CBSE Class 12 Physics: Sample Paper 1: Marking Scheme and Solutions

Based on NCERT · the board's 2026-27 pattern | Time: 3 hours · **Maximum marks: 70**

Section A (16 × 1 mark)

1. A crystal of germanium is to be made p-type. Of the following, the suitable dopant is [1]

(a) antimony (Sb) (b) arsenic (As)
(c) indium (In) (d) phosphorus (P)

Answer: (c) A p-type dopant must be trivalent (third group) so that it leaves a hole in one bond; In is trivalent. Sb, As and P are pentavalent donors and give n-type material.

2. A small sphere carries a charge of +5.0 nC. Take $1/(4\pi\varepsilon_0) = 9 \times 10^9$ N m^2 C^{-2}. Taking the potential at infinity as zero, the electrostatic potential at a point 15 cm from its centre is [1]

(a) 300 V (b) 2000 V
(c) 45 V (d) 3000 V

Answer: (a) $V = (1/4\pi\varepsilon_0)\, q/r = 9 \times 10^9 \times 5.0 \times 10^{-9} / 0.15 = 45/0.15 = 300$ V. Dividing by r^2 gives 2000 V (the field's form, not the potential's); leaving out r gives 45 V; taking r as 1.5 cm gives 3000 V.

3. A charged particle moves with velocity v through a region of uniform magnetic field B. The magnetic force on it is zero when [1]

(a) v is parallel or anti-parallel to B (b) v is perpendicular to B
(c) v makes 45° with B (d) the particle is an electron and v is perpendicular to B

Answer: (a) The magnetic force is q(v × B), of magnitude qvB sin θ. It vanishes when θ = 0° or 180°, that is, when v is parallel or anti-parallel to B.

4. A standard resistor in a laboratory should keep its value when the room warms up. The best material for its coil is [1]

(a) manganin (b) copper
(c) silicon (d) aluminium

Answer: (a) Manganin, like nichrome and constantan, has a resistivity that depends very little on temperature, so it is used for wire-bound standard resistors. Copper and aluminium change appreciably; silicon is a semiconductor.

5. A long solenoid with an air core has a self-inductance of 2.0 mH. It is filled completely with a material of relative permeability 400, everything else unchanged. Its self-inductance becomes [1]

(a) 0.0050 H (b) 0.80 H
(c) 0.040 H (d) 320 H

Answer: (b) $L = \mu_r \mu_0 n^2 A l$, so L is multiplied by μ_r: $400 \times 2.0 \times 10^{-3}$ H = 0.80 H. 0.0050 H divides by μ_r; 0.040 H uses $\sqrt{\mu_r}$; 320 H uses μ_r^2.

6. The radius of a nucleus is about 10^{-4} times the radius of its atom. The fraction of the atom's volume occupied by the nucleus is about [1]

(a) 10^{-12} (b) 10^{-16}
(c) 10^{-4} (d) 10^{-8}

Answer: (a) Volume $\propto r^3$, so the fraction is $(10^{-4})^3 = 10^{-12}$: the atom is almost empty, though the nucleus holds more than 99.9% of its mass.

7. The current in a 50 Ω heating element is $i = 2.0 \sin(100\pi t)$ A. The average power dissipated in the element is [1]

(a) 200 W (b) 100 W

(c) 50 W (d) 0 W

Answer: (b) $\bar{p} = \tfrac{1}{2} i_m^2 R = \tfrac{1}{2} \times (2.0)^2 \times 50 = 100$ W. Using $i_m^2 R$ without the ½ gives 200 W; taking $I = i_m/2$ gives 50 W; the average current is zero but i^2 is never negative, so the power is not zero.

8. Ritu sits all afternoon in a sunlit room behind closed glass windows, yet her skin does not tan. This is because ordinary glass [1]

(a) absorbs infrared radiation (b) absorbs ultraviolet radiation

(c) reflects all visible light (d) absorbs X-rays from the sun

Answer: (b) Tanning is the skin's response to ultraviolet: exposure induces more melanin. Ordinary glass absorbs ultraviolet, so the radiation that would tan her does not reach her; visible light clearly passes, since the room is sunlit.

9. A p-n junction has a built-in barrier potential $V_0 = 0.60$ V. When a reverse bias of 2.0 V is applied, the barrier height and the depletion region become [1]

(a) 2.6 V; the depletion region narrows (b) 1.4 V; the depletion region narrows

(c) 2.6 V; the depletion region widens (d) 0.60 V; the depletion region is unchanged

Answer: (c) Reverse bias acts in the same direction as the barrier, so the barrier becomes $V_0 + V = 0.60 + 2.0 = 2.6$ V and the depletion region widens. (b) is the forward-bias result $V_0 - V$.

