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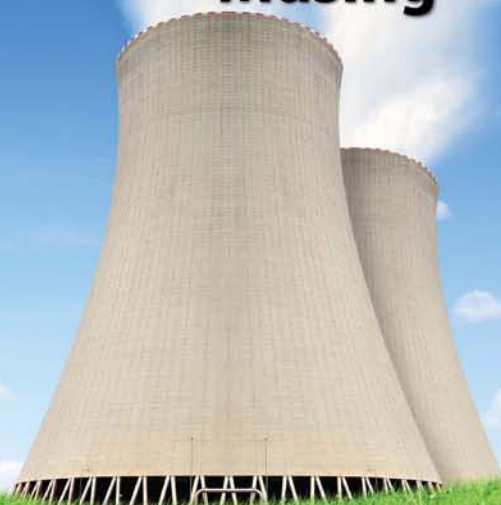
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Volume 24

No. 3

March 2016

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Physics Musing was started in August 2013 issue of Physics For You with the suggestion of Shri Mahabir Singh. The aim of Physics Musing is to augment the chances of bright students preparing for JEE (Main and Advanced) / AIIMS / Other PMTs with additional study material.

In every issue of Physics For You, 10 challenging problems are proposed in various topics of JEE (Main and Advanced) / various PMTs. The detailed solutions of these problems will be published in next issue of Physics For You.

The readers who have solved five or more problems may send their detailed solutions with their names and complete address. The names of those who send atleast five correct solutions will be published in the next issue.

We hope that our readers will enrich their problem solving skills through "Physics Musing" and stand in better stead while facing the competitive exams.

PROBLEM Set 32

SINGLE OPTION CORRECT TYPE

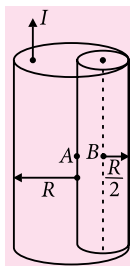
1. Find the inductance of a unit length of two long parallel wires, each of radius a , whose centers are a distance d apart and carry equal currents in opposite directions. Neglect the flux within the wire.

(a) $\frac{\mu_0}{2\pi} \ln\left(\frac{d-a}{a}\right)$ (b) $\frac{\mu_0}{\pi} \ln\left(\frac{d-a}{a}\right)$

(c) $\frac{3\mu_0}{\pi} \ln\left(\frac{d-a}{a}\right)$ (d) $\frac{\mu_0}{3\pi} \ln\left(\frac{d-a}{a}\right)$

2. From a cylinder of radius R , a cylinder of radius $R/2$ is removed, as shown in the figure. Current flowing in the remaining cylinder is I . Then, magnetic field strength is

- (a) zero at point A
(b) zero at point B
(c) $\frac{\mu_0 I}{2\pi R}$ at point A
(d) $\frac{\mu_0 I}{3\pi R}$ at point B.



3. A beam of the light is incident vertically on a glass hemisphere of radius R and refractive index $\sqrt{2}$, lying with its plane side on a table. The axis of beam coincides with the vertical axis passing through the centre of base of the hemisphere and cross sectional radius of beam is $\frac{R}{\sqrt{2}}$. The luminous spot formed on the table is of radius

- (a) R (b) $\frac{R}{\sqrt{2}}$
(c) $\frac{\sqrt{2}R}{(\sqrt{3}+1)}$ (d) $(\sqrt{3}+1)R$

4. Two masses M_1 and M_2 at an infinite distance apart are initially at rest. They start interacting

gravitationally. Find their velocity of approach when they are separated by a distance s .

(a) $\sqrt{\frac{G(M_1+M_2)}{2s}}$ (b) $\sqrt{\frac{GM_1M_2}{s}}$

(c) $\sqrt{\frac{2G(M_1+M_2)}{s}}$ (d) $\sqrt{\frac{Gs}{M_1M_2}}$

5. A system S receives heat continuously from an electrical heater of power 10 W. The temperature of S becomes constant at 50°C when the surrounding temperature is 20°C . After the heater is switched off, S cools from 35.1°C to 34.9°C in 1 minute. The heat capacity of S is

- (a) $100 \text{ J}^\circ\text{C}^{-1}$ (b) $300 \text{ J}^\circ\text{C}^{-1}$
(c) $750 \text{ J}^\circ\text{C}^{-1}$ (d) $1500 \text{ J}^\circ\text{C}^{-1}$

6. A flywheel rotating about an axis experiences an angular retardation proportional to the angle through which it rotates. If its rotational kinetic energy gets reduced by ΔE while it rotates through an angle θ , then

- (a) $\Delta E \propto \theta^2$ (b) $\Delta E \propto \sqrt{\theta}$
(c) $\Delta E \propto \theta$ (d) $\Delta E \propto \theta^{3/2}$

COMPREHENSION TYPE

For questions 7 and 8

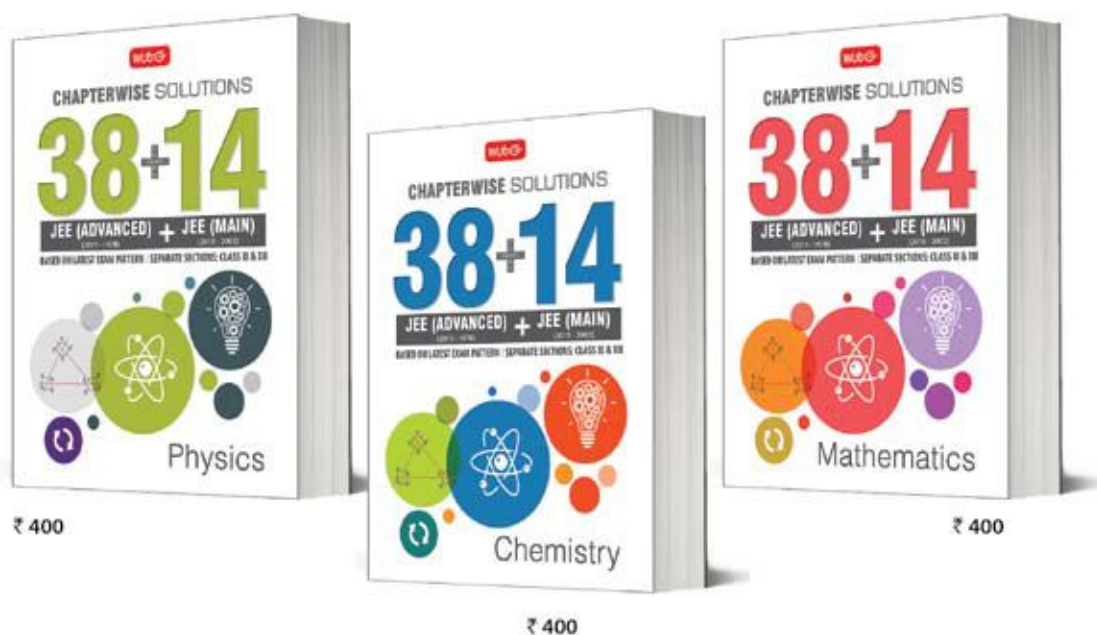
The value of potential energy at the reference point itself can be set equal to zero because we are always concerned only with differences of potential energy between two points and the associated change of kinetic energy. A particle A is fixed at origin of a fixed coordinate system. Another particle B which is free to move experiences a

force $\vec{F} = \left(-\frac{2\alpha}{r^3} + \frac{\beta}{r^2} \right) \hat{r}$ due to particle A where \vec{r} is the

position vector of the particle B relative to A . It is given that the force is conservative in nature and potential energy at infinity is zero. If it has to be removed from the influence of A , energy has to be supplied for such a



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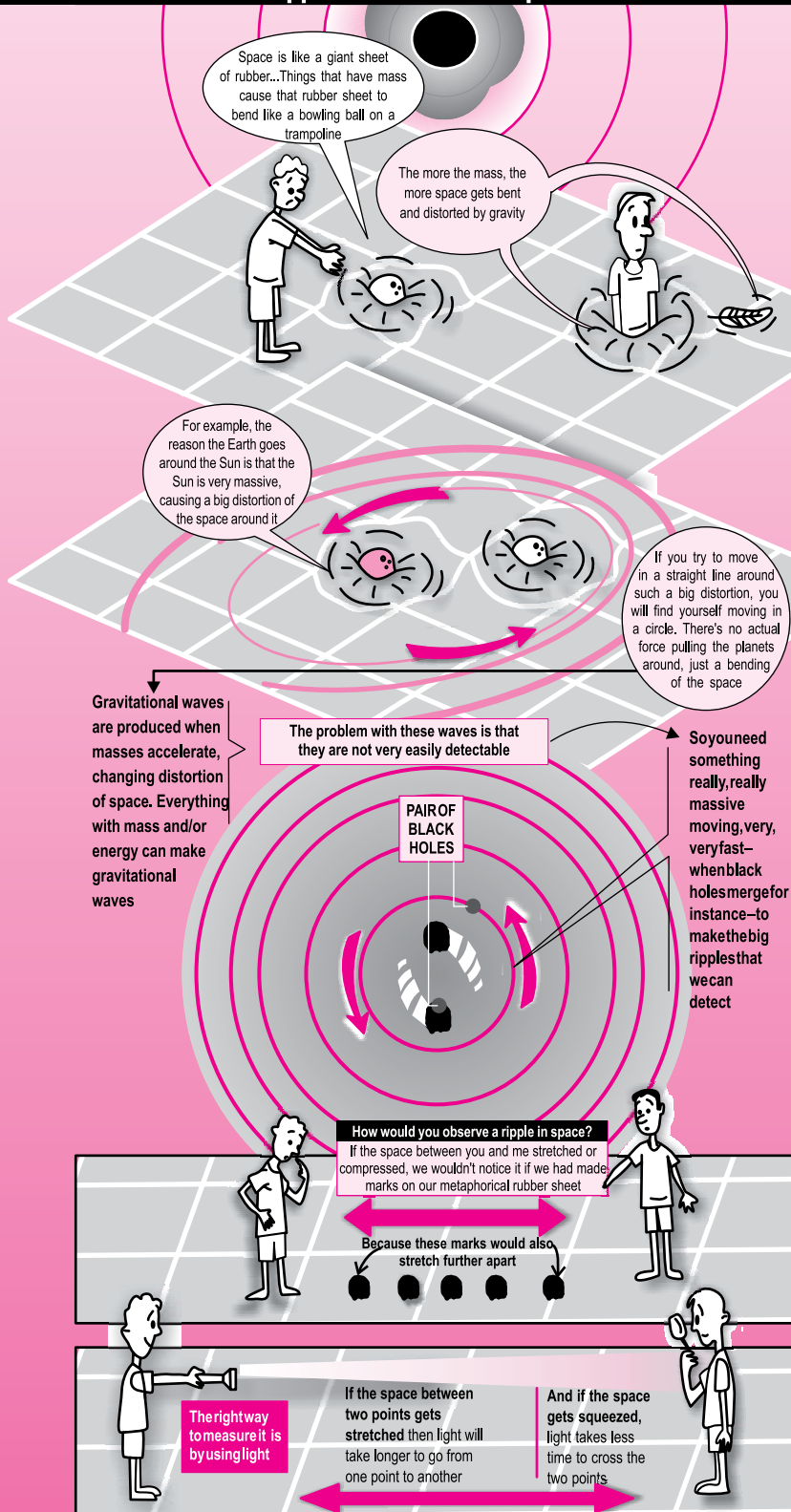


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WHAT IS A GRAVITATIONAL WAVE?

It's a ripple in the fabric of space and time



Courtesy : The Times of India

process. The ionization energy E_0 is the work that has to be done by an external agent to move the particle from a distance r_0 to infinity slowly. Here r_0 is the equilibrium position of the particle.

7. What is the potential energy function of particle as a function of r ?

- (a) $\frac{\alpha}{r^2} - \frac{\beta}{r}$ (b) $-\frac{\alpha}{r^2} + \frac{\beta}{r}$
(c) $-\frac{\alpha}{r^2} - \frac{\beta}{r}$ (d) $\frac{\alpha}{r^2} + \frac{\beta}{r}$

8. Find the ionization energy E_0 of the particle B.

- (a) $\frac{\beta^2}{2\alpha}$ (b) $\frac{2\beta^2}{\alpha}$
(c) $\frac{\beta^2}{4\alpha}$ (d) $\frac{\beta^2}{\alpha}$

For questions 9 and 10

A parallel plate capacitor is filled with dielectric material. If the capacitor is charged, electric field is created inside the dielectric. Due to this field, the electrons (which are not free), experience force in opposite direction of the field. If a very high field is applied in the dielectric, the outer electrons may get detached from the atoms and then the dielectric behaves like a conductor. This phenomenon is called dielectric breakdown. The minimum field at which the breakdown occurs is called the dielectric strength of the material and corresponding potential is called breakdown potential.

There are two capacitors of capacitances C and $2C$. The breakdown potential of each capacitor is V_0 .

9. If they are joined in series, then the maximum potential difference that can be applied across the combination for their safely use will be

- (a) V_0 (b) $\frac{3}{2}V_0$
(c) $2V_0$ (d) $3V_0$

10. If the voltage across the parallel combination of these two capacitors is increased, which capacitor will undergo breakdown first?

- (a) C
(b) $2C$
(c) Both at same moment
(d) None of these

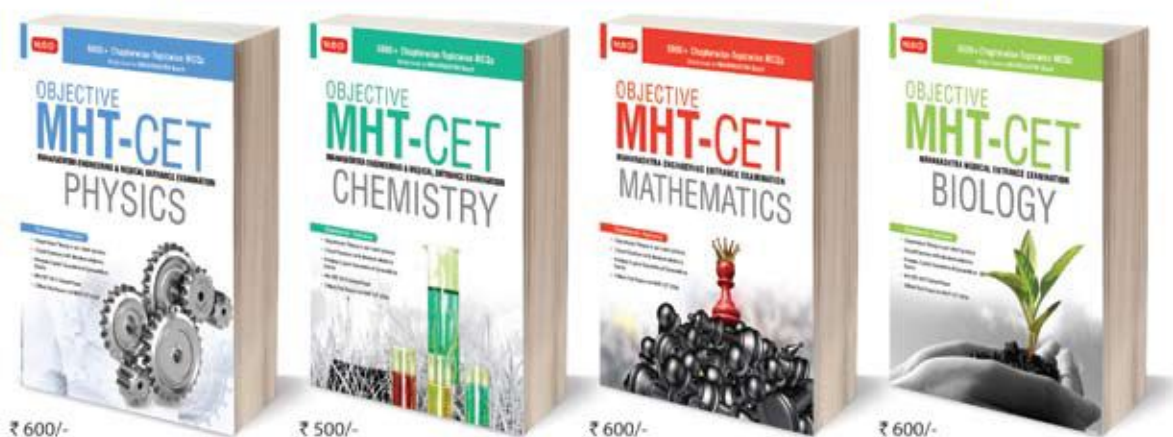


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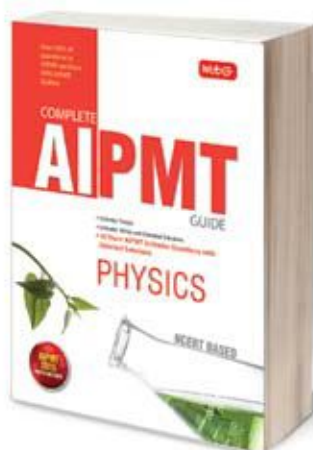
*K P Singh

SET 1 ROTATIONAL MOTION | GRAVITATION | MECHANICAL PROPERTIES OF SOLIDS AND FLUIDS

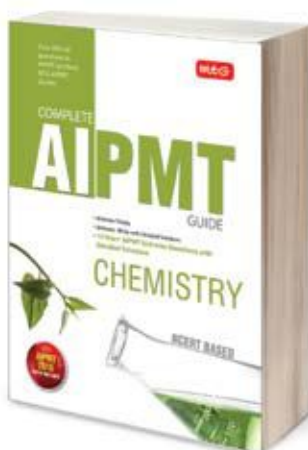
- The ratio of the radii of gyration of a circular disc about a tangential axis in the plane of the disc and of a circular ring of the same radius about a tangential axis in the plane of the ring is
(a) $\sqrt{3} : \sqrt{5}$ (b) $\sqrt{12} : \sqrt{3}$
(c) $1 : \sqrt{3}$ (d) $\sqrt{5} : \sqrt{6}$
- Three identical bodies of mass M are located at the vertices of an equilateral triangle of side L . They revolve under the effect of mutual gravitational force in a circular orbit, circumscribing the triangle while preserving the equilateral triangle. Their orbital velocity is
(a) $\sqrt{\frac{GM}{L}}$ (b) $\sqrt{\frac{3GM}{2L}}$ (c) $\sqrt{\frac{3GM}{L}}$ (d) $\sqrt{\frac{2GM}{3L}}$
- A stone of mass m tied to a string of length L is rotating along a circular path with constant speed v . The torque on the stone is
(a) mLv (b) $\frac{mv}{L}$ (c) $\frac{mv^2}{L}$ (d) zero
- A body A of mass M while falling vertically downwards under gravity breaks into two parts, a body B of mass $\frac{1}{3}M$ and a body C of mass $\frac{2}{3}M$. The centre of mass of bodies B and C taken together as compared to centre of mass of body A ,
(a) shifts depending on height of breaking
(b) does not shift
(c) shifts towards body C
(d) shifts towards body B
- A 20 cm long capillary tube is dipped in water. The water rises upto 8 cm. If the entire arrangement is put in a freely falling elevator, the length of water column in the capillary tube will be
(a) 8 cm (b) 10 cm (c) 4 cm (d) 20 cm
- The excess pressure inside a spherical drop of radius r of a liquid of surface tension T is
(a) directly proportional to r and inversely proportional to T
(b) directly proportional to T and inversely proportional to r
(c) directly proportional to the product of T and r
(d) inversely proportional to the product of T and r .
- A piece of ice is floating in a jar containing water. When the ice melts, then the level of water
(a) rises
(b) falls
(c) remains unchanged
(d) either rises or falls.
- The average depth of Indian ocean is about 3000 m. The fractional compression, $\frac{\Delta V}{V}$ of water at the bottom of the ocean (given that the bulk modulus of the water = $2.2 \times 10^9 \text{ N m}^{-2}$ and $g = 10 \text{ m s}^{-2}$) is
(a) 0.82 % (b) 0.91 % (c) 1.36 % (d) 1.24 %
- If linear density of a rod of length 3 m varies as $\lambda = 2 + x$, then the position of the centre of gravity of the rod is
(a) $\frac{7}{3} \text{ m}$ (b) $\frac{12}{7} \text{ m}$ (c) $\frac{10}{7} \text{ m}$ (d) $\frac{9}{7} \text{ m}$
- A uniform rod of length $8a$ and mass $6m$ lies on a smooth horizontal surface. Two point masses m and $2m$ moving in the same plane with speed $2v$ and v respectively strike the rod perpendicularly at distances a and $2a$ from the mid point of the rod in the opposite directions and stick to the rod. The angular velocity of the system immediately after the collision is
(a) $\frac{6v}{32a}$ (b) $\frac{6v}{33a}$ (c) $\frac{6v}{40a}$ (d) $\frac{6v}{41a}$

*A renowned physics expert, KP Institute of Physics, Chandigarh, 09872662552

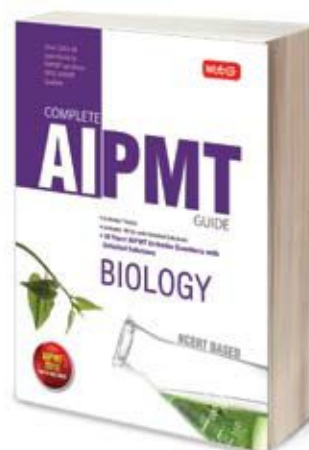
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11. Four wires of the same material are stretched by the same load. Which one of them will elongate most if their dimensions are as follows ?
 (a) $L = 100 \text{ cm}, r = 1 \text{ mm}$
 (b) $L = 200 \text{ cm}, r = 3 \text{ mm}$
 (c) $L = 300 \text{ cm}, r = 3 \text{ mm}$
 (d) $L = 400 \text{ cm}, r = 4 \text{ mm}$
12. The cylindrical tube of a spray pump has a cross-section of 8 cm^2 , one end of which has 40 fine holes each of area 10^{-8} m^2 . If the liquid flows inside the tube with a speed of 0.15 m min^{-1} , the speed with which the liquid is ejected through the holes is
 (a) 50 m s^{-1} (b) 5 m s^{-1}
 (c) 0.05 m s^{-1} (d) 0.5 m s^{-1}
13. Two particles of equal mass have velocities $v_1 = 4\hat{i} \text{ m s}^{-1}$ and $v_2 = 4\hat{j} \text{ m s}^{-1}$. First particle has an acceleration $a_1 = (5\hat{i} + 5\hat{j}) \text{ m s}^{-2}$, while the acceleration of the other particle is zero. The centre of mass of the two particles moves in a path of
 (a) straight line (b) parabola
 (c) circle (d) ellipse
14. The change in potential energy when a body of mass m is raised to a height nR from earth's surface is (R = radius of the earth)
 (a) $mgR \frac{n}{(n-1)}$ (b) mgR
 (c) $mgR \frac{n}{(n+1)}$ (d) $mgR \frac{n^2}{(n^2+1)}$
15. Two drops of equal radius coalesce to form a bigger drop. What is ratio of surface energy of bigger drop to smaller one?
 (a) $2^{1/2} : 1$ (b) $1 : 1$
 (c) $2^{2/3} : 1$ (d) None of these
16. Two capillaries of lengths L and $2L$ and of radii R and $2R$ are connected in series. The net rate of flow of fluid through them will be (given rate of the flow through single capillary, $X = \frac{\pi p R^4}{8 \eta L}$)
 (a) $\frac{8}{9}X$ (b) $\frac{9}{8}X$ (c) $\frac{5}{7}X$ (d) $\frac{7}{5}X$
17. The angle turned by a body undergoing circular motion depends on time as $\theta = \theta_0 + \theta_1 t + \theta_2 t^2$. Then the angular acceleration of the body is
 (a) θ_1 (b) θ_2 (c) $2\theta_1$ (d) $2\theta_2$
18. A planet of mass m moves around the sun of mass M in an elliptical orbit. The maximum and minimum distances of the planet from the sun are r_1 and r_2 respectively. The time period of the planet is proportional to
 (a) $(r_1 + r_2)$ (b) $(r_1 + r_2)^{1/2}$
 (c) $(r_1 - r_2)^{3/2}$ (d) $(r_1 + r_2)^{3/2}$
19. The surface tension of soap solution is 0.03 N m^{-1} . The work done (in J) in blowing to form a soap bubble of surface area 40 cm^2 , is
 (a) 1.2×10^{-4} (b) 2.4×10^{-4}
 (c) 12×10^{-4} (d) 24×10^{-4}
20. Three capillaries of lengths L , $L/2$ and $L/3$ are connected in series. Their radii are r , $r/2$ and $r/3$ respectively. Then, if stream-line flow is to be maintained and the pressure across the first capillary is p , then the
 (a) pressure difference across the ends of second capillary is $8p$
 (b) pressure difference across the third capillary is $43p$
 (c) pressure difference across the ends of the second capillary is $16p$
 (d) pressure difference across the third capillary is $56p$.
21. The moment of inertia of a thin circular disc about an axis passing through its centre and perpendicular to its plane is I . Then, the moment of inertia of the disc about an axis parallel to its diameter and touching the edge of the rim is
 (a) I (b) $2I$ (c) $\frac{3}{2}I$ (d) $\frac{5}{2}I$
22. In an elliptical orbit under gravitational force, in general
 (a) tangential velocity is constant
 (b) angular velocity is constant
 (c) radial velocity is constant
 (d) areal velocity is constant.
23. A layer of glycerine of thickness 1 mm is present between a large surface area and a surface area of 0.1 m^2 . With what force the small surface is to be pulled, so that it can move with a velocity of 1 m s^{-1} ? (Given that coefficient of viscosity = $0.07 \text{ kg m}^{-1} \text{ s}^{-1}$)
 (a) 70 N (b) 7 N
 (c) 700 N (d) 0.70 N
24. The ratio of radii of earth to another planet is $\frac{2}{3}$ and the ratio of their mean densities is $\frac{4}{5}$. If an astronaut can jump to a maximum height of 1.5 m on the earth, with the same effort, the maximum height he can jump on the planet is
 (a) 1 m (b) 0.8 m (c) 0.5 m (d) 1.25 m

25. Two wires of same material and radius have their lengths in ratio 1 : 2. If these wires are stretched by the same force, the strain produced in the two wires will be in the ratio
(a) 2 : 1 (b) 1 : 1 (c) 1 : 2 (d) 1 : 4
26. When the temperature increases, the viscosity of
(a) gas decreases and liquid increases
(b) gas increases and liquid decreases
(c) gas and liquid increase
(d) gas and liquid decrease.
27. A thin uniform square lamina of side a is placed in the xy -plane with its sides parallel to x and y -axis and with its centre coinciding with origin. Its moment of inertia about an axis passing through a point on the y -axis at a distance $y = 2a$ and parallel to x -axis is equal to its moment of inertia about an axis passing through a point on the x -axis at a distance $x = d$ and perpendicular to xy -plane. Then value of d is
(a) $\frac{7}{3}a$ (b) $\sqrt{\frac{47}{12}}a$ (c) $\frac{9}{5}a$ (d) $\sqrt{\frac{51}{12}}a$
28. Gravitational acceleration on the surface of a planet is $\frac{\sqrt{6}}{11}g$, where g is the gravitational acceleration on the surface of the earth. The average mass density of the planet is $\frac{2}{3}$ times that of the earth. If the escape speed on the surface of the earth is taken to be 11 km s^{-1} , the escape speed on the surface of the planet in km s^{-1} will be
(a) 5 (b) 7 (c) 3 (d) 11
29. An open U-tube contains mercury. When 11.2 cm of water is poured into one of the arms of the tube, how high does the mercury rise in the other arm from its initial unit?
(a) 0.56 cm (b) 1.35 cm
(c) 0.41 cm (d) 2.32 cm
30. A manometer connected to a closed tap reads $3.5 \times 10^5 \text{ N m}^{-2}$. When the valve is opened, the reading of manometer falls to $3.0 \times 10^5 \text{ N m}^{-2}$, then velocity of flow of water is
(a) 100 m s^{-1} (b) 10 m s^{-1}
(c) 1 m s^{-1} (d) $10\sqrt{10} \text{ m s}^{-1}$
31. A rope 1 cm in diameter breaks, if the tension in it exceeds 500 N. The maximum tension that may be given to similar rope of diameter 3 cm is
(a) 500 N (b) 3000 N
(c) 4500 N (d) 2000 N
32. Two rain drops reach the earth with different terminal velocities having ratio 9 : 4. Then the ratio of their volumes is
(a) 3 : 2 (b) 4 : 9 (c) 9 : 4 (d) 27 : 8
33. A door 1.6 m wide requires a force of 1 N to be applied at the free end to open or close it. The force that is required at a point 0.4 m distance from the hinges for opening or closing the door is
(a) 1.2 N (b) 3.6 N (c) 2.4 N (d) 4 N
34. A body is released from a point, distant r from the centre of earth. If R is the radius of the earth and $r > R$, then the velocity of the body at the time of striking the earth will be
(a) \sqrt{gR} (b) $\sqrt{2gR}$
(c) $\sqrt{\frac{2gR}{r-R}}$ (d) $\sqrt{\frac{2gR(r-R)}{r}}$
35. A wire of natural length L , Young's modulus Y and area of cross-section A is extended by x . Then the energy stored in the wire is given by
(a) $\frac{1}{2} \frac{YA}{L} x^2$ (b) $\frac{1}{3} \frac{YA}{L} x^2$
(c) $\frac{1}{2} \frac{YL}{A} x^2$ (d) $\frac{1}{2} \frac{YA}{L^2} x^2$
36. Two spherical soap bubbles of radii r_1 and r_2 in vacuum combine under isothermal conditions. The resulting bubble has a radius equal to
(a) $\frac{r_1 + r_2}{2}$ (b) $\frac{r_1 r_2}{r_1 + r_2}$
(c) $\sqrt{r_1 r_2}$ (d) $\sqrt{r_1^2 + r_2^2}$
37. A thin circular ring of mass M and radius R rotates about an axis through its centre and perpendicular to its plane, with a constant angular velocity ω . Four small spheres each of mass m (negligible radius) are kept gently to the opposite ends of two mutually perpendicular diameters of the ring. The new angular velocity of the ring will be
(a) 4ω (b) $\frac{M}{4m}\omega$
(c) $\left(\frac{M+4m}{M}\right)\omega$ (d) $\left(\frac{M}{M+4m}\right)\omega$
38. If ρ is the density of the planet, the time period of nearby satellite is given by
(a) $\sqrt{\frac{4\pi}{3G\rho}}$ (b) $\sqrt{\frac{4\pi}{G\rho}}$ (c) $\sqrt{\frac{3\pi}{G\rho}}$ (d) $\sqrt{\frac{\pi}{G\rho}}$

39. Eight equal drops of water are falling through air with a steady velocity of 10 cm s^{-1} . If the drops combine to form a single drop big in size, then the terminal velocity of this big drop is
 (a) 80 cm s^{-1} (b) 30 cm s^{-1}
 (c) 10 cm s^{-1} (d) 40 cm s^{-1}
40. An annular ring with inner and outer radii R_1 and R_2 is rolling without slipping with a uniform angular speed. The ratio of the forces experienced by the two particles situated on the inner and outer parts of the ring, i.e., $\frac{F_1}{F_2}$ is
 (a) $\frac{R_1}{R_2}$ (b) 1 (c) $\left(\frac{R_1}{R_2}\right)^2$ (d) $\frac{R_2}{R_1}$
41. The potential energy of 4 particles each of mass 1 kg placed at the four vertices of a square of side length 1 m is (in SI units)
 (a) + 4.0 G (b) - 7.5 G
 (c) - 5.4 G (d) + 6.3 G
42. A body is orbiting very close to the earth's surface with kinetic energy KE. The energy required to completely escape from it is
 (a) KE (b) 2 KE (c) $\frac{KE}{2}$ (d) $\frac{3KE}{2}$
43. Three particles each of mass m are kept at vertices of an equilateral triangle of side L . The gravitational field at centre due to these particles is
 (a) zero (b) $\frac{3GM}{L^2}$ (c) $\frac{9GM}{L^2}$ (d) $\frac{12}{\sqrt{3}} \frac{GM}{L^2}$
44. A body weighs 50 g in air and 40 g in water. How much would it weigh in a liquid of specific gravity 1.5?
 (a) 30 g (b) 35 g (c) 65 g (d) 45 g
45. When a number of small droplets combine to form a large drop, then
 (a) total volume decreases
 (b) thermal energy increases
 (c) thermal energy decreases
 (d) surface energy increases.

SET 2

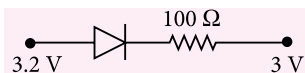
OPTICS | MODERN PHYSICS | SEMICONDUCTOR ELECTRONICS

1. 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 angle of incidence is
 (a) $\cos^{-1}\left(\frac{\mu}{2}\right)$ (b) $2\cos^{-1}\left(\frac{\mu}{2}\right)$
 (c) $2\sin^{-1}(\mu)$ (d) $2\sin^{-1}\left(\frac{\mu}{2}\right)$
2. Consider the nuclear reaction $X^{200} \rightarrow A^{110} + B^{80}$. If the binding energy per nucleon for X, A and B are 7.4 MeV, 8.2 MeV and 8.1 MeV respectively, then the energy released in the reaction is
 (a) 70 MeV (b) 200 MeV
 (c) 190 MeV (d) 10 MeV
3. A ray of light passes through an equilateral prism such that the angle of incidence is equal to the angle of emergence and the latter is equal to $3/4$ the angle of prism. The angle of deviation is
 (a) 25° (b) 30°
 (c) 45° (d) 35°
4. Two light sources are said to be coherent
 (a) when they have same frequency and a varying phase difference
 (b) when they have same frequency and a constant phase difference
 (c) when they have constant phase difference and different frequencies
 (d) when they have varying phase difference and different frequencies.
5. If the energy of the photon is increased by a factor of 4, then its momentum
 (a) does not change
 (b) decreases by a factor of 4
 (c) increases by a factor of 4
 (d) decreases by a factor of 2
6. ν_1 is the frequency of the series limit of Lyman series, ν_2 is the frequency of the first line of Lyman series and ν_3 is the frequency of the series limit of the Balmer series. Then,
 (a) $\nu_1 - \nu_2 = \nu_3$ (b) $\nu_1 = \nu_2 - \nu_3$
 (c) $\frac{1}{\nu_2} = \frac{1}{\nu_1} + \frac{1}{\nu_3}$ (d) $\frac{1}{\nu_1} = \frac{1}{\nu_2} + \frac{1}{\nu_3}$
7. A uniform electric field and a uniform magnetic field exist in a region in the same direction. An electron is projected with a velocity pointed in the same direction. Then the electron will
 (a) be deflected to the left without increase in speed
 (b) be deflected to the right without increase in speed

- (c) not be deflected but its speed will decrease
(d) not be deflected but its speed will increase.

8. The current in the circuit shown in the figure considering ideal diode is

- (a) 20 A
(b) 2×10^{-3} A
(c) 200 A
(d) 2×10^{-4} A



9. Wavelengths of light used in an optical instrument are $\lambda_1 = 4000 \text{ \AA}$ and $\lambda_2 = 5000 \text{ \AA}$, then ratio of their respective resolving powers (corresponding to λ_1 and λ_2) is

- (a) 16 : 25 (b) 9 : 1 (c) 4 : 5 (d) 5 : 4

10. Which of the following is correct, about doping in a transistor?

- (a) Emitter is lightly doped, collector is heavily doped and base is moderately doped.
(b) Emitter is lightly doped, collector is moderately doped and base is heavily doped.
(c) Emitter is heavily doped, collector is lightly doped and base is moderately doped.
(d) Emitter is heavily doped, collector is moderately doped and base is lightly doped.

11. The temperature at which protons in proton gas would have enough energy to overcome Coulomb barrier of $4.14 \times 10^{-14} \text{ J}$ is

(Boltzmann constant = $1.38 \times 10^{-23} \text{ J K}^{-1}$)

- (a) $2 \times 10^9 \text{ K}$ (b) 10^9 K
(c) $6 \times 10^9 \text{ K}$ (d) $3 \times 10^9 \text{ K}$

12. An alpha nucleus of energy $\frac{1}{2}mv^2$ bombards a heavy nuclear target of charge Ze . Then the distance of closest approach for the alpha nucleus will be proportional to

- (a) v (b) $\frac{1}{m^2}$ (c) $\frac{1}{v^4}$ (d) Ze^2

13. The radioactivity of a certain material drops to 1/16 of the initial value in 2 h. The half life of this radio nuclide is

- (a) 10 min (b) 20 min (c) 30 min (d) 40 min

14. The de Broglie wavelength of the electron in the ground state of the hydrogen atom is (Radius of the first orbit of hydrogen atom = 0.53 \AA)

- (a) 1.67 \AA (b) 3.33 \AA (c) 1.06 \AA (d) 0.53 \AA

15. At two points P and Q on screen in Young's double slit experiment, waves from slits S_1 and S_2 have a path difference of 0 and $\frac{\lambda}{4}$ respectively. The ratio of intensities at P and Q will be

- (a) 3 : 2 (b) 2 : 1 (c) $\sqrt{2} : 1$ (d) 4 : 1

16. A prism having refractive index 1.414 and refracting angle 30° has one of the refracting surfaces silvered. A beam of light incident on the other refracting surface will retrace its path, if the angle of incidence is

- (a) 45° (b) 60° (c) 30° (d) 0°

17. The focal lengths of the objective and the eye piece of telescope are 100 cm and 10 cm respectively. The magnification of the telescope when final image is formed at infinity is

- (a) 0.1 (b) 10 (c) 100 (d) ∞

18. If the kinetic energy of a free electron doubles, its de Broglie wavelength changes by the factor

- (a) $\sqrt{2}$ (b) $\frac{1}{\sqrt{2}}$ (c) 2 (d) $\frac{1}{2}$

19. The maximum efficiency of full wave rectifier is

- (a) 100 % (b) 25.2 % (c) 40.6 % (d) 81.2 %

20. When an unpolarized light of intensity I_0 is incident on a polarizing sheet, the intensity of the light which does not get transmitted is

- (a) $\frac{I_0}{2}$ (b) $\frac{I_0}{4}$ (c) zero (d) I_0

21. ${}_2^4\text{He} + {}_4^9\text{Be} \rightarrow {}_0^1n + ?$

The missing ion in the given nuclear reaction is

- (a) proton (b) oxygen-12
(c) carbon-12 (d) nitrogen-12

22. An electron is moving in an orbit of a hydrogen atom from which there can be a maximum of six transitions. An electron is moving in an orbit of another hydrogen atom from which there can be a maximum of three transitions. The ratio of the velocities of the electron in these two orbits is

- (a) $\frac{1}{2}$ (b) $\frac{2}{1}$ (c) $\frac{5}{4}$ (d) $\frac{3}{4}$

23. An α -particle of mass $6.4 \times 10^{-27} \text{ kg}$ and charge $3.2 \times 10^{-19} \text{ C}$ is situated in a uniform electric field of $1.6 \times 10^5 \text{ V m}^{-1}$. The velocity of the particle at the end of $2 \times 10^{-2} \text{ m}$ path when it starts from rest is

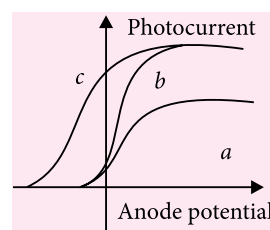
- (a) $2\sqrt{2} \times 10^5 \text{ m s}^{-1}$ (b) $8 \times 10^5 \text{ m s}^{-1}$
(c) $16 \times 10^5 \text{ m s}^{-1}$ (d) $4\sqrt{2} \times 10^5 \text{ m s}^{-1}$

24. Two thin lenses have a combined power of +9 D. When they are separated by a distance of 20 cm,

their equivalent power becomes $+\frac{27}{5}$ D. Their individual powers (in dioptre) are

- (a) 4, 5 (b) 3, 6 (c) 2, 7 (d) 1, 8

25. Two beams of red and violet colours are made to pass separately through a prism of angle 60° . In the minimum deviation position, the angle of refraction inside the prism will be
 (a) greater for red colour
 (b) equal but not 30° for both the colours
 (c) greater for violet colour
 (d) 30° for both the colours.
26. Of the following transitions in the hydrogen atom, the one which gives an emission line of the highest frequency is
 (a) $n = 1$ to $n = 2$ (b) $n = 2$ to $n = 1$
 (c) $n = 3$ to $n = 10$ (d) $n = 10$ to $n = 3$
27. In Millikan's oil drop experiment, a charged drop of mass 1.8×10^{-14} kg is stationary between the plates. The distance between the plates is 0.9 cm and potential difference between the plates is 2000 V. The number of electrons in the oil drop is
 (a) 10 (b) 5 (c) 50 (d) 20
28. In CE mode, the input characteristics of a transistor is the variation of
 (a) I_B against V_{BE} at constant V_{CE}
 (b) I_C against V_{CE} at constant V_{BE}
 (c) I_B against I_C (d) I_E against I_C .
29. The radioactivity of a sample is I_1 at a time t_1 and I_2 at a time t_2 . If the half life of the sample is $\tau_{1/2}$, then the number of nuclei that have disintegrated in the time $(t_2 - t_1)$ is proportional to
 (a) $I_1 t_2 - I_2 t_1$ (b) $I_1 - I_2$
 (c) $\frac{I_1 - I_2}{\tau_{1/2}}$ (d) $(I_1 - I_2) \tau^{1/2}$
30. A particle of mass M at rest decays into two masses m_1 and m_2 with non-zero velocities. The ratio of de Broglie wavelengths of the particles $\frac{\lambda_1}{\lambda_2}$ is
 (a) $\frac{m_2}{m_1}$ (b) $\frac{m_1}{m_2}$ (c) $\frac{\sqrt{m_1}}{\sqrt{m_2}}$ (d) 1
31. A fish at a depth of 12 cm in water is viewed by an observer on the bank of a lake. To what height the image of the fish is raised? (Refractive index of water = $4/3$)
 (a) 9 cm (b) 12 cm (c) 3.8 cm (d) 3 cm
32. The transition from the state $n = 4$ to $n = 1$ in a hydrogen like atom results in ultraviolet radiation. Infrared radiation will be obtained in the transition from
 (a) $2 \rightarrow 1$ (b) $3 \rightarrow 2$ (c) $4 \rightarrow 2$ (d) $5 \rightarrow 3$
33. The wavelength of the light used in Young's double slit experiment is λ . The intensity at a point on the screen is I , where the path difference is $\frac{\lambda}{6}$. If I_0 denotes the maximum intensity, then the ratio of I and I_0 is
 (a) 0.866 (b) 0.5 (c) 0.707 (d) 0.75
34. Two media having speeds of light 2×10^8 m s $^{-1}$ and 2.4×10^8 m s $^{-1}$, are separated by a plane surface. What is the angle for a ray going from medium I to medium II?
 (a) $\sin^{-1}\left(\frac{5}{6}\right)$ (b) $\sin^{-1}\left(\frac{5}{12}\right)$
 (c) $\sin^{-1}\left(\frac{1}{\sqrt{2}}\right)$ (d) $\sin^{-1}\left(\frac{1}{2}\right)$
35. The figure shows 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. Then



