PHYSICS (CODE - 042)
SAMPLE PAPER 3
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. Two identical metal spheres, one carrying charge +Q and the other charge –Q/3, are brought into contact and then separated. The charge on each sphere after separation is:

(A) +Q/3 on each

(B) +Q/3 on one and –Q/3 on the other

(C) +Q/6 on each

(D) +Q/2 on each

2. A copper wire and an aluminium wire of the same length have the same resistance. The ratio of their cross-sectional areas (copper : aluminium) is (given ρcopper < ρaluminium):

(A) Greater than 1

(B) Less than 1

(C) Equal to 1

(D) Cannot be determined

3. A current-carrying straight conductor is placed parallel to a uniform magnetic field. The force experienced by the conductor is:

(A) Maximum

(B) Zero

(C) Half of the maximum possible value

(D) Dependent only on the length of the conductor

4. Curie temperature is the temperature above which:

(A) A paramagnetic material becomes diamagnetic

(B) A ferromagnetic material becomes paramagnetic

(C) A diamagnetic material becomes ferromagnetic

(D) A paramagnetic material becomes ferromagnetic

5. A jet plane with a wingspan of 25 m is flying horizontally with a speed of 200 m/s in a region where the vertical component of Earth's magnetic field is 5×10^{-5} T. The emf induced between the tips of its wings is:

(A) 0.25 V

(B) 0.025 V

(C) 2.5 V

(D) 0.0025 V

6. In an AC circuit containing only an inductor, the current:

(A) Leads the voltage by 90°

(B) Lags the voltage by 90°

(C) Is in phase with the voltage

(D) Lags the voltage by 180°

7. X-rays and gamma rays both belong to the electromagnetic spectrum. Which of the following correctly distinguishes them?

(A) X-rays travel faster than gamma rays in vacuum

(B) Gamma rays originate from nuclear processes, while X-rays typically originate from energy transitions of inner atomic electrons

(C) X-rays cannot be diffracted, unlike gamma rays

(D) Gamma rays have a longer wavelength than X-rays

8. A concave mirror produces a virtual, erect, and magnified image only when the object is placed:

(A) Beyond the centre of curvature

(B) At the centre of curvature

(C) Between the focus and the pole

(D) At the focus

9. In Young's double slit experiment, white light is used instead of monochromatic light. The central fringe observed will be:

(A) Dark

(B) White

(C) Red

(D) Violet

10. The stopping potential in a photoelectric experiment depends on:

(A) The intensity of the incident light only

(B) The frequency of the incident light and the work function of the metal

(C) The area of the metal surface

(D) The distance between the source and the metal surface

11. The mass defect in a nucleus is a measure of:

(A) The mass of the electrons in the atom

(B) The binding energy holding the nucleons together

(C) The number of neutrons only

(D) The radius of the nucleus

12. The logic gate whose output is HIGH only when both inputs are HIGH is:

(A) OR gate

(B) NOR gate

(C) AND gate

(D) NAND gate

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 field inside a charged conductor in electrostatic equilibrium is zero. Reason (R): Any excess charge on a conductor resides entirely on its outer surface.

14. Assertion (A): Two bulbs rated 100 W and 60 W, both designed for 220 V, are connected in series across a 220 V supply; the 60 W bulb glows brighter. Reason (R): For a series combination with the same current flowing through both, the bulb with higher resistance dissipates more power, and the 60 W bulb has a higher resistance than the 100 W bulb.

15. Assertion (A): A convex lens always forms a real image of a real object. Reason (R): A convex lens is a converging lens.

16. Assertion (A): Heavy water is preferred over ordinary water as a moderator in nuclear reactors. Reason (R): Heavy water absorbs fewer neutrons than ordinary water while still slowing them down effectively.

SECTION B

Question numbers 17 to 21 carry 2 marks each.

17. Derive an expression for the electric field on the axial line of an electric dipole of dipole moment p, at a distance r from its centre (r >> a, where 2a is the separation between the charges). [2]

18. State the principle on which a potentiometer works. Why is a potentiometer preferred over a voltmeter for measuring the emf of a cell? [2]

OR

Two resistors of 4 Ω and 6 Ω are connected (i) in series, and (ii) in parallel, across a 12 V battery. Find the current drawn from the battery in each case.