10. Point charges +2 μC and +8 μC are fixed 12 cm apart in vacuum. A third charge placed on the line between them feels no net force. Its distance from the +2 μC charge is [1]

(a) 2.4 cm (b) 8 cm

(c) 6 cm (d) 4 cm

Answer: (d) The two forces cancel when $2/x^2 = 8/(12 - x)^2$, i.e. $(12 - x)/x = 2$, so $x = 4$ cm, nearer the smaller charge. 2.4 cm comes from dividing in the ratio of the charges instead of the square root of that ratio.

11. An α-particle and a proton, each of kinetic energy K, are in turn aimed head-on at the same nucleus. The ratio of the distance of closest approach of the α-particle to that of the proton is (charge of α-particle = 2e, charge of proton = e) [1]

(a) 1/2 (b) 1

(c) 4 (d) 2

Answer: (d) For a projectile of charge q, $K = (1/4\pi\varepsilon_0)(q)(Ze)/d$, so $d = qZe/(4\pi\varepsilon_0 K) \propto q$ at the same K and Z. $d\alpha/dp = 2e/e = 2$. The mass of the projectile does not enter, since K is given; 4 squares the charge ratio and 1/2 inverts it.

12. The refractive index of a piece of glass with respect to air depends on [1]

(a) the wavelength of the light (b) the angle of incidence

(c) the thickness of the glass (d) the angle of refraction

Answer: (a) n21 is a property of the pair of media and depends on the wavelength of light, not on the angle of incidence. Because it differs for different colours, white light splits into its colours (dispersion).

13. Assertion (A): The objective of a reflecting telescope has no chromatic aberration. Reason (R): A mirror objective can be supported over its whole back surface. [1]

(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) A is false, but R is true.

Answer: (b) Both statements are true. A mirror forms images by reflection, which does not depend on wavelength, so it has no chromatic aberration. Support over the back surface is a separate advantage, about weight and mechanical strength; it does not explain the absence of chromatic aberration.

14. Assertion (A): Work has to be done to push the north pole of a bar magnet towards a closed coil. Reason (R): The current induced in the coil makes its face towards the magnet a north pole, which repels the approaching magnet. [1]

(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) A is false, but R is true.

Answer: (a) Both are true. By Lenz's law the induced current opposes the rising flux, so the near face becomes a north pole and repels the magnet; the person pushing does work against this force, and that work appears as Joule heat. R is the reason for A.

15. Assertion (A): In the energy level diagram of hydrogen, the levels come closer together as n increases. Reason (R): The total energy of the electron in a hydrogen atom is negative, showing that the electron is bound to the nucleus. [1]

(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) A is false, but R is true.

Answer: (b) Both are true. The crowding follows from $E_n \propto 1/n^2$: the gaps $E_{n+1} - E_n$ shrink as n grows. The sign of the energy only says the electron is bound; a negative energy alone does not fix how the levels are spaced, so R does not explain A.

16. Assertion (A): Ultraviolet lamps are used to kill germs in water purifiers. Reason (R): Ordinary glass absorbs ultraviolet radiation. [1]

(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) A is false, but R is true.

Answer: (b) Both are true statements from the chapter. A rests on ultraviolet's ability to destroy germs; the absorption of ultraviolet by glass is a separate property and does not explain A.

Section B (5 × 2 marks)

17. A uniform wire of resistance 32 Ω is cut into four pieces of equal length, and the four pieces are joined in parallel. Find the resistance of the combination. [2]

Or *Wires A and B are made of the same metal. A has length l and diameter d; B has length 3l and diameter 2d. Find the ratio $R_A : R_B$ of their resistances.*

Each piece has a quarter of the length and the same cross-section, so $R \propto l$ gives 32/4 = 8.0 Ω each. Four equal resistors in parallel: R = 8.0/4 = 2.0 Ω.

- resistance of each piece, 8.0 Ω, from $R \propto l$ (1)
- four in parallel: 2.0 Ω (1)

Or:

$R = \rho l/A$ with $A = \pi d^2/4$, so $R \propto l/d^2$. $R_A/R_B = (l/d^2)/(3l/4d^2) = 4/3$, so $R_A : R_B = 4 : 3$.

- $R \propto l/d^2$ from $R = \rho l/A$ (1)
- $R_A : R_B = 4 : 3$ (1)

18. A thin lens of power +6 D is to be placed in contact with a second thin lens so that the combination has a focal length of +50 cm. Find the power and the focal length of the second lens, and name its type. [2]

Or *A thin lens of power +5 D is to be placed in contact with a second thin lens so that the combination diverges light with a focal length of 50 cm. Find the power and the focal length of the second lens, and name its type.*

Required power P = 1/f = 1/(0.50 m) = +2 D. Powers in contact add: P = P1 + P2, so P2 = 2 − 6 = −4 D. f2 = 1/P2 = −0.25 m = −25 cm. The power is negative, so the second lens is a concave (diverging) lens.

