time period of this combination will be

1) $2\sqrt{3}s$ 2) $\frac{2}{3}s$

3) 2s 4) $\frac{2}{\sqrt{3}}s$

12. The magnetic moment produced in a substance of 1g is 6×10^{-7} Am^2 . If its density is $5g/cm^3$, then the intensity of magnetization in A/m will be:

1) 8.3×10^{6} 2) 3.0

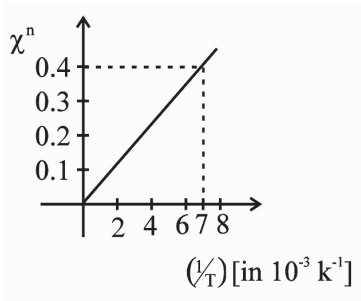
3) 1.2×10^{-7} 4) 3×10^{-6}

13. The dipole moment of each molecule of a paramagnetic gas is $1.5\times10^{-23}Am^2$. The temperature of gas is 27^0C and the number of molecules per unit volume in it is $2\times10^{26}m^{-3}$. The maximum possible intensity of magnetization in the gas will be:

1) 3×10^{3} A/m 2) 4×10^{-3} A/m

3) 5×10^{5} A/m 4) 6×10^{-4} A/m

14. The $\chi - 1/T$ graph for an alloy of paramagnetic nature is shown in figure. The curie constant is, then



1) 57K 2) 2.8×10^{-3} k

3) 570k 4) 17.5×10^{-3} k

15. The magnetic susceptibility of a paramagnetic substance at -73^oC is 0.0060, then its value at -173^oC will be

1) 0.0050 2) 0.0120

3) 0.0180 4) 0.0045

16. **Statement-I :** Electromagnets are made of soft iron

Statement-II : Coercivity of soft iron is small.

1) Both Statement-I is true, Statement-II is true

2) Both Statement-I is false, Statement-II is false

3) Statement-I is true, Statement-II is false

4) Statement-I is false, Statement-II is true

17. Needles N_1, N_2 and N_3 are made of a ferromagnetic, a paramagnetic and a diamagnetic substance respectively. A magnet when brought close to them will

1) attract N_1 strongly, N_2 weakly and repel N_3 weakly

2) attract N_1 strongly, but repeal N_2 and N_3 weakly

3) attract all three of them

4) attract N_1 and N_2 strongly but repel N_3

18. The area of hysterisis loop of material is equivalent to 250 SI units. When 10kg material is magnetised by an alternating field of 50Hz, the energy lost in 1hr will be: [if the density of material is $7.5gm / cm^3$]

1) 3×10^{2} erg 2) 6×10^{4} J

3) 6×10^{4} J 4) 3×10^{2} J

19. Regarding paramagnetic substances, which of the followings are true

i) Independent of temperature

ii) If paramagnetic liquid is filled in a narrow u-tube and one limb is placed between the pole pieces of an electromagnet, the level of the liquid rises when the magnetic field is switched on

iii) The susceptibility χ decreases as temperature increases

1) (i), (ii) 2) (ii), (iii)

3) (i), (iii) 4) (i), (ii), (iii)

20.

Column - A		Column - B	
1)	Intensity of magnetisation	i)	$\frac{C}{T}$
2)	Magnetic susceptibility	ii)	$\mu_0(1+x)$
3)	Permeability	iii)	$\frac{\vec{M}}{V}$
4)	Curie's law	iv)	$\vec{I}/\vec{H}$

1) 1-(iii); 2-(iv); 3-(ii); 4-(i)

2) 1-(i); 2-(ii); 3-(iii); 4-(iv)

3) 1-(ii); 2-(i); 3-(iv); 4-(iii)

4) 1-(i); 2-(iii); 3-(iv); 4-(ii)

SECTION - II QUESTIONS

NUMERICAL TYPE

21. Rate of change of torque 'τ' with deflection 'θ' is maximum for a magnet suspended freely in a uniform magnetic field of induction 'B' when 'θ' equal to:

22. An iron rod of volume 10^{-4} m^3 and relative permeability 1000, is placed inside a long solenoid wound with 5 turns/cm. If a current of 0.5A is passed through the solenoid, the magnetic moment of the rod is

23. Two identical bar magnets with length 10cm and weight 50g are arranged vertically and with their like poles facing. The upper magnet hangs in the air above the lower one so that the distance between nearest poles of magnet is 3mm. Moment of each magnet in Am^2 is:

24. The distance of two points on the axis of a magnet from its center is 10cm and 20cm respectively. The ratio of magnetic intensity at these points is 12.5:1. The length of the magnet will be (in cm)

25. A bar magnet has a length of 8cm. The magnetic field at a point at a distance 3cm from the centre in the broad side on position is found to be 4×10^{-6} T. Then the pole strength of the magnet is x $\times10^{-4}$ A-m; where x is

Chapter 16

ELECTROMAGNETIC INDUCTION AND AC

SYNOPSIS

Magnetic Flux

- Magnetic flux over an area held in a magnetic field represents the number of magnetic lines of force crossing the area normally.
- Magnetic flux over a small area $\vec{ds}$ held in a magnetic field $\vec{B}$ is

  $$d\phi = \vec{B}.\vec{ds} = B\ ds\ \cos\theta$$

  where θ is the angle between directions of field vector and area vector.
- The total magnetic flux through the surface

  $\phi = \int \vec{B}.\vec{ds} = \vec{B}.\vec{A}$, if the field is uniform throughout the surface.
- The magnetic flux linked with a coil of N turns and area A placed in a uniform magnetic field of induction B,

  $$\phi = NBA\cos\theta$$
- Flux is a scalar quantity.
- SI unit of magnetic flux is weber. 1 Wb = 1 T.m^2

Electromagnetic Induction

- It is the phenomenon of generation of emf in a circuit by changing the magnetic flux associated with it.

Laws of Electromagnetic Induction

Faraday's Law (Magnitude of Induced emf)

- **First Law** – Whenever the magnetic flux linked with a circuit changes, an emf is induced in it. This induced emf lasts so long as the change in flux lasts
- **Second Law** – The magnitude of induced emf in a circuit is directly proportional to the rate of change of magnetic flux linked with it.

Lenz's Law (Direction of Induced emf)

- The polarity of induced emf is always such as to oppose or tends to oppose the cause of change in flux.
- Lenz's law is a consequence of the law of conservation of energy.
- Induced emf $e = -\frac{d\phi}{dt}$
- Induced current $i = \frac{e}{R} = -\frac{1}{R}\frac{d\phi}{dt}$
- Induced charge $q = \int i\ dt = \int -\frac{d\phi}{R} = \frac{\phi_1 - \phi_2}{R}$

Flemings Right Hand Rule

- Stretch out the thumb, fore figure and middle figure of the right hand along mutually perpendicular directions with fore figure along the direction of magnetic field and the thumb along the direction of motion of the conductor, then the direction along which the middle finger points will give the direction of induced current.

Motional emf

When a conducting rod of length *l* moves with a velocity *v* in a uniform magnetic field *B*, the motional emf between its two ends,

$$e = Blv\sin\theta$$

where θ is the angle made by the direction of magnetic field with the plane containing its length and velocity.

- When a conducting rod of length L is rotated with uniform angular velocity ω in a perpendicular magnetic field of strength B, the induced emf generated,

$$e = \frac{B\omega L^2}{2} = BAf$$

where f is the frequency of rotation and A is the area of the circle.

Self-Induction

- It is the property of a coil due to which the coil opposes any change in the strength of current through it by inducing an emf.
- Coefficient of self-induction or self-inductance,

$$L = \frac{\text{Flux linked with a coil}}{\text{Current through the coil}} = \frac{\phi}{i}$$

$$L = \frac{\text{emf induced in the coil}}{\text{Rate of change of current through the coil}} = \frac{e}{\frac{d\phi}{dt}}$$

- SI unit of L is ***Henry (H)***
- Self-inductance of a solenoid of *N* turns, length *l* and area *A* with a core material having relative permeability μ_r

$$L = \frac{\mu_0 \mu_r N^2 A}{\ell}$$

Mutual Induction

- It is the property of two coils due to which a change of current in one of them induces an instantaneous emf in the other.
- Coefficient of mutual induction or mutual inductance,

$$M = \frac{\text{Flux linked with one of the coils}}{\text{current through the other coil}} = \frac{\phi_1}{i_2} = \frac{\phi_2}{i_1}$$

$$M = \frac{\text{emf induced in one of the coil}}{\text{Rate of change of current through the other coil}} = \frac{e_2}{\frac{d\phi_1}{dt}} = \frac{e_1}{\frac{d\phi_2}{dt}}$$

- SI unit of M is ***Henry (H)***
- Mutual inductance of two long coaxial solenoids each of length *l* and area *A*

$$L = \frac{\mu_0 \mu_r N_1 N_2 A}{l}$$

- For two coupled coils, $M = K\sqrt{L_1 L_2}$,where K is the coefficient of coupling between the coils.
- When K = 1, the coils are said to be tightly coupled.

Energy Stored in an Inductor

- The energy stored in the magnetic field of an inductor,

$$E = \frac{1}{2} L i^2$$

Eddy Current

- Eddy currents are loops of electrical current induced within conductors by a changing magnetic field in the conductor.
- Eddy currents are also known as Foucault's current.
- Eddy currents can be minimized by using laminated cores.

Alternating Current

- Working principle of an ac generator is electromagnetic induction.
- The instantaneous emf produced by an ac generator $E = E_0 \sin \omega t$
- $E_0 = NBA\omega$ is the peak value of emf
- Instantaneous value of current $I = I_0 \sin \omega t$

Characteristics of AC

- Cycle – One complete set of positive and negative values of ac
- Time period (T) – The time taken to complete one cycle of ac

$$T = \frac{2\pi}{\omega}$$

- Frequency (ν) – The number of ac cycles per second

$$v = \frac{1}{T} = \frac{\omega}{2\pi}$$

- Instantaneous value – The value of ac at a particular instant of time

$$E = E_0 \sin \omega t$$

- Peak Value (E_0 or I_0) – The maximum value of ac on either direction of the cycle
- The average value of ac over a complete cycle is always zero.
- The average value of ac is defined only for half cycles.

$$E_{avg} = \frac{2E_0}{\pi} = 0.637E_0$$

$$I_{avg} = \frac{2I_0}{\pi} = 0.637I_0$$

RMS value or virtual value or effective value of ac

$$E_{rms} = \frac{E_0}{\sqrt{2}} = 0.707E_0$$

$$I_{rms} = \frac{I_0}{\sqrt{2}} = 0.7071_0$$

- The ratio of rms value to the average value of ac is called form factor.

$$\text{form factor} = \frac{I_{rms}}{I_{avg}} = 1.11$$

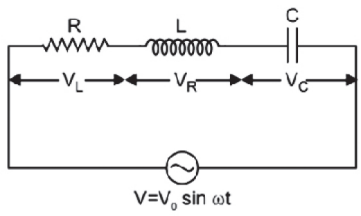
Reactance

- The opposition offered to ac by a coil of inductance L or by a capacitor of capacitance C
- Inductive reactance, $X_L = \omega L = 2\pi fL$
- Capacitive reactance, $X_c = \frac{1}{\omega C} = \frac{1}{2\pi fC}$

AC Circuits

- In a purely resistive circuit, the alternating current and the alternating emf are in same phase.
- In a purely inductive circuit, the alternating current lags behind the alternating emf by a phase angle 90^0.
- In a purely capacitive circuit, the alternating current leads the alternating emf by a phase angle 90^0.

Series LCR Circuit



- The total effective opposition to the flow of ac in an LCR circuit is called impedance Z

$$Z = \sqrt{R^2 + (X_L - X_C)^2}$$

- The reciprocal of impedance is called admittance (K)
- The phase angle by which the emf leads the current in an LCR circuit,

$$\tan \varphi = \frac{X_L - X_C}{R}$$

Power in an AC Circuit

- Instantaneous power, $P_{inst} = EI$
- Average power or true power, $P_{avg} = E_{RMS} I_{RMS} \cos \phi$
- $E_{RMS} I_{RMS}$ is the apparent power and cos θ is the power factor

Series Resonant Circuit

- At resonance $X_L = X_C$
- Resonant angular frequency, $\omega_r = \frac{1}{\sqrt{LC}}$
- Resonant frequency, $f_r = \frac{1}{2\pi\sqrt{LC}}$
- Current through the series LCR circuit is maximum and impedance is minimum at resonance.

  $Z_{Min} = R$ and $I_{Max} = \frac{E}{R}$
- Series resonant circuit is also known as accepter circuit.

Quality factor or Q – factor

$$Q = \frac{X_1}{R} = \frac{L\omega_r}{R}$$

$$Q = \frac{X_C}{R} = \frac{I}{C\omega_r R}$$

$$Q = \frac{1}{R}\sqrt{\frac{L}{C}}$$

Transformer

- Transformers are used for increasing or decreasing alternating voltages through mutual induction
- Transformation ratio or turn ratio, $n = \frac{N_s}{N_P} = \frac{E_s}{E_P} = \frac{I_P}{I_s}$
- Efficiency of a transformer, $\eta = \frac{P_{out}}{P_{in}} = \frac{E_s I_s}{E_P I_p}$

SECTION - I
QUESTIONS

SINGLE CORRECT TYPE

1. A circular loop of area $3m^2$ and resistance 3Ω is lying in y-z plane. The magnetic induction at the location of the loop varies with time t as $\vec{B} = \left[\left(2t^3 - 6t^2\right)\hat{i} + 3t\,\hat{j}\right]T$. The magnitude of maximum current in the loop during the interval from t = 0 to t = 2 s is

1) 3.5 A

2) 12 A

3) 4 A

4) 6 A

2. A circular coil of area 200 cm^2 and 1000 turns having resistance 5Ω is placed in a uniform magnetic field 1T. Initially the coil is placed with its plane perpendicular to the field. Now the coil is rotated about an axis at a constant rate of 2 rad/s such that the flux associated with it varies

i) The instantaneous emf induced in it when the plane of the loop makes an angle 60° with the field is 20V

ii) If the coil is rotated through an angle of 180° in 0.2 s, the average emf induced will be 200V

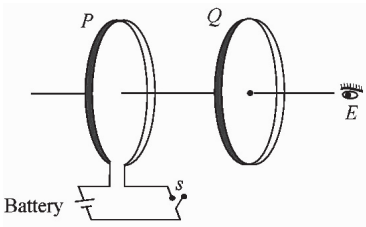
1) only (i) is correct

2) only (ii) is correct

3) both are correct

4) both are incorrect

3. As shown in the figure, P and Q are two coaxial conducting loops separated by some distance. When the switch S is closed, a clockwise current I_P flows in P (as seen by E) and an induced current I_{Q_1} flows in Q. The switch remains closed for a long time. When S is opened, a current I_{Q_2} flows in Q. Then the directions of I_{Q_1} and I_{Q_2} (as seen by E) are



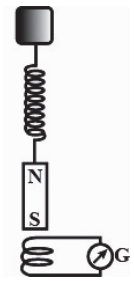
1) Respectively clockwise and anticlockwise

2) Both clockwise

3) Both anticlockwise

4) Respectively anticlockwise and clockwise

4. A magnet NS is suspended from a spring and while it oscillates, the magnet moves in and out of coil C. The coil is connected to a galvanometer G. Then, as the magnet oscillates,



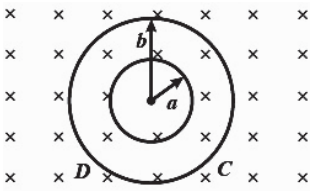
1) G shows no deflection

2) G shows deflection to the left and right but the amplitude steadily decreases

3) G shows deflection to the left the right with constant amplitude

4) G shows deflection on one side

5. Plane figure made of thin wires of resistance R = 50 milli ohm/metre are located in a uniform magnetic field perpendicular into the plane of the figures and which decrease at the rate dB/dt = 0.1m T/s. Then currents in the inner and outer boundary are (The inner radius a = 10cm and outer radius b = 20cm)



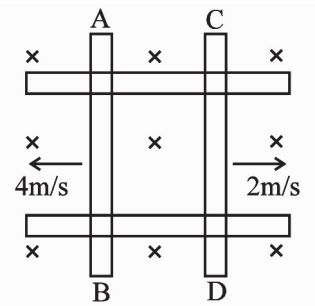
1) 10^{-4} A (Clockwise), 2×10^{-4} A (Clockwise)

2) 10^{-4} A (Anticlockwise), 2×10^{-4} A (Clockwise)

3) 2×10^{-4} A (Clockwise), 10^{-4} A (Anticlockwise)

4) 2×10^{-4} A (Anticlockwise), 10^{-4} A (Anticlockwise)

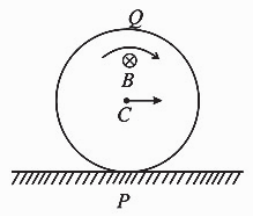
6. Two parallel conducting rails with negligible resistance are 10cm apart. The circuit contains two metal rails AB and CD with resistance 2Ω each along the rails. A uniform magnetic field 0.01T is applied perpendicular to the plane of the rails. If AB and CD move with uniform speed 4m/s and 2m/s away from each other, the induced current in the circuit is:



1) 0.5mA 2) 1.5mA

3) 1mA 4) 2mA

7. A conducting disc of radius R is rolling without slipping on a horizontal surface with a constant velocity v. The uniform magnetic field of magnitude B is applied perpendicular to the plane of the disc. The emf between the points Q and C is



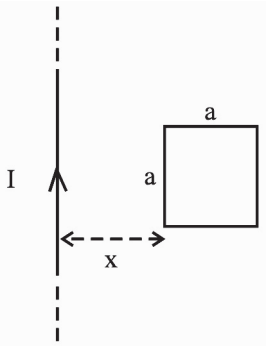
1) BvR

2) 1.5 BvR

3) 2BvR

4) Zero

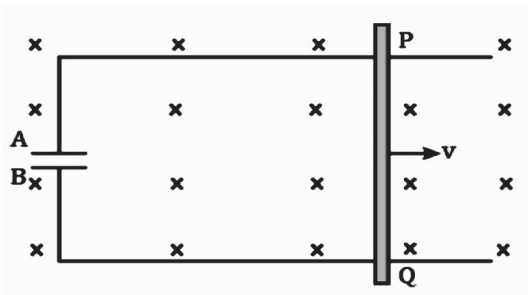
8. A square frame with side a as shown in figure is moved with uniform velocity v from an infinitely long straight wire carrying current I. The emf induced in the frame as a function of distance x



1) $\frac{\mu_0 la^2 v}{2\pi x(x+a)}$ 2) $\frac{\mu_0 laxv}{2\pi x(x+a)}$

3) $\frac{\mu_0 la^2 v}{4\pi x(x+a)}$ 4) zero

9. A conducting rod PQ of length L = 1.0m is moving with a uniform speed v = 2 m/s in a uniform magnetic field B = 4.0T directed into the paper. A capacitor of capacity C=10μF is connected as shown in figure. Then



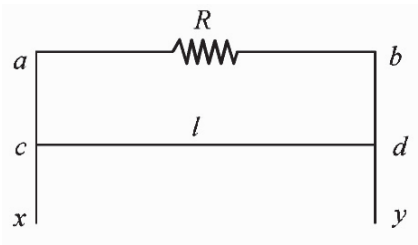
1) q_A = +80μC and q_B = -80μC

2) q_A = -80μC and q_B = +80μC

3) q_A = 0 = q_B

4) Charge stored in the capacitor increases exponentially with time

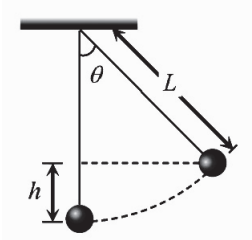
10. A wire cd of length l and mass m is sliding without friction on conducting rails ax and by as shown. The vertical rails are connected to each other with a resistance R between a and b. A uniform magnetic field B is applied perpendicular to the plane abcd such that cd moves with a constant velocity of



1) $\frac{mgR}{B\ell}$ 2) $\frac{mgR}{B^2\ell^2}$

3) $\frac{mgR}{B^3\ell^3}$ 4) $\frac{mgR}{B^2\ell}$

11. A simple pendulum with bob of mass m and conducting wire of length L swings under gravity through an angle 2θ. The earth's magnetic field component in the direction perpendicular to swing is B. Maximum potential difference induced across the pendulum is



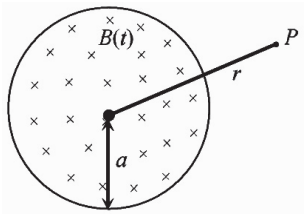
1) $2BL\sin\left(\frac{\theta}{2}\right)(gL)^{1/2}$

2) $BL\sin\left(\frac{\theta}{2}\right)(gL)^{1/2}$

3) $BL\sin\left(\frac{\theta}{2}\right)(gL)^{3/2}$

4) $BL\sin\left(\frac{\theta}{2}\right)(gL)^{2}$

12. A uniform but time-varying magnetic field B(t) exists in a circular region of radius a and is directed into the plane of the paper, as shown. The magnitude of the induced electric field at point P at a distance r from the centre of the circular region



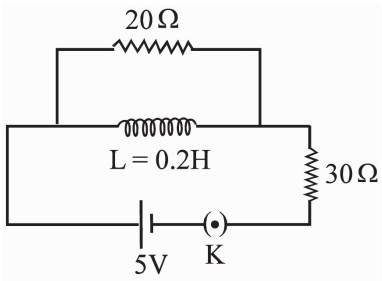
1) Is zero

2) Decreases as $\frac{1}{r}$

3) Increases as r

4) Decreases as $\frac{1}{r^2}$

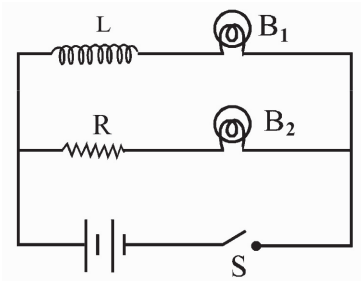
13. An ideal inductance 0.2 H is connected as shown in figure. The current from the cell at the instant of closing key and long time after closing key K



1) $\frac{1}{10}$A and $\frac{1}{6}$A 2) $\frac{1}{5}$A and $\frac{1}{3}$A

3) $\frac{1}{10}$A and $\frac{1}{5}$A 4) $\frac{1}{5}$A and $\frac{1}{6}$A

14. Figure shows an inductor L and a resistance R connected in parallel to a battery through a switch. The resistance of R is the same as that of the coil that makes L. Two identical bulbs are put in each arm of the circuit.



Consider the following statements.

(i) The bulb B_2 lights up earlier when S is closed.

(ii) After some time both B_1 and B_2 become equally bright.