SOLUTION OF FEBRUARY 2016 CROSSWORD

				1	G					2	P	A	T	E	R	A					
				3	D	E	W			4	H	O		5	F	E	M	T	O		
			6	L		O					U	L		7	R	U					
	8	F	I	N	D	E	R			9	M	A	R	E	10	E	N	R	I	C	H
		E	M		E	K				12	R	A	D	13	L	I	D	A	R		
		E	B		S	A		14	D		C		G	R			15	G	16	S	
		D			17	I	O	N	I	Z	A	T	I	O	N			R	U		
		E	18	P		C	N		S		P		A	D				A	N		
		R	O						S		19	L	I	N	A	C		V	S		
20	C	A	L	O	R	I	E	O					T		21	B		I	P		
		22	B	A	R	Y	O	N	N							L		T	O		
			R			23	U		24	A	N	T	I	G	R	A	V	I	T	Y	
25	Z	B	O	S	O	N		N									Z		N		
			I					I		C		26	I	N	F	L	A	T	O	N	
			D	27	L	I	T	R	E								R				

WINNERS (February 2016)

- Amey Gupta (UP)
- Rohit Garg (Haryana)

Solution Senders (January 2016)

- Harsh Verma (UP)
- Mayank Kumar (Bihar)
- Lovedeep Singh (Punjab)

- (a) $f_a = f_b$ and $I_a \neq I_b$ (b) $f_a = f_c$ and $I_a = I_c$
 (c) $f_a = f_b$ and $I_a = I_b$ (d) $f_b = f_c$ and $I_b = I_c$
36. If g_E and g_M are the acceleration due to gravity on the surfaces of the earth and the moon respectively and if Millikan's oil drop experiment could be performed on the two surfaces, one will find the ratio $\frac{\text{electronic charge on the moon}}{\text{electronic charge on the earth}}$ to be
 (a) 1 (b) 0 (c) $\frac{g_E}{g_M}$ (d) $\frac{g_M}{g_E}$
37. In common emitter amplifier, the current gain is 62. The collector resistance and input resistance are $5\text{ k}\Omega$ and $500\text{ }\Omega$ respectively. If the input voltage is 0.01 V , the output voltage is
 (a) 0.62 V (b) 6.2 V (c) 62 V (d) 620 V
38. A thin convex lens of crown glass having refractive index 1.5 has power 1 D . What will be the power of similar convex lens but refractive index 1.6?
 (a) 0.6 D (b) 0.8 D (c) 1.2 D (d) 1.6 D
39. When a monochromatic point source of light is at a distance 0.2 m from a photoelectric cell, the saturation current and cut-off voltage are 12.0 mA and 0.5 V respectively. If the same source is placed 0.4 m away from the photoelectric cell, then the saturation current and the stopping potential respectively are
 (a) 4 mA and 1 V (b) 12 mA and 1 V
 (c) 3 mA and 1 V (d) 3 mA and 0.5 V
40. When a piece of metal is illuminated by a monochromatic light of wavelength λ , then stopping potential is 3 V_S . When same surface is illuminated by light of wavelength 2λ , then stopping potential becomes V_S . The value of threshold wavelength for photoelectric emission will be
 (a) 4λ (b) 8λ (c) $\frac{4}{3}\lambda$ (d) 6λ
41. For compound microscope, $f_o = 1\text{ cm}$, $f_e = 2.5\text{ cm}$. An object is placed at distance 1.2 cm from object lens. What should be length of microscope for normal adjustment?
 (a) 8.5 cm (b) 8.3 cm (c) 6.5 cm (d) 6.3 cm
42. In Young's double slit interference pattern, the fringe width
 (a) can be changed only by changing the wavelength of incident light
 (b) can be changed only by changing the separation between the two slits
 (c) can be changed either by changing the wavelength or by changing the separation between two sources
 (d) is a universal constant and hence cannot be changed.
43. An α -particle and a proton are accelerated from rest by a potential difference of 100 V . After this, their de Broglie wavelengths are λ_α and λ_p respectively. The ratio $\frac{\lambda_p}{\lambda_\alpha}$ to the nearest integer, is
 (a) 3 (b) 4 (c) 6 (d) 5
44. If the binding energy of the electron in a hydrogen atom is 13.6 eV , the energy required to remove the electron from the first excited state of Li^{2+} is
 (a) 30.6 eV (b) 13.6 eV
 (c) 3.4 eV (d) 122.4 eV
45. If λ is the wavelength of hydrogen atom from the transition $n = 3$ to $n = 1$, then what is the wavelength for doubly ionised lithium ion for same transition?
 (a) $\frac{\lambda}{3}$ (b) 3λ (c) $\frac{\lambda}{9}$ (d) 9λ

ANSWER KEYS

SET 1

- | | | | | | | | |
|---------|---------|---------|---------|---------|---------|---------|---------|
| 1. (d) | 2. (a) | 3. (d) | 4. (b) | 5. (d) | 6. (b) | 7. (c) | 8. (c) |
| 9. (b) | 10. (d) | 11. (a) | 12. (b) | 13. (a) | 14. (c) | 15. (c) | 16. (a) |
| 17. (d) | 18. (d) | 19. (b) | 20. (a) | 21. (d) | 22. (d) | 23. (b) | 24. (b) |
| 25. (c) | 26. (b) | 27. (b) | 28. (c) | 29. (c) | 30. (b) | 31. (c) | 32. (d) |
| 33. (d) | 34. (d) | 35. (a) | 36. (d) | 37. (d) | 38. (c) | 39. (d) | 40. (a) |
| 41. (c) | 42. (a) | 43. (a) | 44. (b) | 45. (b) | | | |

SET 2

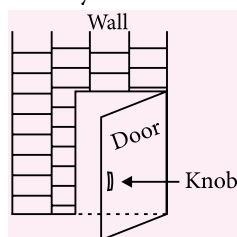
- | | | | | | | | |
|---------|---------|---------|---------|---------|---------|---------|---------|
| 1. (b) | 2. (a) | 3. (b) | 4. (b) | 5. (c) | 6. (a) | 7. (c) | 8. (b) |
| 9. (d) | 10. (d) | 11. (a) | 12. (d) | 13. (c) | 14. (b) | 15. (b) | 16. (a) |
| 17. (b) | 18. (b) | 19. (d) | 20. (a) | 21. (c) | 22. (d) | 23. (d) | 24. (b) |
| 25. (d) | 26. (b) | 27. (b) | 28. (a) | 29. (d) | 30. (d) | 31. (d) | 32. (d) |
| 33. (d) | 34. (a) | 35. (a) | 36. (a) | 37. (b) | 38. (c) | 39. (d) | 40. (a) |
| 41. (b) | 42. (c) | 43. (a) | 44. (a) | 45. (c) | | | |

CORE CONCEPT on

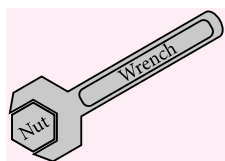
Torque

Have you ever given it a thought that-

- Why are door knobs always attached towards the extreme end, far away from the hinged end?



- Why are the handle bars of wrenches made large?



Now that you have started thinking, the obvious answer that you come across is that it becomes easier to rotate them. But why it is so?

The answer is TORQUE!

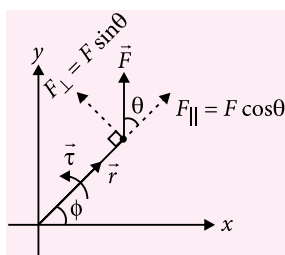
Torque of an applied force represents the rotational capability of the applied force to rotate the line joining the point of application of the applied force and the axis of rotation (AOR).

Let us see for example, a force \vec{F} being applied on a point object whose position vector is \vec{r} as given here.

Is this \vec{F} capable of changing the orientation of \vec{r} , i.e., is it capable of changing ϕ ? To understand this we break

two components of the applied force \vec{F}

- F_{\parallel} : The component of the applied force which is parallel to the position vector. This component clearly cannot change the orientation, it changes the distance r .



- F_{\perp} : The component of the applied force which is perpendicular to the position vector.

This component clearly can change the orientation, hence we should try to maximise its value.

Therefore keep in mind, whenever we talk of rotation capability of \vec{F} , we think of \vec{F}_{\perp} .

It is also observed that if we fix \vec{F} , and only change the point of application, increasing r increases rotation capability and decreasing r decreases the rotation capability.

Hence the rotation capability of \vec{F} , i.e., the torque of \vec{F} with respect to origin is

$$\tau = rF_{\perp} = rF \sin\theta = (r \sin\theta)F = r_{\perp} F$$

where r_{\perp} can be seen as the component of position vector which is perpendicular to the applied force.

The rotation will also have a direction, either clockwise or anticlockwise with respect to an observer.

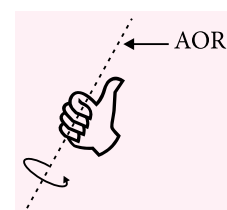
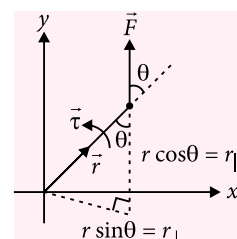
For example in the above example the torque is anticlockwise.

In vector representation, we can find it by using right hand curl rule where we curl the fingers of the right hand in the sense of rotation keeping the thumb straight, and the direction in which thumb points gives us the direction of the axis of rotation (AOR), somewhat as given here.

Let the plane of paper be the xy plane. Hence we use following conventions to represent clockwise/ anticlockwise rotation.

- Clockwise:**

↻ or \otimes or $(-\hat{k})$



Contributed By: Bishwajit Barnwal, Aakash Institute, Kolkata

2. Anticlockwise:



In vector form, torque of the applied force is

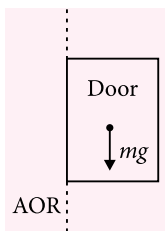
$$\vec{\tau} = \vec{r} \times \vec{F}$$

Remember that torque of a force is axis/point of observation dependent, since \vec{r} is the position vector of the point with respect to origin which was our point of observation. Hence changing it means changing $\vec{\tau}$. So, when can the torque of a force be zero?

Two cases

1. Applied force passes through the point of observation/AOR. $\vec{r} \times \vec{F} = 0$

2. Applied force is parallel to AOR. The door is hinged at one of its sides which behaves as AOR and the weight mg tends to turn its AOR itself which is fixed. Hence mg will not create any torque here.



Angular momentum (\vec{L})

It is a measure of the amount of rotational motion of an object with respect to an observation point in the same way as linear momentum is seen as the amount of translational motion in the object.

It is measured in 3 different ways depending upon the type of motion.

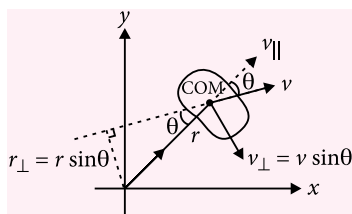
1. Pure translation:

$$\vec{L} = \vec{r} \times \vec{p} = \vec{r} \times (m\vec{v}) = m(\vec{r} \times \vec{v})$$

where \vec{r} is the position vector of the COM with respect to point of observation.

∴ With respect to origin,

$$\begin{aligned} L &= mvr \sin\theta \\ &= m(v \sin\theta)r \text{ or } mv(r \sin\theta) \\ &= mv_{\perp}r \text{ or } mvr_{\perp} \end{aligned}$$



2. Pure rotation :

The velocity of an elemental mass dm , $v = \omega r$.

∴ With respect to AOR,

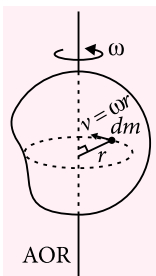
$$dL_{AOR} = (dm)(\omega r)(r)$$

$$\therefore dL_{AOR} = (dmr^2)\omega$$

$$\therefore L_{AOR} = \int dL_{AOR} = \left(\int dm r^2 \right) \omega$$

$$\therefore \vec{L}_{AOR} = I_{AOR} \vec{\omega}$$

where $I_{AOR} = \int dm r^2$ represents the moment of inertia (MOI) about the chosen axis of rotation.



Correlating it with linear momentum $\vec{p} = m\vec{v}$, it is clear that MOI has the same role to play in rotational mechanics which is played by mass in translational mechanics.

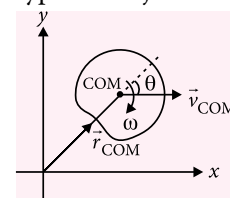
In this article, I am assuming, that you know the standard MOI results of different types of objects.

3. Translation + Rotation :

∴ With respect to origin

$$\vec{L} = \vec{r}_{COM} \times m\vec{v}_{COM}$$

$$+ I_{COM} \vec{\omega}$$



Relation between torque and angular momentum

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

$$\begin{aligned} \therefore \frac{d\vec{L}}{dt} &= \vec{r} \times \frac{d\vec{p}}{dt} + \frac{d\vec{r}}{dt} \times \vec{p} = \vec{r} \times \vec{F} + (\vec{v} \times \vec{p}) \\ &= \vec{r} \times \vec{F} \quad \left\{ \because \vec{v} \text{ is parallel to } \vec{p} \right\} \end{aligned}$$

$$\therefore \vec{\tau} = \frac{d\vec{L}}{dt} \quad \{\text{Newton's 2nd law in rotational mechanics.}\}$$

For an object rotating about an axis,

$$\vec{L}_{AOR} = I_{AOR} \vec{\omega}$$

$$\Rightarrow \frac{d\vec{L}_{AOR}}{dt} = I_{AOR} \frac{d\vec{\omega}}{dt} \Rightarrow \vec{\tau}_{AOR} = I_{AOR} \vec{\alpha}$$

where $\vec{\alpha} = \frac{d\vec{\omega}}{dt}$ = angular acceleration.

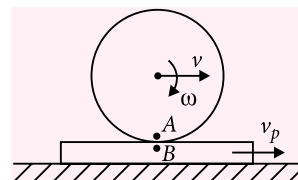
This relation is similar to $\vec{F} = m\vec{a}$ of translational mechanics.

Hence the equation says that the torque of all the forces acting on the object with respect to AOR is equal to the product of MOI about the chosen axis multiplied with angular acceleration.

Pure Rolling

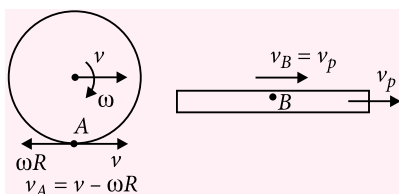
It is a special case of translation and rotation of an object where the point of contact of the object does not slip over the surface on which it is kept which is possible only if the velocity of the object at the point of contact is same as the surface. Let us see an example to understand better.

The sphere of radius R is rolling on a plank which is also moving. Let us find a condition for pure rolling. We have chosen two points A and B, one on the rolling object and the other on the plank. Both these points are in contact.



∴ For pure rolling,

$$v_A = v_B$$



$$\therefore v - \omega R = v_p$$

This is the required condition!

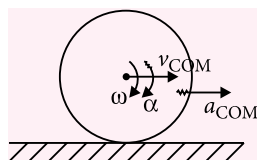
What if the sphere was rolling on a fixed surface?

In such case, $v_p = 0$

$$\therefore v = \omega R.$$

∴ $v = \omega R$ is not the condition for pure rolling in all cases, it is only when the surface is fixed.

Let us consider an object rolling on ground with instantaneous values of linear velocity of COM v_{COM} , angular velocity ω , linear acceleration of COM a_{COM} and angular acceleration α as shown.

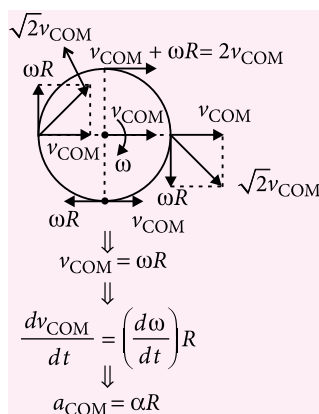


Note: To differentiate between velocity and acceleration, I have shown velocity with straight tail and acceleration with zig-zag tail.

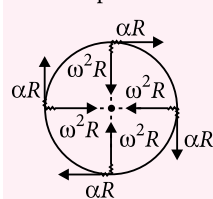
Let us find out the velocity and acceleration of any arbitrary point on the sphere.

To find the acceleration, we first find the acceleration of each point with respect to the COM and then we add the acceleration of COM vectorially to each of these points.

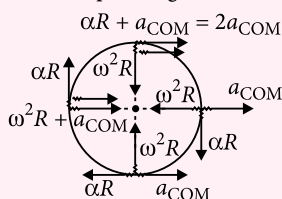
Remember that with respect to COM each point on sphere has tangential as well as radial acceleration.



with respect to COM



with respect to ground

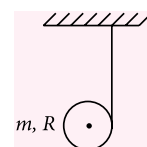


Note here that, the point of contact is tangentially unaccelerated but is radially accelerated.

Now before we start solving questions, remember that for torque calculations, torque is axis specific. Hence you can choose any arbitrary point for applying $\tau = I\alpha$, but we prefer those points through which maximum number of unknown forces pass through. The advantage is that the torque of such forces will be zero. But be careful in the selection since, it should not be an accelerated point else we will have to consider a pseudo force on the object which would pass through the COM and might have a torque of its own. Whenever in confusion about the selection of the point; prefer COM, since even if it is accelerated, pseudo force will pass through it and hence would not have any torque.

Now, Let us solve some questions.

Q1: A string is wrapped around a disc and one end of string tied to a ceiling and released. Find the acceleration of the COM.



Soln.: For translational mechanics,

$$mg - T = ma_{COM} \quad \dots(i)$$

For rotational mechanics, I prefer the point of contact P, which is on the straight string, since, the torque of tension would be zero, hence we get α in one equation directly

$$\therefore \tau_p = I_p \alpha$$

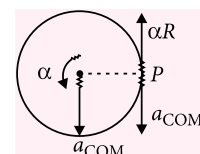
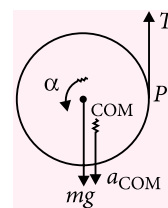
$$\Rightarrow mgR = \frac{3}{2}mR^2\alpha \Rightarrow \alpha R = \frac{2}{3}g \quad \dots(ii)$$

Now, a_{COM} and α are related, and the relation between them is the constraint relation.

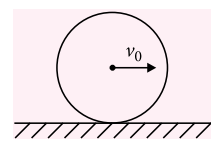
The acceleration of point P is zero. Hence,

$$\therefore a_p = 0 \Rightarrow a_{COM} - \alpha R = 0$$

$$\Rightarrow a_{COM} = \alpha R = \frac{2}{3}g$$



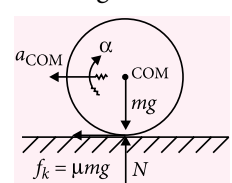
Q2: A solid sphere is projected by giving it a translational velocity v_0 on a rough horizontal surface with friction coefficient μ as shown.



Find the velocity of COM after pure rolling starts.

Soln.: Since slipping starts, kinetic friction would act in backward direction due to which COM decelerates and sphere attains angular acceleration in anticlockwise direction as shown.

$$f_k = ma_{COM} \Rightarrow \mu mg = ma_{COM} \Rightarrow a_{COM} = \mu g \quad \dots(i)$$



With respect to COM,

$$\tau_{\text{COM}} = I_{\text{COM}} \alpha$$

$$\Rightarrow (\mu mg)R = \left(\frac{2}{5}mR^2\right)\alpha \Rightarrow \alpha R = \frac{5\mu g}{2} \quad \dots(\text{ii})$$

\therefore Linear velocity (v) and angular velocity (ω), t seconds later are,

$$v = u + a_{\text{COM}} t = v_0 - \mu g t \quad \dots(\text{iii})$$

$$\omega = \omega_0 + \alpha t$$

$$= \frac{5\mu g}{2R} t \quad (\because \omega_0 = 0) \quad \dots(\text{iv})$$

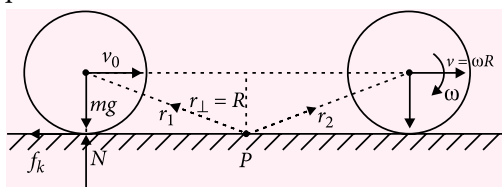
When pure rolling starts,

$$v = \omega R$$

$$\Rightarrow v_0 - \mu g t = \frac{5}{2} \mu g t \Rightarrow v_0 = \frac{7}{2} \mu g t \Rightarrow t = \frac{2}{7} \frac{v_0}{\mu g}$$

$$\therefore v = v_0 - \mu g t = v_0 - \frac{2}{7} v_0 = \frac{5}{7} v_0$$

Alternatively, let me show you a smart way to solve this question.



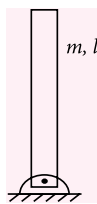
About the point P on ground, arbitrarily chosen, there is no external torque, hence angular momentum remains conserved.

$$L_P \text{ initially} = L_P \text{ finally}$$

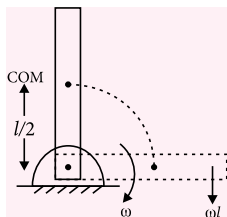
$$\Rightarrow mv_0 r = mvr + I_{\text{COM}} \omega$$

$$= mvr + \frac{2}{5}mR^2 \omega = mvr + \frac{2}{5}mvr \Rightarrow v = \frac{5}{7} v_0$$

Q3: The rod is hinged at one end and released by disturbing it from its unstable equilibrium position. Find the speed of the free end when the rod become horizontal.



Soln.: The only forces acting on the rod are normal force exerted at the hinge and weight. The point of application of normal force is always at instantaneous rest hence it cannot perform any net non zero work. Hence only gravity is performing work.

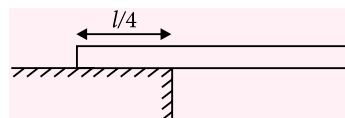


$$\therefore PE_{\text{loss}} = KE_{\text{gain}}$$

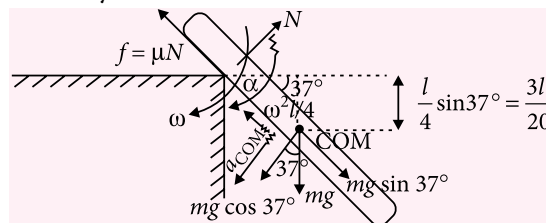
$$\Rightarrow mg \frac{l}{2} = \frac{1}{2} \frac{ml^2}{3} \omega^2 \quad \{\because \text{it is a case of pure rotation, so only rotational KE about AOR}\}$$

$$\Rightarrow \omega l = \sqrt{3gl} = \text{velocity of free end.}$$

Q4: On releasing the rod of mass m and length l from the position shown, it is found that rod rotated about the extreme edge of the table and started slipping after turning through an angle of 37° . Find the friction coefficient between table and rod.



Soln.: Again till slipping does not start, friction cannot perform any net work.



$$mg \frac{3l}{20} = \frac{1}{2} \left(\frac{ml^2}{12} + m \left(\frac{l}{4} \right)^2 \right) \omega^2$$

$$\Rightarrow \frac{3gl}{10} = \frac{7}{48} \omega^2 l^2 \Rightarrow \omega^2 l = \frac{72}{35} g \quad \dots(\text{i})$$

For rotational motion, about the point of contact

$$\tau = I \alpha$$

$$\Rightarrow (mg \cos 37^\circ) \frac{l}{4} = \left(\frac{ml^2}{12} + m \left(\frac{l}{4} \right)^2 \right) \alpha$$

$$\Rightarrow mg \frac{l}{5} = \frac{7ml^2}{48} \alpha \Rightarrow \alpha l = \frac{48g}{35} \quad \dots(\text{ii})$$

Along the normal,

$$mg \cos 37^\circ - N = ma_{\text{COM}} = m \frac{\alpha l}{4}$$

$$\Rightarrow \frac{4}{5} mg - N = \frac{m}{4} \cdot \frac{48g}{35} = \frac{12mg}{35}$$

$$\Rightarrow N = \left(\frac{4}{5} - \frac{12}{35} \right) mg = \frac{16}{35} mg \quad \dots(\text{iii})$$

Along the length of rod,

$$mg \sin 37^\circ - f_k = m \omega^2 \frac{l}{4}$$

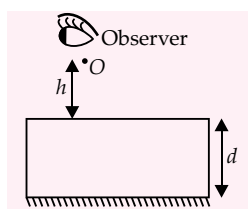
$$\Rightarrow mg \frac{3}{5} - \mu \frac{16mg}{35} = \frac{m}{4} \cdot \frac{72g}{35} \Rightarrow \frac{16}{35} \mu = \frac{3}{5} - \frac{18}{35} = \frac{3}{35}$$

$$\Rightarrow \mu = \frac{3}{16}$$

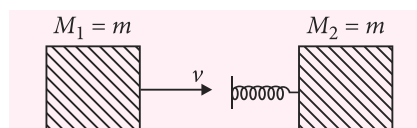
PRACTICE PAPER 2016 JEE MAIN

Exam Dates
OFFLINE : 3rd April
ONLINE : 9th & 10th April

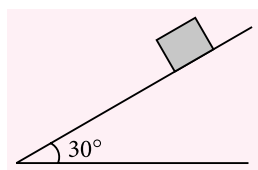
1. A spaceship is launched into a circular orbit close to earth's surface. The additional velocity that should be imparted to the spaceship in the orbit to overcome the gravitational pull is
(Radius of earth = 6400 km and $g = 9.8 \text{ m s}^{-2}$)
(a) 11.2 km s^{-1} (b) 8 km s^{-1}
(c) 3.2 km s^{-1} (d) 1.5 km s^{-1}
2. A hole is drilled in a copper sheet. The diameter of the hole is 4.24 cm at 27.0°C . What is the change in the diameter of the hole when the sheet is heated to 227°C ? Coefficient of linear expansion of copper is $1.70 \times 10^{-5} \text{ }^\circ\text{C}^{-1}$.
(a) $1.44 \times 10^{-2} \text{ cm}$ (b) $2.44 \times 10^{-3} \text{ cm}$
(c) $1.44 \times 10^{-2} \text{ mm}$ (d) $2.44 \times 10^{-3} \text{ mm}$
3. The number density of free electrons in a copper conductor estimated is $8.5 \times 10^{28} \text{ m}^{-3}$. How long does an electron take to drift from one end of a wire 3.0 m long to its other end? The area of cross-section of the wire is $2.0 \times 10^{-6} \text{ m}^2$ and it is carrying a current of 3.0 A.
(a) 6 h 23 min (b) 7 h 33 min
(c) 7 h 43 min (d) 6 h 53 min
4. A point luminous object (O) is at a distance h from front face of a glass slab of width d and of refractive index μ . On the back face of slab is a reflecting plane mirror. An observer sees the image of object in mirror [figure]. Distance of image from front face as seen by observer will be



- (a) $h + \frac{2d}{\mu}$ (b) $2h + 2d$
(c) $h + d$ (d) $h + \frac{d}{\mu}$
5. Two particles A and B having charges $8 \times 10^{-6} \text{ C}$ and $-2 \times 10^{-6} \text{ C}$ respectively, are held fixed with a separation 20 cm. Where should a third charged particle be placed so that it does not experience a net electric force?
(a) 0.2 m from B (b) 0.5 m from A
(c) 0.6 m from A (d) 0.1 m from B
6. Two blocks M_1 and M_2 having equal mass are to move on a horizontal frictionless surface. M_2 is attached to a massless spring as shown in figure. Initially M_2 is at rest and M_1 is moving toward M_2 with speed v and collides head-on with M_2 .



- (a) While spring is fully compressed, all the kinetic energy of M_1 is stored as potential energy of spring.
(b) While spring is fully compressed the system momentum is not conserved, though final momentum is equal to initial momentum.
(c) If spring is massless, the final state of the M_2 is state of rest.
(d) If the surface on which blocks are moving has friction, then collision cannot be elastic.
7. A block of mass $m = 2 \text{ kg}$ is resting on a rough inclined plane of inclination 30° as shown in figure. The coefficient of friction between the block and the plane $\mu = 0.5$. What minimum force F should be applied perpendicular to the plane on the block, so that block does not slip on the plane? ($g = 10 \text{ m s}^{-2}$)



- (a) 2.68 N (b) Zero
(c) 4.34 N (d) 6.24 N

8. The density of a solid ball is to be determined in an experiment. The diameter of the ball is measured with a screw gauge, whose pitch is 0.5 mm and there are 50 divisions on the circular scale. The reading on the main scale is 2.5 mm and that on the circular scale is 20 divisions. If the measured mass of the ball has a relative error of 2%, the relative percentage error in the density is

- (a) 0.9% (b) 2.4%
(c) 3.1% (d) 4.2%

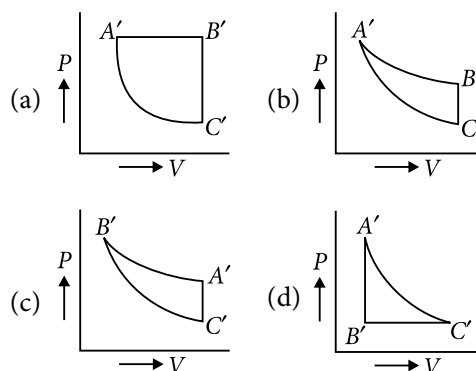
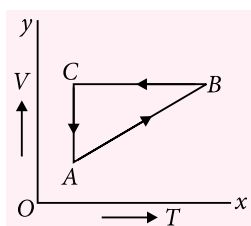
9. A carpet of mass M , made of an extensible material is rolled along its length in the form of a cylinder of radius R and kept on a rough floor. If the carpet is unrolled, without sliding to a radius $R/2$, the decrease in potential energy is

- (a) $\frac{1}{2}MgR$ (b) $\frac{7}{8}MgR$
(c) $\frac{5}{8}MgR$ (d) $\frac{3}{4}MgR$

10. A liquid of density ρ_0 is filled in a wide tank to a height h . A solid rod of length L , cross-section A and density ρ is suspended freely in the tank. The lower end of the rod touches the base of the tank and $h = L/n$ (where $n > 1$). Then the angle of inclination θ of the rod with the horizontal in equilibrium position is

- (a) $\sin^{-1}\left(\sqrt{\frac{\rho_0}{\rho}}\right)$ (b) $\sin^{-1}\left(n\sqrt{\frac{\rho_0}{\rho}}\right)$
(c) $\sin^{-1}\left(\frac{1}{n}\sqrt{\frac{\rho_0}{\rho}}\right)$ (d) $\sin^{-1}\left(\frac{1}{n}\sqrt{\frac{\rho}{\rho_0}}\right)$

11. A cyclic process $ABCA$ shown in V - T diagram, is performed with a constant mass of an ideal gas. Which of the following graphs in figure represents the corresponding process on a P - V diagram?



12. In a metre bridge experiment null point is obtained at 20 cm from one end of the wire when resistance X is balanced against another resistance Y . If $X < Y$, then where will be new position of the null point from the same end, if one decides to balance a resistance of $4X$ against Y ?

- (a) 50 cm (b) 80 cm (c) 40 cm (d) 70 cm

13. When a metal surface is illuminated with light of wavelength λ , the stopping potential is V_0 . When the same surface is illuminated with light of wavelength 2λ , the stopping potential is $\frac{V_0}{4}$. If the velocity of light in air is c , the threshold frequency of photoelectric emission is

- (a) $\frac{c}{6\lambda}$ (b) $\frac{c}{3\lambda}$ (c) $\frac{2c}{3\lambda}$ (d) $\frac{4c}{3\lambda}$

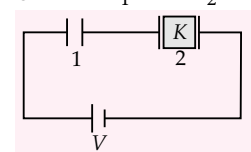
14. Two identical capacitors 1 and 2 are connected in series to a battery as shown in figure. Capacitor 2 contains a dielectric slab of dielectric constant K as shown. Q_1 and Q_2 are the charges stored in the capacitors. Now the dielectric slab is removed and the corresponding charges are Q'_1 and Q'_2 . Then

(a) $\frac{Q'_1}{Q_1} = \frac{K+1}{K}$

(b) $\frac{Q'_2}{Q_2} = \frac{K+1}{2}$

(c) $\frac{Q'_2}{Q_2} = \frac{K+1}{2K}$

(d) $\frac{Q'_1}{Q_1} = \frac{K}{2}$



15. Two pendulums differ in lengths by 22 cm. They oscillate at the same place so that one of them makes 30 oscillations and the other makes 36 oscillations during the same time. The lengths (in cm) of the pendulums are

- (a) 72 and 50 (b) 60 and 38
(c) 50 and 28 (d) 80 and 58

16. An inductance coil is connected to an ac source through a $60\ \Omega$ resistance in series. The source voltage, voltage across the coil and voltage across the resistance are found to be 33 V, 27 V and 12 V respectively. Therefore, the resistance of the coil is
(a) $30\ \Omega$ (b) $45\ \Omega$ (c) $105\ \Omega$ (d) $75\ \Omega$

17. A galvanometer of $50\ \Omega$ resistance has 25 divisions. A current of 4×10^{-4} A gives a deflection of one division. To convert this galvanometer into a voltmeter having a range of 25 V, it should be connected with a resistance of
(a) $2500\ \Omega$ as a shunt (b) $2450\ \Omega$ as a shunt
(c) $2550\ \Omega$ in series (d) $2450\ \Omega$ in series

18. A boy of mass 30 kg starts running from rest along a circular path of radius 6 m with constant tangential acceleration of magnitude 2 m s^{-2} . After 2 s from start he feels that his shoes started slipping on ground. The friction between his shoes and ground is (Take $g = 10\text{ m s}^{-2}$)

(a) $\frac{1}{2}$ (b) $\frac{1}{3}$ (c) $\frac{1}{4}$ (d) $\frac{1}{5}$

19. Two short bar magnets of magnetic moment M each are arranged at the opposite corners of a square of side d such that their centres coincide with the corners and their axes are parallel. If the like poles are in the same direction, the magnitude of the magnetic induction at any of the other corners of the square is

(a) $\frac{\mu_0 M}{4\pi d^3}$ (b) $\frac{\mu_0 2M}{4\pi d^3}$
(c) $\frac{\mu_0 M}{4\pi 2d^3}$ (d) $\frac{\mu_0 M^3}{4\pi 2d^3}$

20. A long glass tube is held vertically in water. A tuning fork is struck and held over the tube. Strong resonances are observed at two successive lengths 0.50 m and 0.84 m above the surface of water. If velocity of sound is 340 m s^{-1} , then the frequency of the tuning fork is
(a) 128 Hz (b) 256 Hz
(c) 384 Hz (d) 500 Hz

21. A particle executes SHM with an amplitude of 2 cm. When the particle is at 1 cm from the mean position, the magnitude of its velocity is equal to that of its acceleration. Then its time period in seconds is

(a) $\frac{1}{2\pi\sqrt{3}}$ (b) $2\pi\sqrt{3}$

(c) $\frac{2\pi}{\sqrt{3}}$ (d) $\frac{\sqrt{3}}{2\pi}$

22. A body of mass m thrown horizontally with velocity v , from the top of tower of height h touches the level ground at distance of 250 m from the foot of the tower. A body of mass $2m$ thrown horizontally with velocity $\frac{v}{2}$, from the top of tower of height $4h$

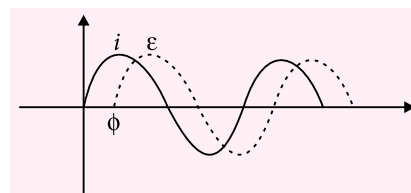
will touch the level ground at a distance x from the foot of tower. The value of x is

(a) 250 m (b) 500 m
(c) 125 m (d) $250\sqrt{2}$ m

23. The Poisson's ratio of a material is 0.4. If a force is applied to a wire of this material, there is a decrease of cross-sectional area by 2%. The percentage increase in its length is

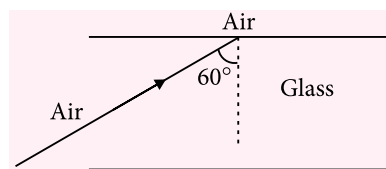
(a) 3% (b) 2.5%
(c) 1% (d) 0.5%

24. When an AC source of emf $\varepsilon = \varepsilon_0 \sin(100t)$ is connected across a circuit, the phase difference between emf (ε) and current (i) in the circuit is observed to be $\frac{\pi}{4}$, as shown in figure. If the circuit consist possibly only of RC or RL in series, find the relationship between the two elements.



(a) $R = 1\text{ k}\Omega$, $C = 5\ \mu\text{F}$ (b) $R = 1\text{ k}\Omega$, $C = 10\ \mu\text{F}$
(c) $R = 1\text{ k}\Omega$, $C = 1\text{ H}$ (d) $R = 1\text{ k}\Omega$, $L = 10\text{ H}$

25. A light ray from air is incident as shown in figure at one end of the glass fibre making an incidence angle of 60° on the lateral surface, so that it just undergoes a total internal reflection. How much time (in μs) would it take to traverse the straight fibre of length 1 km?



(a) 3.85 (b) 4.25 (c) 2.90 (d) 7.30

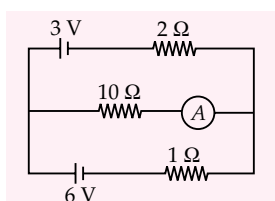
26. If a zener diode ($V_Z = 5 \text{ V}$ and $I_Z = 10 \text{ mA}$) is connected in series with a resistance and 20 V is applied across the combination, then the maximum resistance one can use without spoiling zener action is

(a) $20 \text{ k}\Omega$ (b) $15 \text{ k}\Omega$
(c) $10 \text{ k}\Omega$ (d) $1.5 \text{ k}\Omega$

27. An electromagnetic wave travels along z -axis. Which of the following pairs of space and time varying fields would generate such a wave?

(a) E_x, B_y (b) E_z, B_x
(c) E_y, B_z (d) E_y, B_x

28. In the circuit as shown in figure, the current in ammeter is



(a) $\frac{42}{32} \text{ A}$ (b) $\frac{27}{32} \text{ A}$ (c) $\frac{15}{32} \text{ A}$ (d) $\frac{32}{15} \text{ A}$

29. In Young's double slit experiment, one of the slits is wider than the other, so that the amplitude of the light from one slit is double than that from the other slit. If I_m be the maximum intensity, the resultant intensity when they interfere at a phase difference ϕ is given by

(a) $\frac{I_m}{3} \left(1 + 2 \cos^2 \frac{\phi}{2} \right)$ (b) $\frac{I_m}{5} \left(1 + 4 \cos^2 \frac{\phi}{2} \right)$
(c) $\frac{I_m}{9} \left(1 + 8 \cos^2 \frac{\phi}{2} \right)$ (d) $\frac{I_m}{9} \left(8 + \cos^2 \frac{\phi}{2} \right)$

30. What is the minimum thickness of a thin film required for constructive interference in the reflected light from it? Given, the refractive index of the film = 1.5, wavelength of the light incident on the film = 600 nm.