- P = 1/f = +2 D and P2 = P − P1 = −4 D (1)
- f2 = −25 cm, concave lens (1)

Or:

A diverging combination of focal length 50 cm has f = −0.50 m, so P = 1/f = −2 D. P = P1 + P2 gives P2 = −2 − 5 = −7 D. f2 = 1/P2 = −0.143 m ≈ −14.3 cm. The power is negative, so the second lens is a concave (diverging) lens.

- P = 1/f = −2 D and P2 = P − P1 = −7 D (1)
- f2 ≈ −14.3 cm, concave lens (1)

19. Name two causes of energy loss in an actual transformer and state how each is reduced. [2]

Any two: eddy currents in the core, reduced by a laminated core; hysteresis of the core, reduced by a core of low hysteresis loss; resistance of the windings (I^2R heating), reduced by thick wire for the high-current winding; flux leakage, reduced by winding the primary and secondary one over the other.

- first loss with its remedy (1)
- second loss with its remedy (1)

20. A student says that the line marked E_C in a band diagram shows the place in the crystal where conduction electrons are found. Correct the statement, and say what E_C stands for. [2]

Energy bands are delocalised in space, not at any particular place in the solid; the diagram's vertical axis is energy, not position, and the energies are overall averages. E_C stands for the lowest energy level of the conduction band (the bottom of the band).

- bands are space delocalised; the line marks an energy, not a place (1)
- E_C is the bottom (lowest level) of the conduction band (1)

21. State whether each pair is a pair of isotopes, isobars or isotones: (i) $^{40}_{18}Ar$ and $^{40}_{20}Ca$ (ii) $^{13}_{6}C$ and $^{14}_{7}N$ (iii) $^{35}_{17}Cl$ and $^{37}_{17}Cl$ (iv) ^{2}H and ^{3}H. [2]

(i) Same A = 40, different Z: isobars. (ii) N = 13 − 6 = 7 and N = 14 − 7 = 7, different Z: isotones. (iii) Same Z = 17, different A: isotopes. (iv) Both have Z = 1 (deuterium and tritium), different A: isotopes.

- (i) isobars (0.5)
- (ii) isotones, with N = 7 for both (0.5)
- (iii) isotopes (0.5)
- (iv) isotopes (0.5)

Section C (7 × 3 marks)

22. A 10 μF parallel plate capacitor is charged to 100 V and kept connected to the 100 V battery. A slab of dielectric constant 3 is slid in to fill the gap completely. Find (a) the extra charge that flows from the battery, (b) the increase in the energy stored in the capacitor, and (c) the work done by the battery in sending this charge round, and compare it with (b). [3]

(a) $Q_0 = CV = 10 \times 10^{-6} \times 100 = 1.0 \times 10^{-3}$ C. With the battery connected V is fixed and C becomes 30 μF, so $Q = 3.0 \times 10^{-3}$ C: an extra 2.0×10^{-3} C flows. (b) $U_0 = ½ \times 10 \times 10^{-6} \times 100^2 = 0.050$ J; $U = ½ \times 30 \times 10^{-6} \times 100^2 = 0.15$ J; increase 0.10 J. (c) The battery moves 2.0×10^{-3} C through a potential difference of 100 V: $W = qV = 0.20$ J, twice the increase in stored energy; the other 0.10 J does not stay in the capacitor's field.

- extra charge 2.0×10^{-3} C (1)
- stored energy rises from 0.050 J to 0.15 J, by 0.10 J (1)
- battery work 0.20 J, twice the increase (1)

23. The electric field at a point on the axis of a short dipole, 10 cm from its centre, is 3.2×10^3 N C^{-1}. Find (a) the dipole moment, (b) the magnitude and direction of the field at a point on the equatorial plane 20 cm from the centre. (Take $1/4\pi\varepsilon_0 = 9 \times 10^9$ N m^2 C^{-2}.) [3]

Or *The electric field at a point on the equatorial plane of a short dipole, 5.0 cm from its centre, is 8.0×10^3 N C^{-1}. Find (a) the dipole moment, (b) the magnitude and direction of the field at a point on its axis 10 cm from the centre. (Take $1/4\pi\varepsilon_0 = 9 \times 10^9$ N m^2 C^{-2}.)*

(a) Axial: $E = 2kp/r^3$, so $p = Er^3/2k = 3.2 \times 10^3 \times (0.10)^3/(2 \times 9 \times 10^9) = 1.8 \times 10^{-10}$ C m. (b) Equatorial: $E = kp/r^3 = 9 \times 10^9 \times 1.78 \times 10^{-10}/(0.20)^3 = 2.0 \times 10^2$ N C^{-1}, directed opposite to p. Equivalently, $E_{eq}(2r) = E_{ax}(r)/(2 \times 2^3) = 3.2 \times 10^3/16 = 200$ N C^{-1}.

