PHYSICS (CODE - 042)
SAMPLE PAPER 1
CLASS XII

Time Allowed: 3 hours **Maximum Marks: 70**

General Instructions:

1. There are 33 questions in all. All questions are compulsory.
2. This question paper has five sections: Sections A, B, C, D and E.
3. Section A contains twelve MCQs and four assertion-reason questions of 1 mark each. Section B contains five questions of 2 marks each. Section C contains seven questions of 3 marks each. Section D contains two case-based questions of 4 marks each. Section E contains three long answer questions of 5 marks each.
4. There is no overall choice. However, an internal choice has been provided in two questions in Section B, one question in Section C, and all three questions in Section E.
5. Use of calculators is not allowed.

You may use the following values of physical constants where necessary:

- $c = 3 \times 10^{8}$ m/s
- me = 9.1×10^{-31} kg
- mp = 1.7×10^{-27} kg
- $e = 1.6 \times 10^{-19}$ C
- $\mu_0 = 4\pi \times 10^{-7}$ T m A^{-1}
- $h = 6.63 \times 10^{-34}$ J s
- $\varepsilon_0 = 8.854 \times 10^{-12}$ $C^2 N^{-1} m^{-2}$
- Avogadro's number = 6.023×10^{23} per gram mole

SECTION A

Question numbers 1 to 12 carry 1 mark each and are multiple choice questions.

1. A hollow conducting sphere and a solid conducting sphere of the same material and equal radius carry the same charge Q. How does the electric field just outside the two spheres compare?

(A) The hollow sphere has a stronger field just outside its surface

(B) The solid sphere has a stronger field just outside its surface

(C) Both fields are equal in magnitude

(D) The field depends only on the material, not the charge distribution

2. Two wires of the same material and length, but of radii r and 2r, are connected in series across a battery. The ratio of heat produced in them (thin : thick) is:

(A) 1 : 4

(B) 4 : 1

(C) 1 : 16

(D) 16 : 1

3. A charged particle enters a uniform magnetic field with its velocity making an angle of 90° with the field. The path followed by the particle is:

(A) A straight line

(B) A parabola

(C) A circle

(D) A helix

4. Which of the following substances has a negative, small, and temperature-independent magnetic susceptibility?

(A) Paramagnetic

(B) Diamagnetic

(C) Ferromagnetic

(D) Antiferromagnetic

5. A bar magnet is moved towards a stationary conducting loop with its North pole facing the loop. As seen from the side facing the magnet, the induced current in the loop flows:

(A) Clockwise, opposing the approach of the magnet

(B) Anticlockwise, opposing the approach of the magnet

(C) Clockwise, aiding the approach of the magnet

(D) There is no induced current

6. In a pure capacitive AC circuit, as the frequency of the source is increased, the capacitive reactance:

(A) Increases

(B) Decreases

(C) Remains unchanged

(D) First increases then decreases

7. Arrange the following electromagnetic waves in order of increasing wavelength: X-rays, microwaves, visible light, gamma rays.

(A) Gamma rays < X-rays < visible light < microwaves

(B) Microwaves < visible light < X-rays < gamma rays

(C) X-rays < gamma rays < microwaves < visible light

(D) Gamma rays < visible light < X-rays < microwaves

8. A ray of light travelling in a denser medium is incident on the boundary with a rarer medium at an angle greater than the critical angle. The ray undergoes:

(A) Partial reflection and partial refraction

(B) Total internal reflection

(C) Complete refraction with no reflection

(D) Dispersion into its component colours

9. In Young's double slit experiment, if the separation between the slits is doubled while all other quantities are kept constant, the fringe width:

(A) Doubles

(B) Becomes half

(C) Remains the same

(D) Becomes four times

10. In a photoelectric experiment, if the frequency of incident light is increased while keeping the intensity constant, which of the following increases?

(A) The photoelectric current

(B) The number of photoelectrons emitted per second

(C) The maximum kinetic energy of the emitted photoelectrons

(D) The work function of the metal

11. According to Bohr's model, the radius of the nth orbit of hydrogen atom is proportional to:

(A) n

(B) n^2

(C) 1/n

(D) $1/n^2$

12. In a p-n junction diode under reverse bias, the width of the depletion region:

(A) Decreases
(B) Increases
(C) Remains unchanged
(D) First decreases then increases

Question numbers 13 to 16 have two statements, Assertion (A) and Reason (R). Choose the correct option:
(A) Both A and R are true, and R is the correct explanation of A.
(B) Both A and R are true, but R is not the correct explanation of A.
(C) A is true but R is false.
(D) Both A and R are false.