(a) 100 nm (b) 300 nm (c) 50 nm (d) 200 nm

SOLUTIONS

1. (c): For spaceship orbiting close to earth's surface

$$\frac{mv_o^2}{R} = \frac{GMm}{R^2}$$

$$\text{i.e., } v_o = \sqrt{\frac{GM}{R}} = \sqrt{gR}$$

$$\therefore v_o = \sqrt{(9.8 \times 6.4 \times 10^6)} \cong 8 \text{ km s}^{-1}$$

For escaping from closed to the surface of earth,

$$\frac{GMm}{R} = \frac{1}{2}mv_e^2$$

$$v_e = \sqrt{\frac{2GM}{R}} = \sqrt{2gR}$$

$$\Rightarrow v_e = \sqrt{2} \times v_o = 1.41 \times 8 = 11.2 \text{ km s}^{-1}$$

\therefore The additional velocity to be imparted to the orbiting satellite for escaping is $11.2 - 8 = 3.2 \text{ km s}^{-1}$

2. (a): Given, diameter of the hole, $d_1 = 4.24 \text{ cm}$

Initial temperature, $T_1 = 27 + 273 = 300 \text{ K}$

Final temperature, $T_2 = 227 + 273 = 500 \text{ K}$

Coefficient of linear expansion, $\alpha = 1.70 \times 10^{-5} \text{ } ^\circ\text{C}^{-1}$

Coefficient of superficial expansion, $\beta = 2\alpha$
 $= 3.40 \times 10^{-5} \text{ } ^\circ\text{C}^{-1}$

$$\text{Area of hole at } 27^\circ\text{C}, A_1 = \pi r^2 = \frac{\pi d_1^2}{4}$$

$$= \frac{\pi}{4} (4.24)^2 = 4.494\pi \text{ cm}^2$$

$$\text{Area of hole at } 227^\circ\text{C}, A_2 = A_1(1 + \beta \cdot \Delta T)$$

$$= 4.494\pi [1 + 3.40 \times 10^{-5} \times (227 - 27)]$$

$$= 4.494\pi [1 + 3.40 \times 10^{-5} \times 200]$$

$$= 4.494\pi \times 1.0068$$

$$= 4.525\pi \text{ cm}^2$$

If diameter of hole becomes d_2 at 227°C , then

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

$$4.525\pi = \frac{\pi d_2^2}{4}$$

$$\text{or } d_2^2 = 4.525 \times 4 \text{ or } d_2 = 4.2544 \text{ cm}$$

$$\therefore \text{Change in diameter, } \Delta d = d_2 - d_1$$

$$= 4.2544 - 4.24 = 0.0144 \text{ cm} = 1.44 \times 10^{-2} \text{ cm}$$

3. (b): Given,

Number density of electrons, $n = 8.5 \times 10^{28} \text{ m}^{-3}$

Length of wire, $l = 3 \text{ m}$

Area of cross-section of wire, $A = 2 \times 10^{-6} \text{ m}^2$

Current $I = 3 \text{ A}$

Charge on electron, $e = 1.6 \times 10^{-19} \text{ C}$

Time taken by electron to drift from one end to another of the wire,

$$t = \frac{\text{Length of the wire}}{\text{Drift velocity}} = \frac{l}{v_d} \quad \dots(i)$$

Using the relation,

$$I = neAv_d$$

$$\text{or } v_d = \frac{I}{neA} \quad \dots(ii)$$

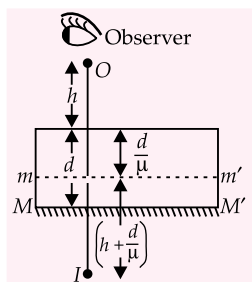
Putting the value from eq. (ii) in eq. (i),

$$t = \frac{I n e A}{I} = \frac{3 \times 8.5 \times 10^{28} \times 1.6 \times 10^{-19} \times 2 \times 10^{-6}}{3}$$

$$\text{or } t = 2.72 \times 10^4 \text{ s} = 7 \text{ h } 33 \text{ min}$$

Thus, the time taken by an electron to drift from one end to another end is 7 h 33 min.

4. (a): As shown in figure glass slab will form the image of bottom i.e., mirror MM' at a depth $\left(\frac{d}{\mu}\right)$ from its front face. So the distance of object O from virtual mirror



mm' will be $\left(h + \frac{d}{\mu}\right)$.

Now as a plane mirror forms image behind the mirror at the same distance as the object is in front of it, the distance of image I from mm' will be $\left(h + \frac{d}{\mu}\right)$ and as the distance of virtual mirror from

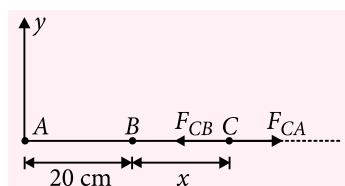
the front face of slab is $\left(\frac{d}{\mu}\right)$, the distance of image I from front face as seen by observer will be

$$= \left[h + \frac{d}{\mu}\right] + \frac{d}{\mu} = h + \frac{2d}{\mu}$$

5. (a): The net electric force on C should be equal to zero, the force due to A and B must be opposite in direction. Hence, the particle should be placed on the line AB . As, A and B have charges of opposite nature, also A has larger magnitude of charge than B . Hence, C should be placed closer to B than A . From figure $BC = x$ (say) and charge on C is Q .

$$\text{Then, } \vec{F}_{CA} = \frac{1}{4\pi\epsilon_0} \cdot \frac{(8 \times 10^{-6})Q}{(0.2 + x)^2} \hat{i}$$

$$\text{and } \vec{F}_{CB} = \frac{-1}{4\pi\epsilon_0} \cdot \frac{(2 \times 10^{-6})Q}{x^2} \hat{i}$$



$$\therefore \vec{F}_C = \vec{F}_{CA} + \vec{F}_{CB} = \frac{1}{4\pi\epsilon_0} \left[\frac{(8 \times 10^{-6})Q}{(0.2 + x)^2} - \frac{(2 \times 10^{-6})Q}{x^2} \right] \hat{i}$$

$$\text{But } |\vec{F}_C| = 0$$

$$\text{Then } \frac{1}{4\pi\epsilon_0} \left[\frac{(8 \times 10^{-6})Q}{(0.2 + x)^2} - \frac{(2 \times 10^{-6})Q}{x^2} \right] = 0$$

which gives, $x = 0.2 \text{ m}$

6. (d): While spring is fully compressed, the entire kinetic energy of M_1 is not stored as potential energy of spring as M_2 may move. If spring is massless, also $M_1 = M_2$, velocities of M_1 and M_2 are interchanged on collision. M_1 comes to rest, instead of M_2 . If surface on which blocks are moving has friction, loss of energy is involved. Collision cannot be elastic. Choice (d) is correct.

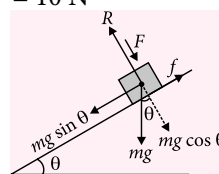
7. (a): $mg \sin \theta = 2 \times 10 \sin 30^\circ = 10 \text{ N}$

$$\text{and } f = \mu R = \mu mg \cos \theta$$

$$= 0.5 \times 2 \times 10 \cos 30^\circ$$

$$= 10 \times 0.866 = 8.66 \text{ N}$$

As $mg \sin \theta > f$, the block tends to slip down the plane.



On applying F perpendicular to plane,

$$R = F + mg \cos 30^\circ$$

To avoid slipping,

$$mg \sin 30^\circ = \mu R = \mu(F + mg \cos 30^\circ)$$

$$\therefore F = \frac{2 \times 10 \times 1/2}{0.5} - 2 \times 10 \frac{\sqrt{3}}{2}$$

$$F = 20 - 17.32$$

$$= 2.68 \text{ N}$$

8. (c): Least count of screw gauge

$$= \frac{\text{pitch}}{\text{no. of division on circular scale}}$$

$$= \frac{0.5 \text{ mm}}{50} = 0.01 \text{ mm.}$$

$$\text{Diameter of ball, } D = \text{MSR} + \text{CSR} \times \text{LC}$$

$$= 2.5 \text{ mm} + 20 \times 0.01 \text{ mm} = 2.7 \text{ mm}$$

$$\text{As density, } \rho = \frac{\text{mass}}{\text{volume}} = \frac{M}{\frac{4\pi}{3} \left(\frac{D}{2}\right)^3}$$

Relative error in the density,

$$\frac{\Delta \rho}{\rho} = \frac{\Delta M}{M} + \frac{3 \Delta D}{D}$$

Relative percentage error in the density is

$$\begin{aligned}\frac{\Delta \rho}{\rho} \times 100 &= \left(\frac{\Delta M}{M} + \frac{3\Delta D}{D} \right) \times 100 \\ &= \frac{\Delta M}{M} \times 100 + \frac{3\Delta D}{D} \times 100 = 2 + 3 \times \frac{0.01}{2.7} \times 100 \\ &= 2\% + 1.11\% = 3.1\%\end{aligned}$$

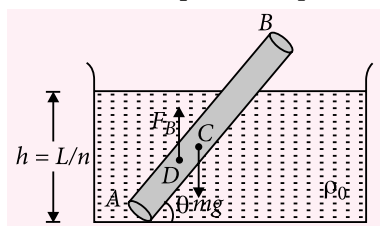
9. (b): The centre of mass of the whole carpet is originally at a height R above the floor. When the carpet unrolls itself and has a radius $R/2$, the centre of mass is at a height $R/2$. The mass left over unrolled is

$$\frac{M\pi(R/2)^2}{\pi R^2} = \frac{M}{4}$$

\therefore The decrease in potential energy

$$= MgR - \left(\frac{M}{4} \right) g \left(\frac{R}{2} \right) = \frac{7}{8} MgR$$

10. (c): Refer to figure, let l be the length of rod immersed in liquid. θ be the angle of inclination of rod with horizontal in equilibrium position.



The weight of rod $= mg = AL\rho g$ acting vertically downwards at the centre of gravity C of the rod.

The upward thrust on rod, $F_B = Al\rho_0 g$ acting vertically upwards at the centre of buoyancy D ; which is the mid point of length of rod inside the liquid.

As the rod is in equilibrium position, then net torque on the rod about point A is zero, i.e.,

$$(AL\rho g) \frac{L}{2} \cos \theta - (Al\rho_0 g) \frac{l}{2} \cos \theta = 0$$

$$\text{or } \frac{L^2}{l^2} = \frac{\rho_0}{\rho} \quad \text{or } \frac{L}{l} = \sqrt{\frac{\rho_0}{\rho}}$$

$$\text{Now, } \sin \theta = \frac{h}{l} = \frac{L/n}{l} = \frac{1}{n} \frac{L}{l} = \frac{1}{n} \sqrt{\frac{\rho_0}{\rho}}$$

$$\text{or } \theta = \sin^{-1} \left[\frac{1}{n} \sqrt{\frac{\rho_0}{\rho}} \right]$$

11. (a): From A to B , $V \propto T$ or $\frac{V}{T} = \text{constant}$

$$\text{As } \frac{PV}{T} = R = \text{constant}$$

$\therefore P$ is constant ($A'B'$ is a straight line \parallel to volume axis).
From B to C , volume V is constant ($B'C'$ is a straight line \parallel to pressure-axis).

From C to A , temperature T is constant.

$\therefore PV = \text{constant}$ (Boyle's law)

So, $C'A'$ is a curve such that $P \propto \frac{1}{V}$.

Hence, correct representation is in figure (a).

$$12. (a): \text{In the first case, } \frac{X}{Y} = \frac{20}{(100-20)} = \frac{20}{80} = \frac{1}{4}$$

$$\text{or } Y = 4X \quad \dots (i)$$

$$\text{In the second case, } \frac{4X}{Y} = \frac{l}{100-l}$$

$$\text{or } \frac{4X}{4X} = \frac{l}{100-l} \quad (\text{Using (i)})$$

$$\text{or } l = 50 \text{ cm}$$

13. (b): According to Einstein's photoelectric equation

$$h\nu = K_{\max} + \phi_0$$

$$\frac{hc}{\lambda} = eV_s + \phi_0$$

where, λ = wavelength of incident light

ϕ_0 = work function

V_s = stopping potential

According to given problem

$$\frac{hc}{\lambda} = eV_0 + \phi_0 \quad \dots (i)$$

$$\frac{hc}{2\lambda} = \frac{eV_0}{4} + \phi_0 \quad \dots (ii)$$

Subtract (ii) from (i), we get

$$\frac{hc}{\lambda} \left(1 - \frac{1}{2} \right) = eV_0 \left(1 - \frac{1}{4} \right)$$

$$\frac{hc}{2\lambda} = \frac{3}{4} eV_0 \quad \text{or} \quad eV_0 = \frac{2}{3} \frac{hc}{\lambda}$$

Substituting the value of eV_0 in eq. (i), we get

$$\frac{hc}{\lambda} = \frac{2}{3} \frac{hc}{\lambda} + \phi_0 \quad \text{or} \quad \phi_0 = \frac{hc}{3\lambda}$$

\therefore Threshold frequency

$$\nu_0 = \frac{\phi_0}{h} = \frac{hc}{3\lambda h} = \frac{c}{3\lambda}$$

14. (c): Let C be the capacitance of capacitor without slab.

Before the slab is removed

$$C_1 = C \text{ and } C_2 = KC$$

$$\therefore C_{\text{net}} = \frac{C_1 C_2}{C_1 + C_2} = \frac{(C)(KC)}{C + KC} = \left(\frac{K}{K+1} \right) C$$

$$\therefore Q_1 = Q_2 = \frac{KCV}{K+1}$$

After the slab is removed, $C_1 = C$ and $C_2 = C$

$$\therefore C_{\text{net}} = \frac{(C)(C)}{C+C} = \frac{C}{2} \quad \therefore Q'_1 = Q'_2 = \frac{CV}{2}$$

$$\text{Hence, } \frac{Q'_1}{Q_1} = \frac{Q'_2}{Q_2} = \frac{K+1}{2K}$$

15. (a): Time period of a pendulum is

$$T = 2\pi\sqrt{\frac{l}{g}} \quad \therefore \frac{T_1}{T_2} = \sqrt{\frac{l_1}{l_2}}$$

$$\text{Also, } \frac{T_1}{T_2} = \frac{N_2}{N_1} \text{ where } N_1 = 30 \text{ and } N_2 = 36$$

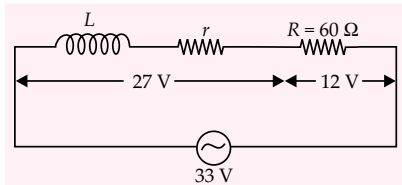
$$\therefore \sqrt{\frac{l_1}{l_2}} = \frac{N_2}{N_1} = \frac{36}{30}$$

$$\text{Also, } l_1 - l_2 = 22 \text{ cm}$$

Solving the eqs. (i) and (ii), we get

$$l_1 = 72 \text{ cm and } l_2 = 50 \text{ cm}$$

16. (b):



Let r be resistance of the coil.

$$\text{Current in the circuit, } I = \frac{12 \text{ V}}{60 \Omega} = 0.2 \text{ A}$$

According to voltage formula

$$27^2 = V_L^2 + V_r^2$$

$$33^2 = V_L^2 + (V_R + V_r)^2$$

Subtract (i) from (ii), we get

$$33^2 - 27^2 = V_R^2 + V_r^2 + 2V_R V_r - V_r^2$$

$$33^2 - 27^2 = 12^2 + 2 \times 12 \times V_r$$

$$V_r = \frac{33^2 - 27^2 - 12^2}{(2 \times 12)} = 9 \text{ V}$$

$$V_r = Ir \Rightarrow r = \frac{V_r}{I} = \frac{9 \text{ V}}{0.2 \text{ A}} = 45 \Omega$$

17. (d): $G = 50 \Omega$

I_g = Current for full scale deflection

= Current per division \times total no. of divisions

$$= 4 \times 10^{-4} \times 25 = 10^{-2} \text{ A}$$

Given $V = 25 \text{ V}$

Hence, required resistance,

$$R = \frac{V}{I_g} - G = \frac{25}{10^{-2}} - 50 = 2500 - 50 = 2450 \Omega$$

This resistance of 2450Ω should be connected in series to convert the galvanometer into a voltmeter.

18. (b): After 2 s, speed of boy will be

$$v = 2 \times 2 = 4 \text{ m s}^{-1}$$

At this moment, centripetal force on the boy is

$$F_c = \frac{mv^2}{R} = \frac{30 \times 16}{6} \text{ N} = 80 \text{ N}$$

Tangential force on the boy is

$$F_t = ma = 30 \times 2 \text{ N} = 60 \text{ N}$$

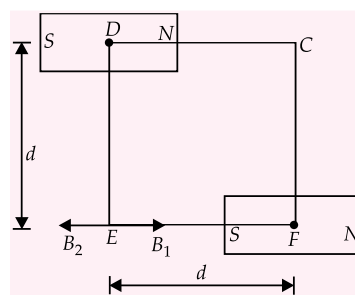
Total force acting on boy is

$$F = \sqrt{F_c^2 + F_t^2} = \sqrt{(80)^2 + (60)^2} = 100 \text{ N}$$

At the time of slipping, $F = \mu mg$

$$\text{or } 100 = \mu \times 30 \times 10 \text{ or } \mu = \frac{1}{3}$$

19. (a):



Magnetic induction at point E due to magnet at F

$$(\text{axial point}) \text{ is } B_1 = \frac{\mu_0}{4\pi} \frac{2M}{d^3}$$

It acts along EF.

Magnetic induction at point E due to magnet at D

$$(\text{equatorial point}) \text{ is } B_2 = \frac{\mu_0}{4\pi} \frac{M}{d^3}$$

It acts along FE.

Resultant magnetic induction (magnitude) at point E is

$$B = B_1 - B_2 = \frac{\mu_0 M}{4\pi d^3}$$

20. (d): From $v = 2v(l_2 - l_1)$

$$v = \frac{v}{2(l_2 - l_1)} = \frac{340}{2(0.84 - 0.50)} = \frac{340}{2 \times 0.34} = 500 \text{ Hz}$$

21. (c): Here, $A = 2 \text{ cm}$

Magnitude of velocity from mean position

$$= \omega \sqrt{A^2 - x^2}$$

and acceleration $= \omega^2 x$.

$$\text{Now, } \omega^2 x = \omega \sqrt{A^2 - x^2} \quad \text{or, } \omega^2 \cdot 1 = \omega \sqrt{4 - 1}$$

$$\text{or, } \omega = \sqrt{3}.$$

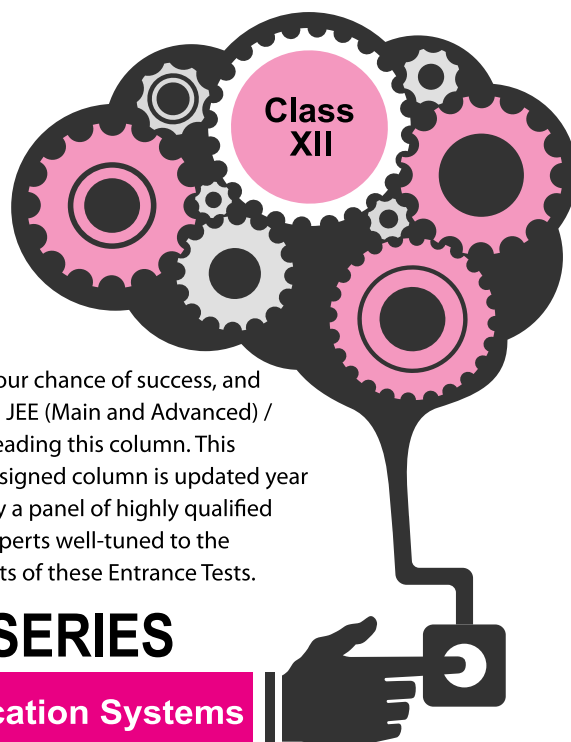
$$\text{As } \omega = \frac{2\pi}{T} \quad \text{or } T = \frac{2\pi}{\omega} = \frac{2\pi}{\sqrt{3}} \text{ s.}$$

Contd. on page no. 71

JEE

ACCELERATED LEARNING SERIES

Unit 9 Electronic Devices | Communication Systems



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ELECTRONIC DEVICES

Classification of Solids

Solids can be classified on the basis of conductivity and energy bands.

Classification on the basis of conductivity

On the basis of conductivity, solids can be classified in three categories.

- **Metals:** Solids having very high electric conductivity are known as metals. Their electric conductivity lies between 10^2 S m^{-1} and 10^8 S m^{-1} .
- **Insulators:** Solids having very low electric conductivity are known as insulators. Their conductivity lies between $10^{-11} \text{ S m}^{-1}$ and $10^{-19} \text{ S m}^{-1}$.
- **Semiconductors:** Solids whose conductivity is intermediate to that of metals and insulators are known as semiconductors. Their conductivity lies between 10^5 S m^{-1} and 10^{-6} S m^{-1} .

Classification on the basis of energy bands

Each electron in an atom has definite energy value. These definite energy values are called energy levels.

In solids, atoms are closely packed. A solid crystal contains about 10^{23} atoms/cm³. So each atom is in the electrostatic field of neighbouring atoms. So in solids where atoms are closely spaced, the atomic energy levels of the electrons broaden and give rise to energy bands.

Types of energy bands

Energy bands are of two types :

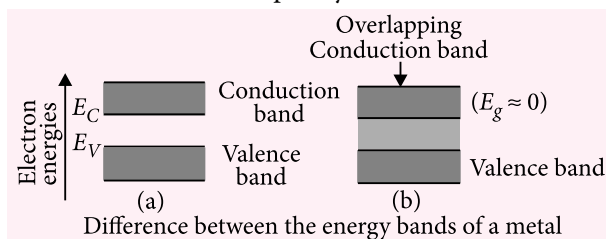
- Valence band
- Conduction band

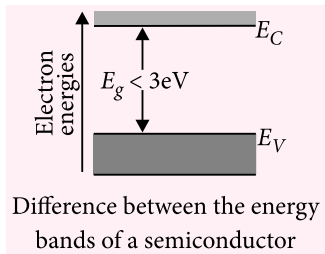
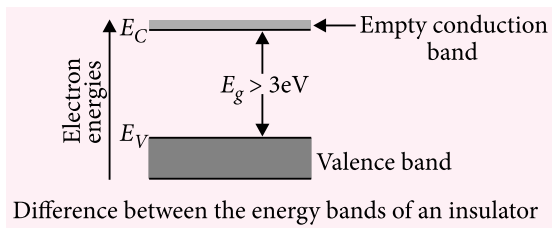
For semiconductors and insulators, the energy bands which consist of closely spaced completely filled energy states at 0 K are called valence bands. The bands with higher energies are called conduction bands.

Forbidden energy gap (E_g) is the energy gap between the top of the highest valence band and bottom of the lowest conduction band.

On the basis of band theory, solids are classified as follows :

- **Metals:** In metals or good conductors, conduction band is either partially filled (figure (a)) or overlaps (figure (b)) the valence band. There is no forbidden energy gap.
- **Semiconductors:** In semiconductors, the two energy bands are distinctly separate without any overlapping.
- **Insulators:** The conduction band is empty and valence band is completely filled.





Intrinsic Semiconductor

A semiconductor in pure form is called intrinsic semiconductor. Germanium (Ge) and silicon (Si) are important examples of intrinsic semiconductors. They are tetravalent elements. They have covalent bonding.

A pure semiconductor has negative temperature co-efficient of resistance. At ordinary temperature some electrons absorb energy from lattices and move to the conduction band. This happens due to breaking of covalent bond because of the effect of thermal energy. Electrons moving to the conduction band leave behind the vacancy of electron, called holes, in the valence band. Hole has positive charge equal to that of electron. Mobility of hole is smaller than that of electron.

The number density (n_e) of electrons in conduction band is equal to the number density (n_h) of holes in the valence band $n_e = n_h = n_i$, where n_i is called the intrinsic carrier concentration.

When electric field is applied across an intrinsic semiconductor, electrons and holes move in opposite directions so that conventional current,

$$I = I_e + I_h,$$

where I_e = free electron current and I_h = hole current.

The deliberate addition of a desirable impurity to intrinsic semiconductor in controlled quantities to promote conductivity is called doping.

Extrinsic Semiconductors

These are obtained by doping the pure semiconductor with small amount of certain impurities of either trivalent or pentavalent atoms.

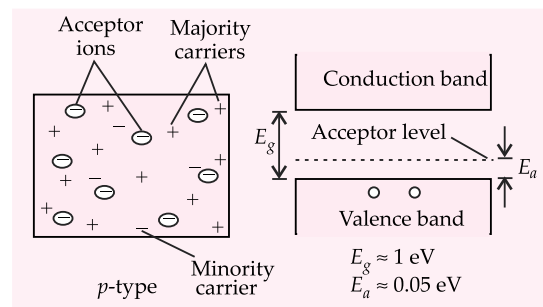
Extrinsic semiconductors are of two types:

- p -type semiconductor
- n -type semiconductor

p -type Semiconductor

When a trivalent impurity like B, Al, Ga or In is added to a pure semiconductor, semiconductor becomes deficient in electrons, *i.e.*, number of holes become more than number of electrons. Such a semiconductor is called p -type semiconductor.

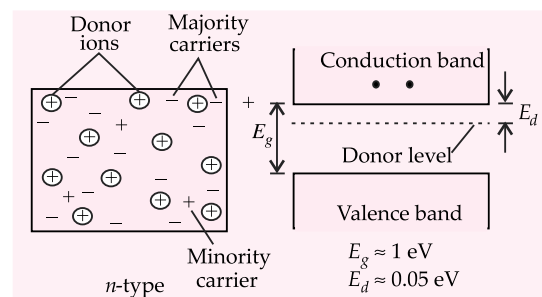
In the p -type semiconductors, holes are majority charge carriers, whereas electrons are minority charge carriers. In p -type semiconductor, the fermi level shifts towards the valence band. The trivalent impurity atoms are called acceptor atoms.



n -type Semiconductor

When a pentavalent impurity, such as P, As, Sb or Bi is added to a pure semiconductor, the number of electrons become more than the holes in the semiconductor and such a semiconductor is called n -type semiconductor.

It has electrons as majority carriers and holes as minority carriers. In n -type semiconductor, the fermi level shifts towards the conduction band. The pentavalent impurity atoms are called donor atoms.



Mass Action Law

In semiconductors due to thermal effect, generation of free electron and hole takes place. Apart from the process of generation, a process of recombination also occurs simultaneously, in which free electron further recombine with hole.

At equilibrium, rate of generation of charge carriers is equal to rate of recombination of charge carriers. The recombination occurs due to electron colliding with a hole, larger value of n_e or n_h , higher is the probability of

their recombination. Hence for a given semiconductor,

$$\text{rate of recombination} \propto n_e \times n_h$$

$$\text{so rate of recombination} = R n_e \times n_h,$$

where R = recombination coefficient

For intrinsic semiconductor, $n_e = n_h = n_i$

$$\text{so rate of recombination} = R n_i^2$$

$$R n_e \times n_h = R n_i^2 \Rightarrow n_i^2 = n_e \times n_h$$

Under thermal equilibrium, the product of the concentration n_e of free electrons and the concentration n_h of holes is a constant. Independent of the amount of doping by acceptor and donor impurities.

$$\text{Mass action law, } n_e \times n_h = n_i^2$$

Conductivity of semiconductor

The conductivity of semiconductor is given by

$$\sigma = e(n_e \mu_e + n_h \mu_h)$$

where μ_e and μ_h are the electron and hole mobilities and e is the electronic charge.

The conductivity of an intrinsic semiconductor is

$$\sigma_i = n_i e (\mu_e + \mu_h)$$

The conductivity of n -type semiconductor is

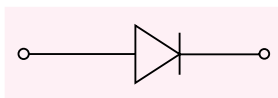
$$\sigma_n = e N_d \mu_e$$

The conductivity of p -type semiconductor is

$$\sigma_p = e N_a \mu_h$$

p - n Junction

When donor impurities are introduced into one side and acceptors into the other side of a single crystal of an intrinsic semiconductor, a p - n junction is formed. It is also known as junction diode. It is symbolically represented by



The most important characteristic of a p - n junction is its ability to conduct current in one direction only. In the other (reverse) direction it offers very high resistance.

The current in the junction diode is given by

$$I = I_0 (e^{eV/kT} - 1)$$

where k = Boltzmann constant, I_0 = reverse saturation current.

In forward biasing, V is positive and low, then forward current,

$$I_f = I_0 (e^{eV/kT} - 1)$$

In reverse biasing, V is negative and high, $e^{eV/kT} < 1$, then reverse current,

$$I_r = -I_0$$

SELF CHECK

- The current voltage relation of diode is given by $I = (e^{1000 V/T} - 1)$ mA, where the applied voltage V is in volts and the temperature T is in degree Kelvin. If a student makes an error measuring ± 0.01 V while measuring the current of 5 mA at 300 K, what will be the error in the value of current in mA?

- (a) 0.05 mA (b) 0.2 mA
(c) 0.02 mA (d) 0.5 mA

(JEE Main 2014)

Depletion Region

In the vicinity of junction, the region containing the uncompensated acceptor and donor ions is known as depletion region. There is a depletion of mobile charges (holes and free electrons) in this region. Since this region has immobile ions which are electrically charged it is also known as the space charge region. The electric field between the acceptor and the donor ions is known as a barrier. For a silicon p - n junction, the barrier potential is about 0.7 V, whereas for a germanium p - n junction it is approximately 0.3 V.

KEY POINT

- The physical distance from one side of the barrier to the other is known as the width of the barrier. The difference of potential from one side of the barrier to the other side is known as the height of the barrier.
- The width of the depletion layer and magnitude of potential barrier depends upon the nature of the material of semiconductor and the concentration of impurity atoms.
- The thickness of the depletion region is of the order of one tenth of a micrometre.

Forward Biasing of a p - n Junction

When the positive terminal of external battery is connected to p -side and negative to n -side of p - n junction, then the p - n junction is said to be forward biased. In forward biasing, the width of the depletion region decreases and barrier height reduces. The resistance of the p - n junction becomes low in forward biasing.

Reverse Biasing of a p - n Junction

When the positive terminal of the external battery is connected to n -side and the negative terminal to p -side of a p - n junction, then the p - n junction is said to be reverse biased. In reverse biasing, the width of the depletion region increases and barrier height increases.

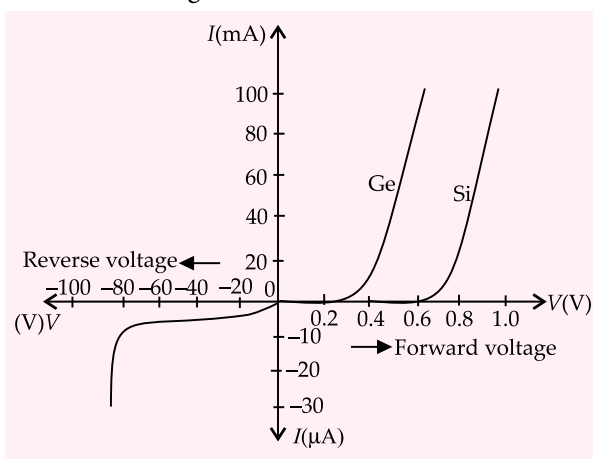
The resistance of the p - n junction becomes high in reverse biasing.

Breakdown Voltage

A very small current flows through p - n junction, when it is reverse biased. The flow of the current is due to the movement of minority charge carriers. The reverse current is almost independent of the applied voltage. However, if the reverse bias voltage is continuously increased, for a certain reverse voltage, the current through the p - n junction will increase abruptly. This reverse bias voltage is thus known as breakdown voltage. There can be two different causes for the breakdown. One is known as Zener breakdown and the other is known as avalanche breakdown.

I - V Characteristics of a p - n Junction

The I - V characteristics of a p - n junction do not obey Ohm's law. The I - V characteristics of a p - n junction are as shown in the figure.



Knee Voltage

In forward biasing, the voltage at which the current starts to increase rapidly is known as cut-in or knee voltage. For germanium it is 0.3 V while for silicon it is 0.7 V.

Dynamic Resistance

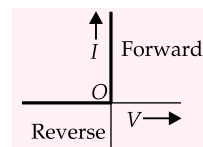
It is defined as the ratio of a small change in voltage ΔV applied across the p - n junction to a small change in current ΔI through the junction.

$$r_d = \frac{\Delta V}{\Delta I}$$

Ideal Diode

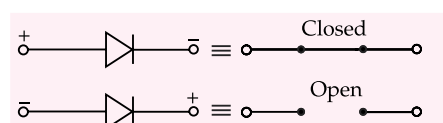
A diode permits only unidirectional conduction. It conducts well in the forward direction and poorly in the reverse direction. It would have been ideal if a diode acts as a perfect conductor (with zero voltage across

it) when it is forward biased, and as a perfect insulator (with no current flow through it) when it is reverse biased. The I - V characteristics of an ideal diode is shown in figure below.



An ideal diode acts like an automatic switch.

In forward bias, it acts as a closed switch whereas in reverse bias it acts as an open switch as shown in the figure below.



SELF CHECK

2. The forward biased diode connection is

- (a) $\frac{-2\text{ V}}{\text{---}} \text{---} \frac{+2\text{ V}}{\text{---}}$ (b) $\frac{+2\text{ V}}{\text{---}} \text{---} \frac{-2\text{ V}}{\text{---}}$
(c) $\frac{-3\text{ V}}{\text{---}} \text{---} \frac{+3\text{ V}}{\text{---}}$ (d) $\frac{2\text{ V}}{\text{---}} \text{---} \frac{4\text{ V}}{\text{---}}$

(JEE Main 2014)

3. A 2 V battery is connected across AB as shown in the figure. The value of the current supplied by the battery when in one case battery's positive terminal is connected to A and in other case when positive terminal of battery is connected to B will respectively be

- (a) 0.2 A and 0.1 A (b) 0.4 A and 0.2 A
(c) 0.1 A and 0.2 A (d) 0.2 A and 0.4 A

(JEE Main 2015)

4. In an unbiased n - p junction electrons diffuse from n -region to p -region because

- (a) holes in p -region attract them
(b) electrons travel across the junction due to potential difference
(c) electron concentration in n -region is more as compared to that in p -region
(d) only electrons move from n to p region and not the vice-versa

(JEE Main 2015)

Rectifier

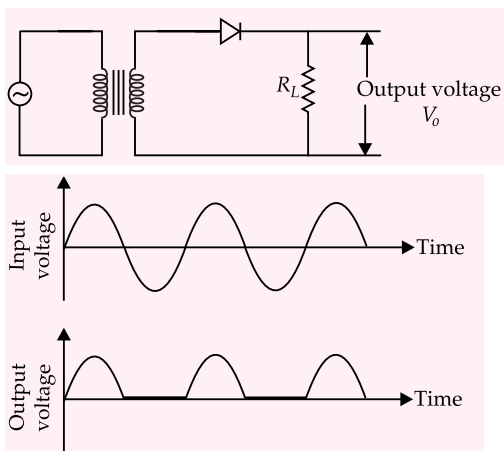
It is a device which converts ac voltage to dc voltage.

Rectifier is based on the fact that, a forward bias $p-n$ junction conducts and a reverse bias $p-n$ junction does not conduct. Rectifiers are of two types

- Half wave rectifier
- Full wave rectifier

Half Wave Rectifier

The circuit diagram, input and output voltage waveforms for a half wave rectifier are as shown in the following figure.



Peak value of current is

$$I_m = \frac{V_m}{r_f + R_L}$$

where r_f is the forward diode resistance, R_L is the load resistance and V_m is the peak value of the alternating voltage.

rms value of current is $I_{rms} = \frac{I_m}{2}$

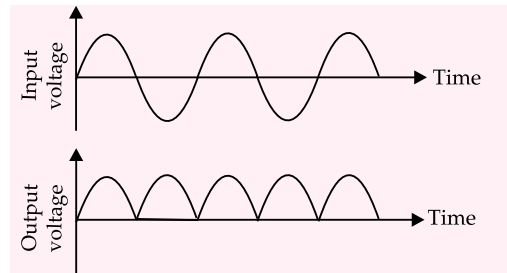
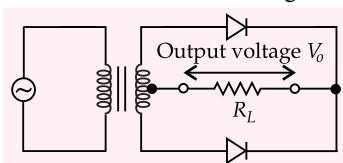
dc value of current is $I_{dc} = \frac{I_m}{\pi}$

Peak inverse voltage is $P.I.V. = V_m$

dc value of voltage is $V_{dc} = I_{dc} R_L = \frac{I_m}{\pi} R_L$

Full Wave Rectifier

The circuit diagram, input and output waveforms for a full wave rectifier are as shown in the figure.



Peak value of current is $I_m = \frac{V_m}{r_f + R_L}$

dc value of current is $I_{dc} = \frac{2I_m}{\pi}$

rms value of current is $I_{rms} = \frac{I_m}{\sqrt{2}}$

Peak inverse voltage is $P.I.V. = 2V_m$

dc value of voltage is $V_{dc} = I_{dc} R_L = \frac{2I_m}{\pi} R_L$

Ripple Frequency

$v_r = v_i = 50 \text{ Hz}$ (half wave rectifier)

$v_r = 2v_i = 100 \text{ Hz}$ (full wave rectifier)

Ripple Factor

The ripple factor is a measure of purity of the dc output of a rectifier, and is defined as

$$r = \frac{\text{rms value of the components of wave}}{\text{average or dc value}}$$

$$r = \sqrt{\left(\frac{I_{rms}}{I_{dc}}\right)^2 - 1}$$

For half wave rectifier,

$$I_{rms} = \frac{I_m}{2}, I_{dc} = \frac{I_m}{\pi}$$

$$r = \sqrt{\left(\frac{I_m/2}{I_m/\pi}\right)^2 - 1} = 1.21$$

For full wave rectifier,

$$I_{rms} = \frac{I_m}{\sqrt{2}}, I_{dc} = \frac{2I_m}{\pi}$$

$$r = \sqrt{\left(\frac{I_m/\sqrt{2}}{2I_m/\pi}\right)^2 - 1} = 0.483$$

Rectification Efficiency

The rectification efficiency tells us what percentage of total input ac power is converted into useful dc output power. Thus, rectification efficiency is defined as

$$\eta = \frac{\text{dc power delivered to load}}{\text{ac input power from transformer secondary}}$$

- For a half wave rectifier,
dc power delivered to the load is

$$P_{dc} = I_{dc}^2 R_L = \left(\frac{I_m}{\pi} \right)^2 R_L$$

Input ac power is

$$P_{ac} = I_{rms}^2 (r_f + R_L) = \left(\frac{I_m}{2} \right)^2 (r_f + R_L)$$

Rectification efficiency

$$\eta = \frac{P_{dc}}{P_{ac}} = \frac{(I_m / \pi)^2 R_L}{(I_m / 2)^2 (r_f + R_L)} \times 100\% = \frac{40.6}{1 + r_f / R_L} \%$$

If $r_f \ll R_L$, maximum rectification efficiency, $\eta = 40.6\%$.

- For a full wave rectifier,
dc power delivered to the load is

$$P_{dc} = I_{dc}^2 R_L = \left(\frac{2I_m}{\pi} \right)^2 R_L$$

Input ac power is

$$P_{ac} = I_{rms}^2 (r_f + R_L) = \left(\frac{I_m}{\sqrt{2}} \right)^2 (r_f + R_L)$$

Rectification efficiency

$$\eta = \frac{P_{dc}}{P_{ac}} = \frac{(2I_m / \pi)^2 R_L}{(I_m / \sqrt{2})^2 (r_f + R_L)} \times 100\% = \frac{81.2}{1 + r_f / R_L} \%$$

If $r_f \ll R_L$, maximum rectification efficiency, $\eta = 81.2\%$.

Form Factor

$$\text{Form factor} = \frac{I_{rms}}{I_{dc}}$$

- For half wave rectifier,

$$\text{Form factor} = \frac{I_m / 2}{I_m / \pi} = \frac{\pi}{2} = 1.57$$

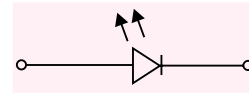
- For full wave rectifier,

$$\text{Form factor} = \frac{I_m / \sqrt{2}}{2I_m / \pi} = \frac{\pi}{2\sqrt{2}} = 1.11$$

Light Emitting Diode (LED)

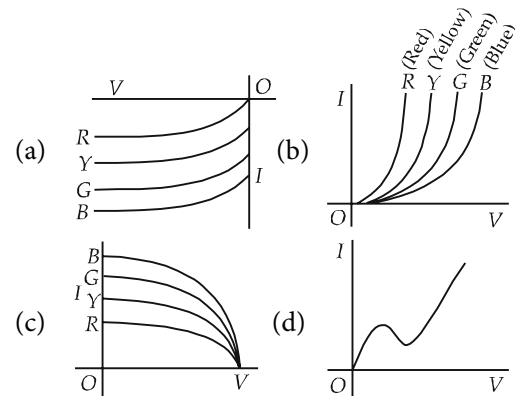
It converts electrical energy into light energy. It is a heavily doped p - n junction which under forward bias emits spontaneous radiation. The I - V characteristics of a LED is similar to that of Si junction diode. But the threshold voltages are much higher and slightly

different for each colour. The reverse breakdown voltages of LEDs are very low, typically around 5 V. The semiconductor used for fabrication of visible LEDs must at least have a band gap of 1.8 eV. The compound semiconductor gallium arsenide phosphide (GaAsP) is used for making LEDs of different colours. GaAs is used for making infrared LED. The symbol of a LED is shown in the figure.