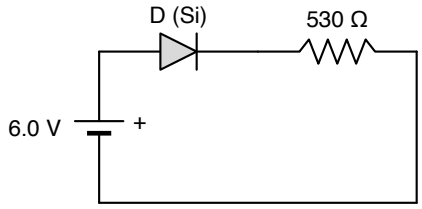
- $p = Er^3/2k = 1.8 \times 10^{-10}$ C m (1)
- equatorial $E = kp/r^3 = 2.0 \times 10^2$ N C^{-1} (1)
- direction opposite to p (1)

Or:

(a) Equatorial: $E = kp/r^3$, so $p = Er^3/k = 8.0 \times 10^3 \times (0.050)^3/(9 \times 10^9) = 1.1 \times 10^{-10}$ C m. (b) Axial: $E = 2kp/r^3 = 2 \times 9 \times 10^9 \times 1.11 \times 10^{-10}/(0.10)^3 = 2.0 \times 10^3$ N C^{-1}, directed along p.

- $p = Er^3/k = 1.1 \times 10^{-10}$ C m (1)
- axial $E = 2kp/r^3 = 2.0 \times 10^3$ N C^{-1} (1)
- direction along p (1)

24. In the circuit shown, the silicon diode may be taken to drop a constant 0.7 V once it conducts. (a) Find the current in the circuit and the voltage across the 530 Ω resistor. (b) The diode is now turned round. What current flows, and across which component does almost all of the 6.0 V appear? [3]



(a) The p-side is connected towards the positive terminal, so the diode is forward biased. $V_R = 6.0 - 0.7 = 5.3$ V; $I = 5.3/530 = 0.010$ A = 10 mA. (b) Reversed, the diode is reverse biased; only the reverse saturation current of a few μA flows, practically zero. Then the resistor drops almost nothing and nearly the full 6.0 V appears across the diode.

- $V_R = 5.3$ V (1)
- I = 10 mA (1)
- reversed: current only of the order of μA (practically zero); almost all 6.0 V across the diode (1)

25. Light travels at 2.25×10^8 m s^{-1} in a liquid. It meets the plane surface between the liquid and air from inside the liquid. Taking $c = 3.00 \times 10^8$ m s^{-1}, find (i) the refractive index of the liquid, (ii) the critical angle for the liquid–air surface. (iii) Using the Huygens construction, explain why there is no refracted wavefront when the angle of incidence exceeds the critical angle. [3]

(i) $n = c/v = 3.00/2.25 = 1.33$ (4/3). (ii) $\sin i_c = n_2/n_1 = 1/(4/3) = 0.75$, $i_c \approx 48.6°$. (iii) Going into the rarer medium, $v_2 > v_1$, so the wavelet from A in air has radius $v_2\tau$ greater than BC = $v_1\tau$. The refracted wavefront is the tangent from C to this wavelet, with $\sin r = (v_2/v_1) \sin i$. When $\sin i > v_1/v_2$, the wavelet's radius $v_2\tau$ exceeds AC, so C lies inside it and no tangent plane can be drawn from C ($\sin r$ would exceed 1): there is no refracted wave, and the light is totally reflected.

- $n = c/v = 4/3$ (1)
- $\sin i_c = 3/4$, $i_c \approx 48.6°$ (1)
- for $i > i_c$ the wavelet radius $v_2\tau$ exceeds AC; no tangent from C, so no refracted wavefront (1)

26. Yellow light of wavelength 589 nm falls on the emitter of a photocell. Only one photon in every 1000 ejects an electron, and the saturation photocurrent is 0.40 μA. Find (a) the number of electrons emitted per second, (b) the number of photons falling on the emitter per second, and (c) the power of the light falling on the emitter. ($h = 6.63 \times 10^{-34}$ J s, $e = 1.6 \times 10^{-19}$ C, $c = 3 \times 10^8$ m s^{-1}) [3]

(a) $n = I/e = 0.40 \times 10^{-6}/1.6 \times 10^{-19} = 2.5 \times 10^{12}$ per second. (b) Photons per second $N = 1000n = 2.5 \times 10^{15}$. (c) Energy of each photon $E = hc/\lambda = (6.63 \times 10^{-34} \times 3 \times 10^8)/(589 \times 10^{-9}) \approx 3.38 \times 10^{-19}$ J; $P = NE = 2.5 \times 10^{15} \times 3.38 \times 10^{-19} \approx 8.4 \times 10^{-4}$ W, about 0.84 mW.