13. Assertion (A): The electric potential inside a uniformly charged hollow conducting sphere is the same at every point and equal to the potential at its surface. Reason (R): The electric field inside a uniformly charged hollow conducting sphere is zero everywhere.

14. Assertion (A): The resistance of a semiconductor decreases with an increase in temperature. Reason (R): The number of charge carriers in a semiconductor increases with an increase in temperature.

15. Assertion (A): A ray of light incident on the flat face of a semicircular glass slab, along a normal to that face, passes straight through undeviated. Reason (R): The angle of incidence at the flat face in this case is zero, so there is no refraction or reflection at that surface.

16. Assertion (A): The binding energy per nucleon is highest for nuclei of medium mass number, around A = 56. Reason (R): Nuclear fusion of light nuclei and nuclear fission of heavy nuclei both release energy because they move the resulting nuclei towards this region of higher binding energy per nucleon.

SECTION B

Question numbers 17 to 21 carry 2 marks each.

17. The electric field of a plane electromagnetic wave travelling along the positive z-axis in vacuum is given by $E = 45 \sin(kz - \omega t)$ V/m, directed along the x-axis. Write the corresponding expression for the magnetic field of the wave, stating its direction and using $B_0 = E_0/c$. [2]

OR

State two important properties of electromagnetic waves related to the directions of the electric field, magnetic field, and the direction of propagation.

18. A cell of emf ε and internal resistance r is connected to a variable external resistance R. Sketch the expected graph of the terminal potential difference V versus the current I drawn from the cell, and use it to explain how ε and r can be determined graphically. [2]

19. Two point charges +q and −q are separated by a distance 2a, forming an electric dipole. Derive the expression for the electric field at a point on the equatorial line of the dipole, at a distance r from its centre ($r >> a$). [2]

OR

Define electric dipole moment. An electric dipole is placed in a uniform electric field E making an angle θ with it. Write the expression for the torque acting on the dipole, and state the orientation for which this torque is maximum.

20. State Ampere's circuital law. Use it to find the expression for the magnetic field at a point inside a long straight solenoid carrying current I, with n turns per unit length. [2]

21. In an alpha-particle scattering experiment, define the term 'impact parameter'. What is its value for a head-on collision, and what does this imply about the trajectory of the alpha particle in that case? [2]

SECTION C

Question numbers 22 to 28 carry 3 marks each.

22. With the help of a circuit diagram, explain the working of a full wave rectifier using a centre-tapped transformer and two p-n junction diodes. Draw the input and output waveforms. [3]

23. State Kirchhoff's two rules for electrical circuits. Using Kirchhoff's voltage law, explain how it embodies the law of conservation of energy in a closed electrical circuit. [3]

24. A hydrogen atom in its ground state absorbs a photon and gets excited to the n = 3 energy level. Calculate (i) the energy of the absorbed photon, and (ii) the wavelength of the photon, given that the ground state energy of hydrogen is –13.6 eV. [3]

OR

Using Bohr's postulates, derive the expression for the total energy of an electron in the nth orbit of a hydrogen atom.

25. A compound microscope has an objective lens of focal length 1.0 cm and an eyepiece of focal length 3.0 cm, separated by 20 cm. An object is placed 1.1 cm from the objective. Calculate the angular magnification of the microscope when the final image is formed at the near point (25 cm) of a normal eye. [3]

26. Derive the relation $A + \delta = i + e$ for light passing through a prism, where A is the angle of the prism, δ is the angle of deviation, i is the angle of incidence, and e is the angle of emergence. Hence state the condition for minimum deviation. [3]

27. A charged particle of mass 2 g and charge 1 μC is projected with a velocity of 3 m/s along the positive x-axis into a region of uniform magnetic field B = 0.2 T directed along the positive z-axis, occupying the region $x > 0$. [3]

(A) What is the nature of the path followed by the charged particle?
(B) Calculate the radius of the circular path.
(C) Will the kinetic energy of the particle change as it moves through the field? Justify your answer.

28. A conducting rod of length 0.5 m rotates with an angular speed of 40 rad/s about an axis passing through one end and perpendicular to the rod, in a uniform magnetic field of 0.4 T parallel to the axis of rotation. Calculate the emf induced between the two ends of the rod. [3]

SECTION D

Question numbers 29 and 30 are case-based questions carrying 4 marks each.