1) only (i) is correct

2) only (ii) is correct

3) both (i) and (ii) are correct

4) both are incorrect

15. An e.m.f. of 15 volt is applied in a circuit containing 5 henry inductance and 10 ohm resistance. The ratio of the currents at time t = ∞ and at t = 1 second is

1) $\frac{e^{1/2}}{e^{1/2}-1}$

2) $\frac{e^{2}}{e^{2}-1}$

3) $1-e^{-1}$

4) e^{-1}

16. A long solenoid of diameter 3.2cm has 200 turns/cm and carries a current of 2A. At its centre a 100 turns closely packed coil of diameter 2.0cm is placed with its axis coinciding with the axis of solenoid. The current in the solenoid is reduced to zero at a steady rate in 20 ms. The induced e.m.f in the coil is :

1) 80 mV 2) 25 mV

3) 100 mV 4) 160 mV

Statement Type Question

17. **Statement I :** Work done to move a charge once around a closed loop in an induced electric field is non zero

Statement II : Line integral of induced electric field over a closed loop is non zero

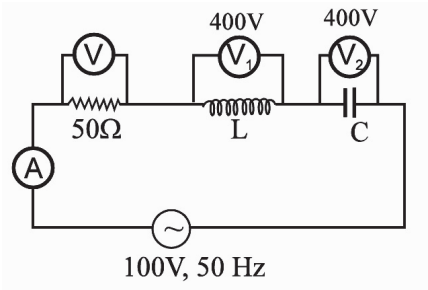
1) Statement I and statement II are correct

2) Statement I and statement II are incorrect

3) Statement I is correct and statement II is incorrect

4) Statement I is incorrect and statement II is correct

18. In the series LCR circuit , the voltmeter reading V and ammeter reading I are



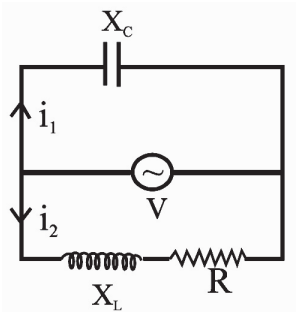
1) V = 100V, I =2A

2) V = 100V, I = 5A

3) V = 400V, I =2A

4) V = 300V, I = 1A

19. In the circuit shown, phase difference between i_1 and i_2 is (Take $X_L = \sqrt{3}R$)



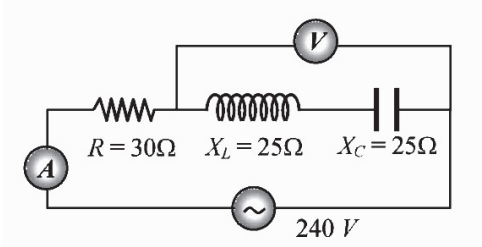
1) 150°

2) 120°

3) 90°

4) 135°

20. In the circuit shown in figure neglecting source resistance the voltmeter and ammeter reading will respectively, will be



1) 0V, 3A

2) 150V, 3A

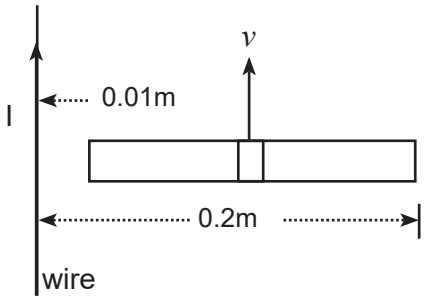
3) 150V, 6A

4) 0V, 8A

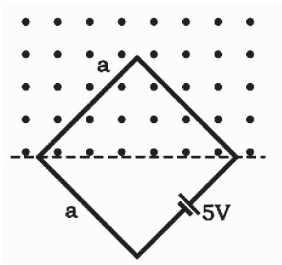
SECTION - II
QUESTIONS

NUMERICAL TYPE

21. A copper rod of length 0.19m is moving with uniform velocity 10m/s parallel to a long straight wire carrying current of 5A. The rod itself is perpendicular to the wire with its ends at distance 0.01m and 0.2m from it. If the induced emf in the rod is 5NμV , the value of N is

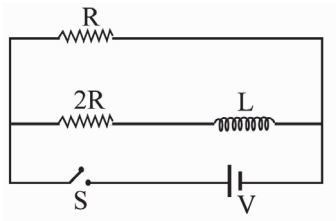


22. A square loop of side 2m and resistance 2.5Ω is placed in a time varying magnetic field B = (5t + 2)T

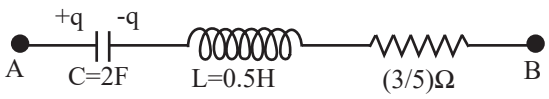


The current in loop in ampere is

23. The ratio of time constants of the circuit during growth of current and decay of current is $\frac{12}{K}$. Find K



24. In the circuit shown, charge q varies with time t as $q = t^3 - t^2 + 4t$, where q is in coulombs and time t is in second. Find potential difference $V_A - V_B$ at time t = 1s



25. An LCR series with a resistance of 100ohm is connected to an ac source of 200V (r.m.s) and angular frequency 300 rad/s. When only the capacitor is removed, the current lags behind the voltage by 60°. When only the inductor is removed the current leads the voltage by 60°. The average power dissipated is _____ watts.

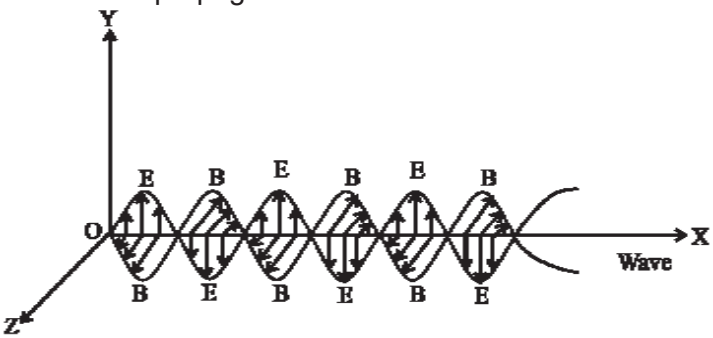
Chapter

17

ELECTROMAGNETIC WAVES

SYNOPSIS

Electromagnetic wave, is a wave radiated by an accelerated charge and which propagates through space as coupled electric and magnetic fields, oscillating perpendicular to each other and to the direction of propagation of the wave.

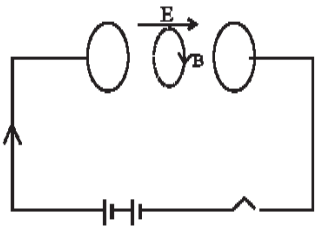


$$\vec{E} = \vec{E}_0 \sin(kx - \omega t)$$

$$\vec{B} = \vec{B}_0 \sin(kx - \omega t)$$

Maxwell developed the theory of E.M. Waves by introducing the idea of the displacement current (I_D). According to Maxwell, the displacement current is that current which comes into existence, between the plates of a capacitor, whenever the electric field changes with respect to time.

$$I_D = \epsilon_0 \frac{d}{dt}(\phi_E) = \epsilon_0 \frac{d}{dt}(EA) = \epsilon_0 A \frac{d(E)}{dt} = \epsilon_0 A \frac{d}{dt}\left(\frac{V}{d}\right) = \frac{\epsilon_0 A}{d}\frac{d(V)}{dt} = C\frac{dv}{dt}$$



According to Maxwell, a changing electric field induces a magnetic field. The time varying electric field between the plates of the capacitor is directed perpendicular to the plane of the plates and the time varying magnetic field (produced by the electric field) is along the perimeter of a circle, in a plane, parallel to the plates of the capacitor. Thus the time varying electric field and the magnetic field are perpendicular to each other. The two fields combine to constitute the EM wave which propagates in space in a direction perpendicular to the directions of both the fields.

The value of I_D is numerically equal to the conduction current I_C. Inside the capacitor, $I_C = 0$ and $i = I_D$. Outside the capacitor, $I_D = 0$ and $i = I_C$.

Magnetic field (B) : On a circular loop of radius r, kept between the capacitor plates of radius R is given by B = $\frac{\mu_0 I_D r}{2\pi R^2}$

$$B_{max} = \frac{\mu_0 I_D}{2\pi R}. \quad B_{\text{along the axis}} = 0$$

The EM waves are governed by **Maxwell's Equations**

1. $\oint_S \vec{E}.\vec{ds} = \frac{q}{\epsilon_0}$ (Gauss' Law in Electrostatics)

2. $\oint_S \vec{B}.\vec{ds} = 0$ (Gauss' Law in magnetism - shows that isolated monopole doesnot exist)

3. $\oint_C \vec{E}.\vec{d\ell} = -\frac{d}{dt}(\phi_B)$ (Faraday's Law of electromagnetic induction)

4. $\oint_C \vec{B}.\vec{d\ell} = \mu_0\left[I + \epsilon_0 \frac{d}{dt}(\phi_E)\right]$ (Ampere - Maxwell Law)

Hertz produced E.M. Waves (oscillating L.C. circuit $\upsilon = \frac{1}{2\pi\sqrt{LC}}$. J.C. Bose transmitted EM waves through short distances. Marconi transmitted EM waves through long distances. EM Waves are transverse progressive waves. They carry energy and momentum. They do not require a medium for the propagation. The variation of E and B have the same frequency and in phase. At any instant the ratio of the amplitudes of electric and magnetic field is a constant and is equal to the velocity of EM waves $\left(\frac{E_0}{B_0} = c\right)$

The velocity of EM waves in free space

$$c = \frac{1}{\sqrt{\mu_0 \epsilon_0}} = \frac{1}{\sqrt{4\pi \times 10^{-7} \times 8.85 \times 10^{-12}}} = 3 \times 10^8 \, m/sec$$

Velocity of EM waves in a medium

$$V = \frac{1}{\sqrt{\mu \epsilon}} = \frac{1}{\sqrt{\mu_0 \mu_r \epsilon_0 \epsilon_r}} = \frac{1}{\sqrt{\mu_0 \epsilon_0}} \times \frac{1}{\sqrt{\mu_r \epsilon_r}} = \frac{c}{\sqrt{\mu_r \epsilon_r}} = \frac{c}{n}$$

where n = $\sqrt{\mu_r \epsilon_r}$ = refractive index of the medium

Propagation constant (Angular wave number)

$$K = \frac{2\pi}{\lambda} = \frac{2\pi}{c/\upsilon} = \frac{2\pi\upsilon}{c} = \frac{\omega}{c} \qquad \therefore c = \frac{\omega}{K}$$

Average energy density of electric field

$$U_E = \frac{1}{4}\epsilon_0 E_0^2 = \frac{1}{4}\epsilon_0 \times 2E_{rms}^2 = \frac{1}{2}\epsilon_0 \times E_{rms}^2 \qquad \left[E_{rms} = \frac{E_0}{\sqrt{2}}\right]$$

Average energy density of magnetic field

$$U_B = \frac{1}{4}\frac{B_0^2}{\mu_0} = \frac{1}{4\mu_0} \times 2B_{rms}^2 = \frac{1}{2\mu_0}B_{rms}^2 \qquad \left[B_{rms} = \frac{B_0}{\sqrt{2}}\right]$$

To show that $\langle U_E = U_B \rangle$

$$U_E = \frac{1}{4}\epsilon_0 E_0^2 = \frac{1}{4}\epsilon_0 (B_0 c)^2 = \frac{1}{4}\epsilon_0 B_0^2 c^2 = \frac{1}{4} \times \epsilon_0 B_0^2 \times \frac{1}{\mu_0 \epsilon_0} = \frac{1}{4}\frac{B_0^2}{\mu_0} = U_B$$

Total average energy density of an electromagnetic wave (U)

$$U_{av} = U = 2 \times U_E = 2 \times \frac{1}{4}\epsilon_0 E_0^2 = \frac{1}{2}\epsilon_0 E_0^2 = \epsilon_0 E_{rms}^2$$

$$\text{OR, } U = 2 \times U_B = 2 \times \frac{1}{4\mu_0}B_0^2 = \frac{1}{2\mu_0}B_0^2 = \frac{B_{rms}^2}{\mu_0}$$

Poynting vector $(\vec{S})$

The energy transported by electromagnetic waves per second per unit area is represented by a vector quantity called the poynting vector. It is denoted by $\vec{S} = \frac{\vec{E} \times \vec{B}}{\mu_0}$

Momentum of E.M. waves = P = $\frac{U}{c}$

For a perfectly absorbing surface, change in momentum = $\frac{U}{c}$

For a perfectly reflecting surface, change in momentum = $\frac{2U}{c}$

Intensity of radiation

$$I = \frac{\text{Energy}}{\text{Area} \times \text{time}} = \text{Energy density} \times c = \frac{1}{2}\epsilon_0 E_0^2 \times c$$

OR $$I = \frac{1}{2\mu_0}B_0^2 c = \frac{1}{2\mu_0}\frac{E_0^2}{c^2} \times c = \frac{1}{2\mu_0}\frac{E_0^2}{c} = \left(\frac{1}{2}\epsilon_0 E_0^2\right)c$$

Also, $I = \frac{P}{4\pi d^2}$; Where P = Power of the source

d = distance from the point source

Electromagnetic spectrum

The orderly distribution of electromagnetic radiations, according to their wavelength or frequency is called electromagnetic spectrum.

γ-rays, X-rays, UV-rays, visible light, I.R. Rays, Microwaves, Radio waves

γ-rays: $\upsilon = 3\times10^{19} \rightarrow 5\times10^{20}\,\text{Hz}$

They are highly energetic radiations and are emitted by radioactive nuclei. Detected by photographic plate, Geiger tubes and ionisation chamber.

X-rays : $\upsilon = 7\times10^{16} \rightarrow 3\times10^{19}\,\text{Hz}$

X-rays are produced when a target of high atomic number is bombarded by fast moving electrons. They possess high penetrating power. They are used both for diagnosis and treatment.

U.V.Rays: $\upsilon = 8\times10^{14} \rightarrow 8\times10^{16}\,\text{Hz}$

They are part of solar spectrum. They can be produced by arcs of mercury and iron. They can be detected by photocells and photographic film. U.V. rays can produce vitamin-D in the skin.

Visible light : $\upsilon = 4\times10^{14} \rightarrow 7\times10^{14}\,\text{Hz}$

Visible light is emitted due to atomic excitation. Human eye is sensitive to only visible part of the EM. spectrum.

I.R. Rays:

$\upsilon = 3\times10^{11} \rightarrow 4\times10^{14}\,\text{Hz}$

Infrared radiactions are “heat radiation” and therefore all hot bodies including the sun are sources of infra-red-rays. They are detected by thermopiles . I.R. rays are responsible for “Green house effect”.

Microwaves

$\upsilon = 3\times10^{8} \rightarrow 3\times10^{11}\,\text{Hz}$

Microwaves are produced by oscillating electronic circuits (Klystron valve, Magnetron valve etc). They are used in RADAR and also in ovens.

Radiowaves

$\upsilon = 3\times10^{3} \rightarrow 3\times10^{8}\,\text{Hz}$

They are produced by oscillating electronic circuits. Radiowaves are used as carrier waves in radio broadcasting and TV Transmission.

General form of wave equation of em wave

$$E = E_0 \sin\left(\vec{k} \cdot \vec{r} - \omega t\right)$$

$$B = B_0 \sin\left(\vec{k} \cdot \vec{r} - \omega t\right)$$

$\vec{k}$ is the wave vector and its direction describes the direction of propagation of wave

$$\vec{k} = k_x \hat{i} + k_y \hat{j} + k_z \hat{k}$$

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

$k = \dfrac{2\pi}{\lambda}$ is the magnitude of wave vector

SECTION - I
QUESTIONS

SINGLE CORRECT TYPE

1. Displacement current goes through the gap between the plates of capacitor when the charge of the capacitor

1) increasing with time

2) increasing with position

3) both a and b

4) zero

2. Maxwell's modified form of Ampere's circuital law is

1) $\oint_s \vec{B}.\vec{ds} = 0$

2) $\oint_s \vec{B}.\vec{ds} = \mu_0 I$

3) $\oint_l \vec{B}.\vec{d\ell} = \mu_0 I$

4) $\oint_l \vec{B}.\vec{d\ell} = \mu_0 I + \mu_0 \varepsilon_0 \frac{d\phi_E}{dt}$

3. Which of the following has zero average value in a plane E.M. wave ?

1) Kinetic energy 2) Magnetic field

3) Electric field 4) Both 2 and 3

4. Speed of E.M. waves through a medium depends upon

1) only electric properties of the medium

2) only magnetic properties of the medium

3) mechanical and thermal properties of medium

4) both electric and magnetic properties of the medium

5. Consider an electromagnetic wave that propagates in the Z direction with an electric field strength of 1 V/m pointing in the Y direction. Then the direction and magnitude of magnetic field pulse that travels along with electric field is :

1) 3.33×10^{-9} T in y direction

2) 3.33×10^{-9} T in z direction

3) 3.33×10^{-9} T in – x direction

4) 6.66×10^{-9} T in x direction

6. The electric field of a plane electromagnetic wave is given by $E = E_0\left(\hat{i}+\hat{k}\right)\sin\left(ky-\omega t\right)$. Associated magnetic field is given by

1) $\frac{E_0}{c}\left(\hat{i}-\hat{k}\right)\cos\left(ky-\omega t\right)$

2) $\frac{E_0}{c}\left(\hat{i}+\hat{k}\right)\sin\left(ky-\omega t\right)$

3) $\frac{E_0}{c}\left(-\hat{i}+\hat{k}\right)\sin\left(ky-\omega t\right)$

4) $\frac{E_0}{c}\left(\hat{i}-\hat{k}\right)\sin\left(ky-\omega t\right)$

7. An EM wave enters a medium from air. The electric fields are

$$\vec{E}_1 = E_{01}\hat{x}\cos\left[2\pi\nu\left(\frac{z}{c}-t\right)\right] \text{in air}$$

$$\vec{E}_2 = E_{02}\hat{x}\cos\left[k\left(2z-ct\right)\right] \text{in medium}$$

where the wave number k and frequency ν refer to their values in air. The medium is non-magnetic, if ε_{r_1} and ε_{r_2} refer to relative permittivities of air and medium respectively. Which of the following options is correct?

1) $\frac{\varepsilon_{r_1}}{\varepsilon_{r_2}} = \frac{1}{2}$ 2) $\frac{\varepsilon_{r_1}}{\varepsilon_{r_2}} = 4$

3) $\frac{\varepsilon_{r_1}}{\varepsilon_{r_2}} = 2$ 4) $\frac{\varepsilon_{r_1}}{\varepsilon_{r_2}} = \frac{1}{4}$

8. A plane electromagnetic wave $E = 100\cos\left[6\times10^{8}t + 4x\right] V/m$ propagate in a medium of dielectric constant

1) 1.5 2) 2.0

3) 2.4 4) 4.0

9. A beam of light travelling along x-axis is described by the electric field Ey= (600 Vm^{-1}) sin ω (t–x/c). Then maximum magnetic force on a charge q=2e, moving along y-axis with a speed of 3×10^{7} m/s is (e =1.6×10^{-19} C)

1) 19.2×10^{-17} N

2) 1.92×10^{-17} N

3) 0.0192 N

4) None of these

10. A plane EM wave is incident on a material surface. If the wave delivers momentum P and energy E, then

1) P = 0, E = 0

2) P ≠ 0, E ≠ 0

3) P ≠ 0, E = 0

4) P = 0, E ≠ 0

11. Which of the following is not transported by the EM wave ?

1) Energy

2) Information

3) Charge

4) Momentum

12. In an em wave, the amplitude of electric field is 1 V/m. The frequency of wave is 5×10^{14} Hz and is moving along z-axis. What is the average energy density of electric field?

1) 4.4×10^{-12}

2) 6.6×10^{-12}

3) 2.2×10^{-12}

4) 8.8×10^{-12}

13. The total average energy density of e.m waves whose electric field variation is given by

E = (50 N/c) sin (ωt - kx) will be nearly

1) 10^{-8} J/m^3

2) 10^{-6} J/m^3

3) 10^{-10} J/m^3

4) 10^{-12} J/m^3

14. About 5% of the power of a 100 W bulb is converted to visible radiation. The average intensity of the visible radiation at a distance of 10m from the bulb is

1) 0.4 W/m^2

2) 4×10^{-5} W/m^2

3) 4×10^{-3} W/m^2

4) 5×10^{-1} W/m^2

15. A plane electromagnetic wave of intensity $6W/m^2$ strikes a small mirror of area $30cm^2$, held perpendicular to the approaching wave. The momentum transferred in kgm/s by the wave to the mirror in each second will be

1) 1.2×10^{-10}

2) 2.4×10^{-9}

3) 3.6×10^{-8}

4) 4.8×10^{-7}

16. An intense light source radiates uniformly in all directions. At a distance 3m from the surface, the radiation pressure on absorbing surface is 9×10^{-11} Pa. Find the total average power output in Watt

1) 1 2) 7

3) 2 4) 3

17. A radar sends the waves towards a distant object and receives the signal reflected by the object. These waves are

1) sound waves

2) X-rays

3) microwaves

4) Radiowaves

18. One requires 11eV of energy to dissociate a carbon monoxide molecule into carbon and oxygen atoms. The minimum frequency of the appropriate electromagnetic radiation to achieve the dissociation lies in

1) Visible region

2) Infrared region

3) Ultraviolet region

4) Microwave region

19. Given below are two statements. In the light of statements choose the correct option.

Statement I : Radio waves are diffracted by building.

Statement II : Radiowaves are high energy waves.

1) Statement I and statement II are true and statement II is the correct explanation of statement I.

2) Statement I and statement II are true and statement II is not the correct explanation of statement I.

3) Statement I is true but statement II is false.

4) Both statement I and statement II are false.

20. **Assertion :** If the earth did not have an atmosphere, the day will be warmer and the night will be cooler.

Reason : The earth's atmosphere produce green-house effect.

1) If both Assertion and Reason are true and Reason is the correct explanation of Assertion.

2) If both Assertion and Reason are true but Reason is not the correct explanation of Assertion.

3) If Assertion is true but Reason is false.

4) If both Assertion and Reason are false.

SECTION - II
QUESTIONS

NUMERICAL TYPE

21. A parallel capacitor made of circular plates each of radius 10.0cm has a capacitance of 200pF. The capacitor is connected to 200V AC supply with an angular frequency of 200rad/s. The amplitude of magnetic field at a point 2.0cm from the axis between the plates is a $\times 10^{-13}$ T. Find the value of 'a'

22. A plane electromagnetic wave of frequency 50MHz travels in free space along the positive x-direction. At a particular point in space and time, $\vec{E} = 6.3\hat{j}\,V/m$. The corresponding magnetic field $\vec{B}$ at that point is $x \times 10^{-8}\hat{k}\,T$. Find the value of x

23. An electromagnetic wave is propagating with intensity $I = 3.85\ W/m^2$ in a medium with $\varepsilon = 9\varepsilon_0$ and $\mu = \mu_0$. The amplitude of electric field inside the medium is _____V/m.