SELF CHECK

5. The I - V characteristic of an LED is

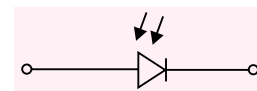


(JEE Main 2013)

Photodiode

A photodiode is a special type p - n junction diode fabricated with a transparent window to allow light to fall on the diode. It is operated under reverse bias. When it is illuminated with light of photon energy greater than the energy gap of the semiconductor, electron-hole pairs are generated in near depletion region.

The symbol of a photodiode is shown in the figure below.



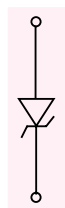
Solar Cell

It converts solar energy into electrical energy. A solar cell is basically a p - n junction which generates emf when solar radiation falls on the p - n junction.

It works on the same principle (photovoltaic effect) as the photodiode, except that no external bias is applied and the junction area is kept large.

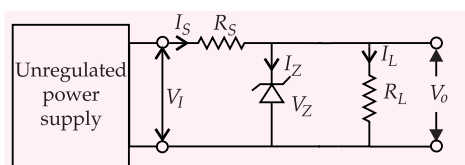
Zener diode

It was invented by C. Zener. It is designed to operate under reverse bias in the breakdown region and is used as a voltage regulator. The symbol for Zener diode is shown in the figure.



Zener Diode as a Voltage Regulator

The circuit diagram for Zener diode as a voltage regulator is shown in the figure below.

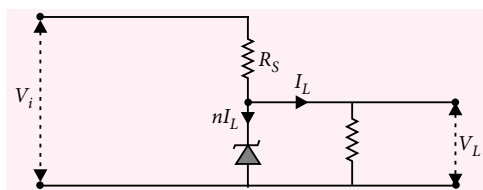


KEY POINT

- The Zener diode is always reverse biased and this reverse-bias voltage should be greater than the breakdown voltage.

SELF CHECK

6. The value of the resistor, R_S , needed in the dc voltage regulator circuit shown here, equals



- $(V_i - V_L)/n I_L$
- $(V_i + V_L)/n I_L$
- $(V_i - V_L)/(n + 1) I_L$
- $(V_i + V_L)/(n + 1) I_L$

(JEE Main 2015)

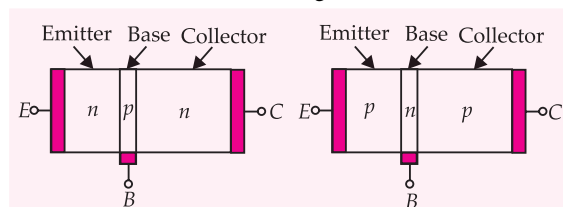
Transistor

A transistor is basically a silicon or germanium crystal containing three separate regions. It can either be $n-p-n$ -type or $p-n-p$ -type. It has three regions. The middle region is called the base and the two outer regions are called the emitter and the collector. Although the two outer regions are of the same type (n -type or p -type), their functions cannot be interchanged. The two regions have different physical and electrical properties. In most transistors, the collector region is made physically larger than the emitter region since it is required to dissipate more heat. The base is very lightly doped, and is very

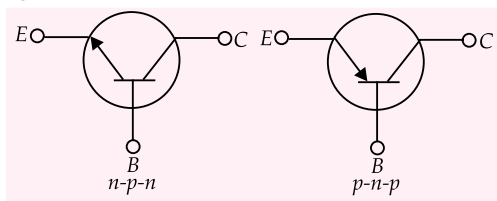
thin. The emitter is heavily doped. The doping of the collector is between the heavy doping of the emitter and the light doping of the base. The function of the emitter is to emit or inject electrons (holes in case of a $p-n-p$ transistor) into the base. The base passes most of these electrons (holes in case of $p-n-p$) onto the collector. The collector has the job of collecting or gathering these electrons (holes in case of a $p-n-p$) from the base.

A transistor has two $p-n$ junctions. One junction is between the emitter and the base, and is called the emitter-base junction, or simply the emitter junction. The other junction is between the base and the collector, and is called collector-base junction, or simply collector junction.

The schematic representations of a $n-p-n$ and $p-n-p$ transistors are shown in the figure.



The symbols for $n-p-n$ and $p-n-p$ transistors are shown in the figure below.



In operation of a transistor, $I_E = I_B + I_C$

where I_E is emitter current, I_B is base current, I_C is the collector current.

A transistor can be operated in any one of the following three configurations :

- Common emitter (CE)
- Common base (CB)
- Common collector (CC)

Input Characteristics of a Transistor

The variation of the input current with the input voltage for a given output voltage is known as input characteristics of a transistor.

Output Characteristics of a Transistor

The variation of the output current with the output

voltage for a given input current is known as output characteristics of a transistor.

Action of a Transistor

A transistor has two junctions-emitter junction and a collector junction. There are four possible ways of biasing these two junctions as shown in the table. In condition I, where emitter junction is forward biased and collector junction is reverse biased. This condition is often described as forward reverse (FR).

Condition	Emitter junction	Collector junction	Region of operation
I. FR	Forward biased	Reverse biased	Active
II. FF	Forward biased	Forward biased	Saturation
III. RR	Reverse biased	Reverse biased	Cut off
IV. RF	Reverse biased	Forward biased	Inverted

Transistor as a Switch

When the transistor is used in the cut off region or saturation region, it acts as a switch.

Transistor as an Amplifier

When the transistor is used in the active region, it acts as an amplifier.

Common Emitter Amplifier

In the common emitter transistor amplifier, the input signal voltage and the output collector voltage are 180° out of phase.

dc Current Gain

It is defined as the ratio of the collector current (I_C) to the base current (I_B).

$$\beta_{dc} = \frac{I_C}{I_B}$$

ac Current Gain

It is defined as ratio of change in collector current (ΔI_C) to the change in base current (ΔI_B).

$$\beta_{ac} = \frac{\Delta I_C}{\Delta I_B}$$

Voltage Gain

It is defined as the ratio of output voltage to the input voltage.

$$A_v = \frac{V_o}{V_i} = -\beta_{ac} \times \frac{R_o}{R_i}$$

where R_o and R_i are the output and input resistances.

Negative sign represents that output voltage is opposite in phase with the input voltage.

Power Gain

It is defined as the ratio of the output power to the input power.

$$A_p = \frac{\text{Output power } (P_o)}{\text{Input power } (P_i)} = \beta_{ac} \times A_v$$

Note : Voltage gain (in dB) = $20 \log_{10} \frac{V_o}{V_i} = 20 \log_{10} A_v$

$$\text{Power gain (in dB)} = 10 \log \frac{P_o}{P_i}$$

Common base Amplifier

In common base transistor amplifier, the input signal voltage and the output collector voltage are in the same phase.

dc Current Gain

It is defined as the ratio of collector current (I_C) to the emitter current (I_E).

$$\alpha_{dc} = \frac{I_C}{I_E}$$

ac Current Gain

It is defined as the ratio of change in collector current (ΔI_C) to the change in emitter current (ΔI_E).

$$\alpha_{ac} = \left(\frac{\Delta I_C}{\Delta I_E} \right)$$

Voltage Gain

It is defined as the ratio of output voltage to the input voltage.

$$A_v = \frac{V_o}{V_i} = \alpha_{ac} \times \frac{R_o}{R_i}$$

Power Gain

It is defined as the ratio of output power to the input power.

$$A_p = \frac{\text{output power } (P_o)}{\text{input power } (P_i)} = \alpha_{ac} \times A_v$$

Relationship Between α and β

$$\beta = \frac{\alpha}{1 - \alpha}; \alpha = \frac{\beta}{1 + \beta}$$

KEY POINT

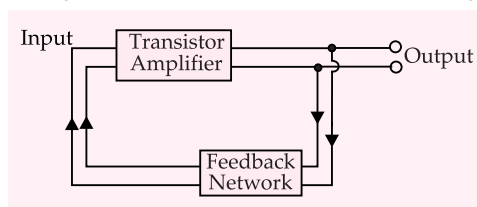
- Due to large value of the current amplification factor, the CE configurations of transistor is preferred over the CB and CC configurations.

Transistor as an Oscillator

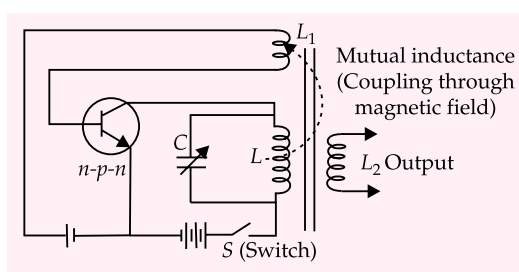
A transistor can be used as an oscillator.

An oscillator generates ac output signal without any input ac signal. An oscillator is a self sustained amplifier in which a part of output is fed back to the input in the same phase (called positive feedback).

The block diagram of an oscillator is shown in the figure.



The circuit diagram of the tuned collector oscillator is shown in the figure below.



The frequency of the oscillation is given by

$$\nu = \frac{1}{2\pi\sqrt{LC}}$$

LOGIC GATES

A digital circuit with one or more input signals but only one output signal is known as logical gate. The logic gates are the basic building blocks of a digital system. Each logic gate follows a certain logical relationship between input and output voltage.

There are three basic logic gates :

- OR gate
- AND gate
- NOT gate

Truth Table

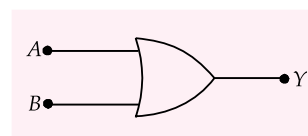
It is a table that shows all possible input combinations and the corresponding output combinations for a logic gate.

OR Gate

An OR gate has two or more inputs but only one output. It is called OR gate because the output is high if any or

all the inputs are high.

The logic symbol of OR gate is



The truth table for OR gate is

Input		Output
A	B	Y
0	0	0
0	1	1
1	0	1
1	1	1

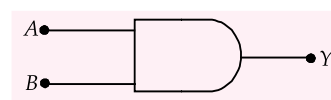
The Boolean expression for OR gate is

$$Y = A + B$$

AND Gate

An AND gate has two or more inputs but only one output. It is called AND gate because output is high only when all the inputs are high.

The logic symbol of AND gate is



The truth table for AND gate is

Input		Output
A	B	Y
0	0	0
0	1	0
1	0	0
1	1	1

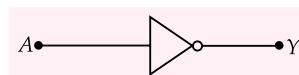
The Boolean expression for AND gate is

$$Y = A \cdot B$$

NOT Gate

The NOT gate is the simplest of all logic gates. It has only one input and one output. NOT gate is also called inverter because it inverts the input.

The logic symbol of NOT gate is



The truth table for NOT gate is

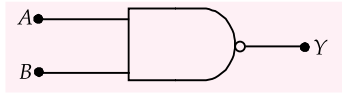
Input	Output
A	Y
0	1
1	0

The Boolean expression for NOT gate is

$$Y = \bar{A}$$

NAND Gate

It is an AND gate followed by a NOT gate.
The logic symbol for NAND gate is



The truth table for NAND gate is

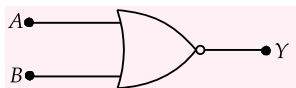
Input		Output
A	B	Y
0	0	1
0	1	1
1	0	1
1	1	0

The Boolean expression for NAND gate is

$$Y = \overline{A \cdot B}$$

NOR Gate

It is an OR gate followed by a NOT gate.
The logic symbol of NOR gate is



The truth table for NOR gate is

Input		Output
A	B	Y
0	0	1
0	1	0
1	0	0
1	1	0

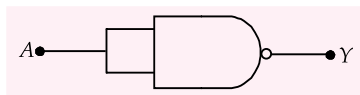
The Boolean expression for NOR gate is

$$Y = \overline{A + B}$$

NAND as a Universal Gate

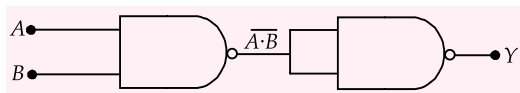
NAND gate is called as universal gate because with the repeated use of NAND gate we can construct any basic gate.

NOT gate from NAND gate



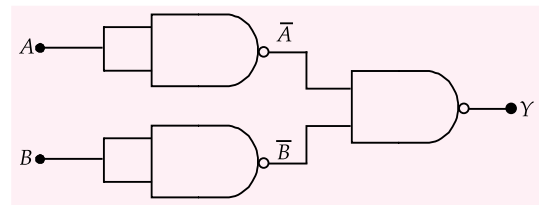
$$Y = \bar{A}$$

AND gate from NAND gate



$$Y = \overline{\overline{A \cdot B}} = A \cdot B$$

OR gate from NAND gate

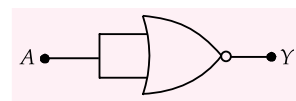


$$Y = \overline{\overline{A} \cdot \overline{B}} = \overline{\overline{A} + \overline{B}} = A + B$$

NOR Gate as a Universal Gate

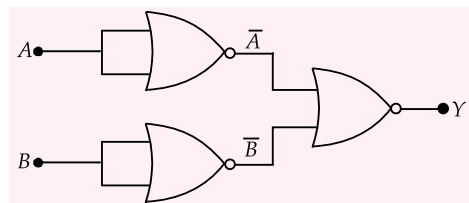
NOR gate is called as universal gate because with the repeated use of NOR gate we can construct any basic gate.

NOT gate from NOR gate



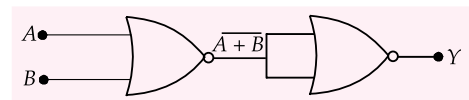
$$Y = \bar{A}$$

AND gate from NOR gate



$$Y = \overline{\overline{A} + \overline{B}} = \overline{\overline{A} \cdot \overline{B}} = A \cdot B$$

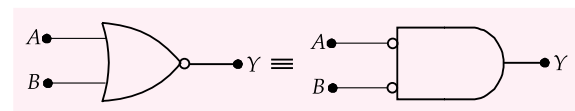
OR gate from NOR gate



$$Y = \overline{\overline{A + B}} = A + B$$

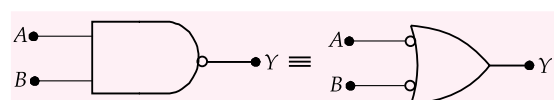
De Morgan's Theorems

$$\overline{A + B} = \bar{A} \cdot \bar{B}$$



NOR gate is equivalent to bubbled AND gate.

$$\overline{A \cdot B} = \bar{A} + \bar{B}$$



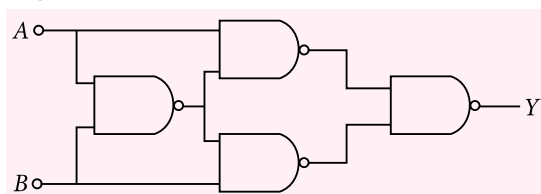
NAND is equivalent to bubbled OR gate.

Boolean Identities

$A + B = B + A$	$A \cdot B = B \cdot A$
$A + (B + C) = (A + B) + C$	$A \cdot (B \cdot C) = (A \cdot B) \cdot C$
$A \cdot (B + C) = A \cdot B + A \cdot C$	$A + B \cdot C = (A + B) \cdot (A + C)$
$A + 0 = A$	$A \cdot 0 = 0$
$A + 1 = 1$	$A \cdot 1 = A$
$A + A = A$	$A \cdot A = A$
$A + \bar{A} = 1$	$A \cdot \bar{A} = 0$
$\bar{\bar{A}} = A$	$\bar{\bar{A}} = A$
$\overline{A + B} = \bar{A} \cdot \bar{B}$	$\overline{A \cdot B} = \bar{A} + \bar{B}$
$A + A \cdot B = A$	$A \cdot (A + B) = A$
$A + \bar{A} \cdot B = A + B$	$A \cdot (\bar{A} + B) = A \cdot B$

SELF CHECK

7. Truth table for system of four NAND gates as shown in figure is



(a)

A	B	Y
0	0	0
0	1	0
1	0	1
1	1	1

(b)

A	B	Y
0	0	1
0	1	1
1	0	0
1	1	0

(c)

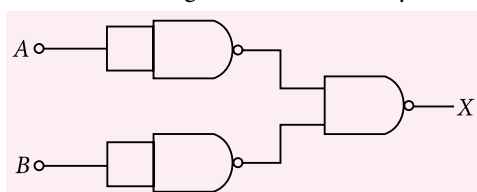
A	B	Y
0	0	1
0	1	0
1	0	0
1	1	1

(d)

A	B	Y
0	0	0
0	1	1
1	0	1
1	1	0

(AIEEE 2012)

8. The combination of gates shown below yields

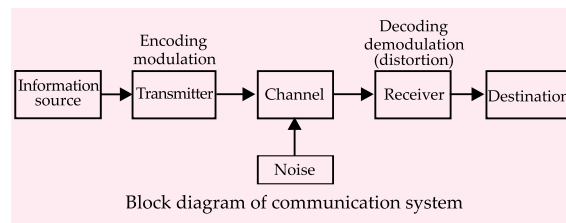


- (a) NAND gate (b) OR gate
(c) NOT gate (d) XOR gate

(AIEEE 2010)

COMMUNICATION SYSTEMS

The set up used for exchanging information between a sender and receiver is called communication system.



A communication system is composed of three basic units :

- **Transmitter** : The part of communication system, which sends out the information is called transmitter.
- **Transmission channel** : The medium or the link, which transfer message signal from the transmitter to the receiver of communication channel.
- **Receiver** : The part of the communication system, which pick up the information sent out by the transmitter is called receiver.

Signal

A processed information converted into electrical pulse for transmission is called a signal.

There are two forms of signal :

- **Analog signal** : A signal, which is a continuous function of time. In an analog signal, current or voltage value varies continuously with time.
- **Digital signal** : A signal, which is a discontinuous function of time, which has only two levels (either low or high) is called a digital signal.
- **Transducer** : A device which converts energy in one form to another is called a transducer.

Bandwidth of Signals

The frequency range of a signals is called its bandwidth. Different types of signals require different ranges of frequencies for proper communication.

These ranges of frequencies are called bandwidths of the corresponding signals.

- Speech signals – Bandwidth is 2800 Hz. (from 300 Hz to 3100 Hz)
- For music – Bandwidth is 20 kHz.
- Video signals – Bandwidth is about 4.2 MHz.

Bandwidth of Transmission Medium

For co-axial cable, bandwidth offered is 750 MHz,

(Normally operated below 18 GHz)

For free space communication,

- Standard AM broadcast (~ 540-1600 kHz)
- FM broadcast (~ 88-108 MHz)
- Television (~ 54-890 MHz)
- Satellite communication
(5.925-6.425 GHz for Uplink)
(3.7-4.2 GHz for Downlink)

Modulation

Modulation process is used for transmission of signal from transmitter to receiver. In modulation, a high frequency carrier wave is used to carry the information signal over a long distance.

The process of changing some characteristics e.g. amplitude, frequency or phase of carrier wave in accordance with instantaneous value of modulating signal is known as modulation.

Need of Modulation

The sound waves within the range of human hearing have frequency range from 20 Hz to 20 kHz. The sound waves cannot be transmitted from a radio transmitter by converting them into electrical waves (audio signal) directly for the following reasons;

- For efficient transmission and reception, the transmitting and receiving antenna must have a length equal to quarter wavelength of the audio signal. For a frequency of 15 kHz of audio signal, the length of the antenna comes out to be of the order of 5000 m. To set up a vertical antenna of this size is practically impossible.
- The energy radiated from an antenna is practically zero, when the frequency of the signal to be transmitted is below 15 kHz. It also makes the direct transmission of audio signal as impractical.
- Due to the fact that all audio signals from different sources possess frequencies in the same range i.e., 20 Hz to 20 kHz, an audio signal cannot be transmitted directly. It is because, the audio signal from different transmitting stations will get hopelessly and inseparably mixed up.

The aforementioned difficulties faced during the transmission of audio signal, if transmitted directly, are overcome by the process of modulation.

The following are three types of modulation.

Amplitude Modulation

In amplitude modulation the amplitude of carrier

wave is varied in accordance with the amplitude of the audio frequency modulating signal. The frequency of amplitude modulated wave remains unchanged as that of the carrier wave.

If modulating signal $m(t) = A_m \sin \omega_m t$... (i)

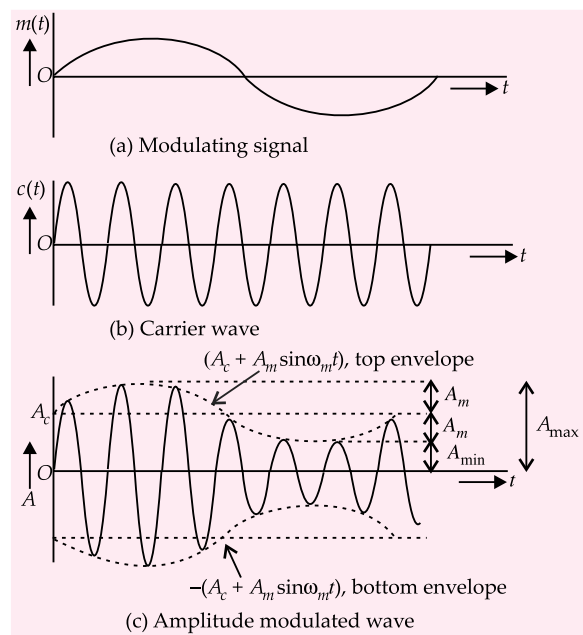
and carrier wave $c(t) = A_c \sin \omega_c t$... (ii)

where ω_c = angular frequency of carrier wave.

ω_m = angular frequency of modulating signal.

A_m, A_c = Peak amplitudes of modulating and carrier waves respectively.

$\mu = \frac{A_m}{A_c}$ (amplitude modulation index), $\mu \leq 1$ or else distortion occurs.



The amplitude modulated signal given by

$$c_m(t) = A_c \sin \omega_c t + \mu \frac{A_c}{2} \cos(\omega_c - \omega_m)t - \frac{\mu A_c}{2} \cos(\omega_c + \omega_m)t$$

This modulated wave contains frequencies $(\omega_c - \omega_m)$, ω_c and $(\omega_c + \omega_m)$.

$\omega_c - \omega_m$ and $\omega_c + \omega_m$ are called the lower side band and upper side band frequencies respectively.

In amplitude modulation (AM):

- Index of AM, $\mu = \frac{A_m}{A_c} = \frac{A_{\max} - A_{\min}}{A_{\max} + A_{\min}}$

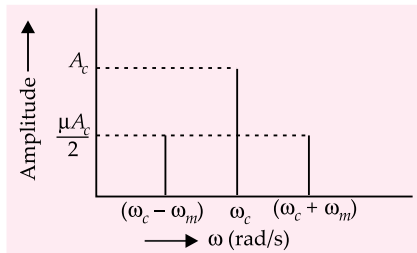
A_c = Peak amplitude of high frequency carrier wave.

A_m = Peak amplitude of low frequency modulating signal.

- Required bandwidth = $(\omega_c + \omega_m) - (\omega_c - \omega_m) = 2\omega_m$

- For detection of AM wave, essential condition is $\frac{1}{f_c} \ll RC$ where RC = time constant of the circuit.

The amplitude modulated signal contains d.c component and also some different frequencies which are not required. This signal is made to pass through a band pass filter which rejects the d.c. components and also low and high frequencies. It allows a band of frequencies $\omega_c - \omega_m$, ω_c , $\omega_c + \omega_m$ to pass through.



The frequency spectrum of amplitude modulated wave is shown in above figure. The two side band frequencies have equal amplitude ($= \mu A_c/2$) which never exceeds half the carrier amplitude.

The amplitude modulation index (μ) define the quality of the transmitted signal. When modulation index (μ) is small, variation in carrier amplitude will not be large, therefore, audio signal being transmitted will not be strong. As the modulation index (μ) increases but less than 1, the audio signal on reception becomes more clear.

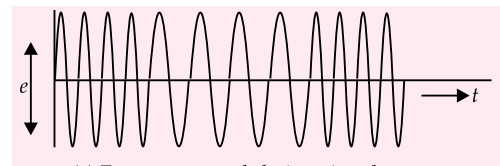
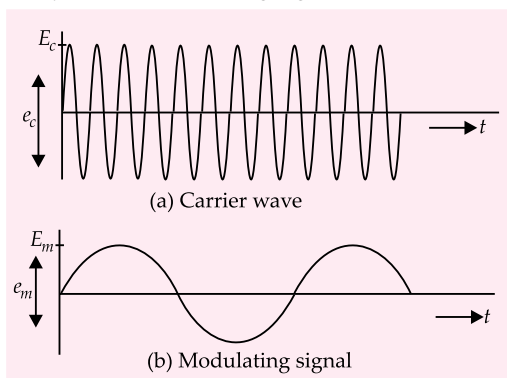
Frequency Modulation

In frequency modulation, the frequency of carrier wave is varied in accordance with the audio frequency signal. The instantaneous values of the voltage of carrier waves and modulating signal can be represented as

$$e_c = E_c \cos \omega_c t \quad \dots (i)$$

$$\text{and } e_m = E_m \cos \omega_m t \quad \dots (ii)$$

where e_c , E_c , ω_c are the instantaneous value, peak value, angular frequency of the carrier and e_m , E_m and ω_m are the instantaneous value, peak value and the angular frequency of the modulating signal.



(c) Frequency modulating signal

The frequency of modulated signal varies between

$$f_{\min} \left(= f_c - \frac{k_f E_m}{2\pi} \right) \text{ and } f_{\max} \left(= f_c + \frac{k_f E_m}{2\pi} \right)$$

where k_f is the proportionality constant and determines the maximum variation in frequency of modulated wave for a given modulating signal.

The maximum swing of frequency of modulated wave from the carrier frequency is called frequency deviation (δ).

$$\delta = f_{\max} - f_c = f_c - f_{\min}$$

The modulation index (m_f) of the frequency modulating wave is

$$m_f = \frac{\delta}{f_m} = \frac{f_{\max} - f_c}{f_m} = \frac{f_c - f_{\min}}{f_m}$$

Bandwidth of FM : In frequency modulated signal, the audio signal is contained in the sidebands. Since the sidebands are separated from each other by the frequency of modulating signal (f_m),

bandwidth = $2n \times$ frequency of modulating signal

where n is the number of significant sidebands pairs.

Advantages of frequency modulation : The following are a few advantages of frequency modulation over amplitude modulation.

- FM reception is quite immune to noise as compared to AM reception. Noise is a form of amplitude variations in the transmitted signal due to atmosphere, industries, etc. In FM receivers, the noise can be reduced by increasing the frequency deviation or by making use of amplitude limiters.
- FM transmission is highly efficient as compared to AM transmission.
- In FM transmission, all the transmitted power is useful; whereas in AM transmission, most of the power goes waste in the transmitted carrier, which contains no useful information.
- Due to a large number of sidebands, FM transmission can be used for the stereo sound transmission.

Disadvantages : The following are a few disadvantages of FM transmission:

- The bandwidth in FM transmission is about 10 times as large as that needed in AM transmission. As a

result, much wider frequency channel is required in FM transmission.

- FM reception is limited to line-of-sight. Due to this, area of reception for FM is much smaller than that for AM.
- FM transmitting and receiving equipments are very complex as compared to those employed in AM transmission.

SELF CHECK

9. A signal of 5 kHz frequency is amplitude modulated on a carrier wave of frequency 2 MHz. The frequencies of the resultant signal is/are
- 2005 kHz, 2000 kHz and 1995 kHz
 - 2000 kHz and 1995 kHz
 - 2 MHz only
 - 2005 kHz and 1995 kHz

(JEE Main 2015)

Demodulation

The process of detection or demodulation is the inverse process of modulation. In the process of demodulation, audio signal is separated from the modulated signal.

Modem and Fax

Modem is contraction of the term modulator and demodulator. A modem acts as a modulator in transmitting mode and as a demodulator in receiving mode. The electronic transmission of a document at a

distant place via telephone line is known as facsimile or FAX.

Earth's Atmosphere

The gaseous envelope surrounding the earth is called earth's atmosphere. Earth's atmosphere mainly consists of nitrogen 78%, oxygen 21% along with a little portion of argon, carbon dioxide, water vapour, hydrocarbons, sulphur compounds and dust particles.

Earth's atmosphere helps in the propagation of electromagnetic waves from one place to another place. The various regions of earth's atmosphere are as follows:

- **Troposphere** : It extends upto a height of 10 km, over earth's surface.
- **Stratosphere** : It extends from 10 km to 50 km. There is an ozone layer in stratosphere which mostly absorbs high energy radiations like ultraviolet radiations etc. coming from outer space.
- **Mesosphere** : It extends from 50 km to 65 km.
- **Ionosphere** : It extends from 65 km to 400 km.
- In this region, the temperature rises to some extent with height, hence it is called thermosphere. The ionosphere which is composed of ionised matter (*i.e.*, electrons and positive ions) plays an important role in space communication. The ionosphere is subdivided into four main layers as D , E , F_1 and F_2 as shown in the table.

Name of the layer	Approximate height over earth's surface	Exists during	Frequencies most affected
D	65-75 km	Day only	Reflects LF, absorbs MF and HF to some degree
E	100 km	Day only	Helps surface waves, reflects HF
F_1	170-190 km	Day time, merges with F_2 at night	Partially absorbs HF waves yet allowing them to reach F_2 .
F_2	300 km at night, 250-400 km during day time	Day and night	Efficiently reflects HF waves, particularly at night

Radio waves

The electromagnetic waves of frequency ranging from a few kilohertz to few hundred megahertz are called radio waves..

Frequency range and wavelength range of radiowaves are given in the table.



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S. No.	Frequency band	Frequency range	Wavelength range	Main use
1.	Very-low frequency (VLF)	3 kHz to 30 kHz	10 km to 100 km	Long distance point to point communication
2.	Low frequency (LF)	30 kHz to 300 kHz	1 km to 10 km	Marine and navigational purpose
3.	Medium frequency (MF)	300 kHz to 3 MHz	100 m to 1 km	Marine and broadcasting purposes
4.	High frequency (HF)	3 MHz to 30 MHz	10 m to 100 m	Communications of all types
5.	Very high frequency (VHF)	30 MHz to 300 MHz	1 m to 10 m	T.V., Radar and air navigation
6.	Ultra-high frequency (UHF)	300 MHz to 3000 MHz	10 cm to 1 m	Radar and microwave communication
7.	Super-high frequency (SHF)	3 GHz to 30 GHz	1 cm to 10 cm	Radar, radio relays and navigation purposes
8.	Extremely high frequency (EHF)	30 GHz to 300 GHz	1 mm to 1 cm	Optical fibre communication

Space Communication

The term space communication refers to sending receiving and processing of information through space. There are three types of space communication.

Ground wave propagation

This mode of propagation can exist when the transmitting and receiving antenna are close to the surface of the earth. For radiating high efficiency signals, the size of the antenna should be of the order of $\lambda/4$. λ = wavelength of the signal.

The field component of such a launched wave soon becomes vertically polarised as it glides over the surface of the earth. The electrical fields due to the wave induce charges on the earth's surface. The ground wave is weakened as a result of energy absorbed by the earth during its propagation. These losses make ground waves unsuitable for very long range communication.

Ground wave propagation can be sustained only at low frequencies (~ 500 kHz to 1500 kHz) or for radio broadcast at long wavelengths.



KEY POINT

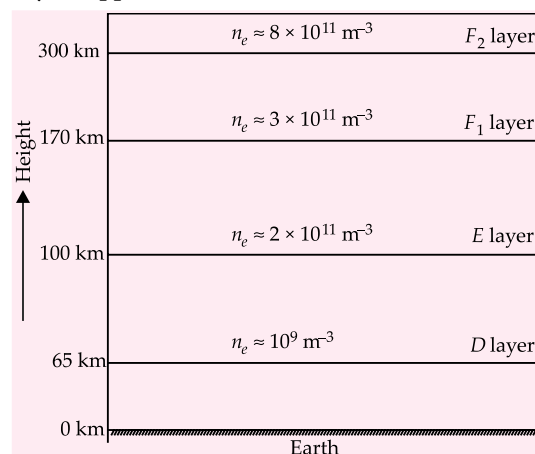
- The ground wave propagation is generally used for local band broadcasting and is commonly called medium wave. The maximum range of ground or surface wave propagation depends on :
 - frequency of the radio waves and
 - power of the transmitter.

Sky wave propagation (Ionospheric propagation)

A transmitted wave going up is reflected back by the ionosphere which forms an ionised layer of electrons and ions around the earth. The ionosphere (including

mesosphere and part of stratosphere) extends from about 65 km to 400 km above the earth's surface. Constituent gases are ionised in it by solar radiation. Through out the ionosphere, there are several layers in which the ionisation density either reaches a maximum or remains roughly constant. These regions are designated as $D(65-75$ km), $E(100$ km) and $F(130$ km-400 km) in order of approximate heights above earth's surface.

During day time the F layer splits into separate layers called F_1 (170-190 km over earth's surface) and F_2 (250-400 km over earth's surface). During night F_1 layer usually disappears.



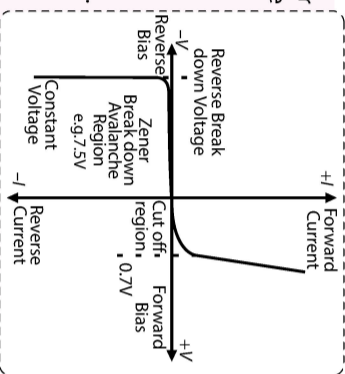
Region of high conductivity is confined to a relatively thin layer at the lower edge of E -region and to the upper part of D -region. Therefore high frequencies are attenuated when they penetrate this region. D and E layer disappears during night and low and medium frequency communication also becomes possible.

Ionisation density increases as we go up from D layer to

TYPES OF SEMICONDUCTORS

SEMICONDUCTOR DIODE

- **P-n Junction Diode** : In layman language, when a p-type semiconductor is brought into contact with an n-type semiconductor such that structure remains continuous at boundary, p-n junction diode is formed.
- Forward and Reverse biased characteristic of p-n junction diode.
- Forward Bias Characteristics
 - Width of depletion layer decreases
 - Effective barrier potential decreases
 - Low resistance offered at junction and high current flow of the order of mA.
- Reverse Bias Characteristics
 - Width of depletion layer increases
 - Effective barrier potential increases
 - High resistance offered at the junction and low current flow of the order of μA .
 - Reverse break down occurs at a high reverse biased voltage where the ordinary diodes get damaged.



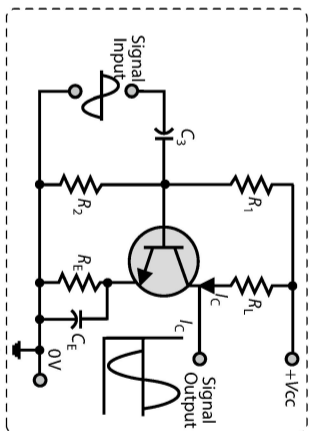
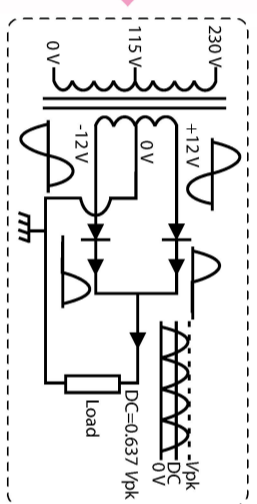
INTRINSIC SEMICONDUCTORS

- The pure semiconductors having thermally generated current carriers.
 - Here $n_e = n_h = n_i$ where n_e = Electron density
 n_h = Hole density
 n_i = Density of intrinsic carriers.

EXTRINSIC SEMICONDUCTORS

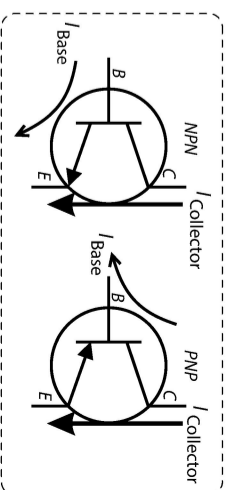
- The semiconductor whose conductivity is mainly due to impurity. On the basis of doping there are two type of extrinsic semiconductors.
 - p-type semiconductor \Rightarrow obtained by doping a trivalent impurity atom.
 - \Rightarrow Here $n_h \gg n_e$
 - n-type semiconductor \Rightarrow Obtained by doping a pentavalent impurity atom.
 - \Rightarrow Here $n_e \gg n_h$
- Electrical conductivity of a semiconductor is
$$\sigma = e [n_e \mu_e + n_h \mu_h]$$

n_e = electron density
 n_h = electron and hole mobility



JUNCTION TRANSISTOR

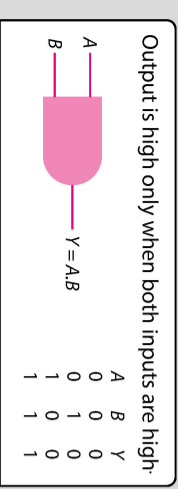
- It is a semiconductor device containing three separate region having a fundamental action of transfer resistor.
- **Junction transistors are of two types**
 - n-p-n transistor: A thin layer of p-type semiconductor is sandwiched between two n-type.
 - p-n-p transistor: A thin layer of n-type semiconductor is sandwiched between two p-type.
- **There are three configurations of transistors**
 - CB (Common Base)
 - CE (Common Emitter)
 - CC (Common Collector).
- **Biasing rule for a junction transistor**
 - Emitter base EB junction must be forward biased and collector base junction must be reverse biased.
 - At any point in the circuit $I_E = I_B + I_C$ must hold.
- **Transistor characteristics**
 - Input resistance $(r_i) = \left(\frac{\Delta V_{BE}}{\Delta I_B} \right)_{V_{CE} \text{ constant}}$
 - Output resistance $(r_o) = \left(\frac{\Delta V_{CE}}{\Delta I_C} \right)_{I_B \text{ constant}}$
 - Current amplification factor
 - For CE (n-p-n) $\beta_{ac} = \left(\frac{\Delta I_C}{\Delta I_B} \right)_{V_{CE} \text{ constant}}$
 - For CB (p-n-p) $\alpha_{ac} = \left(\frac{\Delta I_C}{\Delta I_E} \right)_{V_{CB} \text{ constant}}$
 - Relation between α and β : $\beta = \frac{\alpha}{1 - \alpha}$ and $\alpha = \frac{\beta}{1 + \beta}$



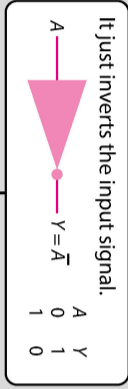
DIGITAL ELECTRONICS AND LOGIC GATES

Digital electronic circuit uses discrete signals. A digital circuit operates in a binary manner only in two states designated as 0 (off) and 1 (on) using different logic gates.