29. Read the passage given below and answer the questions that follow: [4]

A p-n junction diode allows current to flow easily in one direction (forward bias, when the p-side is connected to the positive terminal of the battery) but offers very high resistance in the other direction (reverse bias). This asymmetric behaviour is exploited in rectifier circuits, which convert alternating current into direct current. In a forward-biased diode, the applied voltage reduces the width of the depletion region and lowers the potential barrier, allowing majority charge carriers to cross the junction easily once the applied voltage exceeds a threshold value (about 0.7 V for silicon and 0.3 V for germanium).

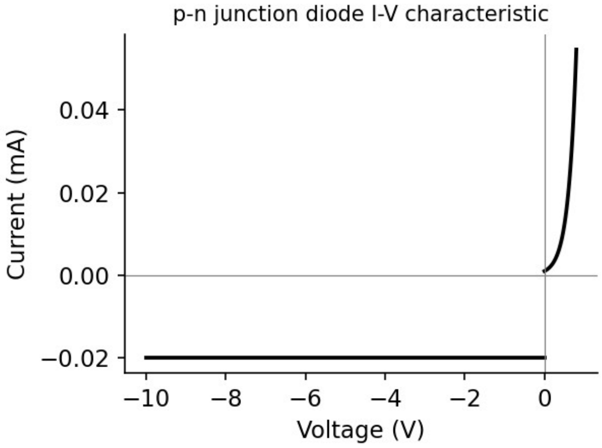
I. Why does a silicon diode require a higher forward voltage to start conducting compared to a germanium diode? [1]

II. In a circuit, a silicon diode (threshold 0.7 V) and a germanium diode (threshold 0.3 V) are connected in parallel with opposite polarities across a 6 V battery in series with a resistor. Which diode conducts first as the voltage is increased from zero, and why?

OR

Explain why the reverse saturation current in a p-n junction diode is much smaller than the forward current at the same magnitude of applied voltage. [1]

III. Sketch the typical I-V characteristic curve of a p-n junction diode, clearly showing the forward and reverse bias regions. [2]

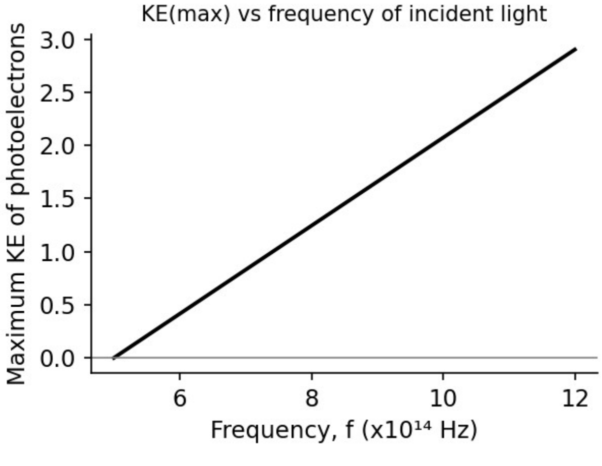


30. Read the passage given below and answer the questions that follow: [4]

The photoelectric effect refers to the emission of electrons from a metal surface when light of suitable frequency falls on it. Einstein explained this effect by proposing that light consists of discrete packets of energy called photons, each carrying energy hf, where h is Planck's constant and f is the frequency of the light. According to Einstein's photoelectric equation, the maximum kinetic energy of the emitted photoelectrons is KEmax = hf – ϕ_0, where ϕ_0 is the work function of the metal, the minimum energy needed to eject an electron from its surface. If the frequency of the incident light is less than the threshold frequency $f_0 = \phi_0/h$, no photoelectrons are emitted, however intense the light.
I. A metal has a work function of 2.14 eV. Will photoelectrons be emitted if light of frequency 4.0×10^{14} Hz is incident on it? Justify mathematically. [2]
II. If the frequency of the incident light in part I is increased while keeping the intensity constant, how will the photoelectric current be affected?

OR

How would increasing the intensity of light (at a frequency above the threshold) affect the photoelectric current? [1]
III. Sketch a graph of the maximum kinetic energy of the photoelectrons versus the frequency of the incident light, and state what the slope of this graph represents. [1]



SECTION E

Question numbers 31 to 33 are long answer questions carrying 5 marks each.