24. A new system of unit is evolved in which give the values of μ_0 and ε_0 are 2 and 8 respectively. Then, the speed of light in this system will be

25. The electric field associated with an em wave in vacuum is given by $\vec{E} = 40\cos\left(kz - 6\times 10^8 t\right)\hat{i}$, where E, Z and t are in volt/m, meter and seconds respectively. The value of wave vector $\hat{k}$ in (rad/metre) is

Chapter

18 RAY OPTICS AND OPTICAL INSTRUMENTS

SYNOPSIS

Mirror

i) $f = \frac{R}{2}$

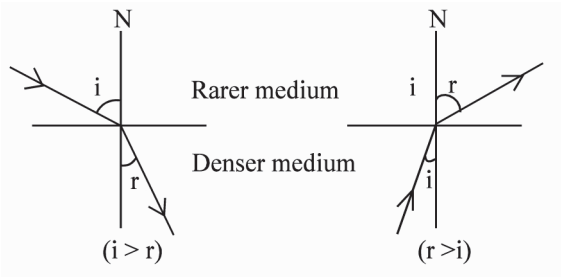
ii) $P(D) = \frac{-1}{f(m)}$

iii) $\frac{1}{f} = \frac{1}{v} + \frac{1}{u}$

iv) $m = \frac{-v}{u} = \frac{f-v}{f} = \frac{f}{f-u}$

Refraction

The phenomenon of bending of light when it travels from one medium to another medium is known as refraction.



When the ray passes from rarer to denser medium, the refracted by bends towards the normal and when it passes from denser to rarer medium, the refracted ray bends away from the normal. When light passes from one medium to another medium, the frequency and colour of light remains same but the wave length and velocity of light changes.

Laws of refraction

(i) The incident ray, the refracted ray and the normal at the point of incidence are in same plane

(ii) The ratio sin of angle incidence to sin of angle of refraction is a constant for a given pair or media and for a given colour of light

$ie = \frac{\sin i}{\sin r}$ a constant (n). This is known as Snell's law

If light passes from medium (1) to (2) the constant is ${}_1n_2 = \frac{n_2}{n_1}$; ${}_2n_1 = \frac{n_1}{n_2}$

Also we can write ${}_1n_2 = \frac{1}{{}_2n_1}$

What happen if ray of light falls normally at the surface of separation of two media

The ray goes undeviate, ie. no refraction possible

$$n = \frac{\sin i}{\sin r} \text{ Here } i = 0;\ \sin r = \frac{\sin i}{n} = \frac{\sin 0}{n} = 0 \therefore\ r = 0$$

Absolute refractive index

Refractive index of a medium with respect to air or vacuum is called absolute refractive Index, denoted by n or μ

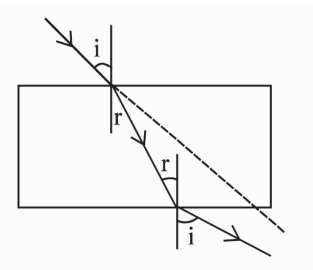
Absolute refractive index of a medium is the ratio of the sine of angle of incidence to the sine of angle of refraction when refraction takes place from air or vacuum to the medium.

$$n = \frac{\sin i}{\sin r}$$

Since there is a change in the direction of light as it goes from one medium into another depends on the speeds of light in the two media.

Refractive index of medium = $\frac{\text{velocity of light in vacuum}}{\text{velocity of light in medium}} = \frac{c}{v}$

Expression for the lateral shift when a ray of monochromatic light passing through a parallel sided glass slab.

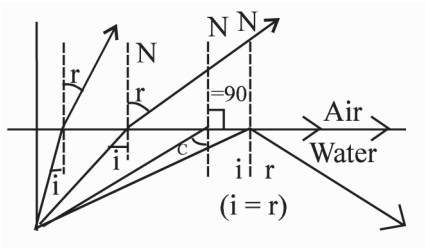


$$L.S = \frac{t}{\cos r}\sin(i - r)$$

t = thickness i = angle of incidence

r = angle of refraction

Critical angle



When a ray of light passes from denser to rarer medium, the refracted ray bends away from the normal (as i increases, r also increases). At a particular angle of incidence, the refracted ray just grasses the surface of separation. This angle of incidence is known as critical angle (C). At this case angle of refraction is 90^0. At critical angle , r = 90

$$n = \frac{\sin 90}{\sin C} = \frac{1}{\sin C}$$

Relative critical angle

The critical angle of a medium B with respect to a rarer medium A is related to the refractive index by the formula.

$${}_A n_B = \frac{1}{\sin_A C_B}$$

where ${}_A C_B$ is the critical angle of medium B with respect to A.

Some typical critical angles are listed below

Substance	Refractive index	Critical angle
Water	1.33	48.75°
Crown glass	1.52	41.14°
Dense flint glass	1.65	37.31°
Diamond	2.42	24.41°

Total internal reflection

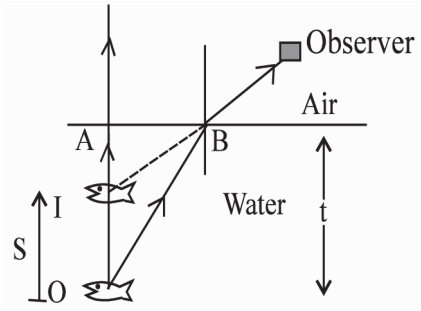
If the angle of incidence is increased beyond the critical angle, the incident ray is reflected back to the same medium obeying the laws of reflection (i = r). This is known as total internal reflection

The conditions for total internal reflection are

i) The light must travel from denser to rarer medium

ii) The angle of incidence must be greater than the critical angle

(c) Real and apparent depth: A fish at the bottom of a lake appears to be raised due to refraction. Let I is the apparent position of the fish. A0 is the real depth; AI is the apparent depth 0I is the displacement or shift of the image. (The fish is really at 0).



Refractive index of the medium

$$n = \frac{\text{Real depth}}{\text{App.depth}} = \frac{AO}{AI} \text{ or } \frac{AO}{n}$$

To find the shifts(S) in the position of the images

S = AO – AI

$$S = AO - \frac{AO}{n} = AO(1 - 1/n)$$

But AO = t, the real depth

$$S = t\left(1 - \frac{1}{n}\right)$$

Expression for refractive index of prism

$$n = \frac{\sin\left(\frac{A+D}{2}\right)}{\sin(A/2)} \text{ where}$$

n = refractive index A = angle of prism D = angle of minimum deviation

Deviation produced by a thin prism

A thin prism is a prism of small refracting angle. For a prism $d = i_1 + i_2 - A$

$$n = \frac{\sin i_1}{\sin r_1} = \frac{\sin i_2}{\sin r_2} \qquad r_1 + r_2 = A$$

When A is small r_1 and r_2 are small. When r_1 and r_2 are small i_1 and i_2 will be small (sinq = q when q is small)

$$n = \frac{\sin i_1}{\sin r_1} = \frac{i_1}{r_1} \therefore i_1 = nr_1$$

Similarly $i_2 = nr_2$ Substituting $d = nr_1 + nr_2 - A$

$= n(r_1 + r_2) - A$ [\ $r_1 + r_2 = A$] $d = A(n-1)$

Thus deviation is independent of the angle of incidence.

The factors on which the angle of deviation produced by a thin prism depends are

$d = A(n-1)$

1. Refractive index of the medium

2. Surrounding medium

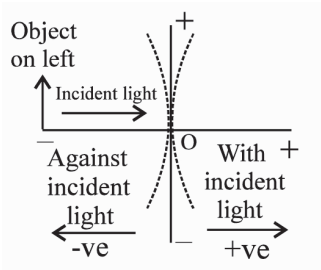
3. Angle of prism

If n_v and n_R the refractive indices for violet and red colours for a medium and n the average refractive index,

The $\omega = \frac{n_v - n_R}{(n-1)}$ where $n = \frac{n_v + n_R}{2}$

The new Cartesian sign convention for reflection and refraction at spherical surfaces

This convention borrows the technique of fixing signs from co - ordinate geometry



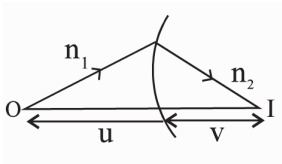
1. The pole of the spherical surface will be the origin O and the principal axis along the X - axis

2. All distances are measured from the pole. Distances measured in the direction of incidence will be positive and opposite to the direction of incidence negative.

3. Distances measured perpendicular to the principal axis will be positive if measured upwards and negative if measured downwards.

One advantage of this system is that, if the object is placed to the left of the spherical surface, Cartesian convention of sign comes into operation.

Relation between u, v and R



$$\frac{n_2}{v} = \frac{n_1}{u} = \frac{n_2 - n_1}{R}$$

R, +ve for convex surface

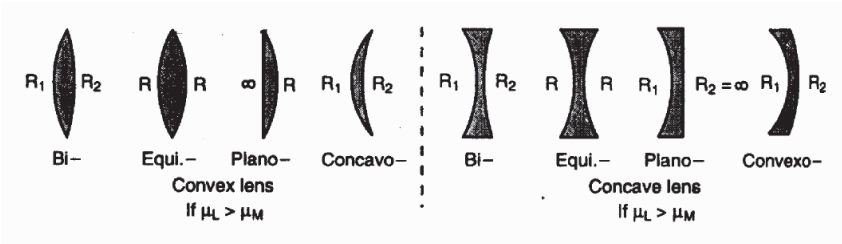
R_1 –ve for concave surface

n_1 – R index of the medium where the object is placed

The lens

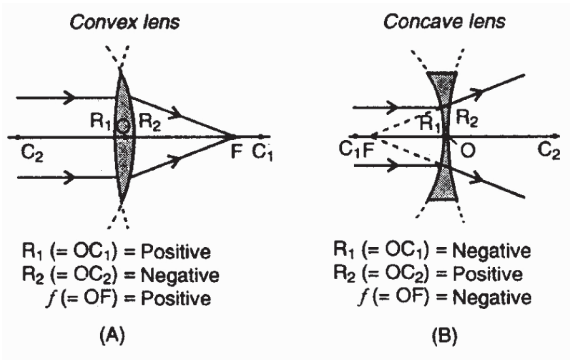
A lens is a piece of transparent material with two refracting surfaces such that at least one is curved and refractive index of its material is different from that of the surroundings.

Different types of lenses



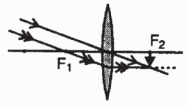
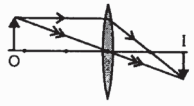
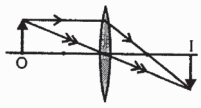
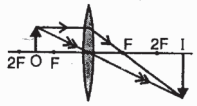
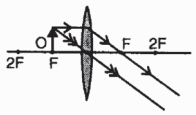
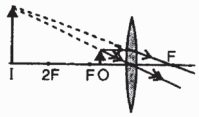
Sign Convention

1. Whenever and where ever possible, rays of light are taken to travel from left to right
2. Transverse distances measured above the principal axis are taken to be positive while those below it negative
3. Longitudinal distances are measured from optical centre and are taken to be positive if in the direction of light propagation and negative if opposite to it.e.g., according to our convention in case of a:

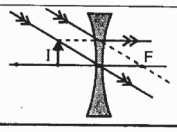
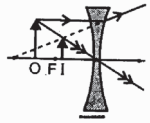


while using the sign convention it must be kept in mind that:

Ray diagrams

S. No.	Position of Object	Ray-Diagram	Details of Image
1.	At infinity		Real, inverted Diminished ($m \ll -1$) At F
2.	Between ∞ and $2F$		Real, inverted Diminished ($m < -1$) Between F and $2F$
3.	At $2F$		Real, inverted Equal ($m = -1$) At $2F$
4.	Between $2F$ and F		Real, inverted Enlarged ($m > -1$) Between $2F$ and ∞
5.	At F		Real, inverted Enlarged ($m \gg -1$) At infinity
6.	Between F and O		Virtual, erect Enlarged ($m > +1$) Between ∞ and object on same side.

(b) For Divergent or Concave Lens

S. No.	Position of Object	Ray-Diagram	Details of Image
1.	At infinity		Virtual, erect Diminished ($m \ll +1$) At F
2.	In front of lens		Virtual, erect Diminished ($m < +1$) Between F and optical centre.

Formula for thin lens (Len's maker's formula)

$\therefore \frac{1}{f} = (n-1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right) - (4)$ and it is known as Len's maker's formula from (4) and (3)

$$\frac{1}{f} = \frac{1}{v} - \frac{1}{u}$$

This is known as the Lens formula or the law of distances for a lens

Power of a lens

It is the reciprocal of focal length. $P = \frac{1}{f(m)}$ and $\frac{100}{f(cm)}$ and $\frac{100}{f(cm)}$ is measured in dioptre (D).

Power is positive for the converging lens and negative for diverging lens.

SECTION - I
QUESTIONS

SINGLE CORRECT TYPE

1. A ray of light is incident at 50^0 on one of the two plane mirrors arranged at an angle of 60^0 between them, The ray then touches the second mirror, get reflected back to the first mirror, makes an angle of incidence θ. The value of θ is :

1) 50^0 2) 60^0

3) 70^0 4) 80^0

2. A ray of light from a source s is incident normally on a plane mirror fixed at a distance 1.5m from the source. When the mirror is rotated through a small angle 3.5°, the spot of the mirror is found to move through a distance Y on the screen. Find out the value of Y :

1) 0.18m

2) 0.36m

3) 0.54m

4) 0.72m

3. A car has a rear view mirror of radius of curvature 2m. A motorcycle is approaching the car at 15m/s. If the car is stationary how fast is the image of the bike approaching the car when the bike is 40m away.

1) 0.003m/s

2) 0.006m/s

3) 0.009 m/s

4) 0.012 m/s

4. A candle flame 3cm is placed at distance of 3m from a wall. How far from wall must a concave mirror be placed in order that it may form an image of flame 9cm high on the wall

1) 225 cm 2) 300 cm

3) 450 cm 4) 650 cm

5. There is a concave mirror of radius of curvature 20cm. A point object placed at a distance 15cm from the mirror. If point object start moving with speed 2mm/s perpendicular to the principal axis. Then at this instant what will be the speed of image in mm/s

1) 3 2) 5

3) 1 4) 4

6. A concave mirror of focal length 10cm and convex mirror of focal length 15cm are placed facing each other 40cm apart. A point object is placed between the mirrors on their common axis at 15cm from the concave mirror. The position and nature of the image produced by the successive reflections first at the concave mirror and then at the convex mirror is

1) 6 cm behind the convex mirror and real

2) 6 cm behind the convex mirror and virtual

3) 30 cm behind the convex mirror and real

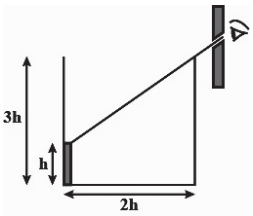
4) 30 cm behind the convex mirror and virtual

7. A small air bubble is inside a glass cube of side 32 cm. When viewed from one face, the bubble appears to be at 15cm and viewed from the opposite face it appears to be at 5cm. The refractive index of the material of the cube is

1) 1.5 2) 1.6

3) 1.7 4) 1.45

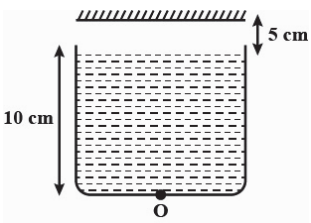
8. An observer can see through a pinhole the top end of a thin rod of height h placed as shown in figure. The beaker height is 3h and its radius h. When beaker is filled with a liquid upto 2h, he can see the lower and of the rod. The refractive index of the liquid is



1) $\frac{5}{2}$ 2) $\sqrt{\frac{5}{2}}$

3) $\sqrt{\frac{3}{2}}$ 4) $\frac{3}{2}$

9. Consider the situation shown in figure. Water $\left(\mu_w = \frac{4}{3}\right)$ is filled in a beaker upto a height of 10cm. A plane mirror fixed at a height of 5cm from the surface of water. Distance of image from the mirror after reflection from it of an object O at the bottom of the beaker is



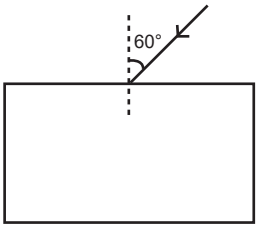
1) 15 cm

2) 12.5 cm

3) 7.5 cm

4) 10 cm

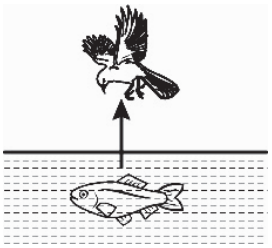
10. A slab of refractive index μ is placed in air and light is incident at an angle 60^0 from vertical. The minimum value of μ for which total internal reflection takes place at the vertical surface



1) $\sqrt{\frac{3}{2}}$ 2) $\sqrt{\frac{3}{2}}$

3) $\frac{\sqrt{7}}{2}$ 4) 2

11. A fish rising vertically up towards the surface of water with speed 3 ms^{-1} observes a bird diving vertically down towards it with speed 9 ms^{-1}. The actual velocity of bird is : (n_w = 4/3)



1) 4.5 ms^{-1} 2) 5.4 ms^{-1}

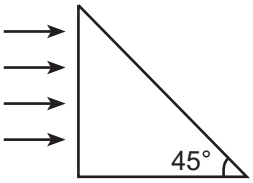
3) 3.0 ms^{-1} 4) 3.4 ms^{-1}

12. A ray of light passes from vacuum into a medium of refractive index μ, the angle of incidence is found to be twice the angle of refraction. Then the angle of incidence is

1) $\cos^{-1}\left(\frac{\mu}{2}\right)$ 2) $2\cos^{-1}\left(\frac{\mu}{2}\right)$

3) $2\sin^{-1}(\mu)$ 4) $2\sin^{-1}\left(\frac{\mu}{2}\right)$

13. A beam of light consisting of red, green and blue colours is incident on a right angled prism. The refractive indices of the material of the prism for the above red, green and blue wavelength are 1.39, 1.44 and 1.47 respectively. The prism will



1) Separate part of red colour from the green and the blue colours

2) Separated part of the blue colour from the red and green colours

3) Separate all the colours from one another

4) Not separate even partially any colour from the other two colours

14. Angle of a prism is 30^0 and its refractive index is $\sqrt{2}$ and one of the surface is silvered. At what angle of incidence, a ray should be incident on one surface so that after reflection from the silvered surface. It retraces its path

1) 30^0

2) 60^0

3) 45^0

4) $\sin^{-1}\sqrt{1.5}$

15. A thin prism P_1 of angle 4^0 and refractive index 1.54 is combined with another thin prism P_2 whose refractive index is 1.72 to produce dispersion without deviation. The angle of P_2 is:

1) 4^0 2) 5.33^0

3) 2.6^0 4) 3^0

16. Light from a point source in air falls on a convex spherical glass surface (μ=1.5, R = 20cm) . The distance of light source from glass surface is 100cm. At what position is the image formed

1) 25 cm

2) 50 cm

3) 100 cm

4) 200 cm

17. A source of light is located at double focal length from a convergent lens. The focal length of the lens is f = 30 cm. At what distance from the lens should a flat mirror be placed, so that the rays reflected from the mirror are parallel after passing through the lens for the second time?

1) 60 cm

2) 30 cm

3) 45 cm

4) 15 cm

18. A biconvex thin lens is prepared from glass of refractive index 3/2. The two bounding surfaces have equal radii of 25 cm each. One of the surfaces is silvered from outside to make it reflecting. Where should an object be placed before thin lens so that the image coincides with the object.

1) 25 cm

2) 12.5 cm

3) 50 cm

4) Infinity

19. The focal lengths of the objective and the eye-piece of a compound microscope are 2.0cm and 3.0 cm respectively. The distance between the objective and the eye-piece is 15.0 cm. The final image formed by the eye-piece is at infinity. The two lenses are thin. The distances in cm of the object and the image produced by the objective measured from the objective lens are respectively

1) 2.4 and 12.0

2) 2.4 and 15.0

3) 2.3 and 12.0

4) 2.3 and 3.0

20. Magnifying power of an astronomical telescope for normal adjustment is 10 and length of the telescope is 110cm. Magnifying power of the same telescope, when the image is formed at the near point is

1) 14 2) 18

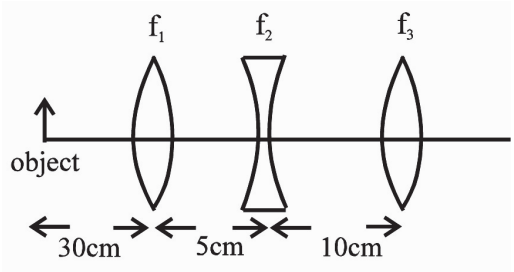
3) 23 4) 26

SECTION - II QUESTIONS

NUMERICAL TYPE

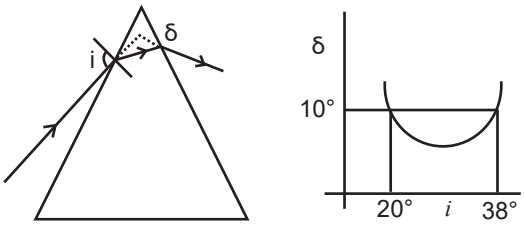
21. An object is placed at a distance of 20cm on the axis of a convex mirror and a plane mirror is placed between them at a distance of 5 cm from the convex mirror such that the image formed by both the mirrors coincide. Focal length of the convex mirror is (in cm)

22. The position of the final image formed by the given lens combination from the third lens will be at a distance of (f_1 = +10cm, f_2 = -10cm, f_3 = 30cm)



23. A large glass slab (μ=5/3) of thickness 8 cm is placed over a point source of light on a plane surface. It is seen that light emerges out of the top surface of the slab from a circular area of radius R cm. What is the value of R (in cm)

24. A ray is incident on prism at an angle i with normal, when it comes out of prism its angular deviation is δ. Graph between δ and i is given. Prism angle in degree is



25. A point object is placed at a distance of 23 cm from a convex lens of focal length 20 cm. If a glass slab of thickness t and refractive index 1.5 is inserted between the lens and object. The image is formed at infinity. The thickness t in cm is :

Chapter 19

WAVE OPTICS

SYNOPSIS

1. **Wave front** | **Intensity** | **Amplitude**

a. Spherical	$I \alpha \frac{1}{r^2}$	$A \alpha \frac{1}{r}$
b. Cylindrical	$I \alpha \frac{1}{r}$	$A \alpha \frac{1}{\sqrt{2}}$
c. Plane	$I \alpha r^0$	$A \alpha r^0$

2. Relation between **phase difference and path difference** $\Delta\phi = \frac{2\pi}{\lambda}\Delta L$, ΔL - Path difference

3. **Amplitude of the resultant wave**

$$A = \sqrt{A_1^2 + A_2^2 + 2A_1A_2\cos\phi}$$

$$I \alpha A^2$$

ie $I \alpha A_1^2 + A_2^2 + 2A_1A_2\cos\phi$

$I = I_1 + I_2 + 2\sqrt{I_1I_2}\cos\phi$

4. $$\frac{I_{max}}{I_{min}} = \frac{\left(\sqrt{I_1}+\sqrt{I_2}\right)^2}{\left(\sqrt{I_1}-\sqrt{I_2}\right)^2} = \frac{(A_1+A_2)^2}{(A_1-A_2)^2}$$

5. $I = I_{max}\cos^2\frac{\phi}{2}$

6. $$\frac{W_1}{W_2} = \frac{I_1}{I_2} = \frac{A_1^2}{A_2^2}\left(W \rightarrow \text{slit width}\right)$$