- $n = I/e = 2.5 \times 10^{12}$ s^{-1} (1)
- $N = 2.5 \times 10^{15}$ s^{-1} (1)
- $E \approx 3.38 \times 10^{-19}$ J, $P \approx 0.84$ mW (1)

27. Give two observations that support treating a bar magnet as equivalent to a current-carrying solenoid. What happens when each of them is cut in half across its length? [3]

(i) Iron filings (or a field-line plot) show very similar patterns round a bar magnet and round a current-carrying finite solenoid. (ii) A small compass needle moved near each is deflected in the same way. Cutting either in half gives two smaller magnets (two smaller solenoids), each with its own north and south pole and a smaller magnetic moment; the field lines remain continuous, leaving one face and entering the other.

- similar field-line or iron-filing patterns (1)
- similar compass deflections (1)
- cut: two smaller magnets/solenoids, each with N and S (1)

28. A galvanometer of resistance 30 Ω gives full-scale deflection for 4.0 mA. Find (a) the shunt that converts it into an ammeter of range 0 to 1.0 A, (b) the resistance of this ammeter, (c) the series resistance that converts it into a voltmeter of range 0 to 6.0 V. [3]

(a) The coil and the shunt are in parallel, so they share one potential difference, and the shunt carries $I - I_g$. With $V = IR$, $I_g \cdot R_G = (I - I_g) \cdot r_s$, so $r_s = (4.0 \times 10^{-3} \times 30)/(1.0 - 0.004) = 0.12\ \Omega$. (b) $R_G r_s/(R_G + r_s) = 30 \times 0.12/30.12 \approx 0.12\ \Omega$, close to r_s since $R_G \gg r_s$. (c) In series one current I_g flows through the coil and R, and their potential differences add: $V = I_g(R_G + R)$, so $R = V/I_g - R_G = 6.0/(4.0 \times 10^{-3}) - 30 = 1470\ \Omega$.

- shunt $r_s = 0.12\ \Omega$ (1)
- ammeter resistance $\approx 0.12\ \Omega$ (1)
- series resistance $1470\ \Omega$ (1)

Section D (2 × 4 marks)

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

A student repeats the essentials of the Geiger–Marsden experiment in a simulation. A beam of α-particles, each of kinetic energy 5.0 MeV, falls on a very thin foil of silver (Z = 47). The simulation treats each α-particle as being scattered by at most one nucleus, and holds the silver nucleus fixed during the encounter, since it is many times heavier than the α-particle. It reports that nearly all the α-particles pass with little or no deflection, while a very small number are turned back, and that an α-particle aimed head-on comes momentarily to rest 27 fm from the centre of the nucleus before reversing.

(a) The very small number of α-particles turned back shows that [1]

(a) the silver atom has no electrons

(b) the positive charge and most of the mass of the atom are concentrated in a very small volume

(c) the α-particles lose all their charge in the foil

(d) the positive charge is spread uniformly over the atom

Answer: (b) Few rebounds mean few head-on collisions, which means the mass and positive charge sit in a very small volume. A uniform spread could not reverse any α-particle.

(b) If the kinetic energy of the α-particles is raised to 7.5 MeV, the distance of closest approach in a head-on encounter becomes [1]

(a) 40.5 fm

(b) 12 fm

(c) 22 fm

(d) 18 fm

Answer: (d) $d = 2Ze^2/(4\pi\varepsilon_0 K) \propto 1/K$, so $d = 27 \times 5.0/7.5 = 18$ fm. 40.5 fm takes $d \propto K$; 12 fm takes $d \propto 1/K^2$; 22 fm takes $d \propto 1/\sqrt{K}$.

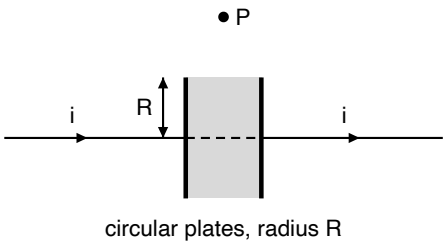
(c) Why is it reasonable to treat each α-particle as scattered by at most one nucleus, and why do the electrons of the silver atoms play no appreciable part in the scattering? [2]

The foil is very thin and the atom is mostly empty space with a tiny nucleus, so an α-particle is unlikely to pass close to more than one nucleus; one trajectory per nucleus is enough. The electrons are very light compared with the α-particle, so they cannot deflect it appreciably.