31. Attempt either (A) or (B). [5]

(A)

I. Derive an expression for the capacitance of a parallel plate capacitor with a dielectric slab of thickness t (t < d, the plate separation) and dielectric constant K inserted between the plates. [3]

II. A parallel plate capacitor is charged by a battery to a potential difference V and then disconnected from the battery. The separation between the plates is then increased using an insulating spacer. Explain, with justification, whether the energy stored in the capacitor increases, decreases, or stays the same. [2]

OR

(B)

I. Two point charges of +2 µC and +8 µC are placed 30 cm apart. Find the point on the line joining the charges where the electric field is zero. [3]

II. Explain why the electrostatic potential is necessarily constant throughout the volume of a conductor in electrostatic equilibrium, and has the same value on its surface as in its interior. [2]

32. Attempt either (A) or (B). [5]

(A)

I. Derive the lens maker's formula for a thin convex lens. [3]

II. An equiconvex lens made of glass of refractive index 1.5 has a focal length of 20 cm in air. Find the radius of curvature of each face. [2]

OR

(B)

I. Define the angle of deviation for a ray of light passing through a prism. Derive the relation $A + \delta = i + e$. [3]

II. State the condition for minimum deviation in a prism, and show that at minimum deviation, the refracted ray inside the prism travels parallel to its base. [2]

33. Attempt either (A) or (B). [5]

(A)

I. State the working principle of a moving coil galvanometer. What modification is needed to convert it into a linear-scale instrument? [2]

II. A galvanometer of resistance 100 Ω gives a full-scale deflection for a current of 2 mA. How can it be converted into an ammeter reading up to 2 A? Calculate the value of the resistance required. [3]

OR

(B)

I. State the working principle of a transformer. Explain, using the concept of mutual induction, why a transformer works only with alternating current and not with direct current. [2]

II. An ideal transformer has 500 turns in the primary coil and 25 turns in the secondary coil. The primary is connected to a 220 V AC source, and the secondary is connected to a load of resistance 4 Ω. Calculate (a) the secondary voltage, (b) the secondary current, and (c) the primary current, assuming 100% efficiency. [3]

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SECTION A

1. (C) Both fields are equal in magnitude – the electric field just outside any charged conductor depends only on the surface charge density ($E = \sigma/\varepsilon_0$), and since both spheres have the same charge Q on the same surface area (equal radius), σ and hence E are equal for both, regardless of whether the sphere is hollow or solid. [1]

2. (B) 4 : 1. Resistance $R = \rho L/A \propto 1/r^2$ (for fixed L), so R(thin, radius r) = 4 × R(thick, radius 2r). Since the wires are in series, the same current I flows through both, and heat produced $H = I^2Rt \propto R$. Hence H(thin) : H(thick) = R(thin) : R(thick) = 4 : 1. [1]

3. (C) A circle – when velocity is perpendicular to B, the magnetic force provides centripetal force of constant magnitude, giving uniform circular motion in the plane perpendicular to B. [1]

4. (B) Diamagnetic – diamagnetic substances have a small negative susceptibility that is essentially independent of temperature. [1]

5. (A) Clockwise, opposing the approach of the magnet – by Lenz's law, the induced current opposes the increasing flux due to the approaching North pole, so the loop face towards the magnet acts as a North pole (repelling it), which (viewed from the magnet's side) corresponds to a clockwise current. [1]

6. (B) Decreases – capacitive reactance $X_c = 1/(\omega C) = 1/(2\pi fC)$, which is inversely proportional to frequency. [1]

7. (A) Gamma rays < X-rays < visible light < microwaves – in order of increasing wavelength (equivalently decreasing frequency/energy): gamma rays, X-rays, ultraviolet, visible light, infrared, microwaves, radio waves. [1]

8. (B) Total internal reflection – when the angle of incidence in the denser medium exceeds the critical angle, all the light is reflected back into the denser medium. [1]

9. (B) Becomes half – fringe width $\beta = \lambda D/d$, which is inversely proportional to the slit separation d; doubling d halves β. [1]

10. (C) The maximum kinetic energy of the emitted photoelectrons – by Einstein's photoelectric equation, $KE_{max} = hf - \phi_0$, so increasing f (at constant intensity) increases KEmax, while the photoelectric current (determined by intensity, i.e. number of photons per second) stays the same. [1]

11. (B) n^2 – the Bohr radius of the nth orbit is given by $r_n = n^2 (4\pi\varepsilon_0\hbar^2)/(mZe^2)$, i.e. $r_n \propto n^2$. [1]