7. For constructive interference $\phi = 2n\pi\left(n = 0,1,2,3...\right)$

$\Delta L = n\lambda\left(n = 0,1,2,3....\right)$

8. For destructive interference $\phi = \left(2n-1\right)\pi\left(n = 1,2,3...\right)$

$\Delta L = \left(2n-1\right)\frac{\lambda}{2}\left(n = 1,2,3...\right)$

9. In YDSE for constructive interference $d\sin\theta = n\lambda$ (n = 0, 1, 2, 3...)

and for destrutive interference $d\sin\theta = (2n-1)\frac{\lambda}{2}\left(n = 1,2,3...\right)$

Distance to the nth bright fringe from central maximum

$y_{nb} = \frac{nD\lambda}{d}\left(n = 0,1,2,3...\right)$ and to the nth dark fringe $y_{nd} = (2n-1)\frac{D\lambda}{2d}\left(n = 1,2,3...\right)$

Fringe width, $\beta = \frac{D\lambda}{d}$; Angular fringe width $\theta = \frac{\beta}{D} = \frac{\lambda}{d}$

10. Fringe visibility $V = \frac{I_{max} - I_{min}}{I_{max} + I_{min}} = \frac{2\sqrt{I_1 I_2}}{I_1 + I_2}$

11. $n\lambda = a$ constant $n_1\lambda_1 = n_2\lambda_2$ (when two bright fringes coincides)

12. $\frac{\Delta\beta}{\Delta D} = \frac{\lambda}{d}$

13. If YDSE is performed in a medium $\beta^1 = \frac{\beta}{\mu}$

14. If transparent sheet is introduced in the path of one of the two waves

$y_0 = \frac{D}{d}\left(\mu - 1\right)t$; $y_0 = \frac{\beta}{\lambda}\left(\mu - 1\right)t$

15. Diffraction

Position of the secondary minimum a $\sin\theta = n\lambda\left(n = 1,2,3...\right)$

Position of the secondary maximum

$a\sin\theta = (2n-1)\frac{\lambda}{2}(n = 1, 2, 3...)$ First sec. min $0 = \frac{\lambda}{a} = \frac{x}{D}$ i.e. $x = \frac{D\lambda}{a}$

Angular width of the central maximum $2\theta = \frac{2\lambda}{a}$

Linear width of the central maximum $2x = \frac{2D\lambda}{a} = (2\theta)D$

17. Polarization

Malu's law (Cosine squared law) $I_2 = I_1 \cos^2\theta$ $I_1 = \frac{I_0}{2}$

if θ = 90 (ie polaroids are crossed) $I_2 = 0$ if $\theta = 0$ $I_2 = I_1$

Brewsters law

$\frac{n_d}{n_r} = \tan\theta_B$; $\tan\theta_B = \frac{1}{\sin c}$

SECTION - I
QUESTIONS

SINGLE CORRECT TYPE

1. The two light beams having intensities I and 9I interfere to produce a fringe pattern on a screen. The phase difference between the beams is $\frac{\pi}{2}$ at point P and π at point Q. Then the difference between the resultant intensities at P and Q will be:

1) 2I 2) 6I

3) 5I 4) 7I

2. The coherent light sources having intensity in the ratio 2x produce an interference pattern. The ratio $\frac{I_{max}-I_{min}}{I_{max}+I_{min}}$ will be

1) $\frac{\sqrt{2x}}{2x+1}$ 2) $\frac{\sqrt{2x}}{x+1}$

3) $\frac{2\sqrt{2x}}{x+1}$ 4) $\frac{2\sqrt{2x}}{2x+1}$

3. Two light waves having the same wavelength λ in vacuum are in phase initially. Then the first wave travels a path L_1 through a medium of refractive index n_1 while the second wave travels a path of length L_2 through a medium of refractive index n_2. After this the phase difference between the two waves is :

1) $\frac{2\pi}{\lambda}\left(\frac{L_2}{n_1}-\frac{L_1}{n_2}\right)$ 2) $\frac{2\pi}{\lambda}\left(\frac{L_1}{n_1}-\frac{L_2}{n_2}\right)$

3) $\frac{2\pi}{\lambda}(n_1L_1-n_2L_2)$ 4) $\frac{2\pi}{\lambda}(n_2L_1-n_1L_2)$

4. On a hot summer night, the refractive index of air is smallest near the ground and increases with height form the ground. When a light beam is directed horizontally the Huygens' principle leads us to conclude that as it travels, the light beam

1) bends downwards

2) bends upwards

3) becomes narrower

4) goes horizontally without any deflection

5. In Young's double slit experiment, the fringe width is 12 mm. If the entire arrangement is placed in water of refractive index $\frac{4}{3}$, then the fringe width becomes (in mm):

1) 16 2) 9

3) 48 4) 12

6. In a Young's double slit experiment, 16 fringes are observed in a certain segment of the screen when light of wavelength 700 nm is used. If the wavelength of light is changed to 400 nm, the number of fringes observed in the same segment of the screen would be:

1) 24 2) 30

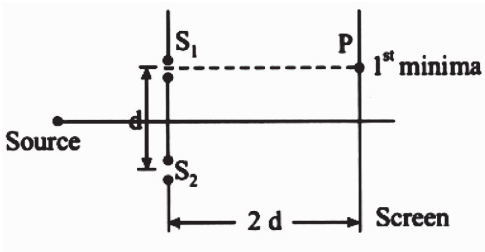
3) 18 4) 28

7. In a Young's double slit experiment, the slits are placed 0.320 mm apart. Light of wavelength λ=500nm is incident on the slits. The total number of bright fringes that are observed in the angular range -30°≤ θ ≤30° is

1) 640 2) 320

3) 321 4) 641

8. Consider a Young's double slit experiment as shown in figure. What should be the slit separation d in terms of wavelength λ such that the first minima occurs directly in front of the slit (S_1)?



1) $\frac{\lambda}{2\left(\sqrt{5}-2\right)}$ 2) $\frac{\lambda}{\left(\sqrt{5}-2\right)}$

3) $\frac{\lambda}{2\left(5-\sqrt{2}\right)}$ 4) $\frac{\lambda}{\left(5-\sqrt{2}\right)}$

9. This question has statement-I and Statement-II. Of the four choices given after the Statements, choose the one that best describes the two Statements.

Statement I : In Young's double slit experiment, the number of fringes observed in the field of view is small with longer wavelength of light and is large with shorter wavelength of light.

Statement II : In the double slit experiment the fringe width depends directly on the wavelength of light.

1) Statement -I is true, Statement-II is true and the Statement-II is correct explanation of the Statement-I

2) Statement -I is false and the Statement -II is true

3) Statement-I is true Statement-II is true and the Statement -II is not correct explanation of the Statement -I

4) Statement -I is true and the Statement -II is false

10. In Young's double slit experiment, one of the slit is wider than other, so that amplitude of the light from one slit is double of that other slit. If I_m be the maximum intensity the resultant intensity I when they interfere at phase difference ϕ is given by :

1) $\frac{I_m}{9}(4+5\cos\phi)$

2) $\frac{I_m}{3}\left(1+2\cos^2\frac{\phi}{2}\right)$

3) $\frac{I_m}{5}\left(1-4\cos^2\frac{\phi}{2}\right)$

4) $\frac{I_m}{9}\left(1+8\cos^2\frac{\phi}{2}\right)$

11. In a Young's double slit experiment the intensity at a point where the path difference is $\frac{\lambda}{6}$ (λ being the wavelength of light used) is I. If I_0 denotes the maximum intensity, $\frac{I}{I_0}$ is equal to

1) $\frac{3}{4}$ 2) $\frac{1}{\sqrt{2}}$

3) $\frac{\sqrt{3}}{2}$ 4) $\frac{1}{2}$

12. In a single slit diffraction experiment, the width of the slit is made double its original width. Then the central maximum of the diffraction pattern will become

1) narrower and fainter

2) narrower and brighter

3) broader and fainter

4) broader and brighter

13. In an experiment of single slit diffraction pattern, first minimum for red light coincides with first maximum of some other wavelength. If wavelength of red light is 6600Å, then wavelength of first maximum will be :

1) 3300Å 2) 4400Å

3) 5500Å 4) 6600Å

14. A single-slit of width a is illuminated by a monochromatic light of wavelength 600nm. The value of 'a' for which first minimum appears at θ=30° on the screen will be

1) 0.6μm 2) 1.2μm

3) 1.8μm 4) 3μm

15. In a double-slit experiment, green light (5303Å) falls on a double slit having a separation of 19.44μm and a width of 4.05μm. The number of bright fringes between the first and the second diffraction minima is:

1) 10 2) 05

3) 04 4) 09

16. Two polaroids A and B are placed in such a way that the pass-axis of polaroids are perpendicular to each other. Now, another polaroid C is placed between A and B bisecting angle between them. If intensity of unpolarised light is I_0 then intensity of transmitted light after passing through polaroid B will be:

1) $\frac{I_0}{4}$

2) $\frac{I_0}{2}$

3) $\frac{I_0}{8}$

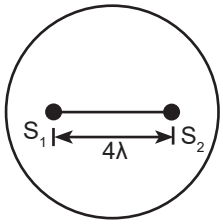
4) Zero

17. 'n' polarizing sheets are arranged such that each makes an angle 45° with the preceding sheet. An unpolarized light of intensity I is incident into this arrangement. The output intensity is found to be I/64. The value of n will be :

1) 6 2) 3

3) 5 4) 4

18. If two coherent sources are placed at a distance 3λ from each other, symmetric to the center of the circle shown in figure. Then the number of bright fringes shown on the screen placed along the circumference is



1) 16 2) 12

3) 8 4) 4

19. Unpolarized light of intensity I is incident on a system of two polarizers. A followed by B. The intensity of emergent light is 1/2. If a third polarizer C is placed between A and B, the intensity of emergent light is reduced to 1/3. The angle between the polarizers A and C is θ. Then

1) $\cos\theta = \left(\frac{2}{3}\right)^{1/4}$ 2) $\cos\theta = \left(\frac{1}{3}\right)^{1/4}$

3) $\cos\theta = \left(\frac{1}{3}\right)^{1/2}$ 4) $\cos\theta = \left(\frac{2}{3}\right)^{1/2}$

20. The angle of incidence at which reflected light is totally polarized for reflection from air to glass (refractive index n), is

1) $\tan^{-1}(1/n)$

2) $\sin^{-1}(1/n)$

3) $\sin^{-1}(n)$

4) $\tan^{-1}(n)$

SECTION - II QUESTIONS

NUMERICAL TYPE

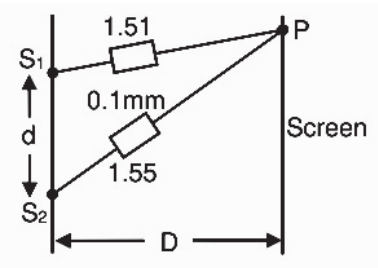
21. A single slit of width 0.1mm is illuminated by a parallel beam of light of wavelength 6000Å and diffraction bands are observed on a screen 0.5m from the slit. The distance of the third dark band from the central bright band is _____ mm.

22. A single slit of width b illuminated by a coherent monochromatic light of wavelength λ. If the second and fourth minima in the diffraction pattern at a distance 1m from the slit are at 3cm and 6cm respectively from the central maximum. What is the width of the central maximum? (i.e. distance between first minimum on either side of the central maximum) (in cm)

23. Orange light of wavelength 6000×10^{-10}m illuminates a single slit of width 0.6×10^{-4}m. The maximum possible number of diffraction minima produced on both sides of the central maximum is _____

24. A source of light is placed in front of a screen. Intensity of light on the screen is I. Two polaroids P_1 and P_2 are so placed in between the source of light and screen that the intensity of light on screen is I/2. P_2 should be rotated by an angle of .... (degrees) so that the intensity of light on the screen becomes $\frac{3I}{8}$.

25. In Young's double slit experiment two slits S_1 and S_2 are 'd' distance apart and the separation from slits to screen is D (as shown in figure). Now if two transparent slabs of equal thickness 0.1 mm but refractive index 1.51 and 1.55 are introduced in the path of beam $\left(\lambda = 4000\,\overset{0}{A}\right)$ from S_1 and S_2 respectively. The central bright fringe spot will shift by .....number of fringes.



Chapter 20

MODERN PHYSICS

SYNOPSIS

Introduction

At normal conditions most of the gases do not conduct electricity. However, it can be made conducting by (i) applying a very high voltage (ii) by reducing the pressure of the gas to a very low value, or (iii) by irradiating the gas with certain radiations such as γ-rays, x-rays, u-v rays etc. The process

of splitting up gas molecule into +ve and –ve ions is called ionisation. If the ionisation is taking place in a tube having +ve and –ve electrodes the arrangement is called a discharge tube. Then +ve and –ve ions move in opposite directions constituting an electric current called ionisation current. The flow of electric current through gases is called discharge of electricity through gases.

The experiments with discharge tubes led to the discovery of x-rays by Roentgen in 1895 and cathode rays (electron) by J.J Thomson in 1897.

Electrons and Photons

Experimental studies on conduction of electricity through gases at low pressures led to the discovery of electrons by J. J. Thomson.

1. The specific charge $\left(\frac{c}{m}\text{value}\right)$ of the electron is determined by Thomson as 1.76×10^{11} C/kg

2. The charge of the electron is determined by Millikan as 1.602×10^{-19} C

3. The mass of the electron is then calculated as 9.11×10^{-31} kg

4. The electron is the integral part of all constituents of matter in all forms and the charge carried by it is considered as the basic unit charge

According to ***Planck's quantum theory,*** light consists of tiny packets of energy called quanta or photons of energy $h\upsilon$ and momentum h/λ.

Electron Emission

Free electrons in the metals are responsible for their electrical conductivity. But, the free electrons normally, can not escape from the metal. A certain energy is required for the emission of electron.

The minimum energy required to escape an electron from a metal surface is called the **work function** ϕ_0 of that metal, and is expressed in eV (electron volt)

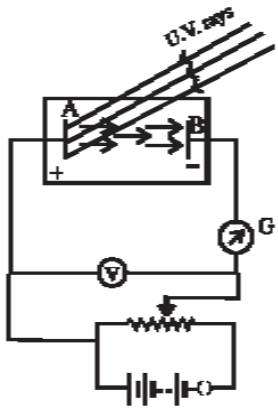
[One eV is the KE acquired by an electron when it is accelerated through a p.d of 1 volt ie, $1eV = 1.602 \times 10^{-19}C \times 1V = 1.602 \times 10^{-19}J$].

Metal	ϕ_0 ***in eV***	***Metal***	ϕ_0 ***in eV***
Cs	2.14	Al	4.25
K2.30	Cu	4.65	
Na	2.75	Ag	4.75
Ca	3.20	Ni	5.15
Pb	4.25	Pt	5.65

The minimum energy required for the electron emission can be supplied by one of the following methods (i) By heating (thermionic emission) (ii) By applying very strong electric field of the order of 10^8 V m^{-1} (field emission) (iii) By irradiating the surface with light rays of suitable frequencies (Photoelectric emission)

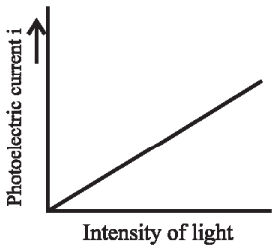
Photoelectric Emission : Discovered by Hertz. The phenomenon of emission of electrons from the surface of the metals when irradiated with radiation(γ rays, X-rays, U.V rays or visible rays) of suitable frequency is called Photoelectric emission.

Experimental Study



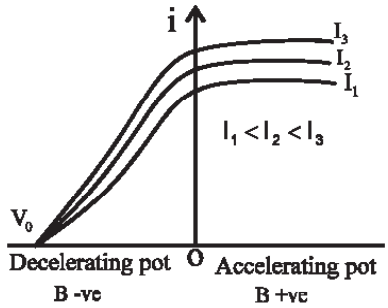
The minimum negative potential V_0 given to the anode for which the photo current stops or becomes zero is called the cut-off or stoping potential. At this conditions, the maximum KE of the emitted electron $\frac{1}{2}mv_{max}^2 = eV_0$

Effect of intensity of light



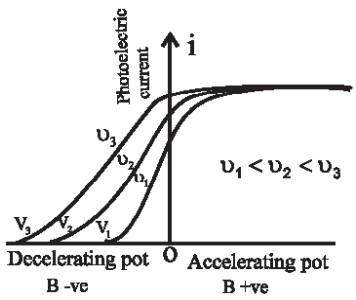
Photoelectric current i or number of photoelectrons emitted is directly proportional to intensity of light.

Effect of p.d between A and B



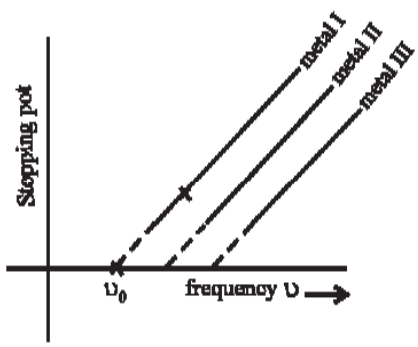
1. Saturation current value increases with intensity I of incident light
2. Cut-off potential V_0 is independent of intensity

Effect of Frequency



1. Saturation current is same for all frequencies when intensity remains constant
2. Below saturation value photoelectric current depends on frequency - the higher the frequency the larger the current.
3. Stopping potential is different for different frequencies - the higher the frequency the greater (-ve value) the stopping potential.

Frequency and stopping potential



The graph with stopping potential against frequency is a straight line for all metals. These lines are parallel and are having same slope $\frac{h}{e}$ (h is Planck's constant and e is the charge of electron).

Frequency υ_0 is called the **threshold frequency** the minimum frequency for photo electric emission.

Einstein's Equation

The electron absorbs the entire energy of only one photon. Part of this is used as work function $(\phi_0 = h\upsilon_0)$ and the rest remains as KE.

Then $\frac{1}{2}mv_{max}^2 = h\upsilon - h\upsilon_0$

Also $\frac{1}{2}mv_{max}^2 = h(\upsilon - \upsilon_0) = eV_0$

Discussion

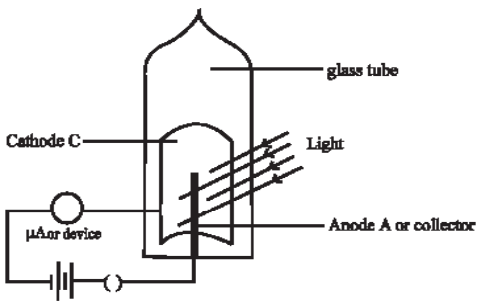
1. Velocity and hence KE of photoelectrons depends on the frequency υ of incident lights.
2. If $\upsilon \le \upsilon_0$ there is no emission of photoelectrons
3. When intensity of light increases number of photoelectrons emitted increases and hence photoelectric current increases
4. When frequency of light increases stopping potential increases (-ve value).
5. If V_0 is the stopping potential, $\frac{1}{2}mv_{max}^2 = eV_0 = h\upsilon - h\upsilon_0$

$$V_0 = \frac{h}{e}\upsilon - \frac{h}{e}\upsilon_0$$

$\frac{h}{e}$ is the slope of the graph between V_0 and υ

Photocell : is a device used to convert light energy to electrical energy. There are three types of photocells. Viz (i) photo emissive cell (ii) photo voltaic cell and (iii) photo conductive cell.

Photo emissive cell



It consists of a glass tube containing a cathode C and anode A. When light incident on C photoelectrons are emitted and are collected by A producing a current in the circuit. The change in intensity of light produces corresponding change in photoelectric current in the circuit.

Photocells are used in burglar alarms, automatic switching arrangements, reproduction of sound in cinemas, automatic counting devices etc.

Particle nature of Radiation - According to Planck, light consists of tiny packets of energy called quanta or photons of energy value $h\upsilon$ and momentum $\frac{h}{\lambda}$. Momentum of photon $P = mc = \frac{h}{\lambda}$ or $\lambda = \frac{h}{mc}$

λ is the attribute of a wave while mc is an attribute of particle. This shows the dual nature of radiation.

1) Interaction of radiation with matter, radiation behaves as if it is made up of particles called photons.

2) Each photon has energy $E(=h\upsilon)$ and momentum $p\left(=h\upsilon/c\right)$ and speed C, the speed of light.

3) All the photons of a particular frequency υ of wavelengths λ have the same energy $E\left(=h\upsilon = hc/\lambda\right)$ and the same momentum $p\left(=\frac{h\upsilon}{c}=\frac{h}{\lambda}\right)$. Photon energy is independent of intensity of radiation.

4) Photons are electrically neutral and are not deflected by electric and magnetic fields.

5) Frequency of photon gives the radiation,a definite energy (or colour) which doesn't change. When photons travel through different media.

6) Velocity of the photon in different media is different (due to change in its wavelength)

7) The rest mass of a photon is zero

8) In a photon-particle collision, the energy and momentum are conserved. However the number of photons may not be conserved in a collision.

Wave nature of particle

From the particle nature of radiation, Louis de Broglie, argued that what is true for radiation must be true for particles also. ie, for a particle of mass m moving with a velocity v a wave must be associated with it. This wave is called de Broglie wave or matter wave. The wave length of de Broglie wave, $\lambda = \frac{h}{mv}$

de Broglie wavelength of an accelerated electron

Velocity of electron accelerated through a p.d of V volts. $v = \sqrt{\frac{2cV}{m}}$

$\therefore$ de Broglie wavelength of the electrons $\lambda = \frac{h}{mv} = \frac{h}{\sqrt{2mcV}} = \frac{12.27}{\sqrt{V}} A^{o}$

For V = 100 volts, $\lambda = 1.227 A^{o}$

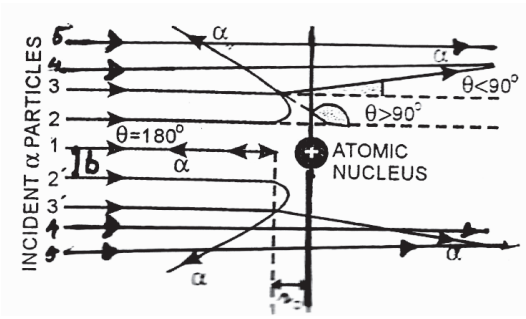
This was verified by Davisson and Germer.

It is not possible to measure both the position and momentum of an electron at the sametime exactly. $\Delta x \Delta p \approx h$.

Atomic Structure and Spectrum

The first atom model was proposed by Thomson. The model failed to explain the origin of spectral lines from the atom and the large angle scattering of α-particles. Then Rutherford proposed another model of atom. According to Rutherford, the atom consists of a central core called atomic nucleus, where the mass and positive charge of the atom are concentrated and the electrons are moving round the nucleus in circular orbits. This model explained large angle scattering of α- particles.

The distance of closest approach $r_0 = \frac{1}{4\pi \in_0} \frac{Ze.2e}{\frac{1}{2}mv^2}$



Impact parameter b is given by $b = \frac{1}{4\pi \in_0} \frac{Ze^2}{\frac{1}{2}mv^2} \cot(\theta/2)$

Number of atoms scatterd at an angle $\theta, N_\theta = \frac{N_0 nt\left(2Ze^2\right)^2}{4\left(4\pi \in_0\right)^2 r^2 \left(mv_0^2\right)^2} \frac{1}{\sin^4(\theta/2)}$ or, $N_\theta \alpha \frac{1}{\sin^4(\theta/2)}$

Rutherford measured the size of the nucleus as of the order 10^{-15} m (ie, fm) and atoms as of the order of 10^{-10}m (ie, A^0). But, the model failed to explain the origin of spectral lines from the atoms.