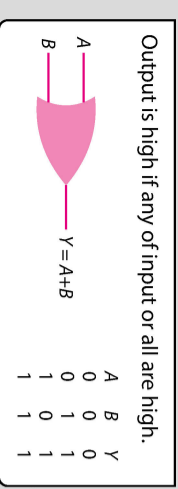
AND Gate



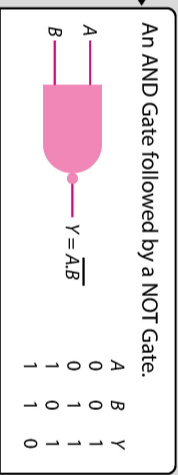
NOT Gate



OR Gate



NAND Gate



NOR Gate



APPLICATIONS OF TRANSISTORS

There are three regions of transistor operation:

- Cut off region
- Active region
- Saturation region
- **Transistor as a Voltage Amplifier**
 - To operate it as an amplifier we need to fix its operating voltage some where in active region where it increase the strength of input ac signal and produces an amplified output signal.
 - Voltage gain, $A_v = \frac{V_o}{V_i} = -\beta_{ac} \frac{R_{out}}{R_{in}}$
 - Power gain, $A_p = A_v \times \beta_{ac}$
- **Transistor as a Switch**
 - A transistor can be used as a switch if it is operated in its cutoff and saturation states only.
- **Transistor as an Oscillator**
 - An oscillator is a generator of an ac signal using positive feedback.
 - Frequency of oscillation is $f = 1 / 2\pi \sqrt{LC}$

F layer and then decreases, due to which their respective refractive indices vary. Therefore the transmitted wave is reflected back in a way similar to the phenomenon of total internal refraction.

$$\text{where } \mu' = \mu_0 \left[1 - \left(\frac{Ne^2}{\epsilon_0 m \omega^2} \right) \right]^{1/2}$$

μ' = refractive index of particular region of ionosphere, m is the mass of the electron, N is the electron density in the ionosphere, ϵ_0 and n_0 are permittivity and refractive index respectively for free space, e = electronic charge. Ionosphere behaves as a rarer medium by which carrier wave is reflected back if its frequency ($f \leq f_c$) where f_c = critical frequency.

$$f_c \approx 9 (N_{\max})^{1/2}$$

N_{\max} = maximum electron density of the ionosphere. f_c is called critical frequency and it represents the highest frequency that will be reflected back from a particular layer at vertical incidence.

Maximum usable frequency (MUF) : It is the highest frequency that can be reflected from a particular layer of ionosphere for a given angle of incidence (i) is given as $MUF = f_c \sec i$.

KEY POINT

- The distance between the transmitting antenna and point where the sky wave is first received after returning to earth is called the skip distance.
- Skip zone is a silent zone where no signal can be picked up.

Space wave propagation (Troposphpherical propagation)

This mode is also known as line of sight communication. To send signals at far away stations, either repeater transmitting stations are necessary or height of the transmitter is increased by locating it in a satellite. If h_T is the height of transmitting antenna and d_T is the distance to the horizon from it, then $d_T = \sqrt{2Rh_T}$, where R is the radius of the earth. d_T is called radio horizon of transmitting antenna.

The maximum line-of-sight distance d_M between the two antennas having heights h_T and h_R above the earth is given by

$$d_M = \sqrt{2Rh_T} + \sqrt{2Rh_R}$$

SELF CHECK

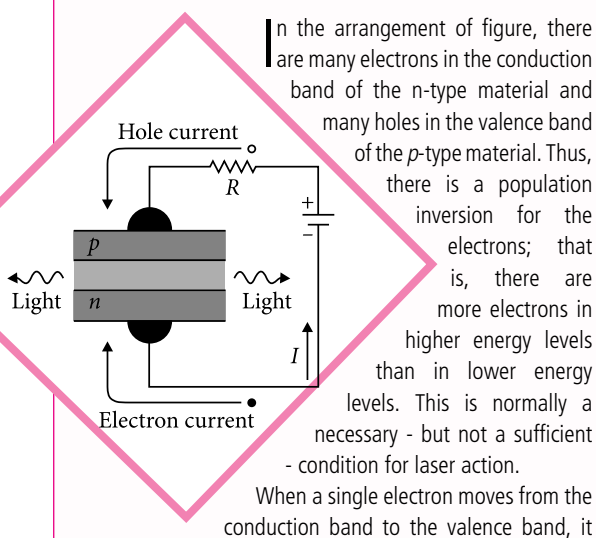
10. A radar has a power of 1 kW and is operating at a frequency of 10 GHz. It is located on a mountain top of height 500 m. The maximum distance upto which it can detect object located on the surface of the earth (Radius of earth = 6.4×10^6 m) is
(a) 16 km (b) 40 km (c) 64 km (d) 80 km

(AIEEE 2012)

ANSWER KEYS (SELF CHECK)

1. (b) 2. (b) 3. (b) 4. (c) 5. (b)
6. (c) 7. (d) 8. (b) 9. (a) 10. (d)

SCIENCE BEHIND THE JUNCTION LASER



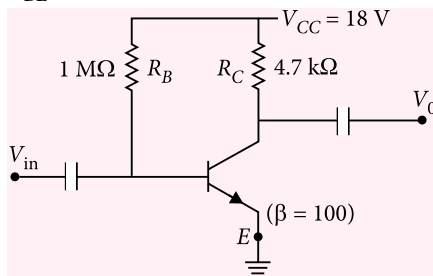
Exam Café

QUESTIONS FOR PRACTICE

1. The input resistance of a common emitter transistor amplifier, if the output resistance is $500\text{ k}\Omega$, the current gain, $\alpha = 0.98$, and power gain is 6.0625×10^6 , is

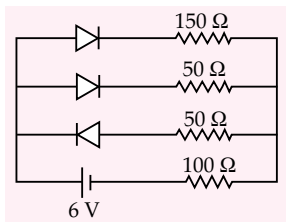
(a) $200\text{ }\Omega$ (b) $300\text{ }\Omega$
(c) $100\text{ }\Omega$ (d) $400\text{ }\Omega$

2. For the transistor amplifier circuit shown below, value of collector bias voltage V_C should be approximately (Take $V_{BE} = 0.7\text{ V}$)



(a) 6 V (b) 8 V
(c) 10 V (d) 11 V

3. The circuit shown in the figure contains three diodes each with forward resistance of $50\text{ }\Omega$ and with infinite backward resistance. If the battery voltage is 6 V , the current through the $100\text{ }\Omega$ resistance is



(a) 0 (b) 36 mA
(c) 43 mA (d) 50 mA

4. For a CE-transistor amplifier, audio signal voltage across the collector resistance of $2\text{ k}\Omega$ is 2 V . Suppose the current amplification factor of the transistor is 100. Find the input signal voltage and base current, if the base resistance is $1\text{ k}\Omega$.

(a) 0.01 V and $10\text{ }\mu\text{A}$
(b) 0.1 V and $14\text{ }\mu\text{A}$
(c) 0.001 V and $100\text{ }\mu\text{A}$
(d) 2.0 V and $10\text{ }\mu\text{A}$

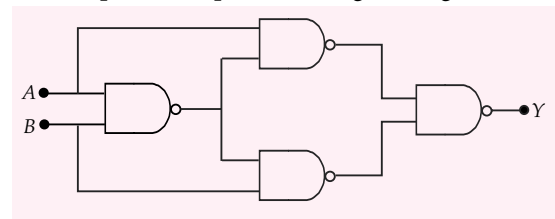
5. What would be the percentage power saving if the carrier and one of the side bands were suppressed in AM wave modulated to a depth of 75% before transmission took place?

(a) 89.02% (b) 9.1%
(c) 7.81% (d) 100%

6. Frequencies higher than 10 MHz were found not being reflected by the ionosphere on a particular day at a place. The maximum electron density of the ionosphere on that day was near to

(a) $1.5 \times 10^{10}\text{ m}^{-3}$ (b) $1.24 \times 10^{12}\text{ m}^{-3}$
(c) $3 \times 10^{12}\text{ m}^{-3}$ (d) None of these

7. The simplified output Y of the given logic circuit is

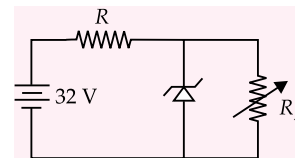


(a) $\bar{A} \cdot B + A \cdot \bar{B}$ (b) $A \cdot \bar{B} + A \cdot B$
(c) $\bar{A} \cdot \bar{B} + A \cdot B$ (d) $A \cdot \bar{B} + \bar{A} \cdot \bar{B}$

8. A sky wave with a frequency of 55 MHz is incident on the D -region of earth's atmosphere at 30° . The angle of refraction is (electron density for D -region is $400\text{ electron cc}^{-1}$)

(a) 60° (b) 15°
(c) 45° (d) 30°

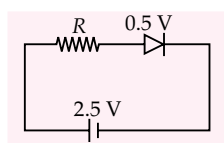
9. A 24 V , 600 mW zener diode is used to provide a 24 V stabilized supply to a variable load R_L , as shown in the figure. The value of the resistance R is



(a) $320\text{ }\Omega$ (b) $640\text{ }\Omega$
(c) $960\text{ }\Omega$ (d) $1280\text{ }\Omega$

10. The diode used in the circuit shown in the figure has a constant voltage drop of 0.5 V at all currents and a maximum power rating of 100 mW . What should be the value of the resistance R connected in series with diode for obtaining maximum current?

- (a) 2.5Ω
 (b) 10Ω
 (c) 12.5Ω
 (d) 15Ω

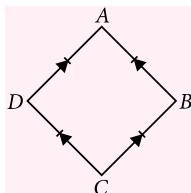


11. The ratio of electron and hole currents in a semiconductor is $\frac{7}{4}$ and the ratio of drift velocities of electrons and holes is $\frac{5}{4}$, then the ratio of concentration of electrons and holes will be

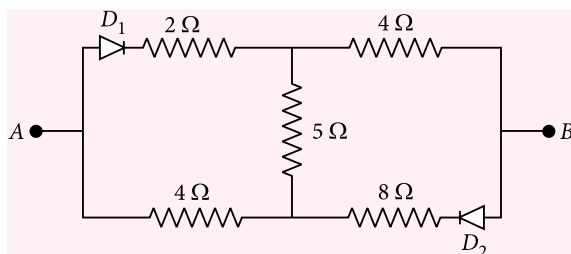
- (a) $\frac{5}{7}$ (b) $\frac{7}{5}$
 (c) $\frac{25}{49}$ (d) $\frac{49}{25}$

12. In bridge rectifier circuit, as shown in figure, the input signal should be connected between

- (a) A and D
 (b) B and C
 (c) A and C
 (d) B and D



13. The equivalent resistance of the circuit as shown in figure, across AB is given by (Assume the diodes to be ideal.)

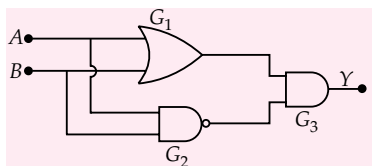


- (a) 6.24Ω (b) 5.64Ω
 (c) 8.24Ω (d) 5.64Ω or 8.24Ω

14. In an *npn* transistor, 10^{10} electrons enter the emitter in 10^{-6} s. 4% of the electrons are lost in the base. The current transfer ratio will be

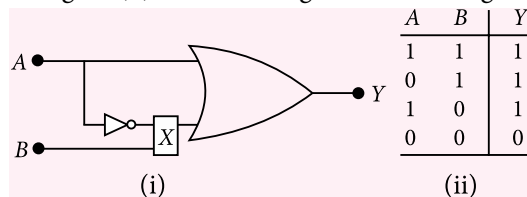
- (a) 0.98 (b) 0.97
 (c) 0.96 (d) 0.94

15. The following configuration of gates is equivalent to



- (a) NAND (b) XOR
 (c) OR (d) AND

16. The logic circuit shown in figure (i) yields the truth table figure (ii). What is the gate X in the diagram?

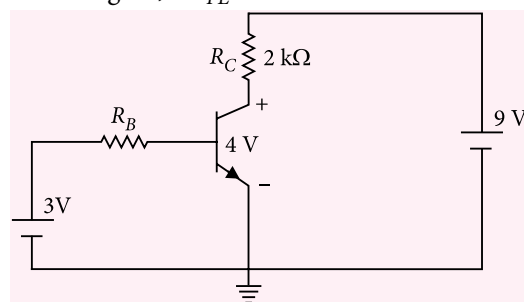


- (a) OR gate (b) AND gate
 (c) NAND gate (d) NOR gate

17. A Si and a Ge diode has identical physical dimensions. The band gap in Si is larger than that in Ge. An identical reverse bias is applied across the diodes.

- (a) The reverse current in Ge is larger than that in Si.
 (b) The reverse current in Si is larger than that in Ge.
 (c) The reverse current is identical in the two diodes.
 (d) The relative magnitude of the reverse currents cannot be determined from the given data only.

18. What is the base resistance R_B in the circuit as shown in figure, if $h_{FE} = 90$?

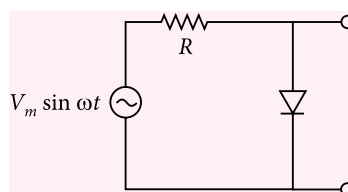


- (a) $29 \text{ k}\Omega$ (b) $82 \text{ k}\Omega$
 (c) $108 \text{ k}\Omega$ (d) $55 \text{ k}\Omega$

19. A ground receiver station is receiving a signal at 5 MHz, transmitted from a ground transmitter at a height of 300 m located at a distance of 100 km. Identify the mode of propagation. (Radius of earth = $6.4 \times 10^6 \text{ m}$; N_{max} of ionosphere = 10^{12} m^{-3})

- (a) ground wave propagation
 (b) space wave propagation
 (c) sky wave propagation
 (d) satellite communication

20. The output of the given circuit in figure



- (a) would be zero at all times
- (b) would be like a half-wave rectifier with positive cycle in output
- (c) would be like a half-wave rectifier with negative cycle in output
- (d) would be like that of a full-wave rectifier.

21. A basic communication system consists of
 (A) transmitter (B) information source
 (C) user of information (D) channel
 (E) receiver

Choose the correct sequence in which these are arranged in a basic communication system.

- (a) ABCDE (b) BADEC
- (c) BDACE (d) BEADC

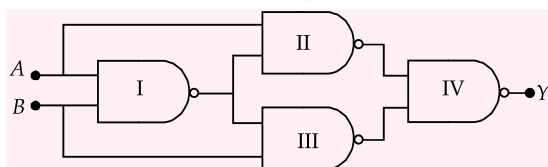
22. A light beam entering an optical fibre makes an angle of 10° with the fibre core-fibre clad boundary surface. If the fibre core and clad refractive indices are 1.5 and 1.49 respectively, can this beam propagate along the fibre?

- (a) No
- (b) Yes
- (c) Refractive indices have nothing to do with beam propagation
- (d) The given data is insufficient

23. An audio signal is modulated by a carrier wave of 20 MHz such that the bandwidth required for modulation is 3 kHz. If $R = 10 \text{ k}\Omega$ and $C = 0.01 \text{ }\mu\text{F}$, can the wave be demodulated?

- (a) Yes
- (b) No
- (c) Can not be predicted
- (d) Data insufficient

24. Select the output Y of the combination of gates as shown in figure for inputs $A = 1, B = 0$; $A = 1, B = 1$ and $A = 0, B = 0$ respectively.



- (a) (0, 1, 1) (b) (1, 0, 1)
- (c) (1, 1, 1) (d) (1, 0, 0)

25. A 50 MHz sky wave takes 4.04 ms to reach a receiver via re-transmission from a satellite 600 km above earth's surface. Assuming re-transmission time by satellite negligible, find the distance between source and receiver.

- (a) 606 km (b) 170 km
- (c) 340 km (d) 280 km

26. When a p - n junction diode made from germanium or silicon is forward-biased, energy is released at the junction due to the recombination of electrons and holes. This energy is in

- (a) Visible region (b) Infrared region
- (c) UV region (d) X-ray region

27. A block of pure silicon at 300 K has a length of 10 cm and an area of 1.0 cm^2 . A battery of emf 2 V is connected across it. The mobility of electron is $0.14 \text{ m}^2 \text{ V}^{-1} \text{ s}^{-1}$ and their density is $1.5 \times 10^{16} \text{ m}^{-3}$. The mobility of holes is $0.05 \text{ m}^2 \text{ V}^{-1} \text{ s}^{-1}$. The hole current is

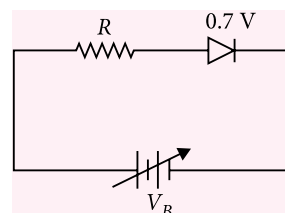
- (a) $2.0 \times 10^{-7} \text{ A}$ (b) $2.2 \times 10^{-7} \text{ A}$
- (c) $2.4 \times 10^{-7} \text{ A}$ (d) $2.6 \times 10^{-7} \text{ A}$

28. The saturation current of a p - n junction diode made from germanium at 27°C is 10^{-5} A . What will be required potential in order to obtain a current of 250 mA in forward bias?

(Boltzmann constant, $k = 1.38 \times 10^{-23} \text{ J K}^{-1}$).

- (a) 0.26 V (b) 2.6 V
- (c) 0.52 V (d) 1.04 V

29. The junction diode in the following circuit requires a minimum current of 1 mA to be above the knee point (0.7 V) of its I - V characteristic curve. The voltage across the junction diode is independent of current above the knee point, if $V_B = 4 \text{ V}$, then the maximum value of R so that the voltage is above knee point will be



- (a) 3.3 k Ω (b) 4.0 k Ω
- (c) 4.7 k Ω (d) 6.6 k Ω

30. Match the column I with column II and select the correct option.

Column I

P. Microphone

Q. Piezo-electric sensor

Column II

1. It converts pressure variation into electrical signals.

2. It is the loss of strength of signal during its propagation through communication channel.

- R. Photo-detector 3. It converts speech signal into electrical signals.
- S. Attenuation 4. It converts light signals into electrical signals.

	P	Q	R	S
(a)	1	2	3	4
(b)	2	3	4	1
(c)	3	4	1	2
(d)	3	1	4	2

SOLUTIONS

1. (a): Voltage gain, $A_V = \beta \frac{R_0}{R_i}$

Also current gain, $\beta = \frac{\alpha}{1 - \alpha} = \frac{0.98}{1 - 0.98} = 49$

$$A_V = 49 \left(\frac{500 \times 10^3}{R_i} \right)$$

Power gain = $\beta A_V = 49^2 \left(\frac{500 \times 10^3}{R_i} \right)$... (i)

and power gain = 6.0625×10^6 ... (ii)

∴ From (i) and (ii), we get

$$\frac{49 \times 49 \times 500 \times 10^3}{R_i} = 6.0625 \times 10^6$$

$$\Rightarrow R_i = \frac{49 \times 5 \times 10^5 \times 49}{6.0625 \times 10^6}$$

∴ $R_i = 198 \Omega \approx 200 \Omega$

2. (c): $I_B = \frac{V_{CC} - V_{BE}}{R_B} = \frac{(18 - 0.7)}{10^6} = 17.3 \mu A$

Also, $I_C = \beta I_B = 100 \times 17.3 \mu A = 1.73 \text{ mA}$

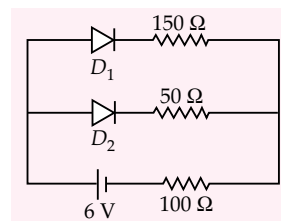
$V_{R_C} = I_C R_C = 1.73 \text{ mA} \times 4.7 \text{ k}\Omega = 8.1 \text{ V}$

$V_C = V_{CC} - V_{R_C} = (18 - 8.1) = 9.9 \text{ V} \approx 10 \text{ V}$

So, the correct option is (c).

3. (b): In the given circuit, the upper two diodes D_1 and D_2 are forward biased and the lower diode D_3 is reverse biased. Hence, no current flows through the lower diode D_3 . The equivalent circuit is as shown in the figure.

As diode D_1 and 150Ω resistor are in series and their combination is in parallel with the series combination of diode D_2 and 50Ω resistor. Their equivalent resistance is



$$\frac{1}{R'} = \frac{1}{r_f + 150 \Omega} + \frac{1}{r_f + 50 \Omega}$$

$$= \frac{1}{50 \Omega + 150 \Omega} + \frac{1}{50 \Omega + 50 \Omega}$$

$$\frac{1}{R'} = \frac{1}{200 \Omega} + \frac{1}{100 \Omega} \text{ or } R' = \frac{200}{3} \Omega$$

Total resistance of the circuit,

$$R = 100 \Omega + \frac{200}{3} \Omega = \frac{500}{3} \Omega$$

Current in the circuit,

$$I = \frac{V}{R} = \frac{6 \text{ V}}{\frac{500}{3} \Omega} = 3.6 \times 10^{-2} \text{ A}$$

$$= 36 \times 10^{-3} \text{ A} = 36 \text{ mA}$$

4. (a): Given, collector resistance

$$R_{\text{output}} = 2 \text{ k}\Omega = 2000 \Omega$$

Current amplification factor of the transistor

$$\beta_{AC} = 100$$

Audio signal voltage, $V_{\text{output}} = 2 \text{ V}$

Input (base) resistance, $R_{\text{input}} = 1 \text{ k}\Omega = 1000 \Omega$

∴ Voltage gain, $A_V = \frac{V_{\text{output}}}{V_{\text{input}}} = \beta_{AC} \frac{R_{\text{output}}}{R_{\text{input}}}$

∴ Input signal voltage

$$V_{\text{input}} = \frac{V_{\text{output}}}{\beta_{AC} (R_{\text{output}} / R_{\text{input}})}$$

$$= \frac{2}{100(2000 / 1000)} = 0.01 \text{ V}$$

Base (input) current, $I_B = \frac{V_{\text{input}}}{R_{\text{input}}} = \frac{0.01}{1000}$

$$= 10 \times 10^{-6} \text{ A} = 10 \mu A$$

5. (a): Here, modulation index, $\mu = \frac{75}{100} = \frac{3}{4}$

Power produced by the AM transmitter

$$P_t = P_c \left(1 + \frac{\mu^2}{2} \right) = P_c \left(1 + \frac{9}{32} \right) = P_c \times \frac{41}{32}$$

$$P_{SB} = P_c \frac{\mu^2}{4} = P_c \times \frac{9}{16 \times 4} = \frac{9}{64} P_c$$

On suppressing, power saved is

$$= P_c + \frac{9}{64} \times P_c = \frac{73}{64} P_c$$

$$\therefore \text{Percentage saving} = \frac{\frac{73}{64} P_c}{P_t} \times 100$$

$$= \frac{\frac{73}{64} P_c}{\frac{41}{32} P_c} \times 100 = \frac{73 \times 32}{64 \times 41} \times 100 = 89.02\%$$

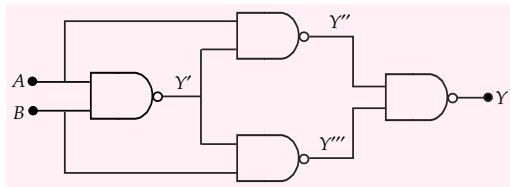
6. (b): $f^2 = \frac{80.6 N}{\cos^2 i}$

where i is angle of incidence and N is electron density. For the wave not being reflected from ionosphere, $i = 0$.

$$\therefore f^2 = \frac{80.6 N}{\cos^2 0^\circ} = 80.6 N$$

$$\text{or } N = \frac{f^2}{80.6} = \frac{(10 \times 10^6)^2}{80.6}$$

$$= \frac{100}{80.6} \times 10^{12} = 1.24 \times 10^{12} \text{ m}^{-3}$$



7. (a):

$$Y' = \overline{A \cdot B} = \overline{A} + \overline{B}$$

$$Y'' = \overline{A \cdot (\overline{A} + \overline{B})} = \overline{A} + \overline{(\overline{A} + \overline{B})}$$

$$= \overline{A} + (\overline{\overline{A}} \cdot \overline{\overline{B}}) = \overline{A} + (A \cdot B)$$

$$Y''' = \overline{B \cdot (\overline{A} + \overline{B})} = \overline{B} + \overline{(\overline{A} + \overline{B})}$$

$$= \overline{B} + (\overline{\overline{A}} \cdot \overline{\overline{B}}) = \overline{B} + (A \cdot B)$$

$$Y = \overline{[\overline{A} + (A \cdot B)] \cdot [\overline{B} + (A \cdot B)]}$$

$$= \overline{[\overline{A} + (A \cdot B)] + [\overline{B} + (A \cdot B)]}$$

$$= \overline{\overline{A} \cdot (\overline{A} + \overline{B}) + \overline{B} \cdot (\overline{A} + \overline{B})}$$

$$= \overline{A \cdot B (\overline{A} + \overline{B})} = \overline{(\overline{A} + \overline{B})(A + B)}$$

$$= A \cdot \overline{A} + \overline{A} \cdot B + A \cdot \overline{B} + B \cdot \overline{B}$$

$$= 0 + \overline{A} \cdot B + A \cdot \overline{B} + 0$$

$$(\because A \cdot \overline{A} = 0 \text{ and } B \cdot \overline{B} = 0)$$

$$= \overline{A} \cdot B + A \cdot \overline{B}$$

8. (d): For D -region, $f = 55 \times 10^6 \text{ Hz}$, $i = 30^\circ$
 $N = 400 \times 10^6 \text{ m}^{-3}$

$$\mu = \sqrt{1 - \frac{81.45 N}{f^2}}$$

$$\mu = \sqrt{1 - \frac{81.45 \times 400 \times 10^6}{(55 \times 10^6)^2}} \approx 1 \quad \therefore \mu = \frac{\sin i}{\sin r} = 1$$

$$\text{or } \sin i = \sin r$$

$$\text{or } i = r = 30^\circ$$

9. (a): Given, $V_Z = 24 \text{ V}$, $P_Z = 600 \text{ mW}$

Current through zener diode

$$I_Z = \frac{P_Z}{V_Z} = \frac{600 \times 10^{-3} \text{ W}}{24 \text{ V}} = 25 \text{ mA}$$

$$\text{Voltage drop across } R = 32 \text{ V} - 24 \text{ V} = 8 \text{ V}$$

$$\therefore R = \frac{8 \text{ V}}{25 \text{ mA}} = 320 \Omega$$

10. (b): Voltage drop across diode, $V_d = 0.5 \text{ V}$

Maximum power rating, $P = 100 \text{ mW}$

$$= 100 \times 10^{-3} \text{ W} = 0.1 \text{ W}$$

$$\text{Diode resistance, } R_d = \frac{V_d^2}{P} = \frac{(0.5 \text{ V})^2}{0.1 \text{ W}} = 2.5 \Omega$$

$$\text{Current in the diode, } I_d = \frac{V_d}{R_d} = \frac{0.5 \text{ V}}{2.5 \Omega} = 0.2 \text{ A}$$

$$\text{Total resistance of the circuit} = \frac{2.5 \text{ V}}{0.2 \text{ A}} = 12.5 \Omega$$

$$\text{Resistance } R \text{ in circuit} = 12.5 \Omega - 2.5 \Omega = 10 \Omega$$

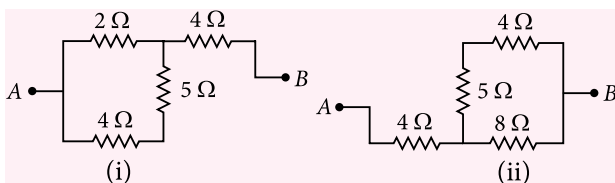
11. (b): $I = nAev_d$ or $I \propto nv_d$

$$\therefore \frac{I_e}{I_h} = \frac{n_e v_e}{n_h v_h}$$

$$\text{or } \frac{n_e}{n_h} = \frac{I_e}{I_h} \times \frac{v_h}{v_e} = \frac{7}{4} \times \frac{4}{5} = \frac{7}{5}$$

12. (d): The input signal should be connected between two points of bridge rectifier such that in positive half wave of input signal, one p - n junction should be forward biased and other should be reverse biased and in negative half wave of input signal, the reverse should take place. It will be so when input is connected between B and D .

13. (d): When positive terminal of external battery is connected to A and negative terminal of battery to B then D_1 is forward biased, will offer least resistance. D_2 is reverse biased, will offer maximum resistance. The effective circuit will be as shown in figure (i).



The effective resistance is $\frac{2 \times 9}{2 + 9} + 4 = 5.64 \Omega$.

When negative terminal of external battery is connected to A and positive terminal of battery to B, then D_1 is reverse biased and D_2 is forward biased. The effective circuit will be as shown in figure (ii).

The effective resistance is $4 + \frac{9 \times 8}{9 + 8} = 8.24 \Omega$.

14. (c): Number of electrons reaching the collector,

$$n_c = \frac{96}{100} \times 10^{10} = 0.96 \times 10^{10}$$

$$\text{Emitter current, } I_e = \frac{n_e \times e}{t}$$

$$\text{Collector current, } I_c = \frac{n_c \times e}{t}$$

$$\begin{aligned} \therefore \text{Current transfer ratio, } \alpha &= \frac{I_c}{I_e} = \frac{n_c}{n_e} \\ &= \frac{0.96 \times 10^{10}}{10^{10}} = 0.96 \end{aligned}$$

15. (b): Output of $G_1 = (A + B)$

$$\text{Output of } G_2 = \overline{A \cdot B}$$

Output of G_3 is

$$\begin{aligned} Y &= (A + B) \cdot (\overline{A \cdot B}) = (A + B) \cdot (\overline{A} + \overline{B}) \\ &= A \cdot \overline{A} + A \cdot \overline{B} + B \cdot \overline{A} + B \cdot \overline{B} = A \cdot \overline{B} + \overline{A} \cdot B \end{aligned}$$

It is the Boolean of XOR gate.

Hence, the given configuration of gates is equivalent to XOR gate.

16. (b): From the truth table we note that, $Y = A + B$ i.e., it is OR gate.

From gate in figure (i), $Y = A + X = A + B$.

$$\text{or } A + X = A + B = A + B \cdot (A + \overline{A})$$

$$(\because A + \overline{A} = 1)$$

$$= A + B \cdot A + B \cdot \overline{A} = A \cdot (1 + B) + \overline{A} \cdot B$$

$$= A + \overline{A} \cdot B$$

So $X = \overline{A} \cdot B$, which is AND gate with input as \overline{A} and B. Thus, gate X is AND gate.

17. (c)

18. (b): Here, h_{FE} = forward current ratio
i.e. $\beta = 90$, $V_{CE} = 4 \text{ V}$, $R_C = 2 \text{ k}\Omega$

If I_C is the collector current, then

$$9 - 4 = I_C R_C \Rightarrow I_C = \frac{5}{2 \times 10^3}$$

$$\text{or } I_C = 2.5 \text{ mA}$$

$$I_B = \frac{I_C}{\beta} = \frac{2.5 \text{ mA}}{90} = 2.78 \times 10^{-5} \text{ A}$$

Since the transistor operates in active region, therefore, $V_{BE} = 0.7 \text{ V}$

$$\begin{aligned} \therefore R_B &= \frac{3 - 0.7}{I_B} = \frac{2.3}{2.78 \times 10^{-5}} \approx 82 \times 10^3 \Omega \\ &= 82 \text{ k}\Omega \end{aligned}$$

19. (c): Maximum distance covered by space wave communication

$$= \sqrt{2Rh_T} = \sqrt{2 \times 6.4 \times 10^6 \times 300} \approx 62 \times 10^3 \text{ m.}$$

Since receiver-transmitter distance is 100 km. Therefore, signal cannot go either by ground wave or space wave.

For sky wave, the value of critical frequency of signal should be

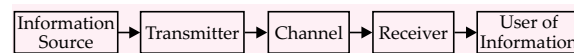
$$f_c = 9(N_{\max})^{\frac{1}{2}} = 9(10^{12})^{\frac{1}{2}} = 9 \times 10^6 \text{ Hz} = 9 \text{ MHz.}$$

As the signal frequency 5 MHz < 9 MHz, so the communication is through sky waves.

20. (c): During positive half cycle of input ac voltage, the p - n junction is forward biased. The resistance of p - n junction is low. The current in the circuit is maximum. In this situation, a maximum potential difference will appear across resistance connected in series of circuit. Due to it, there is no output voltage across p - n junction.

During the negative half-cycle of input ac voltage, the p - n junction is reverse biased. The resistance of p - n junction becomes high which will be more than resistance in series. Due to it, there will be voltage across p - n junction with negative cycle in output.

21. (b): The block diagram of a communication system is shown in the figure.



22. (a): Critical angle of core-cladding surface is

$$\sin C = \frac{\mu_2}{\mu_1} = \frac{1.49}{1.50} = 0.9933 = \sin 83^\circ 21'$$

$$\text{or } C = 83^\circ 21'$$

$$\text{For optical fibre, } \frac{\sin \theta_a}{\sin (90^\circ - \theta_i)} = \frac{\mu_1}{\mu_0}$$

$$\text{or } \frac{\sin \theta_a}{\cos \theta_i} = \frac{\mu_1}{\mu_0}$$

$$\text{or } \cos \theta_i = \frac{\mu_0}{\mu_1} \sin \theta_a = \frac{1}{1.5} \sin 10^\circ$$

$$= \frac{2}{3} \times 0.1736 = 0.1157$$

$$\theta_i = 83^\circ 20'$$

As the angle of incidence at the core and cladding surface is just equal to critical angle, so the ray will not suffer total internal reflection. Hence, the beam cannot propagate along the fibre.

23. (b): $f_c = 20 \text{ MHz} = 20 \times 10^6 \text{ Hz}$

$$\frac{1}{f_c} = \frac{1}{20} \times 10^{-6} = 0.05 \times 10^{-6} = 0.5 \times 10^{-7} \text{ s}$$

$$\text{Bandwidth} = 2f_m = 3 \text{ kHz} = 3 \times 10^3 \text{ Hz}$$

$$f_m = 1.5 \times 10^3 \text{ Hz}$$

$$\frac{1}{f_m} = \frac{1}{1.5} \times 10^{-3} = 0.7 \times 10^{-3} \text{ s.}$$

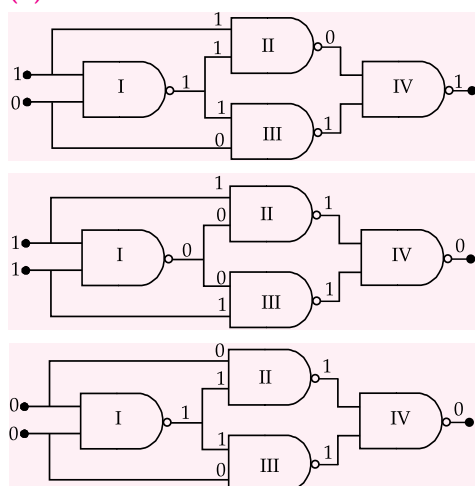
Diode detector can demodulate when

$$\frac{1}{f_c} \ll RC \ll \frac{1}{f_m}$$

$$\therefore RC = 10 \text{ k}\Omega \times 1 \times 10^{-8} \text{ F} = 10^{-4} \text{ s}$$

It can be demodulated.

24. (d):



25. (b): Here,

$$\text{Total time taken, } t = 4.04 \text{ ms} = 4.04 \times 10^{-3} \text{ s}$$

Let x be the distance of satellite from the surface of earth.

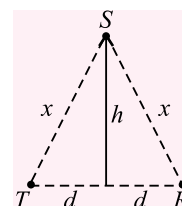
Total time taken (t) =

$$\frac{\text{Total distance travelled } (2x)}{\text{Speed of electromagnetic waves } (c)}$$

$$\therefore x = \frac{ct}{2} = \frac{(3 \times 10^8)(4.04 \times 10^{-3})}{2}$$

$$= 6.06 \times 10^5 \text{ m} = 606 \text{ km}$$

Let T be the source of electromagnetic waves (i.e. transmitter), R be receiver and S be satellite at locations as shown in figure.



$$d^2 = x^2 - h^2 = (606)^2 - (600)^2 = 7236$$

$$\therefore d = 85.06 \text{ km}$$

$$\text{Distance between source and receiver} = 2d = 2 \times 85.06 \approx 170 \text{ km}$$

26. (b): If p - n junction diode is made from germanium or silicon, the energy released due to recombination of free electrons and holes is in the infrared region. However, if the p - n junction diode is made from gallium arsenide or indium phosphide, then the energy released due to recombination of free electrons and holes is in the visible region.

27. (c): In a pure semiconductor,

$$n_e = n_h = 1.5 \times 10^{16} \text{ m}^{-3}$$

$$E = \frac{V}{l} = \frac{2}{10 \times 10^{-2}} = 20 \text{ V m}^{-1}$$

$$v_h = \mu_h \times E = 0.05 \times 20 = 1.0 \text{ m s}^{-1}$$

$$I_h = n_h A e v_h$$

$$= (1.5 \times 10^{16}) \times (1.0 \times 10^{-4}) \times (1.6 \times 10^{-19}) \times 1.0$$

$$= 2.4 \times 10^{-7} \text{ A}$$

28. (a): Here, $I_0 = 10^{-5} \text{ A}$, $T = 27 + 273 = 300 \text{ K}$,

$$I = 250 \times 10^{-3} \text{ A}$$

$$I = I_0 [e^{eV/kT} - 1]$$

$$\text{or } e^{eV/kT} = \frac{I}{I_0} + 1 = \frac{250 \times 10^{-3}}{10^{-5}} + 1 = 25001$$

$$\text{or } \frac{eV}{kT} = \ln(25001) = 10.126 \text{ or } V = \frac{10.126 \times kT}{e}$$

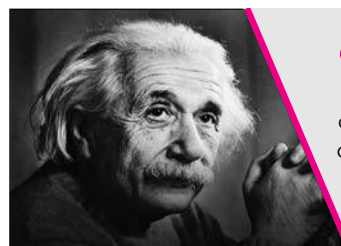
$$= \frac{10.126 \times 1.38 \times 10^{-23} \times 300}{1.6 \times 10^{-19}} = 0.26 \text{ V.}$$

29. (a): As, $V_B = V_{\text{knee}} + IR$

$$\text{or } 4 = 0.7 + 10^{-3} R$$

$$\text{or } R = \frac{3.3}{10^{-3}} = 3.3 \times 10^3 \Omega = 3.3 \text{ k}\Omega$$

30. (d)



“Common sense is nothing more than a deposit of prejudices laid down by the mind before you reach eighteen.”

— Albert Einstein

EXAM PREP 2016

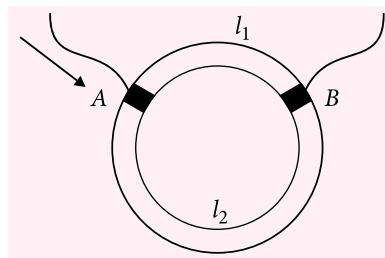
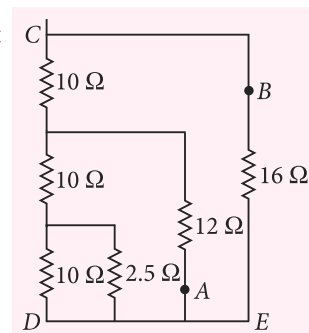
CHAPTERWISE MCQs FOR PRACTICE

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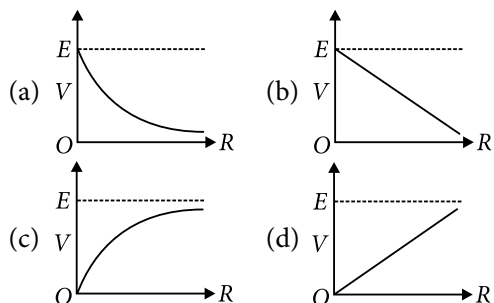
CURRENT ELECTRICITY

- The potential difference applied to an X-ray tube is 5 kV and the current through it is 3.2 mA. Then the number of electrons striking the target per second is
(a) 2×10^{16} (b) 5×10^6
(c) 1×10^{17} (d) 4×10^{15}
- In a hydrogen atom, an electron moves in an orbit of radius 5.0×10^{-11} m with a speed of 2.2×10^6 m s⁻¹. Find the equivalent current.
(Given, electronic charge = 1.6×10^{-19} coulomb)
(a) 1.12×10^{-3} A (b) 1.5×10^{-3} A
(c) 3.2×10^{-6} A (d) 1.12×10^{-6} A
- Masses of the three wires of same material are in the ratio of 1 : 2 : 3 and their lengths in the ratio 3 : 2 : 1. Electrical resistance of these wires will be in the ratio of
(a) 1 : 1 : 1 (b) 1 : 2 : 3
(c) 9 : 4 : 1 (d) 27 : 6 : 1
- The resistance of a wire at 300 K is found to be 0.3 Ω . If the temperature coefficient of resistance of wire is 1.5×10^{-3} K⁻¹, then the temperature at which the resistance becomes 0.6 Ω , is
(a) 720 K (b) 345 K
(c) 993 K (d) 690 K
- What is the drift velocity of electrons, if the current flowing through a copper wire of 1 mm diameter is 1.1 A? Assume that, each atom of copper contributes one electron. (Given, density of Cu = 9 g cm⁻³ and atomic weight of Cu = 63)
(a) 0.3 mm s⁻¹ (b) 0.5 mm s⁻¹
(c) 0.1 mm s⁻¹ (d) 0.2 mm s⁻¹
- In cosmic rays 0.15 protons cm⁻² s⁻¹ are entering the earth's atmosphere. If the radius of the earth is 6400 km, the current received by the earth in the form of cosmic rays is nearly
(a) 0.12 A (b) 1.2 A
(c) 12 A (d) 120 A
- What is the equivalent resistance across the points A and B in the given circuit?
(a) 8 Ω
(b) 12 Ω
(c) 16 Ω
(d) 32 Ω
- A ring is made of a wire having a resistance $R_0 = 12 \Omega$. Find the points A and B as shown in the figure, at which a current carrying conductor should be connected so that the resistance R of the sub-circuit between these points is equal to $8/3 \Omega$.