12. (B) Increases – under reverse bias, majority carriers are pulled away from the junction on both sides, widening the depletion region and increasing the barrier potential. [1]

13. (A) Both A and R are true, and R is the correct explanation – since the field inside the conducting shell is zero, no work is done in moving a test charge from the surface to any interior point, so the potential remains the same throughout the interior, equal to the surface value. [1]

14. (A) Both A and R are true, and R is the correct explanation – in a semiconductor, rising temperature breaks more covalent bonds, increasing the number of free charge carriers (electrons and holes), which increases conductivity and hence decreases resistance. [1]

15. (A) Both A and R are true, and R is the correct explanation – a ray incident normally (along the normal) has zero angle of incidence, so by Snell's law it continues without bending, though a small fraction is still partially reflected (a detail not required for the option). [1]

16. (A) Both A and R are true, and R is the correct explanation – the binding energy per nucleon curve peaks near A = 56 (iron); both fusion (combining light nuclei) and fission (splitting heavy nuclei) move the products closer to this maximum, releasing energy in the process. [1]

SECTION B

17. [2]

Since E and B are mutually perpendicular and both perpendicular to the direction of propagation (positive z-axis), and given E is along the x-axis, B must be along the y-axis (so that E × B points along +z, the direction of propagation). $B_0 = E_0/c = 45/(3\times10^8) = 1.5 \times 10^{-7}$ T $B = 1.5 \times 10^{-7} \sin(kz - \omega t)$ T, directed along the y-axis.

OR

(i) The electric field, magnetic field, and direction of propagation of an electromagnetic wave are mutually perpendicular to one another. (ii) The electric and magnetic fields oscillate in phase with each other, reaching their maximum and zero values simultaneously.

18. [2]

The graph of V versus I is a straight line with a negative slope, described by $V = \varepsilon - Ir$. The y-intercept (at $I = 0$, i.e. open circuit) gives the emf ε of the cell directly, since no current flows and there is no potential drop across the internal resistance. The magnitude of the slope of the V-I graph gives the internal resistance r of the cell, since slope = $-r$ (V decreases by r for every unit increase in I).

19. [2]

Consider a point P on the equatorial line at distance r from the centre O of the dipole. The distance from each charge to P is $\sqrt{(r^2 + a^2)}$. The field due to +q and −q at P are equal in magnitude, $E = kq/(r^2 + a^2)$, directed along the lines joining the charges to P. By symmetry, the components perpendicular to the dipole axis cancel, and the components along the axis (parallel to the dipole moment, but pointing opposite to it) add up. $E_{net} = 2 \times [kq/(r^2 + a^2)] \times [a/\sqrt{(r^2 + a^2)}] = k(2qa)/(r^2 + a^2)^{(3/2)} = kp/(r^2 + a^2)^{(3/2)}$ For r >> a: $E_{equatorial} \approx kp/r^3 = p/(4\pi\varepsilon_0 r^3)$, directed opposite to the dipole moment p.

OR

Electric dipole moment (p) is defined as the product of the magnitude of either charge (q) and the separation between the two charges (2a), directed from the negative to the positive charge: $p = q \times 2a$. Torque on the dipole: $\tau = pE \sin\theta$. This torque is maximum when $\theta = 90°$, i.e. when the dipole is oriented perpendicular to the field.

20. [2]

Ampere's circuital law states that the line integral of the magnetic field B around any closed loop is equal to μ_0 times the total current enclosed by that loop: $\oint B\cdot dl = \mu_0 I_{enclosed}$. For a long solenoid with n turns per unit length carrying current I, consider a rectangular Amperian loop with one side of length L inside the solenoid (parallel to the axis) and the opposite side far outside (where $B \approx 0$). Applying the law: $B \times L = \mu_0 \times (nL) \times I$, giving $B = \mu_0 nI$ (directed along the axis, inside the solenoid).

21. [2]

The impact parameter (b) is the perpendicular distance between the initial velocity direction of the incident alpha particle and the centre of the nucleus (the target). For a head-on collision, the impact parameter is zero ($b = 0$). In this case, the alpha particle travels directly towards the nucleus, comes momentarily to rest at the point of closest approach due to Coulomb repulsion, and then rebounds straight back along the same path, i.e. it is scattered through 180°.