Bohr Atom Model

Bohr modified Rutherford atom model by introducing certain postulates.

1. Every atom consists of the central nucleus and the electrons are revolving round the nucleus in specified orbits. The centripetal force required for the motion is given by

$$\frac{mv^2}{r} = \frac{1}{4\pi \in_0} \frac{Ze^2}{r^2}$$

For hydrogen Z = 1; $\therefore \frac{mv^2}{r} = \frac{1}{4\pi \in_r} . \frac{e^2}{r^2}$.....(1)

2. The electrons can revolve only in orbits for which the angular momentum is an integral multiple of $\frac{h}{2\pi}$

ie; $mvr = n\frac{h}{2\pi}$.....(2)

3. Electrons revolving in the orbit do not radiate energy.

4. Energy is radiated when the electrons jump from an outer orbit to inner orbit. The energy radiated is given by, $h\upsilon = E_2 - E_1$.....(3)

Calculations for hydrogen atom Z = 1

Radius of the orbit r_n

Sq. eq (2) and devide by eq. (1) $r = r_n = \frac{\in_0 h^2}{\pi m e^2}.n^2$.....(4)

or ; $r_n = 0.53 n^2 \ A^0$.....(5)

Velocity of electon v_n

Dividing eqn. (1) by eq (2) $v = v_n = \frac{e^2}{2\in_0 h}\frac{c}{c}.\frac{1}{n}$

or, $v_n = \frac{1}{137}\frac{c}{n}$.....(6)

$\frac{e^2}{2\in_0 hc} = \frac{1}{137} = \alpha$ is called fine structure constant.

Period of revolution of the electron T_n

Period $T_n = \frac{2\pi r_n}{v_n} \infty \ n^3$.....(7)

Energy of electron in the orbit E_n

$$KE = \frac{1}{8\pi\in_0}\frac{e^2}{r^2}; PE = -\frac{1}{4\pi\in_0}\frac{e^2}{r^2}$$

$$TE = KE + PE = E = E_n = \frac{-1}{8\pi\in_0}\frac{e^2}{r^2}$$

Substituting for r, $E = E_n = \frac{-me^4}{8\epsilon_0^2 h^2}.\frac{1}{n^2}$.....(8)

In terms of fine structure constant $E_n = -\frac{1}{2}mc^2\alpha^2.\frac{1}{n^2}$

In eV, $E_n = -13.6.\frac{1}{n^2}$.....(9)

For n = 1 ie; ground state, $E_1 = -13.6eV$, $KE = 13.6eV$, $KE = 13.6eV, PE = -27.2eV$

Spectral lines

From eqn (3) $h\upsilon = E_{n_2} - E_{n_1}$

ie; $h\upsilon = h\frac{c}{\lambda} = \frac{1}{2}mc^2\alpha^2\left[\frac{1}{n_1^2} - \frac{1}{n_2^2}\right]$ or, $\frac{1}{\lambda} = \bar{\upsilon} = R\left[\frac{1}{n_1^2} - \frac{1}{n_2^2}\right]$.....(10)

λ is the wavelength, $\bar{\upsilon}$ wave number

R is Rydberg constant, $R = \frac{1}{2}mc^2\alpha^2 = 1.097\times10^7 m^{-1}$

For hydrogen like atoms

$r_n = \frac{1}{Z}.r_n$ of H, $V_n = Z\times V_n$ of H

$E_n = Z^2\times E_n$ of H, $\frac{1}{\lambda} = Z^2\times\frac{1}{\lambda}$ of H

Spectral series

1. For Lyman Series (U.V. rays) $n_1 = 1$, $n_2 = 2, 3, 4, 5$.....
2. For Balmer series (Visible rays) $n_1 = 2$, $n_2 = 3, 4, 5$,.....
3. For Paschen series (Infra red rays) $n_1 = 3$, $n_2 = 4, 5, 6$, ...
4. For Bracket series (Infra red rays) $n_1 = 4$, $n_2 = 5, 6, 7$, ...
5. For Pfund series (Far infrared rays) $n_1 = 5$, $n_2 = 6, 7, 8$, ...

Spectrum - Emission spectra and Absorption spectra

Emission spectra are of three types

1. Line spectrum : is obtained when substances in atomic state are excited.
   Eg : H spectrum, Hg spectrum, Sodium lamp
2. Band spectrum : is obtained when substance is in molecular state are excited.
   Eg : O_2, N_2, CO_2

3. Continuous spectrum : is obtained when matter in bulk is excited

Eg : Carbon arc, copper arc, hot filament lamp.

Absorption spectra is obtained when a composite light is passing through a less intense medium and the transmitted light is examined through a spectro graph. If the medium is in atomic state, *absorption line spectrum* is obtained and if the medium is in molecular state *absorption band spectrum* is obtained.

Fraunhofer Lines: If the solar rays are examined through a prism spectrometer large number of dark lines are observed in the bright back ground of solar spectrum. These lines are called Fraunhofer lines. These lines are due to absorption of energy by the atoms of the elements present in the photosphere around the sun.

ATOMIC NUCLEI

Atomic nucleus is the central part of every atom. Its size is of the order of 1 fm or 10^{-15} m. The mass of the nucleus is more than 99.9% of the mass of the atom and is expressed in atomic mass unit (a.m.u) or simply u.

$1\,\text{amu} = \frac{1}{12}\text{of mass of } {}_6C^{12} = 1.66\times10^{-27}\,\text{kg}$. When 1 a.m.u is fully converted into energy, the energy produced is 1.49 x 10^{-10} J. (931 MeV)

The nucleus of an atom is represented by ${}_ZX^A$ or ${}^A_ZX$

Where Z is the atomic number ie, number of protons and A is the atomic mass number ie, total number of protons and neutrons

Nuclear size : The nucleus is assumed to be almost spherical. Its volume $\frac{4}{3}\pi R^3 \alpha A$

$\therefore R^3 \alpha A \quad \text{or } R = R_0 A^{1/3}; \qquad R_0 = 1.2\text{fm to } 1.3\,\text{fm}$

Nuclear density : $\rho = \frac{\text{mass}}{\text{volume}} = \frac{\mu A}{\frac{4}{3}\pi R_3^0 A} = 2.29\times10^{17}\,\text{kg/m}^3$

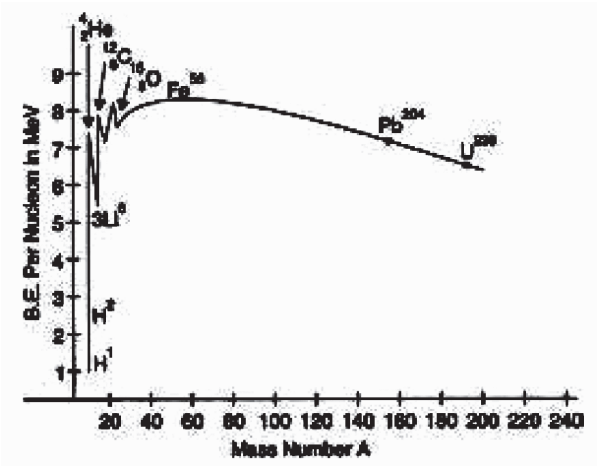
Conservation Laws : The sum of mass-energy, the momentum and the total charge are conserved before and after any nuclear interactions.

Binding Energy and mass defect

$$BE = \text{mass defect} \times c^2$$

$$BE = \left(Zm_p + (A-Z)m_n - M_N\right)c^2$$

$M_N \rightarrow$ mass of nucleus



The importance of BE curve is that it led to the possibility of release of energy during nuclear fission and fusion.

Nuclear forces : Nuclear forces are the strongest attractive forces and are existing between nucleons - which are independent of charge, short range, non central, non-conservative and not obeying inverse square law. The nuclear forces are dependent on spin or angular momentum of nuclei. According to Yukawa, the exchange of π mesons is responsible for nuclear forces.

Nuclear fission: is the process of splitting the nucleus of a heavy atom in to two nuclei of nearly equal mass with release of large energy.

Eg : $_{92}U^{235} +_{0} n^{1} \rightarrow_{56} Ba^{144} +_{36} Kr^{89} + 3_{0}n^{1} + 200MeV$

The three neutrons released can produce further fission and the process is going on, resulting in chain reaction. An uncontrolled chain reaction results in explosion (atom bomb) and a controlled chain reaction gives controlled release of energy and is achieved in nuclear reactors. The main parts of a nuclear reactor are (1) nuclear fuel (U^{235} or Pu^{239}) (2) Moderators - (heavy water, parafin) and control rods (Boron, Cadmium)

Nuclear Fusion : is the fusion of two light nuclei into a single nucleus with release of large energy. This requires large KE and hence very high temperature of the order of 10^7 K. So, fusion process is taking place in the sun and the stars. Then, the process is also called thermonuclear process.

SECTION - I
QUESTIONS

SINGLE CORRECT TYPE

1. The parallel beam of monochromatic light of wave length 500 nm is incident normally on a perfectly absorbing surface. The power through any cross-section of the beam is 10W. Find

a) Number of photon absorbed by the surface per second

b) The force exerted by light beam on the surface

1) (a) 3.5×10^{10} photons/sec (b) 3.5×10^{-8} N

2) (a) 2.5×10^{29} photons/sec (b) 2.3×10^{-8} N

3) (a) 3.5×10^{19} photons/sec (b) 3.5×10^{-2} N

4) (a) 2.5×10^{19} photons/sec (b) 3.3×10^{-8} N

2. A special kind of light bulb emits monochromatic light of wavelength 700 nm. Electrical energy supply to it at the rate of 60 W and the bulb is 50% efficient at converting that energy to light energy. How many photons are emitted by the bulb during its life time of 1 day

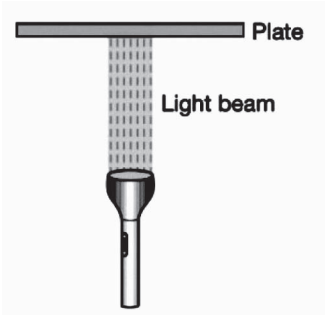
1) 5.070×10^{25}

2) 9.072×10^{24}

3) 3.070×10^{12}

4) 4.072×10^{15}

3. A plate of mass 10 g is in equilibrium in air due to the force exerted by light beam on plate. Calculate power of beam. Assume plate is perfectly absorbing.



1) 1.5×10^{7} W

2) 3×10^{7} W

3) 4.5×10^{7} W

4) 6×10^{7} W

4. In a photoemissive cell with exciting wavelength λ, the fastest electron has a speed υ. If the exciting wavelength is changed to $\frac{3\lambda}{4}$, the speed of the fastest emitted electrons will be

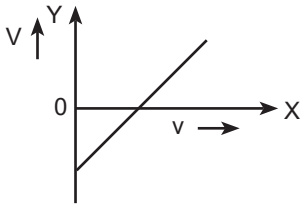
1) $\upsilon\sqrt{\frac{3}{4}}$

2) $\upsilon\sqrt{\frac{4}{3}}$

3) less than $\upsilon\sqrt{\frac{4}{3}}$

4) greater than $\upsilon\sqrt{\frac{4}{3}}$

5. The stopping potential V for photoelectric emission from a metal surface is plotted along Y-axis and frequency v at incident light along X-axis. A straight line is obtained as shown. Planck's constant is given by



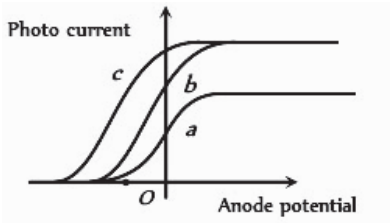
1) Slope of the line

2) Product of slope on the line and charge on the electron

3) Product of intercept along Y-axis and mass of the electron

4) Product of slope and mass of electron

6. The figure shows the variation of photocurrent with anode potential for a photo-sensitive surface for three different radiations. Let I_a, I_b and I_c, be the intensities and f_a, f_b and f_c be the frequencies for the curves a, b and c respectively



1) $f_a = f_b$ and $I_a \neq I_b$

2) $f_a = f_c$ and $I_a = I_c$

3) $f_a = f_b$ and $I_a = I_b$

4) $f_a \neq f_b$ and $I_a = I_b$

7. An electron and a photon have same wavelength. It p is the momentum of electron and E the energy of photon. The magnitude of $\frac{P}{E}$ in SI unit is

1) $\frac{1}{2c}$ 2) $\frac{1}{c}$

3) $\frac{2}{c}$ 4) None of these

8. When a metallic surface is illuminated by a monochromatic light of wavelength λ, the stopping potential for photoelectric current is $3V_0$. When the same surface is illuminated by light of wavelength 2λ, the stopping potential is V_0. The threshold wavelength for this surface for photoelectric effect is

1) 6λ 2) $\frac{4\lambda}{3}$

3) 4λ 4) 8λ

9. A proton, a deutron and an alpha particle are accelerated through potentials of V, 2V and 4V respectively. Their velocities will bear a ratio

1) 1 : 1: 1 2) $1:\sqrt{2}:1$

3) $\sqrt{2}:1:1$ 4) $1:1:\sqrt{2}$

10. A particle of mass m is projected from ground with velocity a making angle θ with the vertical. The de Broglie wavelength of the particle at the highest point is

1) h/mu

2) ∞

3) h/mu sinθ

4) h/mu cosθ

11. An electron of mass 'm' is moving with initial velocity $v_0\hat{i}$ in an electric field $\vec{E} = E_0\hat{i}$ (E_0 is positive). Which of the following is correct de Broglie wavelength at a given time t (λ_0 is initial de Broglie wavelength).

1) $\dfrac{\lambda_0}{\left(1+\dfrac{eE_0}{m\lambda_0}t\right)}$

2) $\dfrac{\lambda_0}{\left(1+\dfrac{eE_0}{mv_0}t\right)}$

3) $\dfrac{h}{\left(1+\dfrac{mv_0}{Ev_0}t\right)}$

4) $\dfrac{h}{\left(1+\dfrac{eE}{mv_0}t\right)}$

12. A particle A of mass m and initial velocity v collides with a particle B of mass $\frac{m}{2}$ which is at rest. The collision is head on and elastic. The ratio of the de Broglie wavelengths λ_A to λ_B after the collision is

1) $\dfrac{\lambda_A}{\lambda_B} = \dfrac{1}{3}$

2) $\dfrac{\lambda_A}{\lambda_B} = 2$

3) $\dfrac{\lambda_A}{\lambda_B} = \dfrac{2}{3}$

4) $\dfrac{\lambda_A}{\lambda_B} = \dfrac{1}{2}$

13. In Rutherford's scattering experiment, if the number of α particles scattered at an angle of 90^0 is 55, then calculate the number of α particles scattered at an angle of 60^0

1) 120 2) 220

3) 320 4) 420

14. A head on collision takes place between an α-particle of kinetic energy 5.5 MeV and a gold nucleus (Z = 79). Calculate the distance of closest approach.

1) 4×10^{-10} m

2) 4×10^{-12}

3) 4×10^{-14} m

4) 4×10^{-16} m

15. Calculate the angular momentum of an electron in Bohr's hydrogen atom whose energy is –3.4 eV?

1) h/π 2) $2h/\pi$

3) $3h/\pi$ 4) $4h/\pi$

16. A small particle of mass *m* moves in such a way that the potential energy $U = -\frac{1}{2}mb^2r^2$ where b is a constant and r is the distance of the particle from the origin taken at the nucleus, Assuming Bohr model of quantization of angular momentum and circular orbits. Radius of the nth allowed orbit is proportional to

1) n

2) $\sqrt{n}$

3) n^2

4) n^3

17. A hydrogen atom emits a photon corresponding to an electron transition from n = 5 to n =1. The recoil speed of hydrogen atom is almost

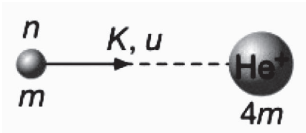
1) 10^{-4} ms^{-1}

2) 2×10^{-2} ms^{-1}

3) 4 ms^{-1}

4) 8×10^{2} ms^{-1}

18. A He^{+} ions is at rest and in ground state. A neutron with initial velocity u, kinetic energy K collides head on with the He^{+} ion. Calculate minimum value of K so that there can be an inelastic collision between these two particles.



1) 41 eV

2) 51 eV

3) 61 eV

4) 71 eV

19. The binding energy per nucleon of $_3Li^7$ and $_2He^4$ nuclei are 5.60 MeV and 7.06 MeV, respectively. In the nuclear reaction $_3Li^7 +_1 H^1 \rightarrow_2 He^+ +_2 He^4 + Q$, the value of energy Q released is

1) 19.6 MeV

2) -2.4 MeV

3) 8.4 MeV

4) 17.3 MeV

20. One milligram of matter is converted into energy, the energy released will be

1) 90 J 2) 9×10^{3} J

3) 9×10^{5} J 4) 9×10^{10} J

SECTION - II
QUESTIONS

NUMERICAL TYPE

21. Calculate the nuclear radius of ^{125}Fe knowing that the nuclear radius of is 3.6 fermi. (Answer in fermi)

22. Energy released by fission of 1 gm U^{235} is $x \times 10^{10}$ J. Then value of x is

23. The radionuclide $^{11}_{6}C$ decays by β^{+} emission.

Write symbolically this decay process.

Given that $m\left(^{11}_{6}C\right) = 11.011434\,u$

$m\left(^{11}_{6}B\right) = 11.009305\,u$

$m_e = 0.000548\,u,\ 1u = 931.5\,MrV/c^2$

then Q value is nearly _____MeV.

24. An electron in a hydrogen atom undergoes a transition from an orbit with quantum number n_i to another with quantum number n_f. V_i and V_f are respectively the initial and final potential energies of the electron. If $\frac{V_i}{V_f} = 6.25$, then the smallest possible n_f is:

25. In a photoelectric emission, from a black surface, threshold frequency is v_0. For two incident radiations of frequencies v_1 and v_2, the maximum values of kinetic energy of the photoelectrons emitted in the two cases is in the ratio 1 : p. If $pv_1 - v_2 = 2v_0$, find the value of $|p|$

Chapter 21

SEMICONDUCTOR ELECTRONICS

SYNOPSIS

Conductors have large number of free electrons. Good conductors : silver, copper, gold.

Insulators have very few free electrons. Good insulators : Mica, glass, paper.

Semiconductors have conductivity much less than that of conductors but slightly more than that of insulators.

Outermost energy band in solids is conduction band; Band gap energy is the difference between the energies of conduction band and valence band.

Types of Semiconductor

1) Intrinsic Semiconductor — eg: pure silicon or pure germanium

2) Extrinsic Semiconductor — eg: Impure Semiconductor

Difference between Intrinsic and extrinsic semiconductors

	Intrinsic	Extrinsic
1	Semiconductor in pure form. It contains only one element like Si or Ge	Pure semiconductor is doped with impurity to increase the conductivity.
2	There is only one type semiconductor	There are two type; N-type and P-type depending on the nature of the material.
3	Number of electrons and holes are equal $n_e = n_h = n_i$ where n_i is intrinsic carrier concentration.	In N-type, number of electrons are greater than number of holes and vice versa in P-type
4	Electrical conductivity is small.	Electrical conductivity is high.
5	Conductivity is increased with increase in temperature.	Conductivity is mainly increased with increase in doping concentration.
6	Conductivity at particular temperature is constant and cannot be changed	By adding impurity, conductivity at particular temperature can be changed.
7	Almost no practical use	Used in electronic devices

Table 1.1

Types of extrinsic semiconductors :

1) N - type semiconductors **2) P-type semiconductors**

- Doping is the process of adding impurity to the intrinsic semiconductor.

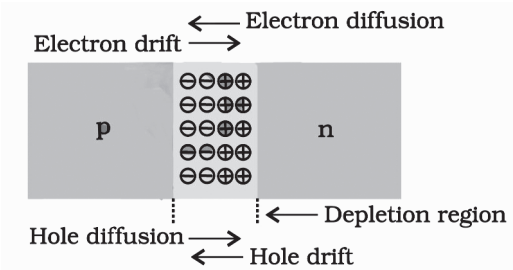
Distinguish between N-type and P-type semiconductors

	N-type	P-type
1	Intrinsic semiconductor with penta valent impurity.	Intrinsic semiconductor with trivalent impurity.
2	Impurities are N, P, As, Sb, Bi	Impurities are B, Al,Ga, In, Tl
3	Impuritiy atoms are called donor impurity which donate extra electrons	Impurity atoms are called acceptor atom which provide extra holes.
4	It has excess of electrons but electrically neutral	It has excess of holes but electrically neutral
5	$n_e > n_h$; electrons are called majority charge carriers and holes are called minority charge carriers.	$n_h > n_e$; holes are called majority charge carriers and electrons are called minority charge carriers
6	Donor energy level is just below the conduction band	Acceptor energy level is just above the valence band
7	Fermi level shifted towards conduction band	Fermi level shifted towards valence band
8	Electrons are due to both doping and thermal generation but $n_e \approx N_D$	Holes are due to both doping and thermal generation but $n_h \approx N_A$
9	Holes are only due to thermal generation	Electrons are only due to thermal generation
10	$I_e >> I_h$ and $I \approx I_e$	$I_h >> I_e$ and $I \approx I_h$
11	$n_h = \frac{n_{i^2}}{n_e} \approx \frac{n_{i^2}}{N_D}$	$n_e = \frac{n_{i^2}}{n_h} \approx \frac{n_{i^2}}{N_A}$

Table 1.2

PN junction diode:

PN junction formation:



- Two important process during PN junction formation are diffusion and drift.
- During formation of PN junction, due to concentration gradient, hole diffused from P to N and electrons diffused from N to P. This motion results in diffusion current.
- As the diffusion of charge carriers continue, a layer of positive charge developed on N - side and a layer of negative charge developed on P - side. This space charge region is called deplition region.
- Larger the doping, smaller is the width of the PN junction.
- Due to the oppositively charged immobile ions, and electric field is directed from positive charge to the negative charge ie, from N - side to P - side.
- Motion of charge carriers due to the electric field is drift current which is opposite to the direction of diffusion current
- In a P-N junction under equilibrium there is no net current.
- Barrier potential prevents the further motion of majority charge carriers.

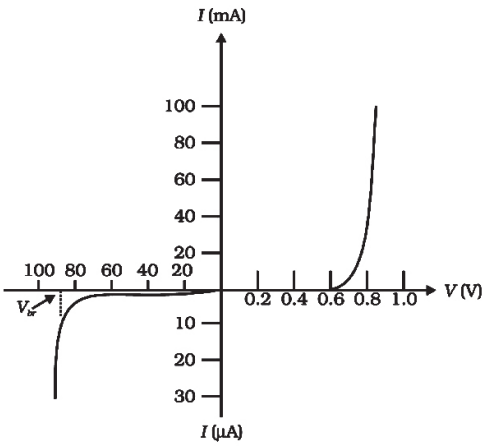
Biasing of PN juction:

Comparison of biasing:

	Forward bias	Reverse bias
1	Positive terminal of cells is connected to P-region and negative terminal is connected to N-region	Positive terminal of cells is connected to N region and negative terminal is connected to P-region
2	External voltage (V) opposes the internal voltage (V_0)	External voltage (V) support the internal voltage (V_0)
3	Effective voltage is $\lvert V - V_0 \rvert$	Effective voltage is $\lvert V + V_0 \rvert$
4	Depletion width decreases	Depletion width increases
5	Diffusion current flows from P to N	Drift current flows from N to P
6	Current due to majority charge carriers	Current due to minority charge carries
7	Current is in milli ampere order	Current is in micro ampere order
8	Forward current rapidly increase at knee voltage or threshold voltage	Reverse current rapidly increase at breakdown voltage
9	It offers low resistance	It offers high resistance
10	For ideal diode it is equivalent to short circuited path	For ideal diode it is equivalent to open circuited path.