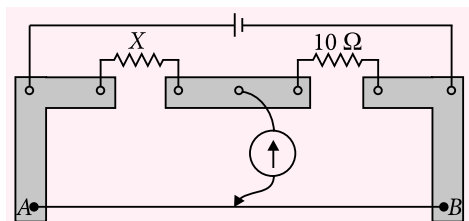
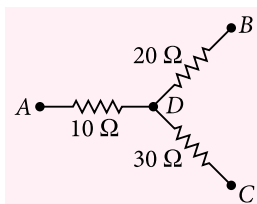


- $\frac{l_1}{l_2} = \frac{5}{8}$
- $\frac{l_1}{l_2} = \frac{1}{3}$
- $\frac{l_1}{l_2} = \frac{3}{8}$
- $\frac{l_1}{l_2} = \frac{1}{2}$

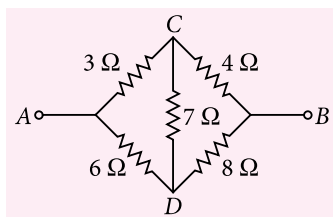
9. A cell having an emf E and internal resistance r , are connected across a variable external resistance R . As the resistance R is increased, the plot of potential difference V across R is given by



10. In the circuit given here, the points A, B and C are at 70 V, zero and 10 V respectively. Then,
 (a) the point D will be at a potential of 60 V
 (b) the point D will be at a potential of 20 V
 (c) currents in the paths AD, DB and DC are in the ratio of 1 : 2 : 3
 (d) currents in the paths AD, DB and DC are in the ratio of 3 : 2 : 1
11. A meter bridge is set-up as shown, to determine an unknown resistance X using a standard $10\ \Omega$ resistor. The galvanometer shows null point when tapping-key is at 52 cm mark. The end-corrections are 1 cm and 2 cm respectively for the ends A and B. The determined value of X is

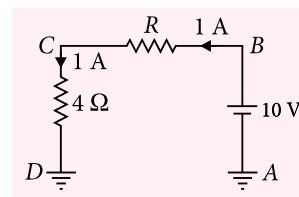


- (a) $10.2\ \Omega$ (b) $10.6\ \Omega$ (c) $10.8\ \Omega$ (d) $11.1\ \Omega$
12. A bridge circuit is shown in the figure. The equivalent resistance between points A and B is

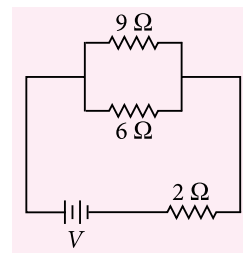


- (a) $21\ \Omega$ (b) $7\ \Omega$ (c) $\frac{252}{85}\ \Omega$ (d) $\frac{14}{3}\ \Omega$

13. In the figure, the potential at points B and C, and the value of resistance R are
 (a) 10 V, 4 V, $4\ \Omega$
 (b) 6 V, 4 V, $6\ \Omega$
 (c) 10 V, 4 V, $6\ \Omega$
 (d) 6 V, 4 V, $4\ \Omega$



14. If the power dissipated in the $9\ \Omega$ resistor in the circuit shown is 36 W, then the potential difference across the $2\ \Omega$ resistor is
 (a) 8 V
 (b) 10 V
 (c) 2 V
 (d) 4 V

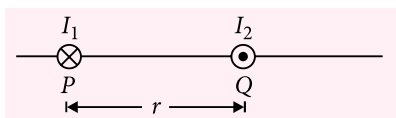


15. Three identical bulbs are connected in series and these together dissipate a power P . If the bulbs are connected in parallel, then the power dissipated will be
 (a) $P/3$ (b) $3P$ (c) $9P$ (d) $P/9$

MOVING CHARGES AND MAGNETISM

16. An element $\Delta \vec{l} = \Delta x \hat{i}$ is placed at the origin and carries a large current $I = 10\text{ A}$. What is the magnetic field on the y -axis at a distance of 0.5 m if $\Delta x = 1\text{ cm}$?
 (a) $4 \times 10^{-8}\text{ T}$ (b) $8 \times 10^{-8}\text{ T}$
 (c) $4 \times 10^{-5}\text{ T}$ (d) $8 \times 10^{-5}\text{ T}$
17. In hydrogen atom, the electron is making $6.6 \times 10^{15}\text{ rev s}^{-1}$ around the nucleus of radius 53 Å . The magnetic field produced at the centre of the orbit is nearly
 (a) 0.12 Wb m^{-2} (b) 1.2 Wb m^{-2}
 (c) 12 Wb m^{-2} (d) 120 Wb m^{-2}
18. The magnetic field normal to the plane of a wire of n turns and radius r which carries a current I is measured on the axis of the coil at a small distance h from the centre of the coil. This is smaller than the magnetic field at the centre by the fraction
 (a) $(2/3)r^2/h^2$ (b) $(3/2)r^2/h^2$
 (c) $(2/3)h^2/r^2$ (d) $(3/2)h^2/r^2$

19. Two parallel wires P and Q placed at a separation of $r = 6$ cm carry electric currents $I_1 = 5$ A and $I_2 = 2$ A in opposite directions as shown in figure. Find the point on the line PQ where the resultant magnetic field is zero.



- (a) 4 cm to the right of Q
 (b) 9 cm to the left of P
 (c) 2 cm to the right of P
 (d) 3 cm to the left of Q
20. Two wires PQ and QR , carry equal currents I as shown in figure. One end of both the wires extends to infinity and $\angle PQR = \theta$. The magnitude of the magnetic field at O on the bisector angle of these two wires at a distance r from point Q is
- (a) $\frac{\mu_0 I}{4\pi r} \sin\left(\frac{\theta}{2}\right)$ (b) $\frac{\mu_0 I}{4\pi r} \cot\left(\frac{\theta}{2}\right)$
 (c) $\frac{\mu_0 I}{4\pi r} \tan\left(\frac{\theta}{2}\right)$ (d) $\frac{\mu_0 I}{2\pi r} \frac{(1 + \cos \theta / 2)}{(\sin \theta / 2)}$
21. A solenoid of length 50 cm and radius of cross-section 1 cm has 1000 turns of wire wound over it. If the current carried is 5 A, the magnetic field on its axis, near the centre of the solenoid is approximately (permeability of free space $\mu_0 = 4\pi \times 10^{-7}$ T m A $^{-1}$)
 (a) 0.63×10^{-2} T (b) 1.26×10^{-2} T
 (c) 2.51×10^{-2} T (d) 6.3 T
22. A long straight wire of radius a carries a steady current I . The current is uniformly distributed across its cross-section. The ratio of the magnetic field at $\frac{a}{2}$ and $2a$ is
 (a) 1 : 4 (b) 4 : 1 (c) 1 : 1 (d) 1 : 2
23. A particle of charge -16×10^{-18} coulomb moving with velocity 10 m s $^{-1}$ along the X -axis enters a region, where a magnetic field of induction B is along the Y -axis and an electric field of magnitude 10^4 V m $^{-1}$ is along the negative Z -axis. If the charged particle continues moving along the X -axis, the magnitude of B is

- (a) 10^3 Wb m $^{-2}$ (b) 10^5 Wb m $^{-2}$
 (c) 10^{16} Wb m $^{-2}$ (d) 10^{-2} Wb m $^{-2}$

24. A deuteron of kinetic energy 50 keV is describing a circular orbit of radius 0.5 m, in a plane perpendicular to magnetic field B . The kinetic energy of a proton that describes circular orbit of radius 0.5 m in the same plane with the same magnetic field is
 (a) 200 keV (b) 50 keV
 (c) 100 keV (d) 25 keV
25. A galvanometer of resistance 25 Ω is connected to a battery of 2 V along with a resistance in series. When the value of this resistance is 3000 Ω , a full scale deflection of 30 units is obtained in the galvanometer. In order to reduce this deflection to 20 units, the resistance in series will be
 (a) 4513 Ω (b) 5413 Ω
 (c) 2000 Ω (d) 6000 Ω
26. The current sensitivity of a moving coil galvanometer increases by 35 %, when its resistance is increased by a factor of 3. The voltage sensitivity of galvanometer changes by a factor
 (a) 35% (b) 45%
 (c) 55% (d) None of these
27. A coil in the shape of an equilateral triangle of side 0.02 m is suspended from its vertex such that it is hanging in a vertical plane between the pole pieces of permanent magnet producing a uniform field of 5×10^{-2} T. If a current of 0.1 A is passed through the coil, what is the couple acting?
 (a) $5\sqrt{3} \times 10^{-7}$ N m (b) $5\sqrt{3} \times 10^{-10}$ N m
 (c) $\frac{\sqrt{3}}{5} \times 10^{-7}$ N m (d) None of these
28. Two thin long parallel wires separated by a distance b are carrying a current I ampere each. The magnitude of the force per unit length exerted by one wire on the other, is
 (a) $\frac{\mu_0 I^2}{b^2}$ (b) $\frac{\mu_0 I}{2\pi b^2}$ (c) $\frac{\mu_0 I}{2\pi b}$ (d) $\frac{\mu_0 I^2}{2\pi b}$
29. A galvanometer of resistance 100 Ω gives a full scale deflection for a current of 10^{-5} A. To convert it into an ammeter capable of measuring upto 1 A, we should connect a resistance of
 (a) 1 Ω in parallel (b) 10^{-3} Ω in parallel
 (c) 10^5 Ω in series (d) 100 Ω in series

30. In a cyclotron, a magnetic induction of 1.4 T is used to accelerate protons. What should be the frequency of applied electric field? The mass and charge of proton are 1.67×10^{-27} kg and 1.6×10^{-19} C respectively.

- (a) 2.5×10^7 Hz (b) 2.14×10^7 Hz
(c) 3.5×10^7 Hz (d) 3.84×10^7 Hz

SOLUTIONS

1. (a): As $I = \frac{q}{t} = \frac{ne}{t}$
 $\therefore n = \frac{It}{e} = \frac{3.2 \times 10^{-3} \times 1}{1.6 \times 10^{-19}} = 2 \times 10^{16}$
2. (a): Here $r = 5.0 \times 10^{-11}$ m,
 $v = 2.2 \times 10^6$ m s⁻¹, $e = 1.6 \times 10^{-19}$ C
 Period of revolution of electron,
 $T = \frac{2\pi r}{v} = \frac{2\pi \times 5.0 \times 10^{-11}}{2.2 \times 10^6}$ s
 Frequency, $\nu = \frac{1}{T} = \frac{2.2 \times 10^6}{2\pi \times 5.0 \times 10^{-11}}$
 $= \frac{2.2 \times 7 \times 10^{17}}{2 \times 22 \times 5} = 7 \times 10^{15}$ s⁻¹
 Current, $I = e\nu = 1.6 \times 10^{-19} \times 7 \times 10^{15}$
 $= 1.12 \times 10^{-3}$ A
3. (d): Mass, $M = \text{volume} \times \text{density} = Al \times d$
 or $A = M/l d$

Resistance, $R = \rho l / A = \rho l / (M/l d) = \frac{\rho l^2 d}{M}$
 So, $R \propto l^2 / M$

Thus, $R_1 : R_2 : R_3 = \frac{l_1^2}{M_1} : \frac{l_2^2}{M_2} : \frac{l_3^2}{M_3}$
 $= \frac{3^2}{1} : \frac{2^2}{2} : \frac{1^2}{3} = 27 : 6 : 1$

4. (c): Given, $R_{300} = 0.3 \Omega$, $R_t = 0.6 \Omega$
 and $T = 300$ K = 27°C
 Temperature coefficient of resistance,
 $\alpha = 1.5 \times 10^{-3} \text{ K}^{-1}$
 $\therefore R_{300} = R_0(1 + \alpha \times 27)$
 $\Rightarrow 0.3 = R_0(1 + 1.5 \times 10^{-3} \times 27)$... (i)
 Again, $R_t = R_0(1 + \alpha t)$
 $\Rightarrow 0.6 = R_0(1 + 1.5 \times 10^{-3} \times t)$... (ii)
 Dividing eq. (ii) and eq. (i), we get

$$\frac{0.6}{0.3} = \frac{1 + 1.5 \times 10^{-3} t}{1 + 1.5 \times 10^{-3} \times 27}$$

$$\Rightarrow 2(1 + 1.5 \times 10^{-3} \times 27) = 1 + 1.5 \times 10^{-3} t$$

$$\Rightarrow 2 + 81 \times 10^{-3} = 1 + 1.5 \times 10^{-3} t$$

$$\Rightarrow 2 + 0.081 = 1 + 1.5 \times 10^{-3} t$$

$$\Rightarrow t = \frac{1.081}{1.5 \times 10^{-3}} = 720^\circ\text{C} = 993 \text{ K}$$

5. (c): As, $I = neAv_d$
 where, the number of electrons

$$n = \frac{\text{Avogadro's number}}{\text{Volume of 63 g of copper}}$$

$$= \frac{6.02 \times 10^{23}}{63 \times 10^{-3}} = \frac{6.02 \times 10^{23}}{7} \text{ cm}^{-3}$$

$$\therefore n = \frac{6.02 \times 10^{29}}{7} \text{ m}^{-3}$$

Also, $v_d = \frac{I}{neA}$

$$= \frac{1.1 \times 7}{6.02 \times 10^{29} \times 1.6 \times 10^{-19} \times \pi \times (0.5 \times 10^{-3})^2}$$

$$= 0.1 \times 10^{-3} \text{ m s}^{-1} = 0.1 \text{ mm s}^{-1}$$

6. (a): Surface area of earth, $A = 4\pi r^2$
 Charge entering the earth per second per unit area
 $J = 0.15 \times 1.6 \times 10^{-19} \text{ cm}^{-2} \text{ s}^{-1}$
 $= 0.15 \times 1.6 \times 10^{-19} \times 10^4 \text{ m}^{-2} \text{ s}^{-1}$
 \therefore Current, $I = JA = J 4\pi r^2$
 $= 0.15 \times 1.6 \times 10^{-19} \times 10^4 \times 4 \times 3.14 \times (6.4 \times 10^6)^2$
 $= 0.12 \text{ A}$

7. (a): $\frac{1}{R_1} = \frac{1}{10} + \frac{1}{2.5} = \frac{5}{10} = \frac{1}{2} \Rightarrow R_1 = 2 \Omega$

Now 2Ω and 10Ω are in series

$$R_2 = 10 + 2 = 12 \Omega$$

R_2 and 12Ω are in parallel

$$\frac{1}{R_3} = \frac{1}{12} + \frac{1}{12} \Rightarrow R_3 = 6 \Omega$$

Now, R_3 and 10Ω are in series

$$R_4 = 10 + 6 = 16 \Omega$$

Now, R_4 and 16Ω are in parallel

$$\therefore \frac{1}{R} = \frac{1}{16} + \frac{1}{16} \Rightarrow R = 8 \Omega$$

8. (d): Resistance of wire, $R = \rho \frac{l}{A}$
 $\therefore R \propto l$

Here, $R_0 = R_1 + R_2 = 12 \Omega$

... (i)

and $\frac{R_1 \times R_2}{R_1 + R_2} = \frac{8}{3} \Omega$ ($\because R_1$ and R_2 are in parallel)

Putting $R_1 + R_2 = 12 \Omega$ in above equation, we get

$$R_1 R_2 = 32 \, \Omega \quad \dots(ii)$$

After solving eq. (i) and (ii), we get

$$R_1 = 4 \, \Omega \text{ and } R_2 = 8 \, \Omega$$

Hence, $\frac{l_1}{l_2} = \frac{R_1}{R_2} = \frac{1}{2}$

9. (c): Here $E = I(R + r) \Rightarrow I = E/(R + r)$

Also, $E = IR + Ir$ or $E = V + Ir$

$$\therefore E = V + \frac{Er}{R+r} \Rightarrow V = E - \frac{E}{R+r} \times r = \frac{ER}{R+r}$$

$$V = \frac{E}{1+r/R}$$

So, graph must be as given in option(c).

10. (d): Applying Kirchhoff's law at junction point D, we get

$$I_1 = I_2 + I_3$$

$$\Rightarrow \frac{V_A - V_D}{10} = \frac{V_D - V_B}{20} + \frac{V_D - V_C}{30}$$

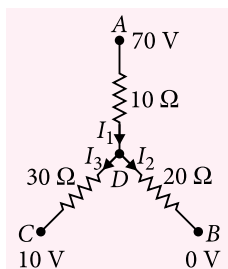
$$\Rightarrow 70 - V_D = \frac{V_D}{2} + \frac{V_D - 10}{3}$$

$$\Rightarrow V_D = 40 \, \text{V}$$

$$\therefore I_1 = \frac{70 - 40}{10} = 3 \, \text{A}$$

$$I_2 = \frac{40 - 0}{20} = 2 \, \text{A}$$

and $I_3 = \frac{40 - 10}{30} = 1 \, \text{A}$



11. (b): Using the condition for balanced Wheatstone bridge, we get

$$\frac{X}{10 \, \Omega} = \frac{(52+1)\text{cm}}{(100-52+2)\text{cm}} = \frac{53}{50}$$

or $X = \frac{53 \times 10}{50} = 10.6 \, \Omega$

12. (d): The Wheatstone bridge is balanced, because

$$\frac{3 \, \Omega}{4 \, \Omega} = \frac{6 \, \Omega}{8 \, \Omega}$$

$\therefore 7 \, \Omega$ resistance is ineffective, we now have $(3 \, \Omega + 4 \, \Omega)$ and $(6 \, \Omega + 8 \, \Omega)$ resistance in parallel.

$$\therefore R_{AB} = \frac{7 \times 14}{7 + 14} = \frac{14}{3} \, \Omega$$

13. (c): Let the potential at points A, B, C and D be V_A , V_B , V_C and V_D respectively.

Potential difference between the points B and A

$$V_B - V_A = 10 \, \text{V}$$

As, earth potential is taken zero, so $V_A = 0$

$$\therefore V_B - 0 = 10 \, \text{V} \text{ or } V_B = 10 \, \text{V}$$

Potential difference between the points C and D

$$V_C - V_D = 1 \times 4 = 4 \, \text{V}$$

$$\therefore V_C - 0 = 4 \text{ or } V_C = 4 \, \text{V}$$

Potential difference between the point B and C

$$= 10 - 4 = 6 \, \text{V} \therefore R = \frac{6}{1} = 6 \, \Omega$$

14. (b): The power dissipated in resistor of $9 \, \Omega$ is

$$P = \frac{V_1^2}{R} \Rightarrow 36 = \frac{V_1^2}{9} \Rightarrow V_1^2 = 36R$$

$$\Rightarrow V_1 = \sqrt{36 \times 9} \Rightarrow V_1 = 6 \times 3 = 18 \, \text{V}$$

\therefore Total current through circuit is

$$V = IR_{\text{eq}} \Rightarrow 18 = I \left(\frac{9 \times 6}{9 + 6} \right) \Rightarrow 18 = I \left[\frac{18}{5} \right] \Rightarrow I = 5 \, \text{A}$$

Potential across $2 \, \Omega$ is

$$V_2 = IR \Rightarrow V_2 = 5(2) = 10 \, \text{V}$$

15 (c): By Joule's law, the power dissipated through a resistor R , having a potential difference V is

$$P = \frac{V^2}{R}$$

When bulbs are connected in series, then

$$R' = R + R + R = 3R$$

Power dissipated, $P = \frac{V^2}{3R} \quad \dots(i)$

When they are connected in parallel, then

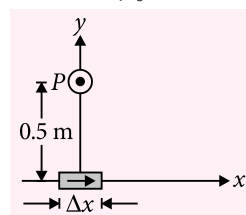
$$\frac{1}{R''} = \frac{1}{R} + \frac{1}{R} + \frac{1}{R} = \frac{3}{R} \Rightarrow R'' = \frac{R}{3}$$

Power dissipated, $P' = \frac{V^2}{R/3} \quad \dots(ii)$

From eq. (i) and (ii), we have

$$P' = 9P$$

16 (a): Here $dl = \Delta x = 1 \, \text{cm} = 10^{-2} \, \text{m}$, $I = 10 \, \text{A}$, $r = y = 0.5 \, \text{m}$, $\theta = 90^\circ$, $\mu_0/4\pi = 10^{-7} \, \text{T m A}^{-1}$



According to Biot-Savart law,

$$dB = \frac{\mu_0}{4\pi} \frac{Idl \sin \theta}{r^2} = \frac{10^{-7} \times 10 \times 10^{-2} \times \sin 90^\circ}{(0.5)^2}$$

$$= 4 \times 10^{-8} \, \text{T}$$

The direction of the field \vec{dB} will be the direction of vector $\vec{dl} \times \vec{r}$.

$$\vec{dl} \times \vec{r} = \Delta x \hat{i} \times y \hat{j} = \Delta xy (\hat{i} \times \hat{j}) = \Delta xy \hat{k}$$

Hence field \vec{dB} is in the $+z$ -direction.

$$\begin{aligned} 17. (a): B &= \frac{\mu_0 I}{2r} = \frac{\mu_0}{2r} \times (ev) \\ &= \frac{4\pi \times 10^{-7} \times 1.6 \times 10^{-19} \times 6.6 \times 10^{15}}{2 \times 53 \times 10^{-10}} \\ &= 0.12 \text{ Wb m}^{-2} \end{aligned}$$

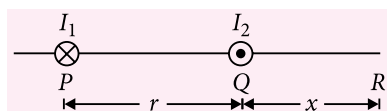
$$18. (d): B_1 = \frac{\mu_0}{4\pi} \frac{2\pi n I}{r} \text{ and } B_2 = \frac{\mu_0}{4\pi} \frac{2\pi n I r^2}{(r^2 + h^2)^{3/2}}$$

$$\text{So, } \frac{B_2}{B_1} = \left(1 + \frac{h^2}{r^2}\right)^{-3/2}$$

Fractional decrease in the magnetic field will be

$$\begin{aligned} \frac{B_1 - B_2}{B_1} &= \left(1 - \frac{B_2}{B_1}\right) \\ &= \left[1 - \left(1 + \frac{h^2}{r^2}\right)^{-3/2}\right] = 1 - \left(1 - \frac{3h^2}{2r^2}\right) = \frac{3h^2}{2r^2} \end{aligned}$$

19. (a): At the required point, the resultant magnetic field will be zero when the fields due to the two wires have equal magnitude and opposite directions. Such point should lie either to the left of P or to the right of Q . But the wire Q has smaller current, the point should lie closer to the right of Q . Let this point be R at distance x from Q , as shown in figure.



Field due to current I_1 at point R ,

$$B_1 = \frac{\mu_0 I_1}{2\pi(r+x)},$$

Field due to current I_2 at point R ,

$$B_2 = \frac{\mu_0 I_2}{2\pi x},$$

But $B_1 = B_2$

$$\therefore \frac{I_1}{r+x} = \frac{I_2}{x}$$

$$\text{or } x = \frac{I_2 r}{I_1 - I_2} = \frac{2 \text{ A} \times 6 \text{ cm}}{5 \text{ A} - 2 \text{ A}} = 4 \text{ cm}$$

20. (d): Perpendicular to O from PQ or QR , $a = r \sin \theta/2$
Magnetic field induction at O due to current through PQ and QR is

$$\begin{aligned} B &= \frac{\mu_0}{4\pi a} [\sin(90^\circ - \theta/2) + \sin 90^\circ] \times 2 \\ &= \frac{\mu_0}{2\pi r \sin \theta/2} (\cos \theta/2 + 1) = \frac{\mu_0}{2\pi r} \frac{I(1 + \cos \theta/2)}{\sin \theta/2}. \end{aligned}$$

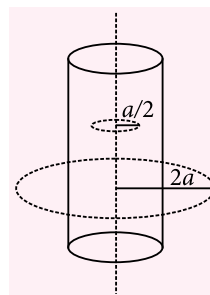
21. (b): The magnetic field is given by $B = \mu_0 n I$
where, $\mu_0 = 4\pi \times 10^{-7} \text{ T m A}^{-1}$

$$n = \frac{1000}{50 \times 10^{-2}}, I = 5 \text{ A}$$

$$\therefore B = 4\pi \times 10^{-7} \times \frac{1000}{50 \times 10^{-2}} \times 5$$

$$B = 1.26 \times 10^{-2} \text{ T}$$

22. (c): Current density, $J = \frac{I}{\pi a^2}$



From Ampere's circuital law

$$\oint \vec{B} \cdot d\vec{l} = \mu_0 \cdot I_{\text{enclosed}}$$

For $r < a$, $B \times 2\pi r = \mu_0 \times J \times \pi r^2$

$$\Rightarrow B = \frac{\mu_0 I}{\pi a^2} \times \frac{r}{2}$$

$$\text{At } r = a/2, B_1 = \frac{\mu_0 I}{4\pi a} \quad \dots(i)$$

For $r > a$, $B \times 2\pi r = \mu_0 I \Rightarrow B = \frac{\mu_0 I}{2\pi r}$

$$\text{At } r = 2a, B_2 = \frac{\mu_0 I}{4\pi a} \quad \dots(ii)$$

$$\text{So, } \frac{B_1}{B_2} = 1$$

23. (a): Given $q = -16 \times 10^{-18} \text{ C}$, $v = 10\hat{i} \text{ m s}^{-1}$

$$\vec{B} = B\hat{j}, \vec{E} = -10^4 \hat{k} \text{ Vm}^{-1}$$

$$\vec{F}_e = q\vec{E} = -16 \times 10^{-18} \times (-10^4 \hat{k})$$

$$= 16 \times 10^{-14} \hat{k} \text{ N}$$

$$\vec{F}_m = q(\vec{v} \times \vec{B}) = -16 \times 10^{-18} (10\hat{i} \times B\hat{j})$$

$$= -16 \times 10^{-17} B \hat{k} \text{ N}$$

As the particle continues to move along the same direction,

$$\begin{aligned} F_m &= F_e \\ \therefore 16 \times 10^{-17} B &= 16 \times 10^{-14} \\ \text{or } B &= 10^3 \text{ Wb m}^{-2} \end{aligned}$$

- 24. (c):** In this case, magnetic force provides necessary centripetal force *i.e.*

$$qvB = \frac{mv^2}{r}$$

Radius of path, $r = \frac{mv}{Bq} = \frac{\sqrt{2mE}}{qB}$

$$\therefore r = \frac{\sqrt{2mE}}{Bq} = \frac{\sqrt{2m_1 E_1}}{Bq}$$

$$\begin{aligned} \text{or } E_1 &= \frac{mE}{m_1} = \frac{(2m_1)}{m_1} \times 50 \text{ keV} \quad [\because m = 2m_1] \\ &= 100 \text{ keV} \end{aligned}$$

- 25. (a):** Current through galvanometer,

$$I_g = \frac{V}{R+G} = \frac{2}{3000+25} = k \times 30 \quad \dots(i)$$

where k is figure of merit of galvanometer. The current corresponding to 20 units deflection of galvanometer,

$$I = \frac{I_g}{30} \times 20 = \frac{2}{3} I_g = \frac{2}{3} \times \frac{2}{3025} \text{ A}$$

If R' is the resistance to be used in series of galvanometer, then

$$I = \frac{V}{R'+G} \quad \text{or} \quad \frac{2}{3} \times \frac{2}{3025} = \frac{2}{R'+25}$$

On solving, we get

$$R' = 4512.5 \, \Omega \approx 4513 \, \Omega$$

- 26. (c):** Given $I_s' = I_s + \frac{35}{100} I_s = \frac{135}{100} I_s$

$$\text{Initial voltage sensitivity, } V_s = \frac{I_s}{R}$$

$$\text{New voltage sensitivity, } V_s' = \frac{I_s'}{R'}$$

$$= \left(\frac{135}{100} I_s \right) \times \frac{1}{3R} = \frac{9}{20} V_s$$

% decrease in voltage sensitivity

$$\left(\frac{V_s - V_s'}{V_s} \right) \times 100\% = \frac{V_s - \frac{9}{20} V_s}{V_s} \times 100\% = 55\%$$

- 27. (a):** Torque, $\tau = IAB \sin \theta$, $I = 0.1 \text{ A}$, $\theta = 90^\circ$

$$A = \frac{1}{2} \times \text{base} \times \text{height}$$

$$\text{or } A = \frac{1}{2} a \times \frac{a\sqrt{3}}{2}$$

$$= \frac{\sqrt{3}a^2}{4} = \frac{\sqrt{3} \times (0.02)^2}{4} = \sqrt{3} \times 10^{-4} \text{ m}^2$$

$$\begin{aligned} \tau &= 0.1 \times \sqrt{3} \times 10^{-4} \times 5 \times 10^{-2} \sin 90^\circ \\ &= 5\sqrt{3} \times 10^{-7} \text{ N m} \end{aligned}$$

- 28. (d):** Let two long parallel thin wires X and Y carry current I and separated by a distance b apart.

The magnitude of magnetic field B at any point on Y due to current I_1 in X is given by

$$B = \frac{\mu_0}{2\pi} \frac{I_1}{b}$$

The magnitude of force acting on length l of Y is

$$F = I_2 B l = I_2 \left(\frac{\mu_0}{2\pi} \frac{I_1}{b} \right) l$$

Force per unit length is

$$\frac{F}{l} = \frac{\mu_0}{2\pi} \frac{I_1 I_2}{b}$$

Given $I_1 = I_2 = I$, therefore

$$\frac{F}{l} = \frac{\mu_0}{2\pi} \frac{I^2}{b}$$

- 29. (b):** $G = 100 \, \Omega$, $I_g = 10^{-5} \text{ A}$, $I = 1 \text{ A}$

To convert the galvanometer into an ammeter, we should connect a resistance S in parallel to it.

$$\therefore I_g \times G = (I - I_g) \times S$$

$$S = \left(\frac{I_g}{I - I_g} \right) \times G = \frac{10^{-5}}{1 - 10^{-5}} \times 100$$

$$\text{or } S = \frac{10^{-3}}{1 - 0.00001} = 10^{-3} \, \Omega$$

- 30. (b):** Here, $B = 1.4 \text{ T}$, $m = 1.67 \times 10^{-27} \text{ kg}$,
 $e = 1.6 \times 10^{-19} \text{ C}$

The time required by a charged particle to complete a semicircle in a dee is

$$t = \frac{\pi m}{eB} = \frac{3.14 \times 1.67 \times 10^{-27}}{1.6 \times 10^{-19} \times 1.4} = 2.34 \times 10^{-8} \text{ s.}$$

Thus, the direction of electric field should reverse after every $2.34 \times 10^{-8} \text{ s}$.

The frequency of the applied electric field should be

$$f_c = \frac{1}{2t} = \frac{1}{2 \times 2.34 \times 10^{-8}} = 2.14 \times 10^7 \text{ Hz.}$$



JEE

Exam on
22nd May

Advanced

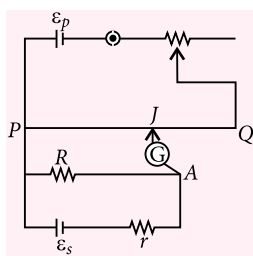
PRACTICE PAPER 2016

PAPER-I

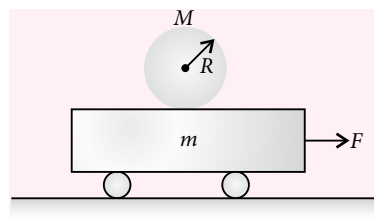
SECTION 1 (MAXIMUM MARKS : 32)

- This section contains EIGHT questions
- The answer to each question is a single digit integer ranging from 0 to 9, both inclusive

1. Let us assume that air is under standard conditions close to the Earth's surface. Presuming that the temperature and the molar mass of air are independent of height, find the air pressure (in atm) in a mine at the depth 5.0 km below the surface. (Molar mass of air is 28 g mol^{-1})
2. A thin convergent lens is placed between an object and a screen whose positions are fixed. There are two positions of the lens at which the sharp image of the object is formed on the screen. Find the transverse dimension (in mm) of the object if at one position the transverse dimension of the image is $h_1 = 8 \text{ mm}$ and at the other $h_2 = 2 \text{ mm}$.
3. One of the circuits for the measurement of resistance by potentiometer is shown in the figure. The galvanometer is connected at point A and zero deflection is observed at length $PJ = 30 \text{ cm}$ when $\epsilon_s = 10 \text{ V}$ and $r = 1 \Omega$. In second case the secondary cell is changed as $\epsilon_s = 5 \text{ V}$ and $r = 2 \Omega$, then zero deflection is observed at length $PJ = 10 \text{ cm}$. What is the current (in A) through resistance R when $PJ = 30 \text{ cm}$?



4. Particle P_1 moving with velocity 10 m s^{-1} experienced a head-on-collision with a stationary particle P_2 of the same mass. As a result of the collision, the kinetic energy of the system decreased by 50%. Find the magnitude of the velocity of particle P_1 after the collision.
5. A 1.0 g sample of pure KCl from the chemistry stockroom is found to be radioactive and to decay at an absolute rate of $1600 \text{ counts s}^{-1}$. The decays are traced to the element potassium and in particular to the isotope ^{40}K , which constitutes 1.18% of normal potassium. The half-life for this decay is 13×10^9 years. Find N . (Molar mass of KCl is 74.9 g mol^{-1} .)
6. A point isotropic source is located on a line perpendicular to the plane of a ring drawn through the centre of the ring. The distance between the centre of the ring and the source is 1 m, the radius of the ring is 0.50 m. Find the rate of mean energy flow (in μW) across the area enclosed by ring if the intensity of source at the centre of ring is equal to $I_0 = 3 \mu\text{W m}^{-2}$.
7. What is the maximum horizontal force F (in N) that may be applied to the plank of mass $3/7 \text{ kg}$ for which the solid sphere does not slip as it begins to roll on the plank. The sphere has a mass 0.5 kg and radius 5 cm . The coefficient of static and kinetic friction between the sphere and the plank are 0.25 and 0.24 respectively.



8. Two long parallel wires of negligible resistance are connected at one end to a resistance R and at other end to a dc voltage source. The distance between the axes of the wire is 20 times greater than the cross-sectional radius of each wire. The resultant force of interaction between the wires turn into zero for $R = 3.6 \times 10^p \Omega$. What is the value of p ? (Neglect the effect of gravity.)

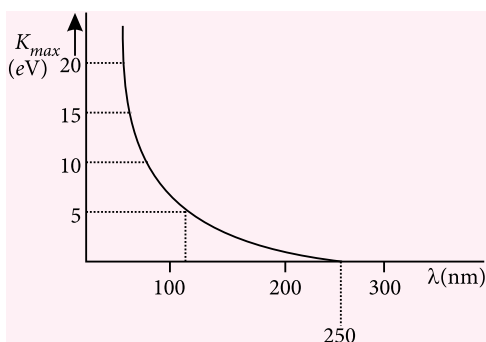
SECTION 2 (MAXIMUM MARKS : 40)

- This section contains TEN questions
- Each question has FOUR options (a), (b), (c) and (d). ONE OR MORE THAN ONE of these four option(s) is(are) correct

9. In two systems of units, the relation between velocity, acceleration and force is $v_2 = \frac{v_1 e^2}{\tau}$, $a_2 = a_1 e \tau$, and $F_2 = \frac{F_1}{e \tau}$, where e and τ are constants. Relation between mass, length and time in the two systems is correctly given by

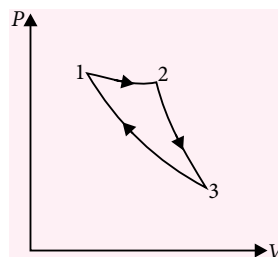
(a) $M_2 = \frac{M_1}{e^2 \tau^2}$ (b) $L_2 = \frac{L_1 e^2}{T^2}$
 (c) $T_2 = \frac{T_1 e}{\tau^2}$ (d) $L_2 = \frac{L_1 e^3}{T^3}$

10. In a photoelectric effect experiment, the maximum kinetic energy of the ejected photoelectrons is measured for various wavelengths of the incident light. Figure shows a graph of this maximum kinetic energy K_{max} as a function of the wavelength λ of the light falling on the surface of the metal. Which of the following statements is/are correct?



- (a) Threshold frequency for the metal is 1.2×10^{15} Hz.
 (b) Work function of the metal is 4.968 eV.
 (c) Maximum kinetic energy of photoelectrons corresponding to light of wavelength 100 nm is nearly 7.4 eV.
 (d) Photoelectric effect takes place with red light.

11. Consider a cycle followed by an engine, shown in figure.



1 to 2 is isothermal

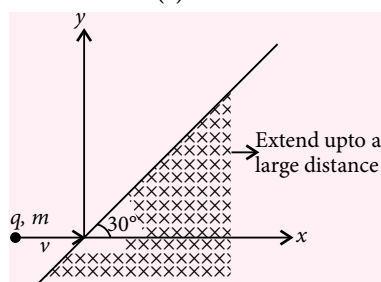
2 to 3 is adiabatic

3 to 1 is adiabatic

Such a process does not exist because

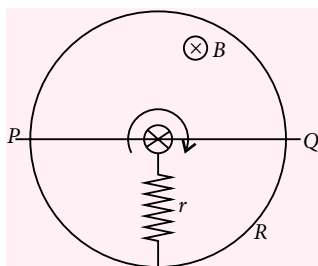
- (a) heat is completely converted into mechanical energy, which is not possible
 (b) mechanical energy is completely converted into heat, which is not possible
 (c) curves representing two adiabatic processes do not intersect
 (d) curves representing an adiabatic process and an isothermal process do not intersect.
12. A motorboat of mass m moves along a lake with velocity v_0 . At the moment $t = 0$ the engine of the boat is shutdown. Assume the resistance of water to be proportional to the velocity of the boat $F = -rv$.
- (a) The motorboat moved a distance mv_0/r with the shutdown engine.
 (b) The motorboat moved a distance $\frac{mv_0}{2r}$ with the shutdown engine.
 (c) The velocity of the motorboat as a function of time is $v_0 e^{-(r/m)t}$.
 (d) The mean velocity of the motorboat over the time interval (beginning with the moment $t = 0$), during which its velocity decreases η times is $v_0(\eta - 1)/\eta \ln \eta$.

13. A charge particle of charge q and mass m is moving with velocity v as shown in figure in a uniform magnetic field B along negative z -direction. Select the correct alternative(s).

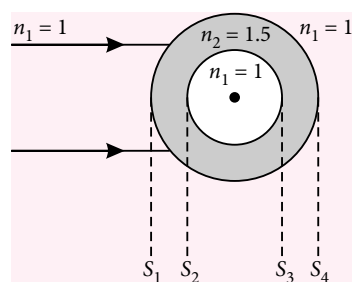


- (a) Velocity of the particle when it comes out from the magnetic field is $\vec{v} = v \cos 60^\circ \vec{i} + v \sin 60^\circ \vec{j}$.
- (b) Time for which the particle was in magnetic field is $\frac{\pi m}{3qB}$.
- (c) Distance travelled in magnetic field is $\frac{\pi m v}{2qB}$.
- (d) None of these.