19. A current of 2 A is passed through a straight conductor placed in a uniform magnetic field of 0.5 T, such that the conductor makes an angle of 30° with the field. If the length of the conductor is 0.4 m, calculate the force experienced by it. [2]

OR

State the working principle of a cyclotron. Why is it not suitable for accelerating electrons to very high speeds?

20. Define self-inductance of a coil. A coil has a self-inductance of 2 H. If the current through it changes from 5 A to 1 A in 0.2 s, calculate the emf induced in the coil. [2]

21. Draw the energy level diagram for the hydrogen atom showing the Lyman and Balmer series of spectral lines, indicating the transitions involved in each series. [2]

SECTION C

Question numbers 22 to 28 carry 3 marks each.

22. Explain, with the help of a circuit diagram, how a Zener diode can be used as a voltage regulator. [3]

23. Three resistors of 2 Ω, 3 Ω, and 6 Ω are connected in parallel, and this combination is connected in series with a 4 Ω resistor and a 12 V battery of negligible internal resistance. Calculate (i) the total resistance of the circuit, and (ii) the total current drawn from the battery. [3]

OR

State Kirchhoff's laws. In a circuit, a battery of emf 10 V and internal resistance 1 Ω is connected to an external resistance of 4 Ω. Calculate the terminal voltage of the battery.

24. A radioactive sample has an activity of 1000 disintegrations per second at t = 0. If its half-life is 10 days, calculate (i) the decay constant, and (ii) the activity of the sample after 30 days. [3]

25. Draw a labelled ray diagram to show the formation of an image by a compound microscope when the final image is formed at infinity. Write the expression for its magnifying power in this case. [3]

26. In a Young's double slit experiment, derive the expression for the fringe width in terms of the wavelength of light used, the slit separation, and the distance of the screen from the slits. [3]

27. Two coherent sources of light, separated by 0.2 mm, produce an interference pattern on a screen placed 1.5 m away, using light of wavelength 6000 Å. Calculate (i) the fringe width, and (ii) the distance of the 5th dark fringe from the central bright fringe. [3]

28. A parallel plate capacitor of capacitance 4 μF is charged to a potential difference of 100 V and then disconnected from the battery. It is then connected in parallel to another uncharged capacitor of capacitance 2 μF. Calculate (i) the common potential difference, and (ii) the loss in energy during this process. [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 transformer is a static electrical device that transfers electrical energy from one circuit to another through electromagnetic induction, without changing the frequency. It consists of two coils, the primary and the secondary, wound on a common laminated soft iron core. An alternating current in the primary coil produces a changing magnetic flux in the core, which induces an emf in the secondary coil. The ratio of the number of turns in the secondary to the primary determines whether the transformer steps up or steps down the voltage. In practice, transformers are not 100% efficient due to energy losses such as copper losses (resistive heating in the windings), hysteresis losses (in magnetising and demagnetising the core), and eddy current losses (induced currents circulating within the core itself); laminating the core reduces eddy current losses significantly.

I. Why is the core of a transformer laminated rather than being a single solid block of iron? [1]

II. A step-up transformer has 200 turns in its primary and 1000 turns in its secondary coil. If the primary is connected to a 220 V AC supply, calculate the secondary voltage.

OR

What is meant by 'copper loss' in a transformer, and how can it be minimised? [1]

III. Explain why a transformer cannot be used to step up or step down a steady DC voltage. [2]

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

Total internal reflection occurs when light travelling in a denser medium strikes the boundary with a rarer medium at an angle of incidence greater than the critical angle for that pair of media, causing all the light to be reflected back into the denser medium with no refraction. This phenomenon is the basis of optical fibres, which consist of a core of high refractive index surrounded by cladding of slightly lower refractive index; light entering the fibre at a suitable angle undergoes repeated total internal reflection at the core-cladding boundary, allowing it to travel long distances through the fibre with minimal loss of intensity, even around bends. Optical fibres are widely used in telecommunications and medical endoscopy.