SECTION C

22. [3]

A centre-tapped transformer's secondary has two halves, each feeding one of two diodes (D1 and D2), with the centre tap grounded and connected to one terminal of the load resistor. During one half of the AC cycle, D1 is forward biased and conducts, while D2 is reverse biased; during the other half, the roles reverse and D2 conducts while D1 is cut off. In each half-cycle, current flows through the load in the same direction (from the centre tap, through the load, back through whichever diode is conducting), so the output across the load is a series of unidirectional pulses at twice the frequency of the input AC, with the same polarity throughout - hence the term full wave rectification. (Circuit diagram: centre-tapped secondary with D1 and D2 connected to the two ends, load resistor connected between the diodes' common cathode/anode point and the centre tap. Waveform: sinusoidal AC input; output is a series of positive humps at double the input frequency.)

23. [3]

Kirchhoff's Current Law (junction rule): the algebraic sum of currents meeting at a junction is zero (i.e. total current entering a junction equals total current leaving it), a statement of conservation of charge. Kirchhoff's Voltage Law (loop rule): the algebraic sum of potential differences (including emfs and IR drops) around any closed loop in a circuit is zero. The voltage law embodies conservation of energy: as a unit charge traverses a closed loop and returns to its starting point, the net work done on it must be zero, since electrostatic potential is a single-valued function of position; any energy supplied by emf sources in the loop must exactly equal the energy dissipated (or otherwise used) across the resistive elements in that loop.

24. [3]

(i) Energy of ground state (n=1): E1 = −13.6 eV. Energy of n=3 state: $E3 = -13.6/3^2 = -1.51$ eV. Energy absorbed = E3 − E1 = −1.51 − (−13.6) = 12.09 eV (ii) Wavelength: E = hc/λ ⇒ λ = hc/E Converting E to joules: $12.09 \times 1.6\times10^{-19} = 1.934\times10^{-18}$ J $\lambda = (6.63\times10^{-34} \times 3\times10^{8})/(1.934\times10^{-18}) \approx 1.028 \times 10^{-7}$ m ≈ 102.8 nm

OR

Bohr's postulates: electrons revolve in stationary circular orbits without radiating energy, and angular momentum is quantised as mvr = nħ. For an electron in the nth orbit of radius rn, the centripetal force is provided by the Coulomb attraction: $mv^2/rn = kZe^2/rn^2$, giving $v = \sqrt{(kZe^2/mrn)}$. Using the quantisation condition and solving simultaneously gives $rn = n^2\hbar^2(4\pi\varepsilon_0)/(mZe^2)$. Total energy = KE + PE = $(1/2)mv^2 + (-kZe^2/rn) = kZe^2/(2rn) - kZe^2/rn = -kZe^2/(2rn)$ Substituting rn gives $En = -mZ^2e^4/(8\varepsilon_0{}^2n^2h^2)$, showing $En \propto -1/n^2$.

25. [3]

Using the lens formula for the objective: 1/v − 1/u = 1/f, with u = −1.1 cm, f = 1.0 cm 1/v = 1/f + 1/u = 1/1.0 + 1/(−1.1) = 1 − 0.909 = 0.0909 v = 11.0 cm Objective's linear magnification: mo = v/u = 11.0/(−1.1) = −10 (magnitude 10) Eyepiece angular magnification (image at near point D = 25 cm): me = 1 + D/fe = 1 + 25/3.0 = 1 + 8.33 = 9.33 Total angular magnification, M = mo × me = 10 × 9.33 ≈ 93.3

26. [3]

Consider a ray incident on face AB of a prism at angle i, refracting to angle r1 at the first surface, travelling to face AC, and emerging at angle e after refracting from angle r2 at the second surface. In the quadrilateral formed by the normals at the two refracting surfaces and the two faces of the prism, the angles at the two normals sum with A to give 360° in one arrangement, leading to A = r1 + r2. The total deviation δ is the sum of deviations at each surface: δ = (i − r1) + (e − r2) = (i + e) − (r1 + r2) = (i + e) − A Rearranging: A + δ = i + e. Condition for minimum deviation: i = e (and correspondingly r1 = r2 = A/2), at which point the deviation δ attains its minimum value δm, giving A + δm = 2i.

27. [3]

(A) Since velocity (along x) is perpendicular to B (along z), the magnetic force provides centripetal force, so the particle moves in a circular path in the xy-plane. (B) Radius $r = mv/(qB) = (2\times10^{-3} \times 3)/(1\times10^{-6} \times 0.2) = (6\times10^{-3})/(2\times10^{-7}) = 3 \times 10^{4}$ m (C) The kinetic energy does not change. The magnetic force on a moving charge is always perpendicular to its velocity, so it does no work on the particle; hence its speed, and therefore its kinetic energy, remains constant throughout the motion.