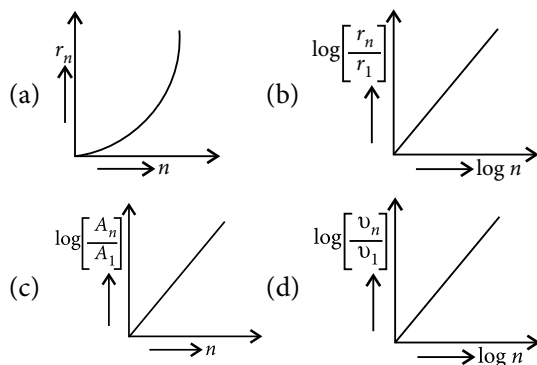
14. Water is flowing smoothly through a closed pipe system. At one point A, the speed of the water is 3.0 m s^{-1} while at another point B, 1.0 m higher, the speed is 4.0 m s^{-1} . The pressure at A is 20 kPa when the water is flowing and 18 kPa when the water flow stops. Then the pressure at B when water
- (a) is flowing is 6.7 kPa .
- (b) is flowing is 8.2 kPa .
- (c) stops flowing is 10.2 kPa .
- (d) stops flowing is 8.2 kPa .
15. In figure, R is a fixed conducting ring of negligible resistance and radius a . PQ is a uniform rod of resistance r . It is hinged at the centre of the ring and rotated about this point in clockwise direction with a uniform angular velocity ω . There is a uniform magnetic field of strength B pointing inward and r is a stationary resistance. Then,



- (a) current through r is zero
- (b) current through r is $\frac{2B\omega a^2}{5r}$
- (c) direction of current in external resistance r is from centre to circumference
- (d) direction of current in external resistance r is from circumference to center.
16. A glass sphere, refractive index 1.5 and radius 10 cm , has a spherical cavity of radius 5 cm concentric with it. A narrow beam of parallel light is directed into the sphere. Find the final image and its nature.

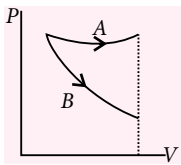
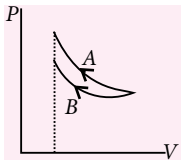
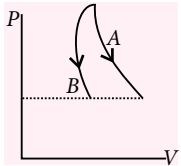
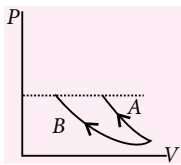


- (a) 25 cm left of S_4 , virtual
- (b) 25 cm right of S_4 , virtual
- (c) 15 cm left of S_4 , virtual
- (d) 20 cm right of S_4 , virtual
17. A hemisphere of radius R is charged uniformly with surface density σ . Then,
- (a) electric potential at the centre is $\frac{\sigma R}{2\epsilon_0}$
- (b) electric potential at the centre is $\frac{\sigma R}{4\epsilon_0}$
- (c) electric field at the centre is $\frac{\sigma}{4\epsilon_0}$
- (d) electric field at the centre is $\frac{\sigma}{2\epsilon_0}$.
18. If, in a hydrogen atom, radius of n^{th} Bohr orbit is r_n , and area enclosed by the n^{th} orbit is A_n , then which of the following graphs are correct?



SECTION 3 (MAXIMUM MARKS : 16)

- This section contains TWO questions
 - Each question contains two columns, Column I and Column II
 - Match the entries in Column I with the entries in Column II
 - One or more entries in Column I may match with one or more entries in Column II
19. An ideal gas undergoes two processes A and B. One of these is isothermal and the other is adiabatic.

Column-I	Column-II
(A) 	(P) Heat supplied during curve A is positive
(B) 	(Q) Work done by gas in both processes positive
(C) 	(R) Internal energy increases in adiabatic process
(D) 	(S) Temperature of gas in process B is constant

20. The uniform rigid bodies A and B are allowed to roll without slipping on a rough inclined plane. column-I describes some of the physical quantities associated with their motions while column-II gives you the relation between a physical quantity for two different bodies [bodies can be cylinder (solid or hollow), sphere (solid or hollow), ring or a disc]. Match the entries of column-I with the entries of column II.

Column-I	Column-II
(A) Acceleration of centre of mass of A and B	(P) Same if A and B have the same radius of gyration about centre of mass, same diameter but are of different materials
(B) Time taken by the two bodies to travel a distance s on the incline would be	(Q) Different if A and B are of same diameter and same mass but having different radius of gyration about centre of mass

(C) Velocity acquired by A and B after travelling through s would be	(R) Same if bodies have same diameter, different radius of gyration about centre of mass and different masses
(D) Minimum coefficient of friction required for pure rolling	(S) Different if bodies have same diameter but different radius of gyration about centre of mass and different masses
	(T) Same if they have same mass and diameter but different radius of gyration about centre of mass

ANSWER KEYS

- (2)
- (4)
- (5)
- (5)
- (8)
- (2)
- (5)
- (2)
- (a, c, d)
- (a, b, c)
- (a, c)
- (a, c, d)
- (a, b)
- (a, d)
- (b, d)
- (a)
- (a, c)
- (a, b, c)
- A \rightarrow (P, Q); B \rightarrow (R, S); C \rightarrow (P, Q); D \rightarrow (R, S)
- A \rightarrow (P, Q, S); B \rightarrow (P, Q, S); C \rightarrow (P, Q, S); D \rightarrow (P, Q, S)



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22. (a): Time of free fall of a body from a height h ,

$$t = \sqrt{\frac{2h}{g}}$$

Distance from the foot of the tower

$$d = vt = v\sqrt{\frac{2h}{g}} = 250 \text{ m}$$

When velocity = $\frac{v}{2}$

and height of tower = $4h$

Then, distance $x = \frac{v}{2}\sqrt{\frac{2(4h)}{g}}$

$$x = v\sqrt{\frac{2h}{g}} = 250 \text{ m}$$

23. (b): Poisson's ratio, $\sigma = 0.4 = \frac{\Delta d/d}{\Delta l/l}$

$$\text{Area, } A = \pi r^2 = \frac{\pi d^2}{4} \quad \text{or} \quad d^2 = \frac{4A}{\pi}$$

Differentiating both sides, we get

$$2d \Delta d = \frac{4}{\pi} \cdot \Delta A$$

$$\text{So, } \Delta A = \frac{2\pi d \Delta d}{4}; \quad \frac{\Delta A}{A} = \frac{\pi \frac{d}{2} \Delta d}{\pi d^2 / 4} = 2 \frac{\Delta d}{d}$$

$$\text{Given } \frac{\Delta A}{A} \times 100 = 2\% \quad \therefore \quad \frac{\Delta d}{d} \times 100 = 1\%$$

$$\text{Also, } \sigma = \frac{\Delta d/d}{\Delta l/l} = 0.4$$

$$\text{or } \frac{\Delta d}{d} = 0.4 \frac{\Delta l}{l} \Rightarrow \frac{\Delta l}{l} \times 100 = \frac{1}{0.4} \frac{\Delta d}{d} \times 100 \\ = 2.5 \times 1\% = 2.5\%$$

24. (b): As the current (i) leads the voltage by $\frac{\pi}{4}$, it is R-C circuit.

$$\text{Hence, } \tan \phi = \frac{X_C}{R}$$

$$\Rightarrow \tan \frac{\pi}{4} = \frac{1}{C\omega R} \Rightarrow C\omega R = 1,$$

$$\text{As } \omega = 100 \text{ rad s}^{-1}$$

$$\Rightarrow CR = \frac{1}{\omega} = \frac{1}{100} \text{ s}$$

Thus, from all the given options, only (b) is correct.

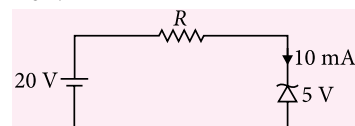
25. (a): Given, $\angle i = 60^\circ$ and $x = 1 \text{ km} = 10^3 \text{ m}$
When the total internal reflection just takes place from lateral surface, $i = C$ i.e., $C = 60^\circ$

$$\Rightarrow \sin C = \frac{1}{\mu} \Rightarrow \sin 60^\circ = \frac{1}{\mu} = \frac{\sqrt{3}}{2} \Rightarrow \mu = \frac{2}{\sqrt{3}}$$

The time taken by light to travel some distance in a medium,

$$t = \frac{\mu x}{c} = \frac{\frac{2}{\sqrt{3}} \times 10^3}{3 \times 10^8} = 3.85 \mu\text{s}$$

26. (d): Voltage available across load resistance R
 $= 20 - 5 = 15 \text{ V}$



$$\therefore R = \frac{15}{10 \times 10^{-3}} = 1.5 \times 10^3 = 1.5 \text{ k}\Omega$$

27. (a): E_x and B_y would generate a plane electromagnetic wave travelling in z -direction. E , B and k form a right handed system where k is along z -axis. (As, $\hat{i} \times \hat{j} = \hat{k}$)
 $\therefore E$ is along x -axis and B is along y -axis.

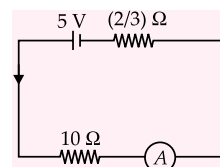
28. (c): The equivalent emf of the two cells in parallel circuit,

$$\epsilon_{\text{eq}} = \frac{\epsilon_1 r_2 + \epsilon_2 r_1}{r_1 + r_2} = \frac{3 \times 1 + 6 \times 2}{2 + 1} = 5 \text{ V}$$

The effective internal resistance of two cells in parallel circuit,

$$r_{\text{eq}} = \frac{r_1 r_2}{r_1 + r_2} = \frac{2 \times 1}{2 + 1} = \frac{2}{3} \Omega$$

The equivalent circuit will be as shown in figure.



$$\text{Current in ammeter, } I = \frac{5 \text{ V}}{10 \Omega + \frac{2}{3} \Omega} = \frac{15}{32} \text{ A}$$

29. (c)

30. (a): Condition for constructive interference is

$$2\mu t = (2n+1) \frac{\lambda}{2}$$

where, $n = 0, 1, 2, 3, \dots$

For minimum thickness, $n = 0$

$$2\mu t = \frac{\lambda}{2} \Rightarrow t = \frac{\lambda}{4\mu} = \frac{600 \times 10^{-9}}{4 \times 1.5} = 100 \text{ nm}$$

AIPMT 2016

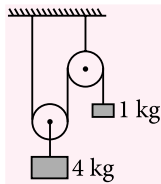
MODEL TEST PAPER

- A particle is acted upon by a force of constant magnitude which is always perpendicular to the velocity of the particle. The motion of the particle takes place in a plane. It follows that
 - its velocity is constant
 - its acceleration is constant
 - its kinetic energy is constant
 - it moves in a straight line.
- The maximum velocity of a particle executing simple harmonic motion is v . If the amplitude is doubled and the time period of oscillation decreased to $1/3$ of its original value, the maximum velocity becomes
 - $18v$
 - $12v$
 - $6v$
 - $3v$
- A particle moves in x - y plane according to the equations $x = 4t^2 + 5t + 16$ and $y = 5t$ where x, y are in metre and t is in second. The acceleration of the particle is
 - 8 m s^{-2}
 - 12 m s^{-2}
 - 14 m s^{-2}
 - 16 m s^{-2}
- In a series LCR circuit, the voltage across the resistance, capacitance and inductance is 10 V each. If the capacitance is short circuited, the voltage across the inductance will be
 - 10 V
 - $\frac{10}{\sqrt{2}} \text{ V}$
 - $10\sqrt{2} \text{ V}$
 - 20 V
- The angle made by the vector $\sqrt{3}\hat{i} + \hat{j}$ with x -axis is
 - 30°
 - 45°
 - 60°
 - 90°
- The current in a circuit containing a battery connected to 2Ω resistance is 0.9 A . When a resistance of 7Ω is connected to the same battery, the current observed in the circuit is 0.3 A . Then the internal resistance of the battery is
 - 0.1Ω
 - 0.5Ω
 - 1Ω
 - 1.5Ω
- Two stars of masses m_1 and m_2 distance r apart revolve about their centre of mass. The period of revolution is
 - $2\pi\sqrt{\frac{r^3}{2G(m_1 + m_2)}}$
 - $2\pi\sqrt{\frac{r^3(m_1 + m_2)}{2G(m_1 m_2)}}$
 - $2\pi\sqrt{\frac{2r^3}{G(m_1 + m_2)}}$
 - $2\pi\sqrt{\frac{r^3}{G(m_1 + m_2)}}$
- The arrangement of NAND gates shown below effectively works as

 - AND gate
 - OR gate
 - NAND gate
 - NOR gate
- Two projectiles A and B thrown with speeds in the ratio $1:\sqrt{2}$ acquired the same heights. If A is thrown at an angle of 45° with the horizontal, the angle of projection of B will be
 - 0°
 - 60°
 - 30°
 - 45°
- A body executes simple harmonic motion. At a displacement x , its potential energy is U_1 . At a displacement y , its potential energy is U_2 . What is the potential energy of the body at a displacement $(x + y)$?
 - $U_1 + U_2$
 - $(\sqrt{U_1} + \sqrt{U_2})^2$
 - $\sqrt{U_1^2 + U_2^2}$
 - $\sqrt{U_1 U_2}$

11. In the system shown in the figure, the acceleration of 1 kg block is

- (a) $\frac{g}{2}$ downwards
(b) $\frac{g}{2}$ upwards
(c) $\frac{g}{4}$ downwards
(d) $\frac{g}{4}$ upwards



12. According to Bernoulli's equation

$$P + \frac{1}{2}\rho v^2 + \rho gh = \text{constant}$$

where P is pressure, ρ is density, v is velocity, h is height and g is acceleration due to gravity. The dimensions of the constant are

- (a) $[ML^2T^{-2}]$ (b) $[MLT^{-2}]$
(c) $[ML^{-1}T^{-2}]$ (d) $[ML^{-2}T^{-1}]$
13. The pressure on the top surface of an aeroplane wing is 0.8×10^5 Pa and the pressure on the bottom surface is 0.75×10^5 Pa. If the area of each surface is 50 m^2 , the dynamic lift on the wing is
(a) 0.5×10^4 N (b) 0.25×10^4 N
(c) 5×10^4 N (d) 25×10^4 N
14. If pressure of CO_2 (real gas) in a container is given by $P = \frac{RT}{2V-b} - \frac{a}{4b^2}$, then mass of the gas in container is
(a) 11 g (b) 22 g (c) 33 g (d) 44 g

15. A coaxial cable consists of two thin cylindrical conducting shells of radii a and b ($a < b$). The inductance per unit length of the cable is

- (a) $\frac{\mu_0}{2\pi} \frac{(a+b)}{a}$ (b) $\frac{\mu_0}{4\pi} \ln\left(\frac{a}{b}\right)$
(c) $\frac{\mu_0}{4\pi} \ln\left(\frac{b}{a}\right)$ (d) $\frac{\mu_0}{2\pi} \ln\left(\frac{b}{a}\right)$

16. Which one of the following statements is not correct regarding a semiconducting material?

- (a) They have negative temperature coefficient of resistance.
(b) They have a moderate forbidden energy gap.
(c) Current is carried by electrons and holes both.
(d) Every semiconducting material is a tetravalent element.

17. A body is thrown upwards with velocity 40 m s^{-1} and it covers 5 m in the last second of its upward journey. If the same body is thrown upwards with velocity 80 m s^{-1} , what distance will it travel in the last second of upward journey? (Take $g = 10 \text{ m s}^{-2}$)
(a) 5 m (b) 10 m (c) 15 m (d) 20 m

18. The magnification produced by an astronomical telescope for normal adjustment is 10 and the length of the telescope is 1.1 m. The magnification, when the image is formed at least distance of distinct vision is
(a) 6 (b) 14 (c) 16 (d) 18

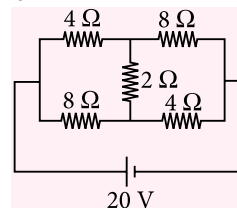
19. A machine gun is mounted on a 2000 kg car on a horizontal frictionless surface. At some instant, the gun fires 10 bullets/second, each of mass 10 g with a velocity of 500 m s^{-1} . The acceleration of the car is
(a) 0.025 m s^{-2} (b) 0.25 m s^{-2}
(c) 0.5 m s^{-2} (d) 500 m s^{-2}

20. A light wave and a sound wave have same frequency ν and their wavelengths are λ_l and λ_s respectively, then

- (a) $\lambda_l = \lambda_s$ (b) $\lambda_l > \lambda_s$
(c) $\lambda_l < \lambda_s$ (d) $\lambda_l = 2\lambda_s$

21. Two wires of the same material and same length but diameters in the ratio 1 : 2 are stretched by the same force. The potential energy per unit volume of the two wires will be in the ratio
(a) 1 : 1 (b) 4 : 1 (c) 2 : 1 (d) 16 : 1

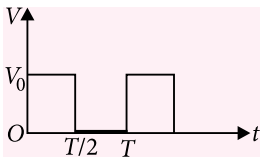
22. In the circuit shown in figure, the current through 2Ω resistance is



- (a) zero (b) $\left(\frac{25}{11}\right) \text{ A}$
(c) $\left(\frac{15}{11}\right) \text{ A}$ (d) $\left(\frac{10}{11}\right) \text{ A}$

23. The radius of gyration of a solid sphere of radius R about a certain axis is also equal to R . If r is the distance between the axis and the centre of the sphere, then r is equal to

- (a) R (b) $0.5R$
(c) $\sqrt{0.6}R$ (d) $\sqrt{0.3}R$

24. In a sample of radioactive substance, what fraction of the initial nuclei will remain undecayed after half of a half-life of the sample?
- (a) $\frac{1}{\sqrt{2}}$ (b) $\frac{1}{2\sqrt{2}}$ (c) $\frac{1}{4}$ (d) $\frac{1}{\sqrt{2}-1}$
25. A proton is projected with a velocity 10^7 m s^{-1} at right angle to a uniform magnetic field of 100 mT. The time taken by the proton to traverse 90° arc is (Mass of proton = $1.6 \times 10^{-27} \text{ kg}$ and charge of proton = $1.6 \times 10^{-19} \text{ C}$)
- (a) $0.05\pi \mu\text{s}$ (b) $0.5\pi \mu\text{s}$
(c) $5\pi \mu\text{s}$ (d) $10\pi \mu\text{s}$
26. A cylindrical drum, open at the top, contains 15 litres of water. It drains out through a small opening at the bottom. 5 litres of water comes out in time t_1 , the next 5 litres in further time t_2 and the last 5 litres in further time t_3 . Then
- (a) $t_1 < t_2 < t_3$ (b) $t_1 > t_2 > t_3$
(c) $t_1 = t_2 = t_3$ (d) $t_1 > t_2 = t_3$
27. When an unpolarized light of intensity I_0 is incident on a polarizing sheet, the intensity of the light which does not get transmitted is
- (a) I_0 (b) zero (c) $\frac{1}{4}I_0$ (d) $\frac{1}{2}I_0$
28. Three identical charges of magnitude $2 \mu\text{C}$ are placed at the corners of a right angled triangle ABC whose base BC and height BA are respectively 4 cm and 3 cm. Forces on the charge at the right angled corner B due to the charges at A and C are respectively F_1 and F_2 . The angle between their resultant force and F_2 is
- (a) $\tan^{-1}\left(\frac{9}{16}\right)$ (b) $\tan^{-1}\left(\frac{16}{9}\right)$
(c) $\sin^{-1}\left(\frac{16}{9}\right)$ (d) $\cos^{-1}\left(\frac{16}{9}\right)$
29. A linearly polarized electromagnetic wave given as $\vec{E} = E_0 \cos(kz - \omega t) \hat{i}$ is incident normally on a perfectly reflecting infinite wall at $z = a$. Assuming that the material of the wall is optically inactive, the reflected wave will be given as
- (a) $\vec{E}_r = -E_0 \cos(kz - \omega t) \hat{i}$
(b) $\vec{E}_r = E_0 \cos(kz + \omega t) \hat{i}$
(c) $\vec{E}_r = -E_0 \cos(kz + \omega t) \hat{i}$
(d) $\vec{E}_r = E_0 \sin(kz - \omega t) \hat{i}$
30. A body of mass 5 kg starts from the origin with an initial velocity $\vec{u} = (30\hat{i} + 40\hat{j}) \text{ m s}^{-1}$. If a constant force $(-6\hat{i} - 5\hat{j}) \text{ N}$ acts on the body, the time in which the y -component of the velocity becomes zero is
- (a) 5 s (b) 20 s (c) 40 s (d) 80 s
31. One mole of gas of specific heat ratio 1.5 being initially at temperature 290 K is adiabatically compressed to increase its pressure 8 times. The temperature of the gas after compression will be
- (a) 580 K (b) 870 K
(c) $290\sqrt{2} \text{ K}$ (d) 1160 K
32. The rms value of potential difference V shown in the figure is
- 
- (a) $\frac{V_0}{\sqrt{3}}$ (b) V_0 (c) $\frac{V_0}{\sqrt{2}}$ (d) $\frac{V_0}{2}$
33. When a proton is released from rest in a room, it starts with an initial acceleration a_0 towards west. When it is projected towards north with a speed v_0 it moves with an initial acceleration $3a_0$ towards west. The electric and magnetic fields in the room are
- (a) $\frac{ma_0}{e}$ east, $\frac{3ma_0}{ev_0}$ down
(b) $\frac{ma_0}{e}$ west, $\frac{2ma_0}{ev_0}$ up
(c) $\frac{ma_0}{e}$ west, $\frac{2ma_0}{ev_0}$ down
(d) $\frac{ma_0}{e}$ east, $\frac{3ma_0}{ev_0}$ up
34. A proton and an alpha particle are accelerated through the same potential difference. The ratio of the de Broglie wavelengths associated with proton and alpha particle respectively is
- (a) $1:2\sqrt{2}$ (b) $2:1$
(c) $2\sqrt{2}:1$ (d) $4:1$
35. The region surrounding a stationary electric dipole has
- (a) electric field only
(b) magnetic field only
(c) both electric and magnetic fields
(d) neither electric nor magnetic field

36. A ray of light from a denser medium strikes a rarer medium at an angle of incidence i . The reflected and refracted rays make an angle 90° with each other. The angle of reflection and angle of refraction are r and r' respectively. The critical angle is

(a) $\sin^{-1}(\tan r)$ (b) $\cos^{-1}(\tan r)$
(c) $\sin^{-1}(\tan r')$ (d) $\sec^{-1}(\tan r)$

37. A man goes at the top of a smooth inclined plane. He releases a bag to fall freely and himself slides down on inclined plane to reach the bottom. If u_1 and u_2 are the respective velocities of the man and bag at the bottom of inclined plane, then

(a) $u_1 > u_2$
(b) $u_1 < u_2$
(c) $u_1 = u_2$
(d) u_1 and u_2 cannot be compared

38. A Carnot refrigerator extracts heat from water at 0°C and rejects it to room at 24.4°C . The work required by the refrigerator for every 1 kg of water converted into ice is

(Latent heat of ice = 336 kJ kg^{-1})

(a) 24.4 kJ (b) 30 kJ
(c) 336 kJ (d) 11.2 kJ

39. If wavelength of photon emitted due to transition of an electron from the third orbit to the first orbit in a hydrogen atom is λ , then the wavelength of photon emitted due to transition of electron from the fourth orbit to the second orbit will be

(a) $\frac{128}{27}\lambda$ (b) $\frac{25}{9}\lambda$ (c) $\frac{36}{7}\lambda$ (d) $\frac{125}{11}\lambda$

40. A bullet is fired normally towards an immovable wooden block. It loses 25% of its kinetic energy in penetrating through a thickness x of the plank. The total thickness penetrated by the bullet into the block is

(a) $4x$ (b) $6x$ (c) $8x$ (d) $2x$

41. A bar magnet suspended freely in a uniform magnetic field is vibrating with a time period of 3 s. If the field strength is increased to 4 times of the earlier field strength, the time period will be

(a) 12 s (b) 6 s (c) 1.5 s (d) 0.75 s

42. The momentum of photon whose frequency is ν is

(a) $\frac{h\nu}{c}$ (b) $\frac{hc}{\nu}$ (c) $\frac{\nu}{hc}$ (d) $\frac{c}{h\nu}$

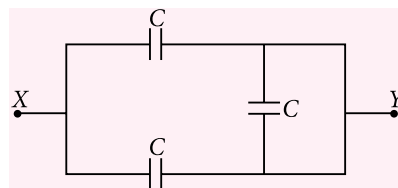
43. Two identical flutes produce fundamental notes of frequency 300 Hz at 27°C . If the temperature of the air in one of the flutes is increased to 31°C , the number of beats heard per second will be

(a) 3 (b) 2 (c) 1 (d) 4

44. The reddish appearance of rising and setting sun is due to

(a) reflection of light (b) diffraction of light
(c) scattering of light (d) interference of light

45. The equivalent capacitance between the points X and Y in the circuit with $C = 1 \mu\text{F}$ is



(a) $0.5 \mu\text{F}$ (b) $1 \mu\text{F}$ (c) $2 \mu\text{F}$ (d) $3 \mu\text{F}$

SOLUTIONS

1. (c) : It is a case of uniform circular motion in which the velocity and acceleration vectors change due to change in direction. As the magnitude of velocity (*i.e.* speed) remains constant, so its kinetic energy is constant.

2. (c) : If A is the amplitude of simple harmonic motion, then

$$v = A\omega$$

But $\omega = \frac{2\pi}{T}$ where T is the time period of oscillation.

$$\therefore v = A \frac{2\pi}{T} \quad \dots(i)$$

When the amplitude is doubled and the time period decreased to $\frac{T}{3}$, the maximum velocity becomes

$$v' = 2A \left(\frac{2\pi}{T/3} \right) = 6 \left(A \frac{2\pi}{T} \right) = 6v \quad (\text{using (i)})$$

3. (a) : As $x = 4t^2 + 5t + 16$ and $y = 5t$

$$\therefore v_x = \frac{dx}{dt} = \frac{d}{dt}(4t^2 + 5t + 16) = 8t + 5$$

$$v_y = \frac{dy}{dt} = \frac{d}{dt}(5t) = 5$$

$$a_x = \frac{dv_x}{dt} = \frac{d}{dt}(8t + 5) = 8$$

$$\text{and } a_y = \frac{dv_y}{dt} = \frac{d}{dt}(5) = 0$$

The acceleration of the particle is

$$\vec{a} = a_x \hat{i} + a_y \hat{j} = 8 \hat{i} + 0 \hat{j} = 8 \hat{i}$$

or $a = \sqrt{8^2} = 8 \text{ m s}^{-2}$

4. (b): As $V_R = V_L = V_C = 10 \text{ V}$

$$\therefore R = X_L = X_C \text{ and } Z = R$$

$$\text{and } V = IR = 10 \text{ V}$$

When the capacitor is short circuited, the impedance of the circuit is

$$Z' = \sqrt{R^2 + X_L^2} = \sqrt{R^2 + R^2} = \sqrt{2}R$$

and the current in the circuit is

$$I' = \frac{V}{Z'} = \frac{10 \text{ V}}{\sqrt{2}R}$$

\therefore The voltage across the inductance is

$$V'_L = I'X_L = \left(\frac{10 \text{ V}}{\sqrt{2}R} \right) R = \frac{10}{\sqrt{2}} \text{ V}$$

5. (a): Let θ be the angle made by $\sqrt{3} \hat{i} + \hat{j}$ with x -axis.

If \hat{i} is the unit vector along x -axis, then

$$\cos \theta = \frac{(\sqrt{3} \hat{i} + \hat{j}) \cdot \hat{i}}{|\sqrt{3} \hat{i} + \hat{j}| |\hat{i}|} = \frac{\sqrt{3}}{\sqrt{\sqrt{3}^2 + 1^2} \sqrt{1^2}} = \frac{\sqrt{3}}{\sqrt{4}} = \frac{\sqrt{3}}{2}$$

or $\theta = \cos^{-1} \left(\frac{\sqrt{3}}{2} \right) = 30^\circ$

6. (b): Let ϵ and r be the emf and internal resistance of the battery respectively. Then

The current in the circuit is

$$I = \frac{\epsilon}{R + r}$$

In the first case,

$$I = 0.9 \text{ A}, R = 2 \Omega$$

$$\therefore 0.9 \text{ A} = \frac{\epsilon}{2 \Omega + r} \quad \dots(i)$$

In the second case,

$$I = 0.3 \text{ A}, R = 7 \Omega$$

$$\therefore 0.3 \text{ A} = \frac{\epsilon}{7 \Omega + r} \quad \dots(ii)$$

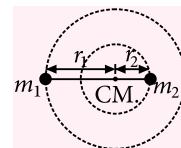
Dividing eqn. (i) by eqn. (ii), we get

$$\frac{0.9 \text{ A}}{0.3 \text{ A}} = \frac{7 \Omega + r}{2 \Omega + r} \text{ or } 3 = \frac{7 \Omega + r}{2 \Omega + r}$$

$$\text{or } 6 \Omega + 3r = 7 \Omega + r \text{ or } 2r = 7 \Omega - 6 \Omega = 1 \Omega$$

$$\text{or } r = \frac{1 \Omega}{2} = 0.5 \Omega$$

7. (d): The situation is shown in figure.



Let the distances of the stars with masses m_1 and m_2 from their centre of mass be r_1 and r_2 respectively. Then

$$r = r_1 + r_2 \quad \dots(i)$$

As the necessary centripetal force for their circular motion is provided by the gravitational force between them, so

$$\frac{Gm_1m_2}{r^2} = m_1r_1\omega^2 = m_2r_2\omega^2$$

$$\text{or } m_1r_1 = m_2r_2 \text{ or } r_2 = \frac{m_1}{m_2} r_1$$

Substituting this value of r_2 in eqn. (i), we get

$$r = r_1 + \frac{m_1}{m_2} r_1 = r_1 \left(1 + \frac{m_1}{m_2} \right) = \frac{r_1(m_2 + m_1)}{m_2}$$

$$\text{or } r_1 = \frac{m_2 r}{m_1 + m_2}$$

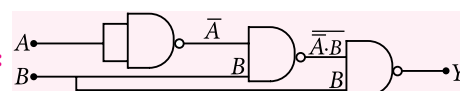
$$\therefore \frac{Gm_1m_2}{r^2} = \frac{m_1m_2r\omega^2}{(m_1 + m_2)}$$

$$\text{or } \omega^2 = \frac{G(m_1 + m_2)}{r^3} \text{ or } \omega = \sqrt{\frac{G(m_1 + m_2)}{r^3}}$$

The period of revolution is

$$T = \frac{2\pi}{\omega} = 2\pi \sqrt{\frac{r^3}{G(m_1 + m_2)}}$$

8. (c):



The truth table of the given circuit is

A	B	\bar{A}	$\bar{A} \cdot B$	$\bar{\bar{A} \cdot B}$	$(\bar{\bar{A} \cdot B}) \cdot B$	$Y = \overline{(\bar{\bar{A} \cdot B}) \cdot B}$
0	0	1	0	1	0	1
0	1	1	1	0	0	1
1	0	0	0	1	0	1
1	1	0	0	1	1	0

which is the truth table of NAND gate.

Thus the given arrangement of NAND gates works as NAND gate.

9. (c): Let the angle of projection of B be θ .

For projectile A

$$\text{Maximum height, } H_A = \frac{u_A^2 \sin^2 45^\circ}{2g}$$

For projectile B

$$\text{Maximum height, } H_B = \frac{u_B^2 \sin^2 \theta}{2g}$$

As both projectiles attained the same heights,

$$\therefore H_A = H_B$$

$$\text{or } \frac{u_A^2 \sin^2 45^\circ}{2g} = \frac{u_B^2 \sin^2 \theta}{2g}$$

$$\text{or } \frac{\sin^2 \theta}{\sin^2 45^\circ} = \frac{u_A^2}{u_B^2} \text{ or } \sin^2 \theta = \left(\frac{u_A}{u_B} \right)^2 \sin^2 45^\circ$$

$$\text{But } \frac{u_A}{u_B} = \frac{1}{\sqrt{2}} \text{ (given)}$$

$$\therefore \sin^2 \theta = \left(\frac{1}{\sqrt{2}} \right)^2 \left(\frac{1}{\sqrt{2}} \right)^2 = \frac{1}{4}$$

$$\text{or } \sin \theta = \frac{1}{2} \text{ or } \theta = \sin^{-1} \left(\frac{1}{2} \right) = 30^\circ$$

10. (b): In simple harmonic motion,

$$\text{Potential energy, } U = \frac{1}{2} kx^2$$

$$\therefore U_1 = \frac{1}{2} kx^2 \quad \dots(i)$$

$$\text{and } U_2 = \frac{1}{2} ky^2 \quad \dots(ii)$$

At a displacement $(x + y)$, the potential energy of the body is

$$\begin{aligned} U &= \frac{1}{2} k(x + y)^2 = \frac{1}{2} k(x^2 + y^2 + 2xy) \\ &= \frac{1}{2} kx^2 + \frac{1}{2} ky^2 + \frac{1}{2} (2kxy) \\ &= U_1 + U_2 + 2\sqrt{U_1 U_2} \text{ (using (i) and (ii))} \\ &= (\sqrt{U_1} + \sqrt{U_2})^2 \end{aligned}$$

11. (b): If a is the downward acceleration of 4 kg block, the upward acceleration of 1 kg block must be $2a$. If T is the tension in each part of string, then

The equation of motion of 4 kg block is

$$4g - 2T = 4a \quad \dots(i)$$

and the equation of motion of 1 kg block is

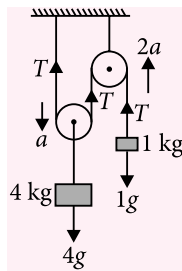
$$T - 1g = 1(2a) \quad \dots(ii)$$

Multiplying eqn. (ii) by 2, we get

$$2T - 2g = 4a \quad \dots(iii)$$

Adding eqns. (i) and (iii), we get

$$2g = 8a$$



$$\text{or } a = \frac{2g}{8} = \frac{g}{4}$$

\therefore The acceleration of 1 kg block

$$= 2a = 2 \left(\frac{g}{4} \right) = \frac{g}{2} \text{ upwards}$$

12. (c): The dimensions of the constant is equal to the dimensions of each term on the left hand side of the equation. So if we consider the dimensions of P , then

$$\begin{aligned} [\text{constant}] &= [P] \\ &= \frac{[MLT^{-2}]}{[L^2]} \quad [\because \text{Pressure} = \frac{\text{Force}}{\text{Area}}] \\ &= [ML^{-1}T^{-2}] \end{aligned}$$

13. (d): The dynamic lift on the wing is

$$F = \Delta PA = (P_1 - P_2)A$$

where P_1 and P_2 are the pressures on the upper and bottom surfaces of the wing respectively and A is the area of each surface.

$$\text{Here, } P_1 = 0.8 \times 10^5 \text{ Pa, } P_2 = 0.75 \times 10^5 \text{ Pa, } A = 50 \text{ m}^2$$

$$\begin{aligned} \therefore F &= (0.8 \times 10^5 \text{ Pa} - 0.75 \times 10^5 \text{ Pa})(50 \text{ m}^2) \\ &= (0.05 \times 10^5 \text{ Pa})(50 \text{ m}^2) \\ &= 2.5 \times 10^5 \text{ N} = 25 \times 10^4 \text{ N} \end{aligned}$$

14. (b): According to van der Waals equation for μ moles of real gas

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

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

Comparing it with the given equation

$$P = \left(\frac{RT}{2V - b} - \frac{a}{4b^2} \right)$$

$$\text{we get, } \mu = \frac{1}{2}$$

$$\text{As } \mu = \frac{\text{mass of the gas}(m)}{\text{molecular mass}(M) \text{ of the gas}}$$

$$\therefore m = \mu M = \frac{1}{2} (12 + 32) = 22 \text{ g}$$

15. (d)

16. (d)

17. (a): For the body thrown upwards

$$u = 40 \text{ m s}^{-1}, D_n = 5 \text{ m, } a = -g = -10 \text{ m s}^{-2}$$

$$\text{As } D_n = u + \frac{a}{2} (2n - 1)$$

$$\therefore 5 = 40 - \frac{10}{2} (2n - 1)$$

On solving, we get $n = 4$

The body thrown upwards with velocity 40 m s^{-1} takes 4 seconds to reach the highest point. So the body thrown upwards with velocity 80 m s^{-1} will take 8 seconds to reach the highest point. Hence distance travelled in 8^{th} second is

$$D'_n = 80 - \frac{10}{2}(2 \times 8 - 1) = 5 \text{ m}$$

Note : A body covers the same distance in the last second of its upward journey whatever be its velocity.

- 18. (b):** Let f_o and f_e be focal lengths of objective and eye piece respectively.

For normal adjustment,

Magnification of the telescope, $m = \frac{f_o}{f_e}$

and length of the telescope, $L = f_o + f_e$

Here, $m = 10$ and $L = 1.1 \text{ m}$

$$\therefore 10 = \frac{f_o}{f_e} \text{ or } f_o = 10f_e \quad \dots(i)$$

$$\text{and } 1.1 = f_o + f_e \quad \dots(ii)$$

Solving eqns. (i) and (ii), we get

$$f_o = 1 \text{ m and } f_e = 0.1 \text{ m}$$

When the image is formed at least distance of distinct vision $D (= 25 \text{ cm})$, then

$$m = \frac{f_o}{f_e} \left(1 + \frac{f_e}{D} \right) = \frac{1 \text{ m}}{0.1 \text{ m}} \left(1 + \frac{0.1 \text{ m}}{0.25 \text{ m}} \right)$$

$$= 10 \left[1 + \frac{2}{5} \right] = 10 \left[\frac{7}{5} \right] = 14$$

- 19. (a):** Here,

Mass of the car, $M = 2000 \text{ kg}$

Mass of the bullet, $m = 10 \text{ g} = 10 \times 10^{-3} \text{ kg}$

Velocity of the bullet, $v = 500 \text{ m s}^{-1}$

Number of bullets fired per second, $n = 10$

As force on the car = rate of change of momentum of the bullets

$$\therefore F = nmv = 10 \times 10 \times 10^{-3} \times 500 \text{ N} = 50 \text{ N}$$

The acceleration of the car is

$$a = \frac{F}{M} = \frac{50 \text{ N}}{2000 \text{ kg}} = 0.025 \text{ m s}^{-2}$$

- 20. (b):** Let v_l and v_s be the velocity of light wave and the velocity of sound wave respectively. Then

$$v = \frac{v_l}{\lambda_l} = \frac{v_s}{\lambda_s} \text{ or } \frac{\lambda_l}{\lambda_s} = \frac{v_l}{v_s}$$

$$\text{But } v_l > v_s \therefore \lambda_l > \lambda_s$$

- 21. (d):** The potential energy per unit volume of the wire is

$$u = \frac{1}{2} \frac{(\text{Stress})^2}{\text{Young's modulus}} = \frac{1}{2} \frac{S^2}{Y}$$

As stress, $S = \frac{\text{force}}{\text{area}}$

$$\therefore \frac{S_1}{S_2} = \left(\frac{F_1}{F_2} \right) \left(\frac{A_2}{A_1} \right)$$

But $F_1 = F_2$ (given)

$$\therefore \frac{S_1}{S_2} = \frac{A_2}{A_1} \quad \dots(i)$$

As the two wires are of the same material, therefore their Young's moduli are the same.

i.e., $Y_1 = Y_2$

$$\therefore \frac{u_1}{u_2} = \left(\frac{S_1}{S_2} \right)^2 = \left(\frac{A_2}{A_1} \right)^2 \quad (\text{using (i)})$$

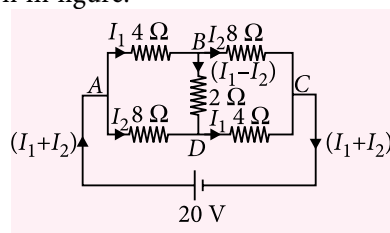
$$= \left[\left(\frac{d_2}{d_1} \right)^2 \right]^2 = \left(\frac{d_2}{d_1} \right)^4 \quad (\text{where, } d = \text{diameter})$$

$$\text{But } \frac{d_1}{d_2} = \frac{1}{2} \text{ (given)}$$

$$\therefore \frac{u_1}{u_2} = \left(\frac{2}{1} \right)^4 = \frac{16}{1}$$

$$\text{or } u_1 : u_2 = 16 : 1$$

- 22. (d):** The distribution of current in various branches is shown in figure.



Applying Kirchhoff's second law to the closed loop ABDA, we get

$$4I_1 + 2(I_1 - I_2) - 8I_2 = 0$$

$$\text{or } 6I_1 = 10I_2 \text{ or } I_1 = \frac{10}{6} I_2 = \frac{5}{3} I_2 \quad \dots(i)$$

Applying Kirchhoff's second law to the closed loop ABCA, we get

$$4I_1 + 8I_2 - 20 = 0 \text{ or } 4\left(\frac{5}{3} I_2\right) + 8I_2 = 20 \quad (\text{using (i)})$$

$$\text{or } \frac{44}{3} I_2 = 20 \text{ or } I_2 = \frac{3 \times 20}{44} = \frac{15}{11} \text{ A}$$

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Substituting this value of I_2 in eqn. (i), we get

$$I_1 = \frac{5}{3} \left(\frac{15}{11} A \right) = \frac{25}{11} A$$

$$\therefore \text{The current in } 2 \Omega = I_1 - I_2 = \frac{25}{11} A - \frac{15}{11} A = \frac{10}{11} A$$

23. (c) : Let M be the mass of the sphere.