I. What is the condition (in terms of angle of incidence) for total internal reflection to occur at an interface? [1]

II. The critical angle for a certain glass-air interface is 42°. Calculate the refractive index of the glass.

OR

Why must the refractive index of the core of an optical fibre be greater than that of the cladding? [1]

III. Explain why optical fibres can transmit light signals around bends with very little loss of intensity. [2]

SECTION E

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

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

(A)

I. State Gauss's theorem in electrostatics. Use it to derive the expression for the electric field due to a uniformly charged infinite plane sheet. [3]

II. Two large parallel plane sheets carry uniform surface charge densities of $+\sigma$ and $-\sigma$. Find the electric field (a) between the sheets, and (b) outside the sheets, on either side. [2]

OR

(B)

I. Derive the expression for the electric field due to a uniformly charged thin spherical shell, at a point (a) outside the shell, and (b) inside the shell. [3]

II. A spherical conducting shell of radius 10 cm carries a charge of 4 μC. Calculate the electric field at a distance of (a) 5 cm from the centre, and (b) 20 cm from the centre. [2]

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

(A)

I. Derive the mirror formula $1/v + 1/u = 1/f$ for a concave mirror, using the ray diagram for a real image formed by a real object placed beyond the centre of curvature. [3]

II. An object is placed 30 cm in front of a concave mirror of focal length 20 cm. Find the position, nature, and magnification of the image formed. [2]

OR

(B)

I. What is total internal reflection? Derive the relation between the critical angle and the refractive index of a medium with respect to air. [3]

II. A ray of light is incident on one face of an equilateral glass prism (refractive index 1.5) at grazing incidence (angle of incidence = 90°). Calculate the angle of emergence from the opposite face. [2]

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

(A)

I. Using Bohr's postulates, derive the expression for the radius of the nth orbit of the hydrogen atom. [3]

II. Calculate the radius of the second Bohr orbit of hydrogen, given the radius of the first orbit is 0.529 Å. [2]

OR

(B)

I. Draw a labelled diagram of a p-n junction diode and explain, in brief, the formation of the depletion region and the potential barrier. [3]

II. In a full wave rectifier circuit, if the peak value of the AC input voltage is 20 V, and each diode has a forward voltage drop of 0.7 V, find the peak value of the output voltage across the load. [2]

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SECTION A

1. (A) +Q/3 on each. When two identical conducting spheres touch, the total charge is shared equally between them. Total charge = Q + (−Q/3) = 2Q/3. Shared equally: each sphere gets (2Q/3)/2 = Q/3. [1]

2. (B) Less than 1. Since R = ρL/A is the same for both wires (same length L, same R), we need A = ρL/R, so A is directly proportional to ρ. Since ρcopper < ρaluminium, it follows that Acopper < Aaluminium, giving a ratio (copper:aluminium) less than 1. [1]

3. (B) Zero – the force on a current-carrying conductor is F = BIL sinθ, where θ is the angle between the current direction and the field; when the conductor is parallel to the field, θ = 0°, so sinθ = 0 and the force is zero. [1]

4. (B) A ferromagnetic material becomes paramagnetic – above the Curie temperature, thermal agitation disrupts the domain alignment responsible for ferromagnetism, and the material behaves as a paramagnetic substance. [1]

5. (A) 0.25 V. Motional emf = Bvl = $(5\times10^{-5}) \times 200 \times 25 = (5\times10^{-5}) \times 5000 = 0.25$ V. [1]

6. (B) Lags the voltage by 90° – in a pure inductor, current lags the applied voltage by a phase angle of 90° (π/2 radians). [1]

7. (B) Gamma rays originate from nuclear processes (transitions within the nucleus), while X-rays typically arise from energy transitions of inner (core) atomic electrons or deceleration of fast electrons; both travel at the same speed (c) in vacuum. [1]

8. (C) Between the focus and the pole – an object placed between the pole and the focus of a concave mirror produces a virtual, erect, magnified image behind the mirror. [1]

9. (B) White – at the centre, the path difference for all wavelengths is zero, so all colours reinforce constructively at the same point, producing a white central fringe (with coloured fringes on either side). [1]