28. [3]

For a rod rotating about one end, the emf induced is: $\varepsilon = (1/2)B\omega L^2$ $\varepsilon = (1/2) \times 0.4 \times 40 \times (0.5)^2 = (1/2) \times 0.4 \times 40 \times 0.25 = 2$ V

SECTION D

29. [4]

I. Silicon has a larger energy band gap (about 1.1 eV) compared to germanium (about 0.7 eV), so a higher applied forward voltage is needed in silicon to supply enough energy to overcome the larger potential barrier at the junction and allow significant current flow. [1]

II. The germanium diode conducts first, since it has a lower threshold (turn-on) voltage of 0.3 V compared to silicon's 0.7 V; as the applied voltage is increased from zero, the germanium diode reaches its threshold and starts conducting significantly before the silicon diode does.

OR: In forward bias, the applied voltage reduces the potential barrier at the junction, allowing a large number of majority carriers to cross and produce a substantial current. In reverse bias, only a small number of minority carriers (thermally generated) are available to cross the junction, and the applied voltage actually increases the barrier, so only a tiny reverse saturation current flows, which is largely independent of the reverse voltage magnitude. [1]

III. The I-V graph shows: in the forward bias region (positive V), current remains nearly zero until the threshold voltage is reached, after which it rises steeply (exponentially); in the reverse bias region (negative V), a very small, nearly constant reverse saturation current flows, until (at very large reverse voltage, not required here) breakdown occurs. [2]

30. [4]

I. Threshold frequency $f_0 = \phi_0/h = (2.14 \times 1.6\times10^{-19})/(6.63\times10^{-34}) = (3.424\times10^{-19})/(6.63\times10^{-34}) \approx 5.16 \times 10^{14}$ Hz. Since the incident frequency (4.0×10^{14} Hz) is less than this threshold frequency, no photoelectrons will be emitted, regardless of the intensity of the light. [2]

II. This scenario does not apply directly since no photoelectrons are emitted below threshold; however, once the frequency is raised above f_0, increasing the frequency further (at constant intensity) would not change the photoelectric current (which depends on the number of photons/intensity), though it would increase the maximum kinetic energy of the emitted photoelectrons.

OR: Increasing the intensity of light (at a frequency above threshold) increases the number of photons incident per second, which increases the number of photoelectrons emitted per second, and hence increases the photoelectric current, while the maximum kinetic energy of the photoelectrons remains unchanged. [1]

III. The graph of KEmax versus frequency is a straight line that intersects the frequency axis at f_0 (the threshold frequency) and has a positive slope. The slope of this graph is equal to Planck's constant, h. [1]

SECTION E

31 (A). [5]

I. Consider a parallel plate capacitor of plate area A and separation d, with a dielectric slab of thickness t and dielectric constant K inserted between the plates. The electric field in the vacuum part (thickness d−t) is $E_0 = \sigma/\varepsilon_0$, and in the dielectric (thickness t) is $E = E_0/K = \sigma/(K\varepsilon_0)$. Potential difference $V = E_0(d-t) + (E_0/K)(t) = (\sigma/\varepsilon_0)[(d-t) + t/K]$ Capacitance $C = Q/V = \sigma A/V = \varepsilon_0 A / [(d-t) + t/K]$ [3]

II. Since the capacitor is disconnected from the battery, the charge Q on its plates remains constant. The energy stored is $U = Q^2/(2C)$. As the separation d increases, the capacitance $C = \varepsilon_0 A/d$ decreases. Since Q is fixed and C decreases, $U = Q^2/(2C)$ increases. So the energy stored in the capacitor increases; this extra energy comes from the mechanical work done in pulling the plates apart against their mutual attraction. [2]

OR (B)

I. Let the point of zero field be at distance x from the +2 µC charge ($0 < x < 30$ cm), so the distance from the +8 µC charge is (30−x) cm. Since both charges are positive, the point of zero field must lie between them (fields from each charge point away from that charge, so they oppose each other only between the two charges). Setting fields equal: $k(2)/x^2 = k(8)/(30-x)^2$ $(30-x)^2/x^2 = 4 \Rightarrow (30-x)/x = 2$ (taking positive root) $\Rightarrow 30-x = 2x \Rightarrow x = 10$ cm So the field is zero at 10 cm from the +2 µC charge (and 20 cm from the +8 µC charge). [3]