- thin foil, mostly empty atoms: at most one close encounter (1)
- electrons too light to deflect the α-particle (1)

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

In a laboratory, Kabir charges a capacitor whose circular plates, each of radius R = 5.0 cm, face each other across a small air gap, as shown. At one instant the current in the connecting wires is 0.40 A. A sensitive probe measures the magnetic field in the plane midway between the plates: inside the gap, and at the point P, 10 cm from the axis and outside the plates. Take $\mu_0 = 4\pi \times 10^{-7}$ T m A^{-1} and $\varepsilon_0 = 8.85 \times 10^{-12}$ C^2 N^{-1} m^{-2}; ignore the spreading of the field at the edges.



circular plates, radius R

(a) The magnetic field at the rim of the plates, 5.0 cm from the axis, at that instant is [1]

(a) 1.6×10^{-6} T (b) 8.0×10^{-7} T

(c) 5.0×10^{-6} T (d) zero, as no charge flows across the gap

Answer: (a) The loop at the rim encloses the whole displacement current, equal to i: $B = \mu_0 i/(2\pi R) = 2 \times 10^{-7} \times 0.40/0.050 = 1.6 \times 10^{-6}$ T. 8.0×10^{-7} T is the field at P (10 cm); 5.0×10^{-6} T uses $\mu_0 i/2R$, the field at the centre of a loop; the displacement current produces a field although no charge crosses.

(b) The magnetic field on the axis, midway between the plates, is [1]

(a) zero (b) 1.6×10^{-6} T

(c) 3.2×10^{-6} T (d) 8.0×10^{-7} T

Answer: (a) Inside, $B = \mu_0 i\, r/(2\pi R^2)$, proportional to r: a loop of zero radius encloses no displacement current, so B = 0 on the axis.

(c) Find the distance from the axis, inside the gap, at which the magnetic field equals the field at P. [2]

At P, outside: $B_P = \mu_0 i/(2\pi \times 0.10) = 2 \times 10^{-7} \times 0.40/0.10 = 8.0 \times 10^{-7}$ T. Inside: $B = \mu_0 i\, r/(2\pi R^2)$. Setting them equal, $r/R^2 = 1/0.10$, so $r = R^2/0.10 = (0.050)^2/0.10 = 0.025$ m = 2.5 cm.

- B inside = $\mu_0 ir/(2\pi R^2)$; $B_P = \mu_0 i/(2\pi \times 0.10) = 8.0 \times 10^{-7}$ T (1)
- $r = R^2/0.10 = 2.5$ cm (1)

Section E (3 × 5 marks)

31. Two long co-axial solenoids have the same length l. The inner one has radius r_1 and n_1 turns per unit length; the outer has n_2 turns per unit length. (a) Derive the mutual inductance M_{12} of the inner solenoid with respect to the outer. (b) State M_{21} and the relation between the two. (c) Take l = 0.60 m, r_1 = 1.5 cm, n_1 = 2000 m^{-1}, n_2 = 1000 m^{-1} and $\mu_0 = 4\pi \times 10^{-7}$ T m A^{-1}. Find M, and the emf induced in the inner solenoid when the current in the outer one rises steadily from 0 to 3.0 A in 0.15 s. (d) How would M change if the space inside were filled with a material of relative permeability μ_r? [5]

Or *Two long co-axial solenoids have the same length l. The inner one has radius r_1 and n_1 turns per unit length; the outer has n_2 turns per unit length. (a) Derive the mutual inductance M_{12} of the inner solenoid with respect to the outer. (b) Explain why M_{21}, found by passing a current through the inner solenoid, comes out the same. (c) Take l = 0.80 m, r_1 = 2.0 cm, n_1 = 1200 m^{-1}, n_2 = 600 m^{-1}, $\mu_0 = 4\pi \times 10^{-7}$ T m A^{-1}. Find M, and the average emf induced in the outer solenoid when a current of 4.0 A in the inner one is switched off in 0.020 s. (d) Find M if the inside is filled with a material of relative permeability 200.*

(a) A current I_2 in the outer solenoid gives $B = \mu_0 n_2 I_2$ inside it (edge effects neglected). The flux linked with the inner solenoid is $N_1\Phi_1 = (n_1 l)(\pi r_1^2)(\mu_0 n_2 I_2)$, so $M_{12} = \mu_0 n_1 n_2 \pi r_1^2 l$. (b) $M_{21} = \mu_0 n_1 n_2 \pi r_1^2 l$ as well (the inner solenoid's flux lies within area πr_1^2), so $M_{12} = M_{21} = M$. (c) $M = 4\pi \times 10^{-7} \times 2000 \times 1000 \times \pi \times (0.015)^2 \times 0.60 = 1.07 \times 10^{-3}$ H. $dI/dt = 3.0/0.15 = 20$ A s^{-1}, so $|\varepsilon| = 1.07 \times 10^{-3} \times 20 = 2.1 \times 10^{-2}$ V = 21 mV. (d) M becomes μ_r times larger: $M = \mu_r \mu_0 n_1 n_2 \pi r_1^2 l$.