10. (B) The frequency of the incident light and the work function of the metal – by Einstein's equation, eV0 = hf – ϕ_0, the stopping potential V0 depends on f and ϕ_0, but not on the intensity of light. [1]

11. (B) The binding energy holding the nucleons together – the mass defect (difference between the sum of masses of free nucleons and the actual nuclear mass) is converted to binding energy via $E = \Delta mc^2$, representing the energy required to separate the nucleus into individual nucleons. [1]

12. (C) AND gate – its output is HIGH (1) only when both inputs are HIGH (1); any other combination gives a LOW output. [1]

13. (A) Both A and R are true, and R is the correct explanation – since the field inside a conductor in equilibrium is zero, any excess charge (which would create a field if distributed through the volume) must reside entirely on the outer surface. [1]

14. (A) Both A and R are true, and R is the correct explanation – for bulbs rated at the same voltage, $R = V^2/P$, so the 60 W bulb (lower rated power) has a higher resistance than the 100 W bulb; in series, the same current flows through both, and power dissipated $P = I^2R$ is higher for the bulb with greater resistance, so the 60 W bulb glows brighter in this series configuration. [1]

15. (D) Both A and R are false – a convex lens does not always form a real image; if the object is placed within the focal length, it forms a virtual, erect, magnified image (as in a simple microscope), so Assertion A is false; R is also an incomplete/insufficient statement as the sole justification since being a converging lens does not guarantee only real images are formed. [1]

16. (A) Both A and R are true, and R is the correct explanation – heavy water (D_2O) is an effective moderator because deuterium nuclei are close in mass to neutrons (efficient at slowing them via elastic collisions) while having a much lower neutron absorption cross-section than ordinary hydrogen, minimising the loss of neutrons needed to sustain the chain reaction. [1]

SECTION B

17. [2]

Consider a dipole with charges +q and −q separated by 2a, and a point P on the axial line at distance r from the centre. Distance from +q to P = (r−a), and from −q to P = (r+a). Field due to +q (away from it, towards P): $E+ = kq/(r-a)^2$ (along the axis, away from dipole) Field due to −q (towards it): $E- = kq/(r+a)^2$ (along the axis, towards −q, i.e. same direction as E+ since P is beyond +q) Net field: $E = kq[1/(r-a)^2 - 1/(r+a)^2] = kq \times [4ar/(r^2-a^2)^2]$ For r >> a: $E \approx 4kqar/r^4 = 2kp/r^3 = 2p/(4\pi\varepsilon_0 r^3) = p/(2\pi\varepsilon_0 r^3)$, directed along the dipole moment direction.

18. [2]

A potentiometer works on the principle that when a constant current flows through a uniform wire of constant cross-section, the potential drop across any length of the wire is directly proportional to that length. A potentiometer is preferred over a voltmeter for measuring emf because, at the balance point, it draws no current from the cell whose emf is being measured (infinite effective resistance at balance), so it measures the true emf; a voltmeter, having finite resistance, always draws some current and measures only the terminal voltage, which is less than the emf.

OR

(i) Series: Rs = 4+6 = 10 Ω. Current, I = V/Rs = 12/10 = 1.2 A (ii) Parallel: 1/Rp = 1/4+1/6 = 3/12+2/12 = 5/12 ⇒ Rp = 12/5 = 2.4 Ω. Current, I = V/Rp = 12/2.4 = 5 A

19. [2]

$F = BIL \sin\theta = 0.5 \times 2 \times 0.4 \times \sin 30° = 0.5 \times 2 \times 0.4 \times 0.5 = 0.2$ N

OR

A cyclotron works on the principle that a charged particle moving perpendicular to a magnetic field can be accelerated to high energies using a relatively low alternating voltage applied repeatedly, by making it move in a spiral path of increasing radius within two D-shaped electrodes (dees), gaining energy each time it crosses the gap between them. A cyclotron is not suitable for accelerating electrons because electrons have a very small mass, so even at moderate energies they reach relativistic speeds; this increases their mass (relativistically) and disrupts the resonance condition (cyclotron frequency depends on mass), causing them to fall out of sync with the alternating voltage.