Table 2.1

V–I characteristics of a PN junction diode:



Forward resistance $r_f = \frac{\Delta V}{\Delta I}$ is very small. For an ideal PN junction the forward resistance is zero

Reverse resistance $r_r = \frac{\Delta V}{\Delta I}$ is large. For Germanium diode it is $40k\Omega$. For silicon diode it is $1000k\Omega$. When the reverse biasing is larger than a certain value, the PN junction breaks down.

There are two types of junction breakdown:

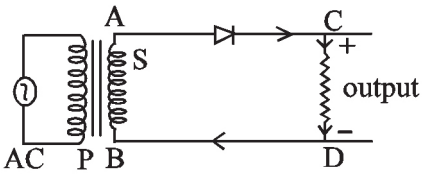
1) Avalanche break down

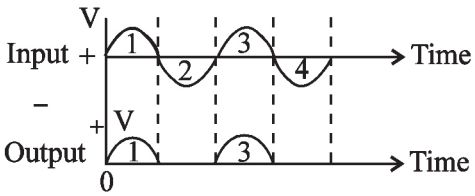
2) Zener breakdown

Avalanche breakdown is due to collision. Avalanche breakdown takes place in lightly doped diodes Zener breakdown takes place in heavily doped diodes.

Application of PN junction diode

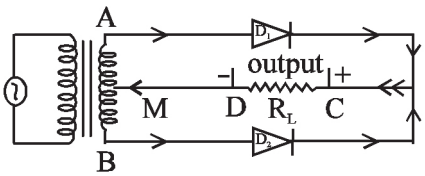
Half wave rectifier:

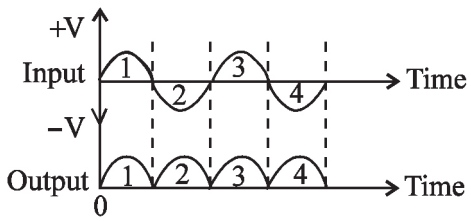




The output of a half wave rectifier is in the form of ripples. In a half wave rectifier the ripple frequency is equal to the input frequency. The number of ripples per second is called ripple frequency.

Full wave rectifier:





Comparission of rectifiers:

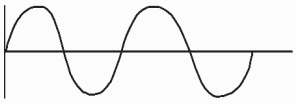
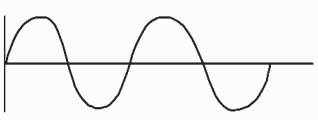
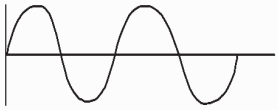
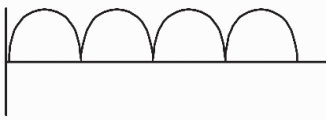
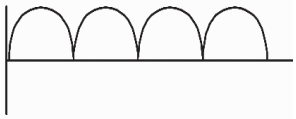
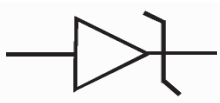
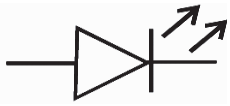
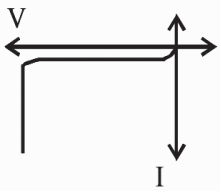
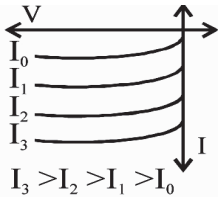
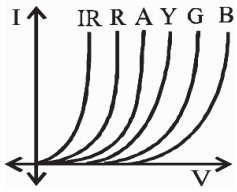
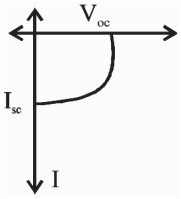
NAME		Half wave rectifier	Full wave rectifier (Centre-Tapped)	Full wave rectifier (Bridge)
1	Number of diodes	1	2	4
2	Transformer	Ordinary transformer	Center taped transformer	Ordinary transformer
3	i/p wave form			
4	o/p wave form			
5	o/p frequency	i/p frequency	2 x i/p frequency	2x i/p frequency
6	efficiency	40.6%	81.2%	81.2%
7	ripple factor	1.21	0.482	0.482
8	I_{rms}	$I_0/2$	$I_0/\sqrt{2}$	$I_0/\sqrt{2}$
9	E_{rms}	$E_0/2$	$E_0/\sqrt{2}$	$E_0/\sqrt{2}$
10	I_{dc} or I_{avg}	I_0/π	$2I_0/\pi$	$2I_0/\pi$
11	E_{dc} or E_{avg}	E_0/π	$2E_0/\pi$	$2E_0/\pi$

Table 2.2

Filter circuits are circuits used to remove the ac components in the output of a rectifier. In forward biased diodes the current is due to diffusion. Forward current is due to majority carriers. In reverse biased diodes the current is due to drifting of electrons and holes.

Special purpose PN juction diodes

1	Name	Zener diode	Photo diode	LED	Solar cell
2	Symbol				
3	Operating region	IIIrd Quadrent	IIIrd Quadrent	Ist Quadrent	IV th Quadrent
4	Biasing	Reverse biasing	Reverse biasing	Forward biasing	No biasing
5	Application	Voltage regulator	1. To measure intensity of light 2. Photodetector	Convert electrical energy to light	Convert light to electrical energy
6	Doping	Heavily doped	Lightly doped	Heavily doped	Lightly doped
7	Deplition width	Narrow	Wide	Narrow	Wide
8	Characteristics				
9	Process during operation	Field ionization or field emission	1. Carrier generation 2. Carrier separation	Radiative recombination	1. Carrier generation 2. Carrier separation 3. Carrier collection

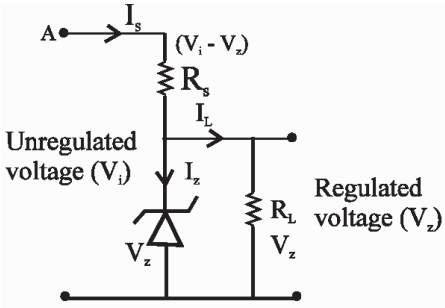
Where : IR - Infra red, R - Red, A - Amber, Y - Yellow, G - Green, B - Blue

Table 2.3

Zener Diode

- Deplition width is less than 10^{-6} m
- Electric field of the junction is high about $5\times10^{6}\,V/m$
- After reverse voltage V_z, zener voltage remains constant even though current through the zener diode varies over a wide range.
- Field ionization or field emission : when reverse voltage, $V = V_z$, the electric field strength is high enough to pull valance electrons from the host atom on the P side which are accelerated to N side. These electrons account for the high current at break down. This emission of electrons from host atom due to high electric field is known as internal field emission.
- The electric field required for field ionization is of the order of 10^6V/m

Zener diode as voltage regulator:



(i) $I_s = \dfrac{V_i - V_z}{R_s}$

(ii) $I_L = \dfrac{V_z}{R_L}$

(iii) $I_Z = I_S - I_L$

(iv) $P_z = V_z I_z$

(v) $R_s = \dfrac{V - V_z}{I_s} = \dfrac{V - V_z}{I_z + I_L}$

- If input voltage increases, current through R_s and zener diode also increases. This increases voltage drop across R_s without any change in voltage drop across zener. This is because in the break down region, zener voltage remains constant even though current through zener changes.
- If we decrease input voltage, current through R_s and zener decrease without any change in voltage across zener.

- Any increase/decrease in the input voltage results in increase/decrease of voltage drop across R_s without any change in voltage across zener diode, thus it act as a voltage regulator.

Opto electric PN junction diode

(i) Photo diode:

- It fabricated with a transparent window to allow the light to fall on it
- When photodiode is illuminated with light (photon) with $h\upsilon > Eg$, then electron-hole pair generates, near the depletion region.
- Due to electric field at junction, electrons and holes are separated before they recombine. [electrones are collected on N - side holes are connected on P-side]
- Magnitude of photo current depends on intensity of incident light
- On illumination of light, fractional change in majority carriers would be much less than that in minority charge carriers. ie, fractional change due to the photo effects on minority carrier dominated reverse bias current is more easily measurable than forward bias.

(ii) LED

- Due to forward bias, minority carrier concentration at the junction increases. Thus they are recombine with majority carrier and energy is released in the form of photon with energy equal to or slightly less than the band gap.
- Intensity of light from LED increases as forward current increases and reaches a maximum at a critical value, further increase in forward current results in decrease of light intensity.
- V-I characteristics of LED is similar to that of silicon but threshold voltage is much higher and different for each colour
- For fabrication of visible LED the energy gap must lie between 1.8 eV and 3 eV.
- $GaAs_{1-x}P_x$ and for LED of different colours
- $GaAs_{0.6}P_{0.4}$ (Eg $\approx$ 1.9 eV) and for Red LED
- GaAs (Eg $\approx$ 1.43 eV) for infra red LED
- LED used in remote controls, burglar alarm system

- advantages (i) low operational voltage and less power

  (ii) fast action, no warm up time required

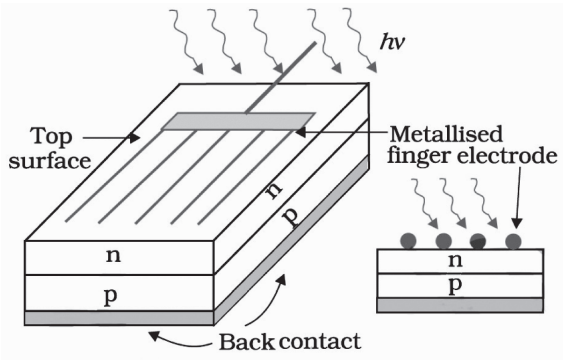
  (iii) nearly monochromatic

  (iv) long life and ruggedness

  (v) fast on-off switching

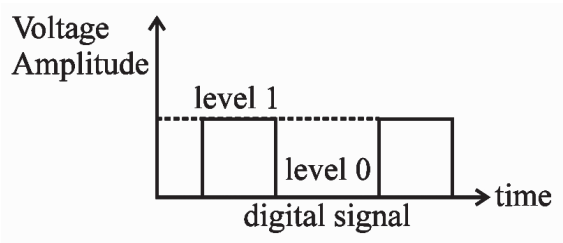
(iii) Solar cell

- Top layer is made to be thin for generation near the depleation area
- Junction area has kept larger for handling more power
- Materials with band gap close to 1.5 eV (between 1eV – 1.8 eV) are ideal for solar cell fabrication eg: Si (1.12 eV), GaAs (1.43 eV), Cd Te (e.45 eV) $CuInSe_2$(1.04 eV)
- Sunlight is not required for a solar cell. Any light with photon energy greater than the band gap can be used.



Digital Electronics

- In digital electronics we use only digital signals
- Digital signal is a pulse wave form, in which discrete values of voltage are possible
- We use binary numbers to represent digital signal ie 0 (say 0V) and 1 (Say 5V)



- In digital system, we follows boolean

algebra

boolean multiplication	boolean addition
0 x 0 = 0	0 + 0 = 0
0 x 1 = 0	0 + 1 = 1
1 x 0 = 0	1 + 0 = 1
1 x 1 = 1	1 + 1 = 1

Logic Gates

- Logic gate is a digital circuit that follows certain logical relationship between the input and output voltages
- Logic gates are basic building blocks of digital electronics
- Logic gate also represented by boolean expressions [We use capital letters of english alphabet for representing variables of boolean expression]
- Operation of logic gate is indicated in a table known as truth table. It is the tabular representation of all the possible combination of inputs and their corresponding outputs.

Basic logic gates

- There are three basic logic gates. AND gate, OR gate and NOT gate.
- We can realize all the boolean expression with the combination of these three logic gates.

Basic logic gates

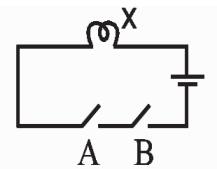
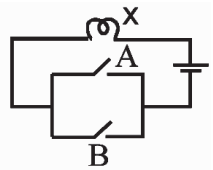
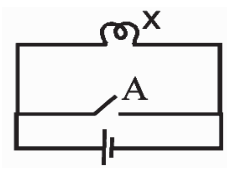
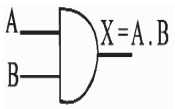
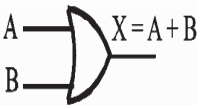
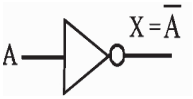
1	Name	AND	OR	NOT
2	Electrical Analogue			
3	Truth table	i/p: A, B; o/p: X 0 0 0 0 1 0 1 0 0 1 1 1	i/p: A, B; o/p: X 0 0 0 0 1 1 1 0 1 1 1 1	i/p: A; o/p: X 0 1 1 0
4	Boolean expression	$X = A.B$	$X = A + B$	$X = \overline{A}$
5	Symbol			
6	Law	AND law $A . 0 = 0$ $A . 1 = A$ $A . A = A$	OR law $A + 0 = A$ $A + 1 = 1$ $A + A = A$	NOT law $A + \overline{A} = 1$ $A . \overline{A} = 0$ $\overline{\overline{A}} = A$

Table 4.1

- Demorgan's law : (i) $\overline{A+B}=\overline{A}.\overline{B}$

  (ii) (i) $\overline{A.B}=\overline{A}+\overline{B}$

- Indentities : (i) A + AB = A

  (ii) A . (A+B) = A

  (iii) (A+B) (A+C) = A + BC

  (iv) $A\left(\overline{A}+B\right)=AB$

Universal logic gates

- There are two universal logic gate, NAND gate and NOR gate.
- We can realize all the boolean expression using repeated use of universal logic gates. ie we can realize other basic gates like OR, AND, NOT etc with these gates. Hence it is considered as basic building blocks of other gates.
- NAND gate is an AND gate followed by a NOT gate similarly NOR gate is an OR gate followed by a NOT gate

Universal logic gates

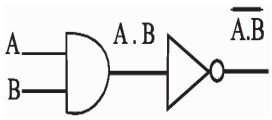
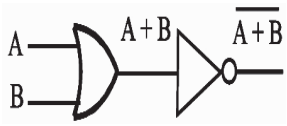
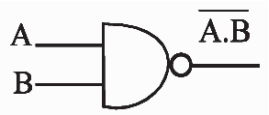
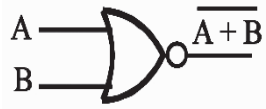
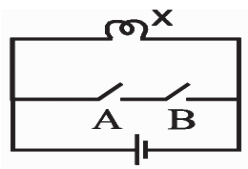
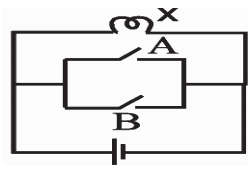
1	Name	NAND	NOR
2	Structure		
3	Symbol		
4	Boolean expression	$X=\overline{A.B}$	$X=\overline{A+B}$
5	Truth table	i/p: A, B; o/p: X 0 0 1 0 1 1 1 0 1 1 1 0	i/p: A, B; o/p: X 0 0 1 0 1 0 1 0 0 1 1 0
6	Electrical analogue		

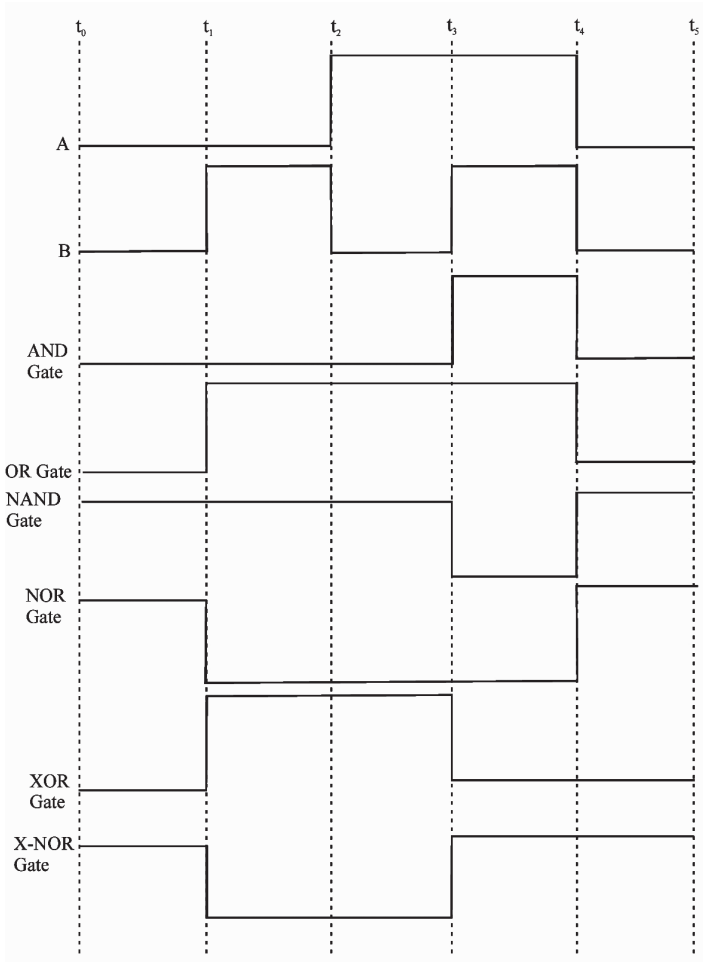
Table 4.2

Exclusive logic gates

- There are two exclusive logic gate XOR gate and XNOR gate

1	Name	XOR	XNOR
2	Symbol		
3	Boolean expression	$X = A \oplus B$ $X = \bar{A}B + A\bar{B}$	$X = \overline{A \oplus B}$ $X = A \odot B$ $X = \bar{A}\bar{B} + AB$
4	Truth table	i/p: A, B; o/p: X 0 0 0 0 1 1 1 0 1 1 1 0	i/p: A, B; o/p: X 0 0 1 0 1 0 1 0 0 1 1 1

Table 4.3



4.3 Realization of other gates using universal logic gates

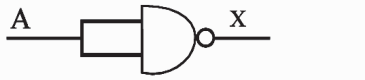
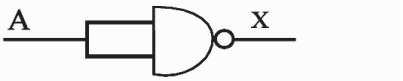
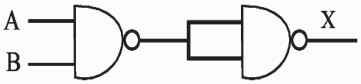
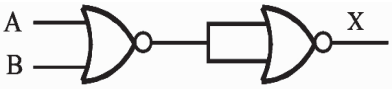
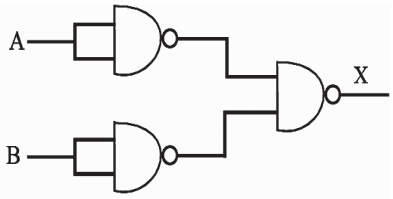
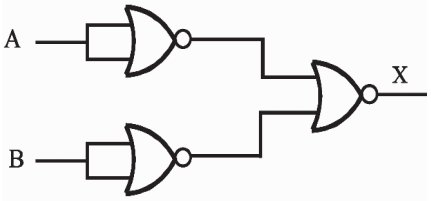
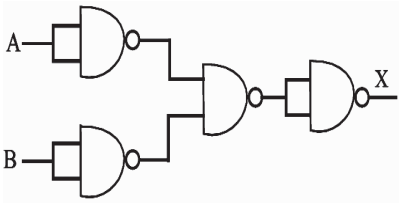
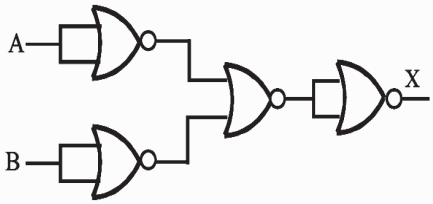
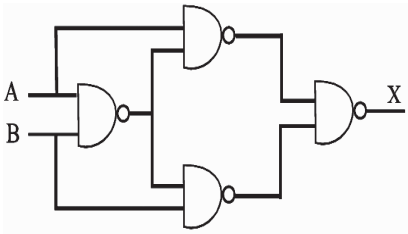
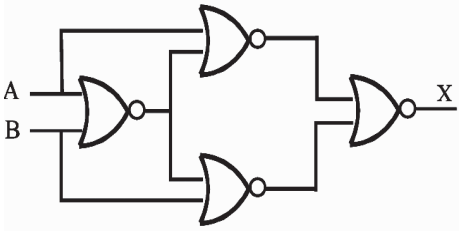
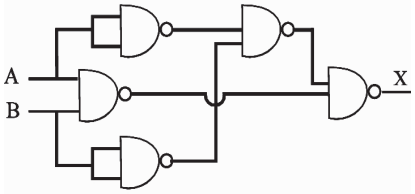
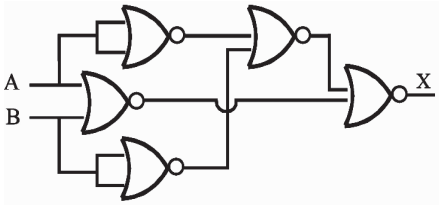
No.of gate used	NAND	NOR
1	 Shorted NAND gate = NOT	 Shorted NAND gate = NOT
2	 AND gate	 OR gate
3	 OR gate	 AND gate
4	 NOR gate	 NAND gate
5	 XOR gate	 X-NOR gate
6	 X-NOR gate	 XOR gate

Table 4.4

SECTION - I
QUESTIONS

1. Pure Si at 300K has equal electron n_e and n_h and hole n_h concentration of $1.5\times10^{16}/m^3$. Doping by indium increases n_h to $4.5\times10^{22}/m^3$. Calculate n_e in doped silicon.

1) $5 \times 10^9/m^3$

2) $2 \times 10^7/m^3$

3) $3 \times 10^5/m^3$

4) $4 \times 10^4/m^3$

2. Suppose a pure Si crystal has 5×10^{28} atoms m^{-3}. It is doped by 1 ppm concentration of pentavalent As. Calculate the number of electrons and hole.(Given that $n_i=1.5\times10^{16}\ m^{-3}$)

1) $4.5\times10^9 / m^3$

2) $2.5\times10^2 / m^3$

3) $6.2\times10^6 / m^2$

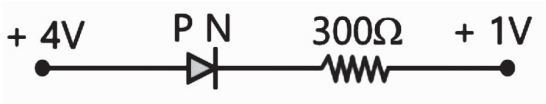
4) $4.2\times10^7 / m^2$

3. For given semiconductor contribution of current due to electron and hole is in ratio 3/1 and the ratio of drift velocity for electron and hole is 5/2, then calculate the ratio of electron to hole concentration.