II. If the potential were not constant throughout the conductor's volume, there would be a non-zero potential gradient (i.e. an electric field) inside the conductor. But in electrostatic equilibrium, free charges have stopped moving, which requires the electric field inside the conductor to be zero everywhere. Since $E = 0$ inside implies no change in potential from point to point, the potential must be constant throughout the conductor's volume, and by continuity, equal to the value on its surface. [2]

32 (A). [5]

I. For refraction at the first surface (radius R1) of a thin lens, using the formula for refraction at a spherical surface: $n2/v1 - n1/u = (n2-n1)/R1$ For refraction at the second surface (radius R2), treating the image from the first surface as the object: $n1/v - n2/v1 = (n1-n2)/R2$ Adding these two equations (the v1 terms cancel): $n1/v - n1/u = (n2-n1)[1/R1 - 1/R2]$ Dividing throughout by n1 and writing $n = n2/n1$ (relative refractive index), and using $1/f = 1/v - 1/u$ for $u \to \infty$ and $v \to f$: $1/f = (n-1)[1/R1 - 1/R2]$, which is the lens maker's formula. [3]

II. For an equiconvex lens, $R1 = +R$ and $R2 = -R$. $1/f = (n-1)[1/R - (-1/R)] = (n-1)(2/R)$ $1/20 = (1.5-1)(2/R) = 0.5 \times 2/R = 1/R$ $R = 20$ cm [2]

OR (B)
I. The angle of deviation (δ) is the angle between the direction of the incident ray (extended) and the direction of the emergent ray, i.e. the total angle through which the light ray is turned from its original path on passing through the prism. Derivation of $A + \delta = i + e$: (see full derivation) the angle of the prism A equals the sum of the two refraction angles at the surfaces ($A = r1 + r2$), and the total deviation is the sum of the individual deviations at each surface ($\delta = (i-r1)+(e-r2) = (i+e)-(r1+r2) = (i+e)-A$), rearranging to give $A + \delta = i + e$. [3]

II. Minimum deviation occurs when the angle of incidence equals the angle of emergence ($i = e$), which by symmetry corresponds to the refracted ray inside the prism travelling parallel to the base of the prism. This can be shown because, at minimum deviation, $r1 = r2 = A/2$, so the path of the ray inside the prism is symmetric with respect to the two refracting faces, meaning it must be parallel to the base, which is symmetric to both faces. [2]

33 (A). [5]

I. A moving coil galvanometer works on the principle that a current-carrying coil placed in a uniform radial magnetic field experiences a torque proportional to the current flowing through it, causing it to deflect against a restoring torque provided by a spring, until the two torques balance; the deflection is thus a measure of the current. To make its scale linear, a radial magnetic field is used (achieved through concave pole pieces and a cylindrical soft iron core), which ensures the magnetic field is always parallel to the plane of the coil, making the deflecting torque directly proportional to the current at all deflection angles. [2]

II. To convert a galvanometer into an ammeter, a small resistance (shunt) is connected in parallel with it, so that most of the current bypasses the galvanometer. Let shunt resistance = S. At full-scale deflection, $Ig = 2$ mA flows through the galvanometer, and $(I - Ig) = (2000 - 2) = 1998$ mA flows through the shunt, with the same voltage across both: $Ig \times G = (I - Ig) \times S$ $2 \times 100 = 1998 \times S$ $S = 200/1998 \approx 0.1\ \Omega$ (a small resistance connected in parallel with the galvanometer) [3]

OR (B)
I. A transformer works on the principle of mutual induction: an alternating current in the primary coil produces a continuously changing magnetic flux, which links with the secondary coil (through a common iron core) and induces an emf in it. A transformer works only with alternating current because mutual induction requires a changing flux; direct current produces a constant (unchanging) flux (after the initial transient), so no emf would be induced in the secondary coil under steady DC conditions. [2]

II. Turns ratio: $Ns/Np = 25/500 = 1/20$ (a) Secondary voltage: $Vs = Vp \times (Ns/Np) = 220 \times (1/20) = 11$ V (b) Secondary current: $Is = Vs/R = 11/4 = 2.75$ A (c) For an ideal transformer (100% efficiency), power is conserved: $Vp \times Ip = Vs \times Is$ $Ip = (Vs \times Is)/Vp = (11 \times 2.75)/220 = 30.25/220 = 0.1375$ A [3]