- $B = \mu_0 n_2 I_2$ and flux linkage $(n_1 l)(\pi r_1^2)(\mu_0 n_2 I_2)$ (1)
- $M_{12} = \mu_0 n_1 n_2 \pi r_1^2 l$ (1)
- M_{21} the same, $M_{12} = M_{21}$ (1)
- M = 1.07 mH and ε = 21 mV (1)
- M multiplied by μ_r (1)

Or:

(a) A current I_2 in the outer solenoid gives $B = \mu_0 n_2 I_2$ inside; flux linkage of the inner one $N_1\Phi_1 = (n_1 l)(\pi r_1^2)(\mu_0 n_2 I_2)$, so $M_{12} = \mu_0 n_1 n_2 \pi r_1^2 l$. (b) A current I_1 in the inner one gives $B = \mu_0 n_1 I_1$ confined to its area πr_1^2, so each of the $n_2 l$ turns of the outer solenoid links flux $\mu_0 n_1 I_1 \pi r_1^2$; $N_2\Phi_2 = \mu_0 n_1 n_2 \pi r_1^2 l\, I_1$, the same M. (c) $M = 4\pi \times 10^{-7} \times 1200 \times 600 \times \pi \times (0.020)^2 \times 0.80 = 9.1 \times 10^{-4}$ H. $dI/dt = 4.0/0.020 = 200$ A s^{-1}; $|\varepsilon| = 9.1 \times 10^{-4} \times 200 = 0.18$ V. (d) $M = 200 \times 9.1 \times 10^{-4} = 0.18$ H.

- $B = \mu_0 n_2 I_2$ and flux linkage of the inner solenoid (1)
- $M_{12} = \mu_0 n_1 n_2 \pi r_1^2 l$ (1)
- inner flux confined to πr_1^2, so M_{21} is the same (1)
- M = 0.91 mH and ε = 0.18 V (1)
- M = 0.18 H with the core (1)

32. (a) Draw a ray diagram for the refraction of a ray through a triangular prism of angle A. Show that the deviation is δ = i + e − A, and use the condition of minimum deviation to obtain n = sin[(A + Dm)/2]/sin(A/2). (b) Sketch how δ varies with the angle of incidence i, and explain why a deviation greater than Dm occurs for two angles of incidence. (c) A ray falls at 60° on one face of a prism of angle 60° and refractive index √3. Show that it passes through the prism at minimum deviation, and find Dm. [5]

Or *(a) A ray passes through a triangular prism of angle A, entering at angle i and leaving at angle e. With a ray diagram, show that r1 + r2 = A and that the deviation is δ = i + e − A. (b) Using the symmetry of i and e in this relation, explain why the deviation is least when i = e, and obtain n = sin[(A + Dm)/2]/sin(A/2). (c) For a prism of angle 60° and refractive index √2, find the angle of incidence for minimum deviation and the angle of minimum deviation.*

(a) The ray meets face AB at i, refracts at r1, meets AC at r2 and emerges at e. The normals at the two faces meet at N; in the quadrilateral AQNR, angles A and QNR add to 180°, and in triangle QNR, r1 + r2 + ∠QNR = 180°, so r1 + r2 = A. The deviation is (i − r1) + (e − r2) = i + e − A. At minimum deviation i = e, so r1 = r2 = r = A/2 and Dm = 2i − A, i = (A + Dm)/2. n = sin i/sin r = sin[(A + Dm)/2]/sin(A/2). (b) The graph falls to a minimum Dm and rises again (a U-shaped curve). Since i and e enter δ = i + e − A symmetrically, the ray path can be reversed with the same deviation: any δ other than Dm occurs once with incidence i and once with incidence e. (c) sin r1 = sin 60°/√3 = 1/2, r1 = 30°; r2 = A − r1 = 30° = r1, so the ray inside is symmetric and e = i = 60°: this is minimum deviation. Dm = i + e − A = 60°.

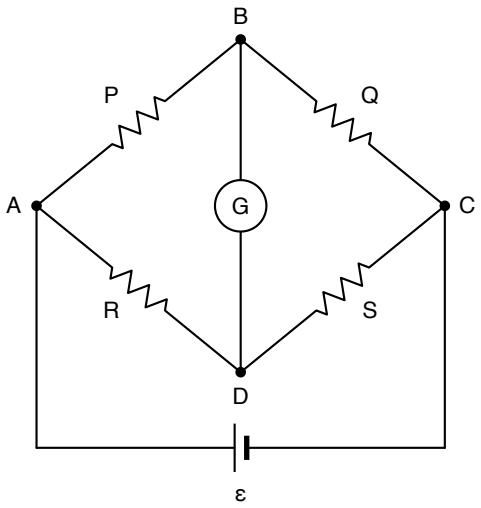
- ray diagram; r1 + r2 = A from the geometry (1)
- δ = i + e − A; at minimum i = e, r = A/2 (1)
- n = sin[(A + Dm)/2]/sin(A/2) obtained (1)
- δ–i curve with a minimum; two values of i by symmetry of i and e (1)
- r1 = r2 = 30°, e = 60°: Dm = 60° (1)