1) $\frac{6}{5}$ 2) $\frac{2}{5}$

3) $\frac{4}{5}$ 4) $\frac{3}{5}$

4. In the circuit given below, the value of the current is



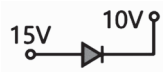
1) 0 amp

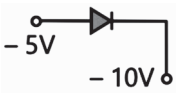
2) 10^{-2} amp

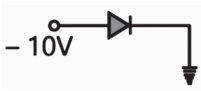
3) 10^2 amp

4) 10^{-3} amp

5. Which one is reverse-biased

1) 

2) 

3) 

4)

6. In a silicon p-n junction, the dominant mechanism for motion of charge carriers in forward and reverse bias :

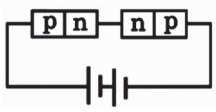
1) are drift and diffusion, respectively

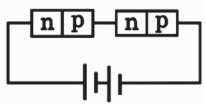
2) are diffusion and drift, respectively

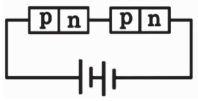
3) is drift in both

4) is diffusion in both

7. In which of the following circuit, the potential drop across the two p-n junction are equal ? Take all p-n junctions to be identical :

i) 

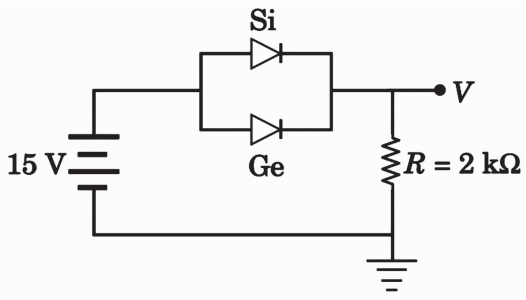
ii) 

iii) 

1) (i) and (ii) 2) (i) and (iii)

3) (ii) and (iii) 4) only (iii)

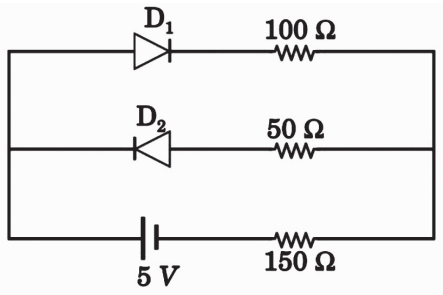
8. Ge and Si diodes in the circuit below conduct at 0.3V and 0.7V, respectively. If the connection of Ge diode in now reversed, the change in value of V is :



1) 0.2V 2) 0.4V

3) 0.7V 4) 0.9V

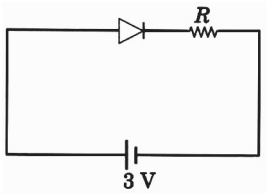
9. Two diodes, D_1 and D_2, each with forward resistance of 50Ω and infinite backward resistance are connected as shown in the circuit below. The current through the 150Ω resistance is :



1) 1.64 A 2) 0.032A

3) 0.0167 A 4) Zero

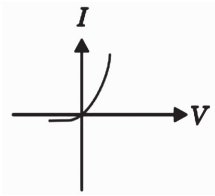
10. In the current versus voltage characteristics of a diode, minimum current of 1mA is required for the knee voltage to be above 0.7V. If the diode is connected in a circuit shown in the figure, the minimum value of R, so that the voltage is above knee point, is:

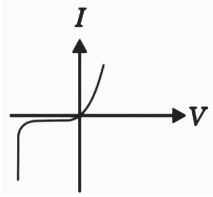


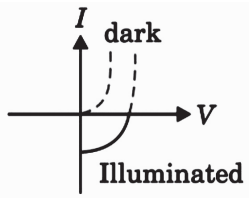
1) 3.7kΩ 2) 2.3kΩ

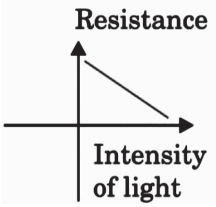
3) 5.2kΩ 4) 1.7kΩ

11. Identify the semiconductor devices whose characteristics are given below, in the order (a), (b), (c), (d) :

a) 

b) 

c) 

d) 

1) Simple diode, Zener diode, Solar cell, Light dependent resistance

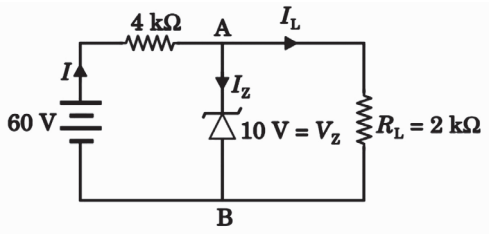
2) Zener diode, Simple diode, Light dependent resistances, Solar cell

3) Solar cell, Light dependent resistance, Zener diode, Simple diode

4) Zener diode, Solar cell, Simple diode, Light dependent resistance

12. A Zener diode is connected to a battery and load as shown below :

The currents I, I_Z and I_L are respectively



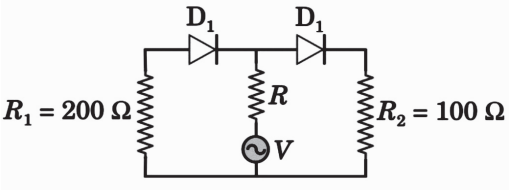
1) 15 mA, 5 mA, 10 mA

2) 15 mA, 7.5mA, 7.5 mA

3) 12.5 mA, 5 mA, 7.5 mA

4) 12.5 mA, 7.5 mA, 5 mA

13. In the circuit given below, D_1 and D_2 are two identical diodes and V is a sinusoidal voltage source. The voltage drop across the resistance R_L.



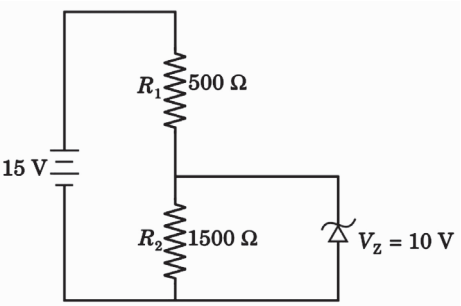
1) is half rectified

2) is fully rectified

3) has same value of peak voltage for positive and negative half cycles

4) has different value of peak voltage for positive and negative half cycles

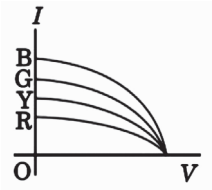
14. In the given circuit the current through Zener diode is :

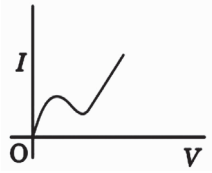


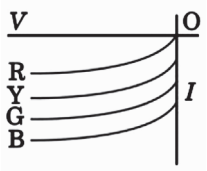
1) 3.3 mA 2) 2.5 mA

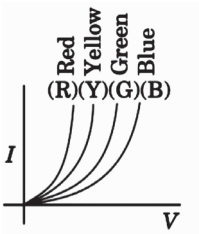
3) 5.5 mA 4) 6.7 mA

15. The I-V characteristic of an LED is :

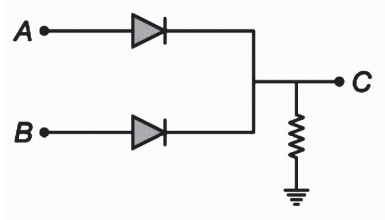
1)


2)


3)


4)


16. In the circuit below, A and B represent two inputs and C represents the output. The circuit represents



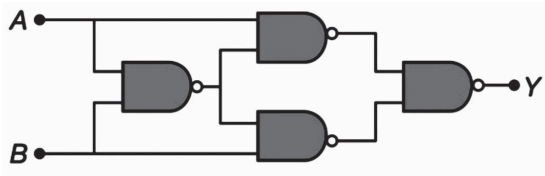
1) OR gate

2) NOR gate

3) AND gate

4) NAND gate

17. Truth table for system of four NAND gate as shown in figure is



1)

A	B	Y
0	0	0
0	1	0
1	0	1
1	1	1

2)

A	B	Y
0	0	1
0	1	1
1	0	0
1	1	0

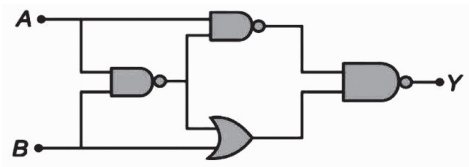
3)

A	B	Y
0	0	1
0	1	0
1	0	0
1	1	1

4)

A	B	Y
0	0	0
0	1	1
1	0	1
1	1	0

18. The output of the given logic circuit is



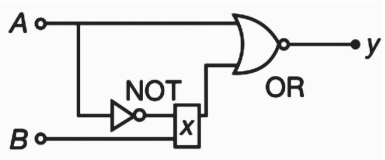
1) $A\overline{B}+\overline{A}B$ 2) $A\overline{B}$

3) $AB+\overline{AB}$ 4) $\overline{A}B$

19. The logic circuit shown in the following figure yields the given truth table

A	B	Y
1	1	1
0	1	1
1	0	1
0	0	0

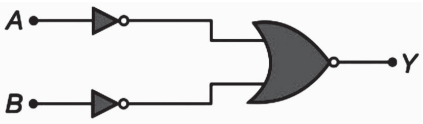
The gate X in the diagram is

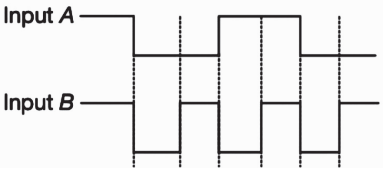


1) NAND 2) XOR

3) AND 4) NOR

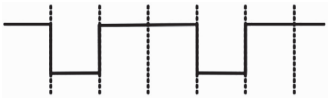
20. The logic circuit shown below has the input wave forms A and B as shown. Pick out the correct output waveform





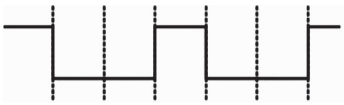
1)

2)



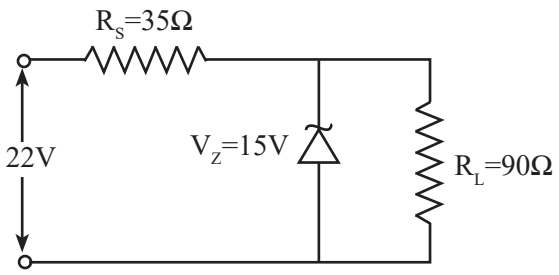
3)

4)



SECTION - II
QUESTIONS

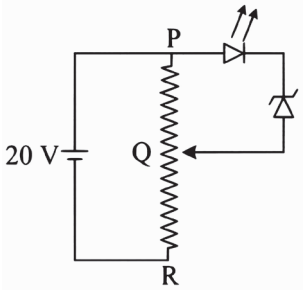
21. The value of power dissipated across the zener diode connected in the circuit as shown in the figure is



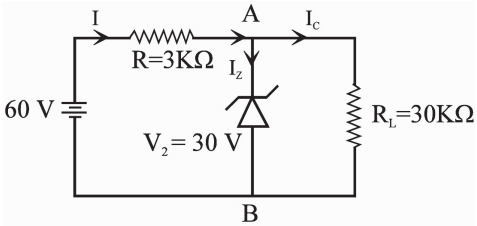
The value of x, to the nearest integer, is

22. An N-type silicon crystal of cross sectional area $10^{-6}m^2$ carries a current of 4.8mA. If free electron density is $10^{22}/m^3$ when the voltage is applied across the length 6cm of the crystal, find how much time taken for the electron to trace full length of the sample

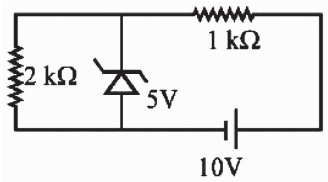
23. A potential divider circuit is connected to a DC source of 20V, with a light-emitting diode (LED) having a forward voltage of 1.8V and a Zener diode with a breakdown voltage of 3.2V. The length PR of the resistive wire is 20cm. The minimum length of PQ required to just make the LED glow is _____ cm.



24. In the figure the current through the diode is (use ideal diode approximations)



25. In connection with the circuit drawn below, the value of current flowing through resistor is



Syllabus for JEE (Main) - 2025

Syllabus for JEE Main Paper 1 (B.E./B.Tech.)- Mathematics, Physics and Chemistry

MATHEMATICS UNIT 1: SETS, RELATIONS AND FUNCTIONS:

Sets and their representation; Union, intersection and complement of sets and their algebraic properties; Power set; Relations, type of relations, equivalence relations, functions; one-one, into and onto functions, the composition of functions.

UNIT 2: COMPLEX NUMBERS AND QUADRATIC EQUATIONS:

Complex numbers as ordered pairs of reals, Representation of complex numbers in the form $a + ib$ and their representation in a plane, Argand diagram, algebra of complex numbers, modulus and argument (or amplitude) of a complex number, Quadratic equations in real and complex number systems and their solutions; Relations between roots and coefficients, nature of roots, the formation of quadratic equations with given roots.

UNIT3: MATRICES AND DETERMINANTS:

Matrices, algebra of matrices, type of matrices, determinants and matrices of order two and three, evaluation of determinants, area of triangles using determinants; Adjoint and inverse of a square matrix; Test of consistency and solution of simultaneous linear equations in two or three variables using matrices.

UNIT 4: PERMUTATIONS AND COMBINATIONS:

The fundamental principle of counting, permutations and combinations; Meaning of $P(n, r)$ and $C(n, r)$. Simple applications.

UNIT 5: BINOMIAL THEOREM AND ITS SIMPLE APPLICATIONS:

Binomial theorem for a positive integral index, general term and middle term and simple applications.

UNIT 6: SEQUENCE AND SERIES:

Arithmetic and Geometric progressions, insertion of arithmetic, geometric means between two given numbers, Relation between A.M and G.M.

UNIT 7: LIMIT, CONTINUITY AND DIFFERENTIABILITY:

Real–valued functions, algebra of functions; polynomial, rational, trigonometric, logarithmic and exponential functions; inverse functions. Graphs of simple functions. Limits, continuity and differentiability. Differentiation of the sum, difference, product and quotient of two functions. Differentiation of trigonometric, inverse trigonometric, logarithmic, exponential, composite and implicit functions; derivatives of order upto two, Applications of derivatives: Rate of change of quantities, monotonic-Increasing and decreasing functions, Maxima and minima of functions of one variable.

UNIT 8: INTEGRAL CALCULAS:

Integral as an anti-derivative, Fundamental integrals involving algebraic, trigonometric, exponential and logarithmic functions. Integration by substitution, by parts and by partial fractions. Integration using trigonometric identities. Evaluation of simple integrals of the type

$\int \frac{dx}{x^2+a^2}$, $\int \frac{dx}{\sqrt{x^2 \pm a^2}}$, $\int \frac{dx}{a^2-x^2}$, $\int \frac{dx}{\sqrt{a^2-x^2}}$, $\int \frac{dx}{ax^2+bx+c}$, $\int \frac{dx}{\sqrt{ax^2+bx+c}}$, $\int \frac{(px+q)dx}{ax^2+bx+c}$,

$\int \frac{(px+q)dx}{\sqrt{ax^2+bx+c}}$ $\int \sqrt{a^2 \pm x^2}\, dx$, $\int \sqrt{x^2 - a^2}\, dx$

The fundamental theorem of calculus, properties of definite integrals. Evaluation of definite integrals, determining areas of the regions bounded by simple curves by simple curves in standard forms.

UNIT 9: DIFFRENTIAL EQUATIONS :

Ordinary differential equations, their order and degree, the solution of differential equation by the method of separation of variables, solution of a homogeneous and linear differential equation of the type $\frac{dy}{dx} + p(x)y = q(x)$.

UNIT 10: CO-ORDINATE GEOMETRY :

Cartesian system of rectangular coordinates in a plane, distance formula, sections formula, locus and its equation, the slope of a line, parallel and perpendicular lines, intercepts of a line on the co-ordinate axis.

Straight line: Various forms of equations of a line, intersection of lines, angles between two lines, conditions for concurrence of three lines, the distance of a point form a line, co-ordinate of the centroid, orthocentre and circumcentre of a triangle.

Circle, conic sections: A standard form of equations of a circle, the general form of the equation of a circle, its radius and centre, equation of a circle when the endpoints of a diameter are given, points of intersection of a line and a circle with the centre at the origin and sections of conics, equations of conic sections (parabola, ellipse and hyperbola) in standard forms.

UNIT 11: THREE DIMENSIONAL GEOMETRY :

Coordinates of a point in space, the distance between two points, section formula, direction ratios and direction cosines and the angle between two intersecting lines. Equation of a line; Skew lines, the shortest distance between them and its equation.

UNIT 12: VECTOR ALGEBRA :

Vectors and scalars, the addition of vectors, components of a vector in two dimensions and three-dimensional spaces, scalar and vector products.

UNIT 13: STATISTICS AND PROBABILITY :

Measures of dispersion; calculation of mean, median, mode of grouped and ungrouped data, calculation of standard deviation, variance and mean deviation for grouped and ungrouped data. Probability: Probability of an event, addition and multiplication theorems of probability, Baye's theorem, probability distribution of a random variable.

UNIT 14: TRIGONOMETRY :

Trigonometrical identities and trigonometrical functions, inverse trigonometrical functions their properties.

Syllabus for JEE (Main) - 2025
PHYSICS

UNIT 1: Units and Measurements

Units of measurements, System of units, SI Units, fundamental and derived units, least count, significant figures, Errors in measurements. Dimensions of Physics quantities, dimensional analysis and its applications.

UNIT 2: Kinematics

The frame of reference, motion in a straight line, speed and velocity, uniform and non-uniform motion, average speed and instantaneous velocity, uniformly accelerated motion, velocity-time, position-time graph, relations for uniformly accelerated motion, relative velocity.

Motion in a plane, projectile motion, uniform circular motion.

UNIT 3: Laws of Motion

Force and inertia, Newton's first law of motion, momentum, Newton's second Law of motion, impulse, Newton's third Law of motion. Law of conservation of linear momentum and its applications, equilibrium of concurrent forces.

Static and Kinetic friction, laws of friction, rolling friction.

Dynamics of uniform circular motion, centripetal force and its applications: vehicle on a level circular road, vehicle on a banked road.

UNIT 4: Work, Energy and Power

Work done by a constant force and a variable force, kinetic and potential energies, work-energy theorem, power.

The potential energy of a spring, conservation of mechanical energy, conservative and non- conservative forces, motion in a vertical circle. Elastic and inelastic collisions in one and two dimensions.

UNIT 5: Rotational Motion

Centre of mass of a two-particle system, centre of mass of a rigid body. Basic concepts of rotational motion, moment of a force, torque, angular momentum, conservation of angular momentum and its applications.

The moment of inertia, the radius of gyration, values of moments of inertia for simple geometrical objects, parallel and perpendicular axes theorems and their applications. Equilibrium of rigid bodies, rigid body rotation and equations of rotational motion, comparison of linear and rotational motions.

UNIT 6: Gravitation

The universal law of gravitation. Acceleration due to gravity and its variation with altitude and depth. Kepler's law of planetary motion. Gravitational potential energy, gravitational potential. Escape velocity, motion of a satellite, orbital velocity, time period and energy of satellite.

UNIT 7: Properties of Solids and Liquids

Elastic behaviour, stress-strain relationship, Hooke's Law, Young's modulus, bulk modulus and modulus of rigidity.

Pressure due to a fluid column, Pascal's law and its applications, effect of gravity on fluid pressure, viscosity, Stoke's law, terminal velocity, streamline and turbulent flow, critical velocity, Bernoulli's principle and its applications.

Surface energy and surface tension, angle of contact, excess of pressure across a curved surface, application of surface tension: drops, bubbles and capillary rise.

Heat, temperature, thermal expansion, specific heat capacity, calorimetry, change of state, latent heat. Heat transfer: conduction, convection and radiation.

UNIT 8: Thermodynamics

Thermal equilibrium and the concept of temperature, zeroth law of thermodynamics, heat, work and internal energy. The first law of thermodynamics, isothermal and adiabatic processes. The second law of thermodynamics: reversible and irreversible processes.

UNIT 9: Kinetic Theory of Gases

Equation of state of a perfect gas, work done on compressing a gas, kinetic theory of gases: assumptions, the concept of pressure, kinetic interpretation of temperature, RMS speed of gas molecules, degrees of freedom, law of equipartition of energy and applications to specific heat capacities of gases, mean free path, Avogadro's number.

UNIT 10: Oscillations and Waves

Oscillations and periodic motion: time period, frequency, displacement as a function of time, periodic functions. Simple harmonic motion (S.H.M.) and its equation, phase, oscillations of a spring: restoring force and force constant, energy in S.H.M.: kinetic and potential energies, simple pendulum: derivation of expression for its time period.

Wave motion, longitudinal and transverse waves, speed of the travelling wave, displacement relation for a progressive wave, principle of superposition of waves, reflection of waves, standing waves in strings and organ pipes, fundamental mode and harmonics, beats.

UNIT 11: Electrostatics

Electric charges: conservation of charge, Coulomb's law forces between two point charges, forces between multiple charges, superposition principle and continuous charge distribution.

Electric field: electric field due to a point charge, electric field lines, electric dipole, electric field due to a dipole, torque on a dipole in a uniform electric field.

Electric flux, Gauss's law and its applications to find field due to infinitely long uniformly charged straight wire, uniformly charged infinite plane sheet and uniformly charged thin spherical shell.

Electric potential and its calculation for a point charge, electric dipole and system of charges, potential difference, equipotential surfaces, electrical potential energy of a system of two point charges and of electric dipole in an electrostatic field.

Conductors and insulators, dielectrics and electric polarization, capacitors and capacitance, the combination of capacitors in series and parallel and capacitance of a parallel plate capacitor with and without dielectric medium between the plates, energy stored in a capacitor.

UNIT 12: Current Electricity

Electric current: drift velocity, mobility and their relation with electric current, Ohm's law, electrical resistance, I-V characteristics of Ohmic and non-ohmic conductors, electrical energy and power, electrical resistivity and conductivity, series and parallel combinations of resistors, temperature dependence of resistance.

Internal resistance, potential difference and emf of a cell, a combination of cells in series and parallel.

Kirchhoff's laws and their applications, Wheatstone bridge, Metre Bridge.

UNIT 13: Magnetic Effects of Current and Magnetism

Biot - Savart law and its application to the current carrying circular loop, Ampere's law and its applications to infinitely long current carrying straight wire and solenoid.

Force on a moving charge in uniform magnetic and electric fields, force on a current-carrying conductor in a uniform magnetic field, the force between two parallel currents carrying conductors-definition of ampere, torque experienced by a current loop in a uniform magnetic field: Moving coil galvanometer, its sensitivity and conversion to ammeter and voltmeter.

Current loop as a magnetic dipole and its magnetic dipole moment, bar magnet as an equivalent solenoid, magnetic field lines, magnetic field due to a magnetic dipole (bar magnet) along its axis and perpendicular to its axis, torque on a magnetic dipole in a uniform magnetic field, para-, dia- and ferromagnetic substances with examples, the effect of temperature on magnetic properties.

UNIT 14: Electromagnetic Induction and Alternating Currents

Electromagnetic induction: Faraday's law, induced emf and current, Lenz's law, eddy currents, self and mutual inductance.