Moment of inertia of the sphere about a diameter is

$$I_{\text{dia}} = \frac{2}{5} MR^2$$

By theorem of parallel axes

Moment of inertia of the sphere about a certain axis at a distance r from its centre is

$$I = I_{\text{dia}} + Mr^2 = \frac{2}{5} MR^2 + Mr^2$$

If k is the radius of gyration at that axis, then

$$I = Mk^2$$

$$\therefore Mk^2 = \frac{2}{5} MR^2 + Mr^2$$

$$\text{or } k^2 = \frac{2}{5} R^2 + r^2$$

But $k = R$ (given)

$$\therefore R^2 = \frac{2}{5} R^2 + r^2$$

$$\text{or } r^2 = R^2 - \frac{2}{5} R^2 = \frac{3}{5} R^2 \quad \text{or } r = \sqrt{\frac{3}{5}} R = \sqrt{0.6} R$$

24. (a) : The fraction of nuclei which remain undecayed after time t is

$$f = \frac{N}{N_0} = \frac{N_0 e^{-\lambda t}}{N_0} = e^{-\lambda t} = e^{-\frac{\ln 2}{T_{1/2}} t} \quad \left(\because \lambda = \frac{\ln 2}{T_{1/2}} \right)$$

$$\text{At } t = \frac{T_{1/2}}{2}$$

$$f = e^{-\left(\frac{\ln 2}{T_{1/2}}\right) \left(\frac{T_{1/2}}{2}\right)} = e^{-\frac{\ln 2}{2}} = e^{-\ln \sqrt{2}} = \frac{1}{e^{\ln \sqrt{2}}} = \frac{1}{\sqrt{2}}$$

25. (a) : When the proton is projected with velocity v at right angle to a uniform magnetic field B , it follows a circular path whose radius r is given by

$$r = \frac{mv}{qB} \quad \text{or} \quad \frac{r}{v} = \frac{m}{qB} \quad \dots(i)$$

where m and q are its mass and charge respectively. The time taken by the proton to traverse 90° ($= \pi/2$) arc is

$$t = \frac{s}{v} = \frac{(\pi/2)r}{v} = \frac{\pi r}{2v} = \frac{\pi m}{2qB} \quad (\text{using (i)})$$

Here, $m = 1.6 \times 10^{-27} \text{ kg}$, $q = 1.6 \times 10^{-19} \text{ C}$,

$$B = 100 \text{ mT} = 100 \times 10^{-3} \text{ T}$$

$$\begin{aligned} \therefore t &= \frac{\pi(1.6 \times 10^{-27} \text{ kg})}{2(1.6 \times 10^{-19} \text{ C})(100 \times 10^{-3} \text{ T})} \\ &= \frac{\pi}{2} \times 10^{-7} \text{ s} = 0.5\pi \times 10^{-7} \text{ s} \\ &= 0.05\pi \times 10^{-6} \text{ s} = 0.05\pi \mu\text{s} \end{aligned}$$

26. (a) : If h is the initial height of liquid in drum above

the small opening, then velocity of efflux, $v = \sqrt{2gh}$.

As the water drains out, h decreases, hence v decreases. This reduces the rate of drainage of water. Due to it, as the drainage continues, a longer time is required to drain out the same volume of water.

Thus, $t_1 < t_2 < t_3$.

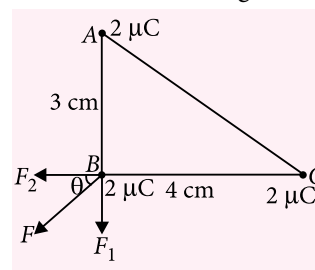
27. (d) : The intensity of light transmitted through the

$$\text{polarizing sheet} = \frac{I_0}{2}$$

\therefore The intensity of light which does not get transmitted

$$= I_0 - \frac{I_0}{2} = \frac{I_0}{2}$$

28. (b) : The situation is shown in figure.



Force on charge at B due to charge at A is

$$F_1 = \frac{1}{4\pi\epsilon_0} \frac{(2 \mu\text{C})(2 \mu\text{C})}{(AB)^2} \text{ along AB}$$

and that due to charge at C is

$$F_2 = \frac{1}{4\pi\epsilon_0} \frac{(2 \mu\text{C})(2 \mu\text{C})}{(BC)^2} \text{ along CB}$$

Let F be the resultant force of F_1 and F_2 .

If F makes an angle θ with F_2 , then

$$\begin{aligned} \tan \theta &= \frac{F_1}{F_2} = \frac{\frac{1}{4\pi\epsilon_0} \frac{(2 \mu\text{C})(2 \mu\text{C})}{(AB)^2}}{\frac{1}{4\pi\epsilon_0} \frac{(2 \mu\text{C})(2 \mu\text{C})}{(BC)^2}} \\ &= \frac{(BC)^2}{(AB)^2} = \frac{(4 \text{ cm})^2}{(3 \text{ cm})^2} = \frac{16}{9} \end{aligned}$$

$$\text{or } \theta = \tan^{-1} \left(\frac{16}{9} \right)$$

- 29. (b):** Since the wall is perfectly reflecting, amplitude (E_0) of the linearly polarized electromagnetic wave remains unchanged.

Further, as the material of the wall is optically inactive, there is no phase change (Stokes' law). The reflected wave differs from incident wave in only one aspect, *i.e.*, it travels along $-z$ axis. Thus,

$$\vec{E}_r = E_0 \cos(-kz - \omega t) \hat{i} = E_0 \cos(kz + \omega t) \hat{i}$$

- 30. (c):** As $\vec{u} = (30\hat{i} + 40\hat{j}) \text{ m s}^{-1}$
 $\therefore u_y = 40 \text{ m s}^{-1}$

$$\text{and } \vec{F} = (-6\hat{i} - 5\hat{j}) \text{ N}$$

$$\therefore F_y = -5 \text{ N}$$

The y -component of the acceleration is

$$a_y = \frac{F_y}{m} = \frac{-5 \text{ N}}{5 \text{ kg}} = -1 \text{ m s}^{-2}$$

Let after time t the y -component of the velocity become zero. Then

$$v_y = u_y + a_y t$$

$$\text{or } 0 = (40 \text{ m s}^{-1}) + (-1 \text{ m s}^{-2})t \text{ or } (1 \text{ m s}^{-2})t = 40 \text{ m s}^{-1}$$

$$\text{or } t = \frac{40 \text{ m s}^{-1}}{1 \text{ m s}^{-2}} = 40 \text{ s}$$

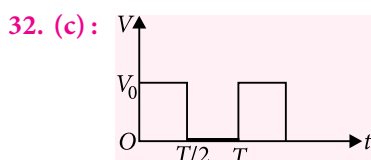
- 31. (a):** If P_1 and T_1 are the pressure and temperature of the gas before compression, P_2 and T_2 are corresponding quantities after compression, then for an adiabatic compression

$$\frac{T_1^\gamma}{P_1^{(\gamma-1)}} = \frac{T_2^\gamma}{P_2^{(\gamma-1)}}$$

$$\text{or } \left(\frac{T_2}{T_1}\right)^\gamma = \left(\frac{P_2}{P_1}\right)^{(\gamma-1)} \quad \text{or } T_2 = T_1 \left(\frac{P_2}{P_1}\right)^{(\gamma-1)/\gamma}$$

$$\text{Here, } T_1 = 290 \text{ K, } \frac{P_2}{P_1} = 8, \gamma = 1.5$$

$$\begin{aligned} \therefore T_2 &= (290 \text{ K})(8)^{(1.5-1)/1.5} \\ &= (290 \text{ K})(8)^{0.5/1.5} = (290 \text{ K})(8)^{1/3} \\ &= 2(290 \text{ K}) = 580 \text{ K} \end{aligned}$$



From graph

$$\begin{aligned} V &= V_0 \text{ for } 0 \leq t \leq \frac{T}{2} \\ V &= 0 \text{ for } \frac{T}{2} \leq t \leq T \end{aligned}$$

The rms value of V is

$$\begin{aligned} V_{\text{rms}} &= \sqrt{\frac{\int_0^T V^2 dt}{\int_0^T dt}} = \sqrt{\frac{\int_0^{T/2} V_0^2 dt + \int_{T/2}^T (0) dt}{T}} = \sqrt{\frac{V_0^2 \int_0^{T/2} dt}{T}} \\ &= \sqrt{\frac{V_0^2}{T} [t]_0^{T/2}} = \sqrt{\frac{V_0^2}{T} \left(\frac{T}{2}\right)} = \sqrt{\frac{V_0^2}{2}} = \frac{V_0}{\sqrt{2}} \end{aligned}$$

- 33. (c):** In this question, the proton moves from rest towards west. It is due to a force on the proton by virtue of electric field along west.

If m and e are the mass and charge of the proton, then the acceleration of proton due to electric field E

$$= \frac{eE}{m} = a_0 \quad \text{or } E = \frac{ma_0}{e} \text{ west}$$

When the proton is projected towards north with a speed v_0 , it moves with an acceleration $3a_0$ towards west, shows that the proton is experiencing forces due to electric field along west and magnetic field acting vertically downwards.

Therefore, the acceleration of proton due to magnetic field

$$= 3a_0 - a_0 = 2a_0.$$

The force on the proton due to magnetic field

$$= ev_0 B = m(2a_0)$$

$$\text{or } B = \frac{2ma_0}{ev_0} \text{ downwards}$$

$$\text{Thus } E = \frac{ma_0}{e} \text{ west and } B = \frac{2ma_0}{ev_0} \text{ down}$$

- 34. (c):** de Broglie wavelength associated with a charged particle of mass m and charge q accelerated through potential difference V is

$$\lambda = \frac{h}{\sqrt{2mqV}}$$

For same V ,

$$\lambda \propto \frac{1}{\sqrt{mq}}$$

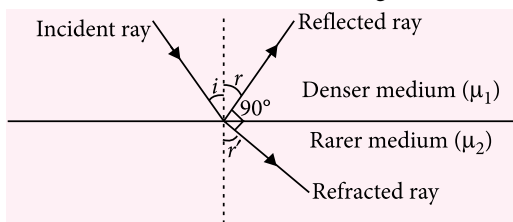
$$\therefore \frac{\lambda_p}{\lambda_\alpha} = \sqrt{\frac{m_\alpha q_\alpha}{m_p q_p}} = \sqrt{\frac{(4m_p)(2e)}{(m_p)(e)}} = \sqrt{\frac{8}{1}} = \frac{2\sqrt{2}}{1}$$

$$\text{or } \lambda_p : \lambda_\alpha = 2\sqrt{2} : 1$$

- 35. (a):** A stationary charge produces an electric field only in the space surrounding it.

Thus the region surrounding a stationary electric dipole has electric field only.

36. (a): The situation is shown in figure.



As the reflected and refracted rays are perpendicular to each other,

$$\therefore r + 90^\circ + r' = 180^\circ$$

$$\text{or } r' = 180^\circ - 90^\circ - r = 90^\circ - r \quad \dots(i)$$

If μ_1 and μ_2 are the refractive indices of denser and rarer medium respectively, then by Snell's law

$$\mu_1 \sin i = \mu_2 \sin r'$$

$$\text{or } \frac{\mu_2}{\mu_1} = \frac{\sin i}{\sin r'}$$

But by law of reflection, $i = r$

$$\therefore \frac{\mu_2}{\mu_1} = \frac{\sin r}{\sin r'} = \frac{\sin r}{\sin(90^\circ - r)} \quad (\text{using (i)})$$

$$= \frac{\sin r}{\cos r} = \tan r \quad \dots(ii)$$

The critical angle C is

$$\sin C = \frac{\mu_2}{\mu_1} = \tan r \quad (\text{using (ii)})$$

$$\text{or } C = \sin^{-1}(\tan r)$$

37. (c): The gravitational force is a conservative force, so the work done by it is independent of path. Hence in both cases

$$\frac{1}{2}mu^2 = mgh$$

where h is the height of the inclined plane.

$$\text{or } u = \sqrt{2gh}$$

Clearly, it is independent of mass.

$$\text{So, } u_1 = u_2$$

38. (b): Here,

Mass of water, $m = 1 \text{ kg}$

Latent heat of ice, $L = 336 \text{ kJ kg}^{-1}$

Temperature of hot reservoir (i.e. room),

$$T_1 = 24.4^\circ\text{C} = 24.4 + 273 = 297.4 \text{ K}$$

Temperature of cold reservoir (i.e. water),

$$T_2 = 0^\circ\text{C} = 0 + 273 = 273 \text{ K}$$

The amount of heat extracted from water at 0°C to convert to ice at 0°C is

$$Q_2 = mL = (1 \text{ kg})(336 \text{ kJ kg}^{-1}) = 336 \text{ kJ}$$

The coefficient of performance (α) of a refrigerator is

$$\alpha = \frac{Q_2}{W} = \frac{T_2}{T_1 - T_2} \quad \therefore W = \frac{Q_2(T_1 - T_2)}{T_2}$$

$$\begin{aligned} \text{or } W &= \frac{(336 \text{ kJ})(297.4 \text{ K} - 273 \text{ K})}{273 \text{ K}} \\ &= \frac{(336 \text{ kJ})(24.4 \text{ K})}{273 \text{ K}} = 30 \text{ kJ} \end{aligned}$$

39. (a)

40. (a): Let the bullet be fired with velocity u . Then its initial kinetic energy is

$$K_i = \frac{1}{2}mu^2 \quad (\text{where } m \text{ is the mass of the bullet})$$

On penetrating through a thickness x , the bullet loses 25% of its kinetic energy. Now its final kinetic energy is

$$\begin{aligned} K_f &= 75\% \text{ of } K_i \\ &= \frac{75}{100} \left(\frac{1}{2}mu^2 \right) = \frac{3}{4} \left(\frac{1}{2}mu^2 \right) \end{aligned}$$

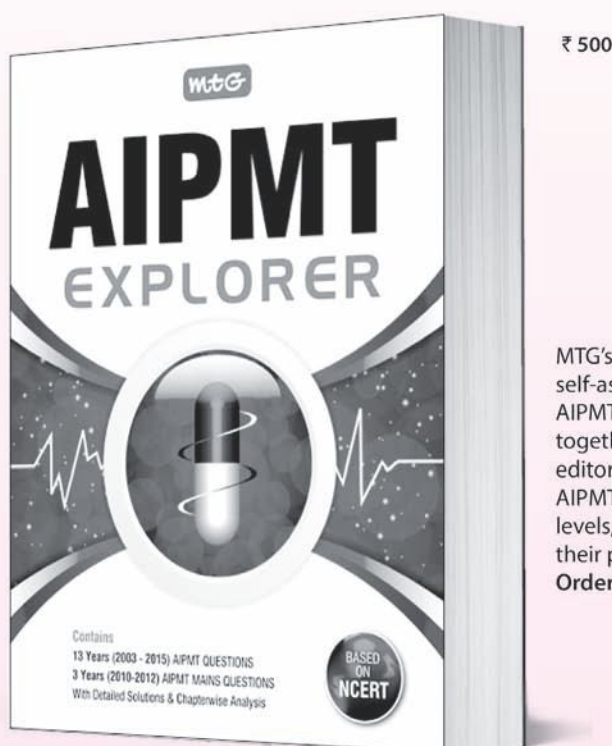
If f is the resistive force offered by the block to the bullet, then by work-energy theorem

$$K_i - K_f = fx$$

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(Engg. & Med.)		
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$$\text{or } \frac{1}{2}mu^2 - \frac{3}{4}\left(\frac{1}{2}mu^2\right) = fx$$

$$\text{or } \frac{1}{4}\left(\frac{1}{2}mu^2\right) = fx \quad \dots(i)$$

Let s be the total thickness penetrated by the bullet into the block. Then by work-energy theorem

$$\frac{1}{2}mu^2 = fs \quad \dots(ii)$$

Dividing eqn. (i) by eqn. (ii), we get

$$\frac{1}{4} = \frac{x}{s} \quad \text{or } s = 4x$$

- 41. (c) :** The time period of vibration of the bar magnet in a uniform magnetic field B is

$$T = 2\pi\sqrt{\frac{I}{MB}} \quad \dots(i)$$

where I and M are its moment of inertia and magnetic moment respectively.

When the field strength is increased to 4 times of its earlier value, the new field strength becomes

$$B' = 4B$$

and the new time period becomes

$$\begin{aligned} T' &= 2\pi\sqrt{\frac{I}{MB'}} = 2\pi\sqrt{\frac{I}{M(4B)}} \\ &= \frac{1}{2}\left(2\pi\sqrt{\frac{I}{MB}}\right) = \frac{T}{2} \quad (\text{using (i)}) \end{aligned}$$

But $T = 3$ s (given)

$$\therefore T' = \frac{3}{2} = 1.5 \text{ s}$$

- 42. (a) :** The energy (E) and momentum (p) of photon are related as

$$E = pc \quad \text{or } p = \frac{E}{c}$$

$$\text{But } E = h\nu \quad \therefore p = \frac{h\nu}{c}$$

- 43. (b) :** Let v_1 and v_2 be the speeds of sound at 27°C and at 31°C respectively.

$$\text{As } v \propto \sqrt{T(\text{in kelvin})}$$

$$\begin{aligned} \therefore \frac{v_2}{v_1} &= \sqrt{\frac{T_2}{T_1}} = \sqrt{\frac{273+31}{273+27}} = \sqrt{\frac{304}{300}} = \left(1 + \frac{4}{300}\right)^{1/2} \\ &= 1 + \frac{1}{2}\left(\frac{4}{300}\right) \quad (\text{by binomial theorem}) \end{aligned}$$

$$= \frac{302}{300} = \frac{151}{150} \quad \dots(i)$$

Since frequency \propto speed of sound

$$\therefore \frac{v_2}{v_1} = \frac{\nu_2}{\nu_1}$$

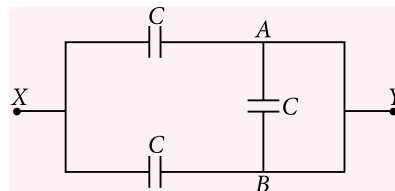
$$\begin{aligned} \text{or } \nu_2 &= \nu_1 \frac{v_2}{v_1} = (300 \text{ Hz})\left(\frac{151}{150}\right) \quad (\text{using (i)}) \\ &= 302 \text{ Hz} \end{aligned}$$

Hence the number of beats heard per second

$$= \nu_2 - \nu_1 = 302 - 300 = 2$$

- 44. (c) :** The reddish appearance of the rising and the setting sun is due to scattering of light.

- 45. (c) :**



In the given circuit, capacitor connected between A and B is short circuited and the remaining two capacitors are in parallel.

\therefore The equivalent capacitance between X and Y is

$$C_{eq} = C + C = 2C = 2(1 \mu\text{F}) = 2 \mu\text{F}$$

Form IV

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| 3. Printer's and Publisher's Name | : Mahabir Singh |
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| Address | : Physics For You,
406, Taj Apartment,
New Delhi - 110029. |
| 4. Editor's Name | : Anil Ahlawat |
| Nationality | : Indian |
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PHYSICS MUSING

SOLUTION SET-31

1. (c): Let at any time t , the displacement of first particle be S_1 and that of second particle be S_2 .

$$S_1 = \frac{1}{2}at^2 \text{ and } S_2 = u\left(t - \frac{1}{a}\right)$$

For $S_2 > S_1$

$$u\left(t - \frac{1}{a}\right) > \frac{1}{2}at^2 \Rightarrow t^2 - \frac{2ut}{a} + \frac{2u}{a^2} < 0$$

$$\frac{1}{a}\left(u - \sqrt{u^2 - 2u}\right) < t < \frac{1}{a}\left(u + \sqrt{u^2 - 2u}\right)$$

Hence, the duration for which particle 2 remains ahead of particle 1

$$\begin{aligned} &= \frac{1}{a}\left[\left(u + \sqrt{u^2 - 2u}\right) - \left(u - \sqrt{u^2 - 2u}\right)\right] \\ &= \frac{2}{a}\sqrt{u(u-2)} \end{aligned}$$

2. (b): According to work energy theorem,

Loss in kinetic energy = Work done

$$\therefore 0 - \frac{1}{2}mv^2 = W_g + W_T \text{ or } W_T = -W_g - \frac{1}{2}mv^2$$

$$= -mg2R - \frac{1}{2}mv^2$$

$$= -0.1 \times 10 \times 2 \times 0.1 - \frac{1}{2} \times 0.1 \times 5^2$$

$$= -0.2 - 0.1 \times 12.5 = -1.45 \text{ J}$$

3. (a): For ball A, $mg(4h) = \frac{1}{2}mv_A^2$

$$\Rightarrow v_A = \sqrt{8gh}$$

Similarly, for ball B,

$$mgh = \frac{1}{2}mv_B^2 \Rightarrow v_B = \sqrt{2gh}$$

Since, the balls collide elastically,

\therefore After collision,

$$v_A = \sqrt{2gh} \text{ and } v_B = \sqrt{8gh}$$

Ratio of heights attained by ball A and B, i.e.,

$$\frac{h_A}{h_B} = \frac{v_A^2}{v_B^2} = \frac{2gh}{8gh} = \frac{1}{4}$$

4. (d): As $L = mvr = \text{constant}$.

$$\therefore T = \frac{mv^2}{r} = \frac{m}{r} \cdot \frac{L^2}{m^2 r^2} = \frac{L^2}{m} r^{-3}$$

5. (b): Note that cohesive force among mercury molecules is greater than adhesive force between glass and mercury molecules. Also, adhesive force between water and glass molecules is greater than cohesive force among water molecules.

6. Let the body be in motion for n seconds. If s_n is the distance covered by the body in n seconds, then

$$\text{from } s = v_0 t + \frac{1}{2}at^2,$$

$$s_n = \frac{1}{2}an^2 \quad (\text{as } v_0 = 0)$$

If s_{nth} is the distance covered in the last second of its motion, then

$$s_{nth} = v_0 + \frac{a}{2}(2n-1) = \frac{a}{2}(2n-1)$$

According to the given condition,

$$s_{nth} = \frac{1}{2}s_n \quad \text{or} \quad \frac{a}{2}(2n-1) = \frac{1}{2}\left(\frac{1}{2}an^2\right)$$

$$\text{or } 2(2n-1) = n^2 \text{ or } n^2 - 4n + 2 = 0$$

$$\text{or } n = \frac{4 \pm \sqrt{(4)^2 - 4(1)(2)}}{2} = \frac{4 \pm \sqrt{8}}{2}$$

(Taking only the positive sign before $\sqrt{8}$, \therefore negative sign implies $n < 1$ s)

$$n = \left(\frac{4 + \sqrt{8}}{2}\right) \text{ s} = 3.4 \text{ s}$$

Also,

$$s = \frac{1}{2}an^2 = \left[\frac{1}{2} \times (4) \times (3.4)^2\right] \text{ m} \simeq 23 \text{ m } (\because a = 4 \text{ m s}^{-2})$$

7. Let O be the centre of the hemisphere and OY be the axis passing through the vertex of the cone.

$$\text{Volume of cone} = \frac{1}{3}\pi r^2 h$$

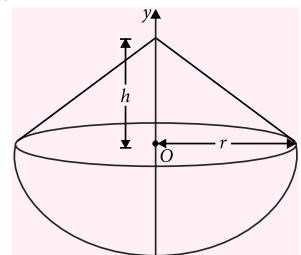
Volume of hemisphere

$$= \frac{2}{3}\pi r^3$$

\therefore Densities are same, masses of the bodies will be proportional to their respective volumes.

If the centre of gravity of the combined mass should lie on O, then,

$$0 = \frac{\left(\frac{1}{3}\pi r^2 h\right)\frac{h}{4} + \left(\frac{2}{3}\pi r^3\right)\left(\frac{-3r}{8}\right)}{\frac{\pi r^2 h}{3} + \frac{2}{3}\pi r^3}$$



$$\Rightarrow \frac{\pi r^2 h^2}{3 \times 4} = \frac{2}{3} \pi r^4 \times \frac{3}{8} \Rightarrow \frac{h^2}{3} = r^2$$

$$\text{or } h = r\sqrt{3}$$

8. If the temperature of surrounding increases by ΔT , the new length of rod becomes

$$l' = l(1 + \alpha \Delta T)$$

Due to change in length, moment of inertia of rod also changes and is given as

$$I'_p = \frac{Ml'^2}{3}$$

As no external force or torque is acting on rod, thus its angular momentum remains constant during heating,

$$\therefore I_p \omega = I'_p \omega'$$

where ω' is the final angular velocity of rod after heating.

$$\text{or } \frac{Ml^2}{3} \omega = \frac{Ml^2(1 + \alpha \Delta T)^2}{3} \omega'$$

$$\text{or } \omega' = \omega(1 - 2\alpha \Delta T)$$

[using binomial expansion for small α]

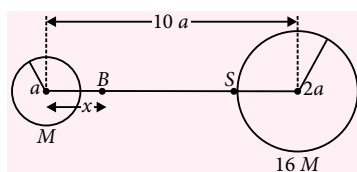
Thus percentage change in angular velocity of rod due to heating can be given as

$$\Delta\omega = \frac{\omega - \omega'}{\omega} \times 100\% = 2\alpha \Delta T \times 100\%$$

9. The distance (from the smaller planet) where the gravitational pulls of the two planets balance each other will be given by

$$\frac{-GMm}{x^2} = \frac{-G(16M)m}{(10a - x)^2}$$

$$\text{i.e., } x = 2a$$



So the body will reach the smaller planet due to the planet's gravitational field if it has sufficient energy to cross the point $B(x = 2a)$, i.e.,

$$\frac{1}{2}mv^2 > m(V_B - V_S)$$

$$\text{Now, } V_S = -\left[\frac{16GM}{2a} + \frac{GM}{10a - 2a}\right] = -\frac{65GM}{8a}$$

$$\text{and } V_B = -\left[\frac{16GM}{8a} + \frac{GM}{2a}\right] = -\frac{20GM}{8a}$$

$$\therefore \frac{1}{2}mv^2 > m\left(\frac{-20GM}{8a} + \frac{65GM}{8a}\right)$$

$$\Rightarrow v > \sqrt{\frac{45GM}{4a}} \quad \text{i.e., } v_{\min} = \frac{3}{2}\sqrt{\frac{5GM}{a}}$$

10. The frequency in n^{th} mode of vibration of one end closed and an open organ pipe are given by

$$v_c = \frac{(2n-1)v}{4l_c}, \quad \text{where } n = 1, 2, 3, \dots$$

Open organ pipe,

$$v_o = \frac{nv}{2l_o}, \quad \text{where } n = 1, 2, 3, \dots$$

Fundamental frequency of closed organ pipe,

$$\frac{v}{4l_c} = 110 \text{ Hz}$$

$$l_c = \frac{330}{4 \times 110} \text{ m} = 0.75 \text{ m}$$

$$\text{First overtone of closed organ pipe} = \frac{3v}{4l_c}$$

$$\text{First overtone of open organ pipe} = \frac{2v}{2l_o}$$

These two produce beats of frequency 2.2 Hz when sounded together, the expressions for beat frequency are

$$\frac{3v}{4l_c} - \frac{2v}{2l_o} = 2.2 \quad \text{or} \quad \frac{2v}{2l_o} - \frac{3v}{4l_c} = 2.2$$

$$\Rightarrow 3 \times 110 - \frac{330}{l_o} = 2.2 \quad \text{or} \quad \frac{330}{l_o} - 3 \times 110 = 2.2$$

$$\Rightarrow l_o = 1.0067 \text{ m or } l_o = 0.9934 \text{ m}$$

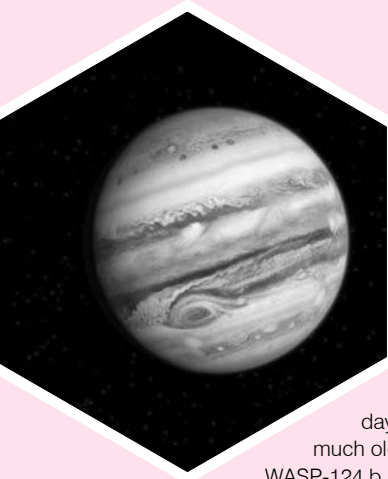
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Five 'hot' Jupiter-like planets discovered

Scientists have discovered five new Jupiter-like planets that are similar in characteristics to our solar system's biggest planet and orbit very close to their host stars.

Researchers from Keele University in UK used the Wide Angle Search for Planets-South (WASP-South) instrument -an array of eight cameras observing selected regions of the southern sky, to study five stars showing planet-like transits in their light curve. The newly discovered planets were designated WASP-119 b, WASP-124 b, WASP-126 b, WASP-129 b and WASP-133 b. The orbital periods of the planets vary from 2.17 to 5.75 days, and their masses range from 0.3 to 1.2 the mass of Jupiter, with radii between one to 1.5 Jupiter radius, researchers said.

WASP-119 b, which has a mass of 1.2 of the mass of Jupiter, and an orbital period of 2.5 days, is a typical hot Jupiter. Its host star has a similar mass to the Sun's but appears to be much older based on its effective temperature and density.

WASP-124 b, less massive than Jupiter, has orbital period of 3.4 days and a much younger parent star.

WASP-126 b is the lowest-mass world found by researchers. Its low surface gravity and a bright host star make the planet a good target for transmission spectroscopy. WASP-126b orbits the brightest star of the five. This means that it can be a target for atmospheric characterisation, deducing the composition and nature of the atmosphere from detailed study," said Coel Hellier from Keele University.

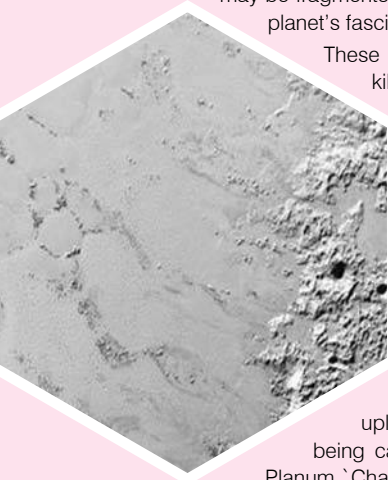
WASP-129 b, similar in size to Jupiter, has the longest orbital period. WASP-133 b has the shortest orbital period of the exoplanets detected by researchers.

Moon can affect rainfall, say scientists

The Moon can affect how heavy the rain is, according to a new study that could help improve weather forecasts and climate models. Researchers at Washington University in the US discovered that because the Moon causes the Earth's atmosphere to bulge towards it when it is overhead, the air becomes warmer to the extent that it can make rain lighter. The change is small, accounting for about 1% of the total variation in rainfall. Tsubasa Kohyama, a doctoral student, said, "This is the first study to connect the tidal force of the moon with rainfall. Lower humidity is less favourable for precipitation.

Nasa craft spots 'floating hills' in Pluto's heart

Nasa's New Horizons spacecraft has captured images of frozen nitrogen glaciers on Pluto carrying numerous 'floating' hills that may be fragments of water ice, giving an insight into the dwarf planet's fascinating and abundant geological activity.



These hills individually measure one to several kilometres across, the images show. The hills, which are in the vast ice plain named Sputnik Planum within Pluto's 'heart', are likely miniature versions of the larger, jumbled mountains on Sputnik Planum's western border.

Since water ice is less dense than nitrogen-dominated ice, scientists believe these water ice hills are floating in a sea of frozen nitrogen and move over time like icebergs in Earth's Arctic Ocean.

The hills are likely fragments of the rugged uplands that have broken away and are being carried by the nitrogen glaciers into Sputnik Planum. 'Chains' of the drifting hills are formed along the flow paths of the glaciers.

Now, we'll listen to the stars, courtesy gravitational waves

The landmark discovery of the first direct evidence of gravitational waves or ripples in space-time, which Albert Einstein predicted a century ago, will enable mankind to listen to the stars, and not just see them, scientists say.

In a breakthrough announcement, scientists from the Laser Interferometer Gravitational Wave Observatory (LIGO) said that they have finally detected the elusive gravitational waves, the ripples in the fabric of space-time.

Studying gravitational waves will push Einstein's general theory of relativity to its limits, while revolutionising our understanding of the most violent events in the universe, according to researchers at Massachusetts Institute of Technology.

Analysis of the waves suggests they originated from a system of two black holes, each with the mass of about 30 Suns, that gravitationally drew closer to each other. The frequency of these waves that LIGO is designed to catch are actually in the audible range for humans.

Accordingly, the signal LIGO received of the black hole merger was played on speakers for eager scientists. "For this binary black hole system, it made a distinctive, rising 'whoooop!' sound," said Matthew Evans, an assistant professor at MIT. "This detection means that the stars are no longer silent. It's not that we just look up and see anymore, like we always have — we actually can listen to the universe now. It's a whole new sense," Evans said.



YOU ASK WE ANSWER

Do you have a question that you just can't get answered?

Use the vast expertise of our mtg team to get to the bottom of the question. From the serious to the silly, the controversial to the trivial, the team will tackle the questions, easy and tough.

The best questions and their solutions will be printed in this column each month.

Q1. If a classroom door is open slightly, you can hear sounds coming from the hallway. Yet you cannot see what is happening in the hallway. What accounts for the difference?

–*Shiva Prasad (Kerala)*

Ans. The space between the slightly open door and the wall is acting as a single slit for waves. Sound waves have wavelengths larger than the slit width, so sound is effectively diffracted by the opening and spread throughout the room. Light wavelengths are much smaller than the slit width, so virtually no diffraction for the light occurs. You must have a direct line of sight to detect the light waves.

Q2. Magnetic field at the centre of a bar magnet is very weak. Why?

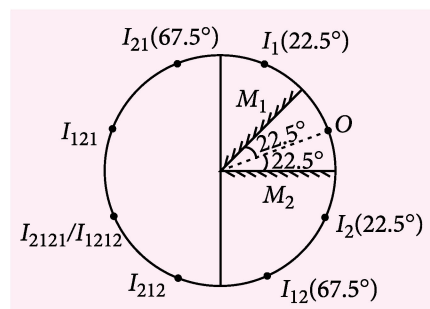
–*Taniya Mondal (West Bengal)*

Ans. We can divide a bar magnet into a large number of tiny bar magnets. Evaluate, the magnetic field as the superposition of the contributions of all small aligned magnets present in the bar. For a point near the centre of the bar, the magnetic field is very small because the contributions of the nearest magnetic dipoles (tiny magnetic bars) is partially cancelled by the rest of the dipoles because its contribution is anti-parallel. Actually, for a large bar magnet the value of magnetic field is negligible at the centre. On contrary, near the edges the magnetic field is greater because there is a minor quantity of dipole magnets to oppose the contribution of the nearest.

Q3. If two mirrors are kept at 45° to each other and a body is placed in the middle, then total number of images formed is _____.

–*Pritish Acharya*

Ans. Required number of images = $\frac{360^\circ}{45^\circ} - 1 = 8 - 1 = 7$



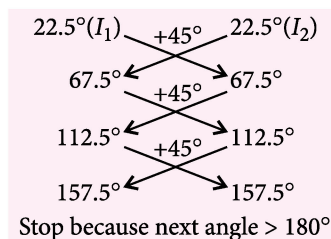
I_1 is the image of O by M_1 .

I_2 is the image of O by M_2 .

I_{12} is the image of I_1 by M_2 .

I_{21} is the image of I_2 by M_1 .

Here last angle made by mirrors with images + angle between the mirror = $2 \times 157.5^\circ + 45^\circ$
= 360°



It implies that final images formed by two mirrors will coincide.

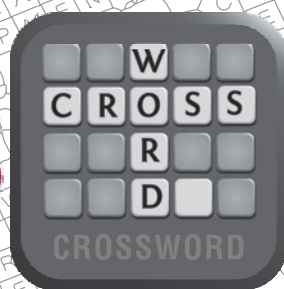
Q4. You charge a capacitor and then remove it from the battery. The capacitor consists of large movable plates, with air between them. You pull the plates farther apart a small distance. What happens to the charge on the capacitor? Is work done in pulling the plates apart?

–*Kushagra (Uttar Pradesh)*

Ans. Because the capacitor is removed from the battery, charges on the plates have nowhere to go. Thus, the charge on the capacitor remains the same as the plates are pulled apart. Because the electric field of large plates is independent of distance, the electric field remains constant. Because the electric field is measure of the rate of change of potential with distance, the potential difference between the plates increases as the separation distance increases. Because the same charge is stored at a higher potential difference, the capacitance decreases. Because energy stored is proportional to both charge and potential difference, the energy stored in the capacitor increases. This energy must be transferred into the system from somewhere, the plates attract each other, so work is done by you on the system of two plates when you pull them apart.

■ ■

CROSS WORD



Readers can send their responses at editor@mtg.in or post us with complete address by 25th of every month to win exciting prizes. Winners' name with their valuable feedback will be published in next issue.

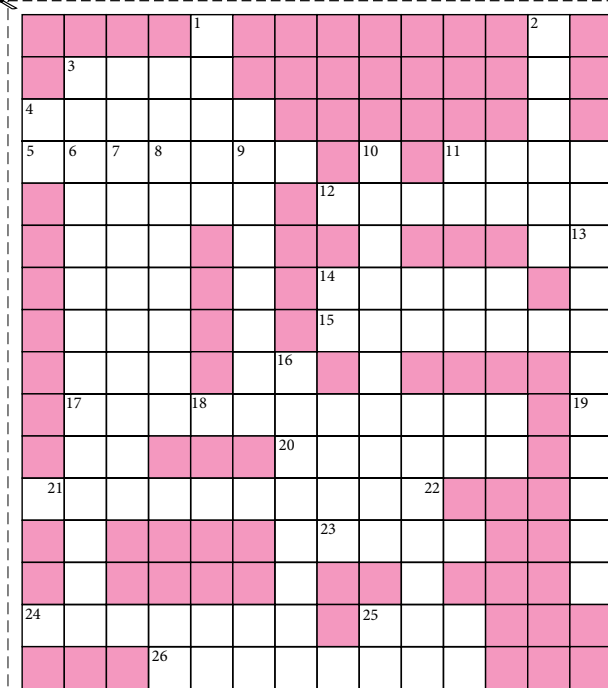
ACROSS

3. A piece of ferromagnetic material that connects two or more magnetic cores. (4)
4. The product of a component of momentum, and the change in corresponding positional coordinate. (6)
5. The ratio of the radiant flux incident on an object to the flux transmitted. (7)
11. A range of frequencies within specified limits used for definite purpose. (4)
12. A mechanical device that prevents any sudden or oscillatory motion of a moving part of any piece of apparatus. (4, 3)
14. Kinetic energy released in matter. (5)
15. A mixture of isotopes of an element in proportions that differ from the natural isotopic composition. (7)
18. A measure of the rate of decay of a periodic quantity. (4, 4)
20. It is an interferometer used to study fine spectrum lines. (6)
21. A primary cell, much used before the introduction of accumulators. (6, 4)
23. Roughly spherical ice particles, usually a few millimeters in radius, produced in very turbulent clouds. (4)
24. The absorption of one particle by a system. (7)
25. A unit of power identical to the watt but used for the reactive power of an alternating current. (3)
26. A line on a chart or graph joining points of equal temperature. (8)

DOWN

1. The equipotential surface of the gravity potential that coincides with the mean sea level. (5)
2. A type of alloy containing magnesium (88%), aluminium (11%) and traces of other elements. (6)
6. A mixture of free electrons and ions or atomic nuclei. (6)
7. The transfer of matter such as water vapour or heat, through the atmosphere as a result of horizontal movement of air. (9)

Cut Here



8. The vascular layer of the eye lying between the retina and the sclera. (7)
9. The distinguishing quality, other than pitch or intensity of a note produced by musical instrument, voice, etc. (6)
10. A small wave. (7)
13. A simple machine that converts rotational motion to linear motion. (5)
16. A permanently electrified substance exhibiting electric charges of opposite sign at its extremities. (8)
17. The elementary particle that mediates the strong interaction between quarks. (5)
19. SI unit of magnetic flux. (5)
22. A radar-like technique employing pulsed or continuous-wave laser beam for remote sensing. (5)

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