Or:

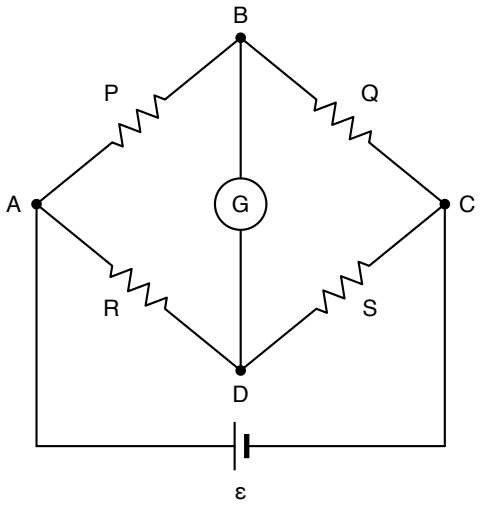
(a) The ray meets face AB at i, refracts at r1, meets AC at r2, emerges at e. The normals at the faces meet at N; in quadrilateral AQNR, A + ∠QNR = 180°; in triangle QNR, r1 + r2 + ∠QNR = 180°; so r1 + r2 = A. The deviation is the sum of the deviations at the two faces: (i − r1) + (e − r2) = i + e − A. (b) The path can be reversed with the same deviation, so a deviation is generally reached at two angles of incidence, i and e; the two coincide only at the minimum, so there i = e, r1 = r2 = A/2 and Dm = 2i − A. Then n = sin i/sin r = sin[(A + Dm)/2]/sin(A/2). (c) r = 30°, sin i = √2 × sin 30° = 1/√2, i = 45°. Dm = 2 × 45° − 60° = 30°.

- ray diagram; r1 + r2 = A from the geometry (1)
- δ = i + e − A (1)
- reversibility: two i for a δ, coincide at minimum, i = e (1)
- n = sin[(A + Dm)/2]/sin(A/2) (1)
- i = 45°, Dm = 30° (1)

33. (a) For the Wheatstone bridge shown, use Kirchhoff's rules to derive the condition for no current through the galvanometer. (b) With P = 12 Ω and Q = 18 Ω, balance is obtained when R = 8.0 Ω. Find S. (c) Show that the bridge stays balanced if the cell and the galvanometer are interchanged. [5]



Or *(a) State the balance condition for the Wheatstone bridge shown and explain why it is a null method. (b) A 9.0 V cell of negligible internal resistance is connected across A and C, with P = 6.0 Ω, Q = 3.0 Ω, R = 8.0 Ω, S = 4.0 Ω and a 5.0 Ω galvanometer. Find the current drawn from the cell. (c) If S is changed to 6.0 Ω, find which of B and D is at the higher potential, and hence the direction of the galvanometer current.*



(a) With $I_g = 0$, the junction rule at B and D gives the same current I_1 in P and Q and the same current I_2 in R and S. Loop ABDA: $-I_1P + I_2R = 0$; loop BCDB: $-I_1Q + I_2S = 0$. Dividing, P/Q = R/S. (b) S = RQ/P = 8.0 × 18/12 = 12 Ω. (c) With the cell across B and D and the galvanometer across A and C, the arms pair as P with R and Q with S; balance needs P/R = Q/S, i.e. PS = QR, the same condition, so it still holds.

- junction rule at B and D with $I_g = 0$ (1)
- two loop equations (1)
- P/Q = R/S (1)
- S = 12 Ω (1)
- PS = QR again after interchange (1)

Or:

(a) P/Q = R/S; the unknown is found from the setting for zero deflection, so the reading does not depend on calibrating the galvanometer. (b) P/Q = R/S = 2, balanced, so the galvanometer carries no current and can be ignored: ABC is 9.0 Ω in parallel with ADC, 12 Ω, R_{AC} = 36/7 Ω, I = 9.0 × 7/36 = 1.75 A. (c) Taking C as zero, V_B = 9.0 × 3.0/9.0 = 3.0 V and V_D = 9.0 × 6.0/14 ≈ 3.9 V (with the galvanometer removed). D is at the higher potential, so current flows through the galvanometer from D to B. (With the galvanometer in place the two potentials shift to 3.16 V and 3.58 V; their order is unchanged.)

- P/Q = R/S and why it is a null method (1)
- bridge balanced, galvanometer ignored (1)
- I = 1.75 A (1)
- V_B = 3.0 V, V_D ≈ 3.9 V (1)
- current from D to B (1)