20. [2]

Self-inductance of a coil is the property by virtue of which the coil opposes any change in the current flowing through it, by inducing an emf in itself; it is numerically equal to the emf induced per unit rate of change of current, or the flux linkage per unit current. $\varepsilon = -L(dI/dt) = -2 \times [(1-5)/0.2] = -2 \times (-20) = 40$ V (magnitude 40 V)

21. [2]

(Energy level diagram description, to be drawn:) Horizontal lines representing energy levels n=1 (−13.6 eV), n=2 (−3.4 eV), n=3 (−1.51 eV), n=4 (−0.85 eV), and so on, approaching 0 eV as $n \to \infty$. Lyman series: all transitions ending at n=1 (from n=2,3,4,... to n=1), lying in the ultraviolet region. Balmer series: all transitions ending at n=2 (from n=3,4,5,... to n=2), lying in the visible region.

SECTION C

22. [3]

A Zener diode is operated in reverse breakdown, where its voltage remains nearly constant (at the Zener voltage, Vz) over a wide range of reverse currents. In a voltage regulator circuit, the Zener diode is connected in reverse bias, in parallel with the load, with a series resistor connecting to the unregulated input voltage. Any increase in input voltage (or decrease in load current) is absorbed by a corresponding change in the current through the Zener diode (via the series resistor), while the voltage across the diode (and hence across the load, since they are in parallel) remains essentially constant at Vz, providing a stable, regulated output voltage regardless of fluctuations in the input voltage or load current, as long as operation stays within the diode's breakdown region.

23. [3]

(i) Parallel combination of 2, 3, 6 Ω: $1/R_p = 1/2+1/3+1/6 = 3/6+2/6+1/6 = 1 \Rightarrow R_p = 1\ \Omega$ Total resistance = $R_p + 4 = 1 + 4 = 5\ \Omega$ (ii) Total current, $I = V/R_{total} = 12/5 = 2.4$ A

OR

Kirchhoff's current law: the algebraic sum of currents at a junction is zero (conservation of charge). Kirchhoff's voltage law: the algebraic sum of potential changes around any closed loop is zero (conservation of energy). Terminal voltage, $V = \varepsilon - Ir$, where $I = \varepsilon/(R+r) = 10/(4+1) = 2$ A $V = 10 - (2\times1) = 8$ V

24. [3]

(i) $\lambda = 0.693/t_{½} = 0.693/10 = 0.0693$ per day (ii) $A = A_0e^{-\lambda t}$. Number of half-lives in 30 days = 30/10 = 3 $A = A_0(1/2)^3 = 1000 \times (1/8) = 125$ disintegrations per second

25. [3]

(Ray diagram description:) The object is placed just beyond the focus of the objective lens, forming a real, inverted, magnified image within the focal length of the eyepiece. This intermediate image acts as the object for the eyepiece, which (with the intermediate image at its focus) produces a final image at infinity, viewed by a relaxed eye. Magnifying power (final image at infinity): $M = (L/f_o) \times (D/f_e)$, where L is the distance between the second focal point of the objective and the first focal point of the eyepiece (approximately the tube length), fo and fe are the focal lengths of the objective and eyepiece, and D is the least distance of distinct vision (25 cm).

26. [3]

Consider two coherent sources S1 and S2 (slits) separated by distance d, and a screen at distance D. For a point P on the screen at distance y from the central point O, the path difference is $\Delta = S_2P - S_1P \approx yd/D$ (using the geometry of the setup and D >> d). For a bright fringe (constructive interference): $\Delta = n\lambda \Rightarrow y_n = n\lambda D/d$ For the (n+1)th bright fringe: $y_{(n+1)} = (n+1)\lambda D/d$ Fringe width, $\beta = y_{(n+1)} - y_n = \lambda D/d$

27. [3]

(i) $\beta = \lambda D/d = (6000\times10^{-10} \times 1.5)/(0.2\times10^{-3}) = (9\times10^{-7})/(2\times10^{-4}) = 4.5 \times 10^{-3}$ m = 4.5 mm (ii) Distance of nth dark fringe from centre = $(n-½)\beta$. For n=5: distance = (5–0.5) × 4.5 mm = 4.5 × 4.5 = 20.25 mm