Alternating currents, peak and RMS value of alternating current/voltage, reactance and impedance, LCR series circuit, resonance, power in AC circuits, wattless current, AC generator and transformer.

UNIT 15: Electromagnetic Waves

Displacement current, electromagnetic waves and their characteristics, transverse nature of electromagnetic waves, electromagnetic spectrum (radio waves, microwaves, infrared, visible, ultraviolet, X-rays, Gamma rays), applications of electromagnetic waves.

UNIT 16: Optics

Reflection of light, spherical mirrors, mirror formula. Refraction of light at plane and spherical surfaces, thin lens formula and lens maker formula, total internal reflection and its applications, magnification, power of a lens, combination of thin lenses in contact, refraction of light through a prism, microscope and astronomical telescope (reflecting and refracting) and their magnifying powers.

Wave optics: wavefront and Huygens 'Principle, laws of reflection and refraction using Huygens principle. Interference: Young's double-slit experiment and expression for fringe width, coherent sources and sustained interference of light. Diffraction due to a single slit, width of central maximum. Polarization: plane-polarized light, Brewster's law, uses of plane- polarized light and Polaroid.

UNIT 17: Dual Nature of Matter and Radiation

Dual nature of radiation, Photoelectric effect, Hertz and Lenard's observations, Einstein's photoelectric equation, particle nature of light. Matter waves: wave nature of particle, de- Broglie relation.

UNIT 18: Atoms and Nuclei

Alpha-particle scattering experiment, Rutherford's model of atom, Bohr model, energy levels, hydrogen spectrum. Composition and size of nucleus, atomic masses, mass-energy relation, mass defect, binding energy per nucleon and its variation with mass number, nuclear fission and fusion.

UNIT 19: Electronic Devices

Semiconductors, semiconductor diode: I-V characteristics in forward and reverse bias, diode as a rectifier; I-V characteristics of LED, the photodiode, solar cell, Zener diode, Zener diode as a voltage regulator.

Logic gates (OR. AND. NOT. NAND and NOR).

UNIT 20: Experimental Skills

Familiarity with the basic approach and observations of the experiments and activities:

1. Vernier calipers -its use to measure the internal and external diameter and depth of a vessel.
2. Screw gauge-its use to determine the thickness/ diameter of thin sheet/wire.
3. Simple pendulum-dissipation of energy by plotting a graph between the square of amplitude and time.
4. Metre scale - the mass of a given object by the principle of moments.
5. Young's modulus of elasticity of the material of a metallic wire.
6. Surface tension of water by capillary rise and effect of detergents,
7. Co-efficient of viscosity of a given viscous liquid by measuring the terminal velocity of a given spherical body.
8. Speed of sound in air at room temperature using a resonance tube,
9. Specific heat capacity of a given (i) solid and (ii) liquid by method of mixtures.
10. The resistivity of the material of a given wire using a metre bridge.
11. The resistance of a given wire using Ohm's law.
12. Resistance and figure of merit of a galvanometer by half deflection method.
13. The focal length of

(i) Convex mirror

(ii) Concave mirror and

(iii) Convex lens, using the parallax method.

14. The plot of the angle of deviation vs angle of incidence for a triangular prism.
15. The refractive index of a glass slab using a travelling microscope.
16. Characteristic curves of a p-n junction diode in forward and reverse bias.
17. Characteristic curves of a Zener diode and finding reverse breakdown voltage.
18. Identification of diode, LED, resistor, a capacitor from a mixed collection of such items

CHEMISTRY

PHYSICAL CHEMISTRY

UNIT I: SOME BASIC CONCEPTS IN CHEMISTRY

Matter and its nature, Dalton's atomic theory, Concept of atom, molecule, element and compound, Laws of chemical combination, Atomic and molecular masses, mole concept, molar mass, percentage composition, empirical and molecular formulae, Chemical equations and stoichiometry.

UNIT 2: ATOMIC STRUCTURE

Nature of electromagnetic radiation, photoelectric effect, spectrum of the hydrogen atom, Bohr model of a hydrogen atom - its postulates, derivation of the relations for the energy of the electron and radii of the different orbits, limitations of Bohr's model, dual nature of matter, de Broglie's relationship, Heisenberg uncertainty principle, elementary ideas of quantum mechanics, the quantum mechanical model of the atom and its important features, concept of atomic orbitals as one-electron wave functions, variation of ψ and ψ^2 with r for 1s and 2s orbitals, various quantum numbers (principal, angular momentum and magnetic quantum numbers) and their significance, shapes of s, p and d - orbitals, electron spin and spin quantum number, rules for filling electrons in orbitals – Aufbau principle, Pauli's exclusion principle and Hund's rule, electronic configuration of elements and extra stability of half-filled and completely filled orbitals.

UNIT 3: CHEMICAL BONDING AND MOLECULAR STRUCTURE

Kossel-Lewis approach to chemical bond formation, the concept of ionic and covalent bonds.

Ionic Bonding: Formation of ionic bonds, factors affecting the formation of ionic bonds; calculation of lattice enthalpy.

Covalent Bonding: Concept of electronegativity, Fajan's rule, dipole moment, Valence Shell Electron Pair Repulsion (VSEPR) theory and shapes of simple molecules.

Quantum mechanical approach to covalent bonding: Valence bond theory - its important features, the concept of hybridization involving s, p and d orbitals, resonance.

Molecular Orbital Theory - Its important features, LCAOs, types of molecular orbitals (bonding, antibonding), sigma and pi-bonds, molecular orbital electronic configurations of homonuclear diatomic molecules, the concept of bond order, bond length and bond energy.

Elementary idea of metallic bonding, hydrogen bonding and its applications.

UNIT 4: CHEMICAL THERMODYNAMICS

Fundamentals of thermodynamics: System and surroundings, extensive and intensive properties, state functions, entropy, types of processes.

The first law of thermodynamics - Concept of work, heat, internal energy and enthalpy, heat capacity, molar heat capacity, Hess's law of constant heat summation, Enthalpies of bond dissociation, combustion, formation, atomization, sublimation, phase transition, hydration, ionization and solution.

The second law of thermodynamics - Spontaneity of processes, ΔS of the universe and ΔG of the system as criteria for spontaneity. $\Delta G°$(Standard Gibbs energy change) and equilibrium constant.

UNIT 5: SOLUTIONS

Different methods for expressing the concentration of solution - molality, molarity, mole fraction, percentage (by volume and mass both), the vapour pressure of solutions and Raoult's Law - Ideal and non-ideal solutions, vapour pressure - composition, plots for ideal and non- ideal solutions, Colligative properties of dilute solutions - a relative lowering of vapour pressure, depression of freezing point, the elevation of boiling point and osmotic pressure, determination of molecular mass using colligative properties, abnormal value of molar mass, van't Hoff factor and its significance.

UNIT 6: EQUILIBRIUM

Meaning of equilibrium is the concept of dynamic equilibrium.

Equilibria involving physical processes: Solid-liquid, liquid-gas, gas-gas and solid-gas equilibria, Henry's law. General characteristics of equilibrium involving physical processes.

Equilibrium involving chemical processes: Law of chemical equilibrium, equilibrium constants (K_p and K_c) and their significance, the significance of ΔG and $\Delta G°$ in chemical equilibrium, factors affecting equilibrium concentration, pressure, temperature, the effect of catalyst, Le Chatelier's principle.

Ionic equilibrium: Weak and strong electrolytes, ionization of electrolytes, various concepts of acids and bases (Arrhenius, Bronsted - Lowry and Lewis) and their ionization, acid-base equilibria (including multistage ionization) and ionization constants, ionization of water, pH scale, common ion effect, hydrolysis of salts and pH of their solutions, the solubility of sparingly soluble salts, solubility products and buffer solutions.

UNIT 7: REDOX REACTIONS AND ELECTROCHEMISTRY

Electronic concepts of oxidation and reduction, redox reactions, oxidation number, rules for assigning oxidation number and balancing of redox reactions.

Electrolytic and metallic conduction, conductance in electrolytic solutions, molar conductivities and their variation with concentration, Kohlrausch's law and its applications.

Electrochemical cells - Electrolytic and Galvanic cells, different types of electrodes, electrode potentials including standard electrode potential, half-cell and cell reactions, emf of a Galvanic cell and its measurement, Nernst equation and its applications, relationship between cell potential and Gibbs' energy change, dry cell and lead accumulator, fuel cells.

UNIT 8: CHEMICAL KINETICS

Rate of a chemical reaction, factors affecting the rate of reactions: concentration, temperature, pressure and catalyst, elementary and complex reactions, order and molecularity of reactions, rate law, rate constant and its units, differential and integral forms of zero and first-order reactions, their characteristics and half-lives, the effect of temperature on the rate of reactions, Arrhenius theory, activation energy and its calculation, collision theory of bi-molecular gaseous reactions (no derivation).

INORGANIC CHEMISTRY

UNIT 9: CLASSIFICATION OF ELEMENTS AND PERIODICITY IN PROPERTIES

Modern periodic law and present form of the periodic table, s, p. d and f block elements, periodic trends in properties of elements atomic and ionic radii, ionization enthalpy, electron gain enthalpy, valence, oxidation states and chemical reactivity.

UNIT 10: p- BLOCK ELEMENTS

Group -13 to Group 18 Elements

General Introduction: Electronic configuration and general trends in physical and chemical properties of elements across the periods and down the groups, unique behaviour of the first element in each group.

UNIT 11: d - and f- BLOCK ELEMENTS

Transition Elements - General introduction, electronic configuration, occurrence and characteristics, general trends in properties of the first-row transition elements - physical properties, ionization enthalpy, oxidation states, atomic radii, colour, catalytic behaviour, magnetic properties, complex formation, interstitial compounds, alloy formation, preparation, properties and uses of $K_2Cr_2O_7$ and $KMnO_4$.

Inner Transition Elements

Lanthanoids - Electronic configuration, oxidation states and Lanthanoid contraction.

Actinoids - Electronic configuration and oxidation states.

UNIT 12: COORDINATION COMPOUNDS

Introduction to coordination compounds. Werner's theory, ligands, coordination number, denticity, chelation, IUPAC nomenclature of mononuclear co-ordination compounds, isomerism, Bonding: Valence bond approach and basic ideas of Crystal field theory, colour and magnetic properties, importance of coordination compounds (in qualitative analysis, extraction of metals and in biological systems).

ORGANIC CHEMISTRY

UNIT 13: PURIFICATION AND CHARACTERISATION OF ORGANIC COMPOUNDS

Purification - Crystallization, sublimation, distillation, differential extraction and chromatography - principles and their applications.

Qualitative analysis - Detection of nitrogen, sulphur, phosphorus and halogens.
Quantitative analysis (basic principles only) - Estimation of carbon, hydrogen, nitrogen, halogens, sulphur and phosphorus.

Calculations of empirical formulae and molecular formulae, numerical problems in organic quantitative analysis,

UNIT 14: SOME BASIC PRINCIPLES OF ORGANIC CHEMISTRY

Tetravalency of carbon, shapes of simple molecules - hybridization (s and p): classification of organic compounds based on functional groups and those containing halogens, oxygen, nitrogen and sulphur, homologous series: Isomerism - structural and stereoisomerism.

Nomenclature (Trivial and IUPAC)

Covalent bond fission - Homolytic and heterolytic, free radicals, carbocations and carbanions, stability of carbocations and free radicals, electrophiles and nucleophiles.

Electronic displacement in a covalent bond

- Inductive effect, electromeric effect, resonance and hyperconjugation.

Common types of organic reactions- Substitution, addition, elimination and rearrangement.

UNITS 15: HYDROCARBONS

Classification, isomerism, IUPAC nomenclature, general methods of preparation, properties and reactions.

Alkanes - Conformations: Sawhorse and Newman projections (of ethane), mechanism of halogenation of alkanes.

Alkenes - Geometrical isomerism, mechanism of electrophilic addition, addition of hydrogen, halogens, water, hydrogen halides (Markownikoffs and peroxide effect), Ozonolysis and polymerization.

Alkynes - Acidic character, addition of hydrogen, halogens, water and hydrogen halides, polymerization.

Aromatic hydrocarbons - Nomenclature, benzene - structure and aromaticity, mechanism of electrophilic substitution, halogenation, nitration.

Friedel-Craft's alkylation and acylation, directive influence of the functional group in mono- substituted benzene.

UNIT 16: ORGANIC COMPOUNDS CONTAINING HALOGENS

General methods of preparation, properties and reactions, nature of C-X bond, mechanisms of substitution reactions.

Uses, environmental effects of chloroform, iodoform, freons and DDT.

UNIT 17: ORGANIC COMPOUNDS CONTAINING OXYGEN

General methods of preparation, properties, reactions and uses.

ALCOHOLS, PHENOLS AND ETHERS
Alcohols: Identification of primary, secondary and tertiary alcohols, mechanism of dehydration.

Phenols: Acidic nature, electrophilic substitution reactions, halogenation, nitration and sulphonation, Reimer - Tiemann reaction.

Ethers: Structure.

Aldehyde and Ketones: Nature of carbonyl group, nucleophilic addition to >C=O group, relative reactivities of aldehydes and ketones, important reactions such as - Nucleophilic addition reactions (addition of HCN, NH_3 and its derivatives), Grignard reagent, oxidation, reduction (Wolf Kishner and Clemmensen), the acidity of α -hydrogen. Aldol condensation, Cannizzaro reaction, Haloform reaction, chemical tests to distinguish between aldehydes and ketones.

Carboxylic Acids: Acidic strength and factors affecting it.

UNIT 18: ORGANIC COMPOUNDS CONTAINING NITROGEN

General methods of preparation, properties, reactions and uses.

Amines: Nomenclature, classification, structure, basic character and identification of primary, secondary and tertiary amines and their basic character.

Diazonium Salts: Importance in synthetic organic chemistry.

UNIT 19: BIOMOLECULES

General introduction and importance of biomolecules.

CARBOHYDRATES – Classification, aldoses and ketoses, monosaccharides (glucose and fructose) and constituent monosaccharides of oligosaccharides (sucrose, lactose and maltose).

PROTEINS - Elementary idea of α -amino acids, peptide bond, polypeptides, proteins: primary, secondary, tertiary and quaternary structure (qualitative idea only), denaturation of proteins, enzymes.

VITAMINS – Classification and functions.

NUCLEIC ACIDS – Chemical constitution of DNA and RNA, biological functions of nucleic acids.

Hormones (General introduction)

UNIT 20: PRINCIPLES RELATED TO PRACTICAL CHEMISTRY

Detection of extra elements (Nitrogen, sulphur, halogens) in organic compounds, detection of the following functional groups, hydroxyl (alcoholic and phenolic), carbonyl (aldehyde and ketones) carboxyl and amino groups in organic compounds.

- The chemistry involved in the preparation of the following:

Inorganic compounds, Mohr's salt, potash alum.

Organic compounds: Acetanilide, p-nitro acetanilide, aniline yellow, iodoform.

- The chemistry involved in the titrimetric exercises – acids, bases and the use of indicators, oxalic-acid vs KMnO4, Mohr's salt vs KMnO4
- Chemical principles involved in the qualitative salt analysis:

Cations – Pb^{2+}, Cu^{2+}, Al^{3+}, Fe^{3+}, Zn^{2+}, Ni^{2+}, Ca^{2+}, Ba^{2+}, Mg^{2+}, NH_4^+

Anions- CO_3^{2-}, S^{2-}, SO_4^{2-}, NO_3^-, NO_2^-, Cl^-, Br^-, I^- (Insoluble salts excluded).

Chemical principles involved in the following experiments:

1. Enthalpy of solution of $CuSO_4$
2. Enthalpy of neutralization of strong acid and strong base.
3. Preparation of lyophilic and lyophobic sols.
4. Kinetic study of the reaction of iodide ions with hydrogen peroxide at room temperature.

Syllabus for JEE (Main) Paper 2A (B.Arch.) - Mathematics, Aptitude Test and Drawing Test

Part - I MATHEMATICS

UNIT 1: SETS, RELATIONS AND FUNCTIONS:

Sets and their representation; Union, intersection and complement of sets and their algebraic properties; Power set; Relations, type of relations, equivalence relations, functions; one-one, into and onto functions, the composition of functions.

UNIT 2: COMPLEX NUMBERS AND QUADRATIC EQUATIONS:

Complex numbers as ordered pairs of reals, Representation of complex numbers in the form $a + ib$ and their representation in a plane, Argand diagram, algebra of complex numbers, modulus and argument (or amplitude) of a complex number, Quadratic equations in real and complex number systems and their solutions; Relations between roots and coefficients, nature of roots, the formation of quadratic equations with given roots.

UNIT3: MATRICES AND DETERMINANTS:

Matrices, algebra of matrices, type of matrices, determinants and matrices of order two and three, evaluation of determinants, area of triangles using determinants; Adjoint and inverse of a square matrix; Test of consistency and solution of simultaneous linear equations in two or three variables using matrices.

UNIT 4: PERMUTATIONS AND COMBINATIONS:

The fundamental principle of counting, permutations and combinations; Meaning of $P(n, r)$ and $C(n, r)$. Simple applications.

UNIT 5: BINOMIAL THEOREM AND ITS SIMPLE APPLICATIONS:

Binomial theorem for a positive integral index, general term and middle term and simple applications.

UNIT 6: SEQUENCE AND SERIES:

Arithmetic and Geometric progressions, insertion of arithmetic, geometric means between two given numbers, Relation between A.M and G.M.

UNIT 7: LIMIT, CONTINUITY AND DIFFERENTIABILITY:

Real–valued functions, algebra of functions; polynomial, rational, trigonometric, logarithmic and exponential functions; inverse functions. Graphs of simple functions. Limits, continuity and differentiability. Differentiation of the sum, difference, product and quotient of two functions. Differentiation of trigonometric, inverse trigonometric, logarithmic, exponential, composite and implicit functions; derivatives of order upto two, Applications of derivatives: Rate of change of quantities, monotonic-Increasing and decreasing functions, Maxima and minima of functions of one variable.

UNIT 8: INTEGRAL CALCULAS:

Integral as an anti-derivative, Fundamental integrals involving algebraic, trigonometric, exponential and logarithmic functions. Integration by substitution, by parts and by partial fractions. Integration using trigonometric identities.

Evaluation of simple integrals of the type

$$\int \frac{dx}{x^2+a^2}, \quad \int \frac{dx}{\sqrt{x^2 \pm a^2}}, \int \frac{dx}{a^2-x^2}, \int \frac{dx}{\sqrt{a^2-x^2}}, \int \frac{dx}{ax^2+bx+c}, \int \frac{dx}{\sqrt{ax^2+bx+c}}, \int \frac{(px+q)dx}{ax^2+bx+c},$$

$$\int \frac{(px+q)dx}{\sqrt{ax^2+bx+c}} \quad \int \sqrt{a^2 \pm x^2}\, dx, \int \sqrt{x^2-a^2}\, dx$$

The fundamental theorem of calculus, properties of definite integrals. Evaluation of definite integrals, determining areas of the regions bounded by simple curves in standard forms.

UNIT 9: DIFFRENTIAL EQUATIONS :

Ordinary differential equations, their order and degree, the solution of differential equation by the method of separation of variables, solution of a homogeneous and linear differential equation of the type

$\frac{dy}{dx} + p(x)y = q(x)$.

UNIT 10: CO-ORDINATE GEOMETRY :

Cartesian system of rectangular coordinates in a plane, distance formula, sections formula, locus and its equation, the slope of a line, parallel and perpendicular lines, intercepts of a line on the co-ordinate axis.

Straight line: Various forms of equations of a line, intersection of lines, angles between two lines, conditions for concurrence of three lines, the distance of a point form a line, co-ordinate of the centroid, orthocentre and circumcentre of a triangle.

Circle, conic sections: A standard form of equations of a circle, the general form of the equation of a circle, its radius and centre, equation of a circle when the endpoints of a diameter are given, points of intersection of a line and a circle with the centre at the origin and sections of conics, equations of conic sections (parabola, ellipse and hyperbola) in standard forms.

UNIT 11: THREE DIMENSIONAL GEOMETRY :

Coordinates of a point in space, the distance between two points, section formula, direction ratios and direction cosines and the angle between two intersecting lines. Equation of a line; Skew lines, the shortest distance between them and its equation.

UNIT 12: VECTOR ALGEBRA :

Vectors and scalars, the addition of vectors, components of a vector in two dimensions and three-dimensional spaces, scalar and vector products.

UNIT 13: STATISTICS AND PROBABILITY :

Measures of dispersion; calculation of mean, median, mode of grouped and ungrouped data, calculation of standard deviation, variance and mean deviation for grouped and ungrouped data. Probability: Probability of an event, addition and multiplication theorems of probability, Baye's theorem, probability distribution of a random variable.

UNIT 14: TRIGONOMETRY :

Trigonometrical identities and trigonometrical functions, inverse trigonometrical functions and their properties.

Part –II APTITUDE TEST

UNIT - 1 Awareness of persons: Buildings, Materials.

Objects, Texture related to Architecture and Build-environment, Visualizing three- dimensional objects from two-dimensional drawings. Visualizing. Different sides of three- dimensional objects. Analytical Reasoning Mental Ability (Visual, Numerical and Verbal)

UNIT – 2 Three dimensional- perception: Understanding and appreciation of scale and proportions of objects, building forms and elements, colour texture harmony and contrast Design and drawing of geometrical or abstract shapes and patterns in pencil. Transformation of forms both 2D and 3D union, subtraction rotation, development of surfaces and volumes, Generation of plans, elevations and 3D views of objects, creating two-dimensional and three-dimensional compositions using given shapes and forms.

Part – III DRAWING TEST

Sketching of scenes and activities from memory of urbanscape (public space, market, festivals, street scenes, monuments, recreational spaces, etc.). landscape (riverfronts. Jungle. Gardens, trees. Plants, etc.) and rural life.

To be conducted in a Drawing sheet.

Note: Candidates are advised to bring pencils, own geometry box set, crasets and colour pencils and crayons for the Drawing Test.

Syllabus for JEE (Main) Paper 2B (B.Planning) - Mathematics, Aptitude Test and Planning
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UNIT - 1 Awareness of persons, Buildings, Materials, Objects and Textures related to Architecture and Build-environment, Visualizing three-dimensional objects from two-dimensional drawings.Visualizing different sides of three-dimensional objects, Analytical Reasoning Mental Ability (Visual, Numerical and Verbal)

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Part – III PLANNING

UNIT-1 GENERAL AWARENESS.

General knowledge questions and knowledge about prominent cities, development issues, government programs etc.

UNIT-2 SOCIAL SCIENCES

The idea of nationalism, nationalism in India, pre-modern world, 19th-century global economy, colonialism and colonial cities, industrialization, resources and development, types of resources, agriculture, water, mineral resources, industries, national economy; Human Settlements.

Power-sharing, federalism, political parties, democracy, the constitution of India.

Economic development- economic sectors, globalization, the concept of development, poverty; Population structure, social exclusion and inequality, urbanization, rural development, colonial cities.

UNIT-3 THINKING SKILLS

Comprehension (unseen passage); map reading skills, scale, distance, direction, area etc.; critical reasoning; understanding of charts, graphs and tables; basic concepts of statistics and quantitative reasoning.