28. [3]

(i) Charge on first capacitor before connecting: $Q_1 = C_1V_1 = 4\times10^{-6} \times 100 = 4\times10^{-4}$ C Common potential, $V = (C_1V_1 + C_2V_2)/(C_1+C_2) = (4\times10^{-4} + 0)/(4+2)\times10^{-6} = (4\times10^{-4})/(6\times10^{-6}) = 66.67$ V (ii) Initial energy = $(1/2)C_1V_1^2 = 0.5 \times 4\times10^{-6} \times 100^2 = 0.5\times4\times10^{-6}\times10000 = 0.02$ J Final energy = $(1/2)(C_1+C_2)V^2 = 0.5 \times 6\times10^{-6} \times (66.67)^2 \approx 0.5\times6\times10^{-6}\times4445 \approx 0.01333$ J Loss in energy = 0.02 – 0.01333 ≈ 0.00667 J (≈ 6.67 mJ)

SECTION D

29. [4]

I. Laminating the core (using thin, insulated sheets of iron instead of a solid block) increases the electrical resistance to any eddy currents that would circulate within the core, significantly reducing eddy current losses (heating) and improving the transformer's efficiency. [1]

II. $V_s/V_p = N_s/N_p \Rightarrow V_s = V_p \times (N_s/N_p) = 220 \times (1000/200) = 220 \times 5 = 1100$ V

OR: Copper loss refers to the energy dissipated as heat due to the resistance of the copper windings (I^2R loss) in both the primary and secondary coils. It can be minimised by using thicker wires (lower resistance) for the windings. [1]

III. A transformer works on the principle of mutual induction, which requires a continuously changing magnetic flux to induce an emf in the secondary coil. A steady DC voltage in the primary produces a constant magnetic flux (after any initial transient), so no emf is induced in the secondary under steady-state conditions; hence a transformer cannot step up or step down a steady DC voltage. [2]

30. [4]

I. Total internal reflection occurs when the angle of incidence (in the denser medium) is greater than the critical angle for that pair of media. [1]

II. $n = 1/\sin(\text{critical angle}) = 1/\sin 42° = 1/0.669 \approx 1.495 \approx 1.5$

OR: The refractive index of the core must be greater than that of the cladding so that light travelling within the core, striking the core-cladding boundary at an angle greater than the critical angle, undergoes total internal reflection and remains confined within the core; if the cladding had equal or higher refractive index, light would simply refract out into the cladding rather than being reflected back. [1]

III. As light travels along the fibre, it repeatedly undergoes total internal reflection at the core-cladding boundary (which reflects 100% of the incident light, with no loss due to refraction/transmission at each reflection), allowing the light to be guided along the length of the fibre, including around gentle bends, with very little loss of intensity, unlike ordinary reflection from a mirror surface which is never perfectly total. [2]

SECTION E

31 (A). [5]

I. Gauss's theorem: the total electric flux through a closed surface equals $Q_{enclosed}/\varepsilon_0$. For an infinite plane sheet with uniform surface charge density σ, consider a cylindrical Gaussian pillbox with its axis perpendicular to the sheet and flat faces on either side, each of area A. By symmetry, the field is perpendicular to the sheet and has equal magnitude E on both faces, pointing away from the sheet (for positive σ); there is no flux through the curved surface. Total flux = $EA + EA = 2EA = (\sigma A)/\varepsilon_0$ $E = \sigma/(2\varepsilon_0)$, independent of the distance from the sheet. [3]

II. (a) Between the sheets: fields from both sheets point in the same direction (from + towards –), so they add: $E = \sigma/(2\varepsilon_0) + \sigma/(2\varepsilon_0) = \sigma/\varepsilon_0$ (b) Outside the sheets (on either side): the fields from the two sheets point in opposite directions and are equal in magnitude, so they cancel: $E = 0$ [2]

OR (B)

I. (a) Outside the shell ($r > R$): by symmetry and Gauss's law, treating the shell as a point charge Q at the centre for external points: $E = Q/(4\pi\varepsilon_0 r^2)$ (b) Inside the shell ($r < R$): a Gaussian sphere of radius $r < R$ encloses no charge (all the charge resides on the shell's surface), so by Gauss's law, $E = 0$ inside the shell. [3]

II. (a) At r = 5 cm (inside the shell, since R = 10 cm): E = 0 (b) At r = 20 cm (outside the shell): $E = kQ/r^2 = (9\times10^9 \times 4\times10^{-6})/(0.2)^2 = (3.6\times10^4)/(0.04) = 9 \times 10^5$ N/C [2]

32 (A). [5]

I. (Derivation using similar triangles from the ray diagram of a real object beyond C, forming a real image between F and C:) Using the properties of similar triangles formed by the incident ray, reflected ray, and the principal axis, and applying the sign convention, one obtains the relation $1/v + 1/u = 1/f$ for a concave mirror (with u and v both measured as per the Cartesian sign convention, u negative for a real object). [3]

II. Using mirror formula: $1/v + 1/u = 1/f$, with $u = -30$ cm, $f = -20$ cm $1/v = 1/f - 1/u = 1/(-20) - 1/(-30) = -1/20 + 1/30 = (-3+2)/60 = -1/60$ $v = -60$ cm (real image, in front of the mirror) Magnification, $m = -v/u = -(-60)/(-30) = -2$ (image is real, inverted, and magnified twice the object size) [2]

OR (B)

I. Total internal reflection is the phenomenon in which light travelling in a denser medium is completely reflected back into that medium at the boundary with a rarer medium, when the angle of incidence exceeds the critical angle, with no light being transmitted (refracted) across the boundary. At the critical angle C, the angle of refraction is 90°. By Snell's law: $n_1 \sin C = n_2 \sin 90° = n_2$ For a denser medium of refractive index n with respect to air ($n_2 = 1$): $n \sin C = 1 \Rightarrow \sin C = 1/n \Rightarrow n = 1/\sin C$ [3]

II. At grazing incidence, $i = 90°$, so $\sin r_1 = \sin 90°/n = 1/1.5 = 0.667$, giving $r_1 \approx 41.8°$. Since $A = r_1 + r_2 = 60°$: $r_2 = 60° - 41.8° = 18.2°$ At the second face: $\sin e = n \sin r_2 = 1.5 \times \sin 18.2° = 1.5 \times 0.312 = 0.468$ $e = \sin^{-1}(0.468) \approx 27.9°$ [2]

33 (A). [5]

I. From Bohr's postulates: the centripetal force on the electron is provided by Coulomb attraction: $mv^2/r_n = ke^2/r_n^2$ ... (i) Quantisation of angular momentum: $mvr_n = n\hbar$ ... (ii) From (ii): $v = n\hbar/(mr_n)$. Substituting into (i): $m[n\hbar/(mr_n)]^2/r_n = ke^2/r_n^2$ $n^2\hbar^2/(mr_n^3) = ke^2/r_n^2$ $r_n = n^2\hbar^2/(mke^2) = n^2\hbar^2(4\pi\varepsilon_0)/(me^2)$ [3]

II. $r_n = n^2 \times r_1$ (since $r_n \propto n^2$). For n=2: $r_2 = 4 \times 0.529 = 2.116$ Å [2]

OR (B)

I. (Diagram description:) A p-n junction diode consists of a p-type semiconductor joined to an n-type semiconductor. Near the junction, electrons from the n-side diffuse into the p-side and holes from the p-side diffuse into the n-side, leaving behind fixed, uncompensated ions (positive on the n-side, negative on the p-side) near the junction; this region, depleted of mobile charge carriers, is called the depletion region. The separated charges create an internal electric field directed from the n-side to the p-side, which opposes further diffusion of carriers, establishing an equilibrium potential difference across the junction known as the potential barrier (about 0.7 V for silicon and 0.3 V for germanium). [3]

II. In a full wave rectifier using two diodes, each conducting diode causes a voltage drop of 0.7 V. Peak output voltage = peak input voltage – voltage drop across the conducting diode = 20 – 0.7 = 19.3 V [2]