CBSE Class 12 Physics: Sample Paper 2: 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 beam of light passes from glass into air. The quantity that does not change is its [1]

(a) frequency (b) wavelength

(c) speed (d) direction of travel, for oblique incidence

Answer: (a) In the Huygens construction a crest from A reaches E as the crest from B reaches C, so $v_1/\lambda_1 = v_2/\lambda_2$: the frequency is unchanged, while speed and wavelength both increase in air and an oblique ray bends.

2. With ε_0 the permittivity and μ_0 the permeability of free space, and c the speed of light in vacuum, [1] the product $\varepsilon_0\mu_0$ equals

(a) 1/c (b) c^2

(c) $1/c^2$ (d) c

Answer: (c) $\varepsilon_0\mu_0 = (4\pi\varepsilon_0)(\mu_0/4\pi) = [1/(9 \times 10^9)] \times 10^{-7} = 1/(3 \times 10^8)^2 = 1/c^2$.

3. To plot the reverse-bias characteristic of a silicon diode, the current should be measured with [1]

(a) a milliammeter, since the reverse current is large (b) a microammeter, since the reverse current is of the order of microamperes

(c) an ammeter reading in amperes, since breakdown may occur (d) a voltmeter in series with the diode

Answer: (b) The reverse current is a drift of minority carriers, only a few μA, so a microammeter is used; a milliammeter suits the forward current, which is in mA.

4. A solid has an electrical conductivity of 2.0×10^{-3} S m^{-1} at room temperature. On the indicative ranges of resistivity, the solid is [1]

(a) a metal, since its resistivity is 2.0×10^{-3} Ω m (b) a semiconductor, since its resistivity is 500 Ω m

(c) an insulator, since its resistivity is 500 Ω m (d) a metal, since its resistivity is 500 Ω m

Answer: (b) $\rho = 1/\sigma = 1/(2.0 \times 10^{-3}\ \text{S m}^{-1}) = 500\ \Omega$ m, which lies in the semiconductor range 10^{-5} to 10^{6} Ω m; insulators start near 10^{11} Ω m. Option (a) takes σ for ρ.

5. The binding energy of the $^4_2$He nucleus is 28.3 MeV. Its mass defect is (take 1 u = 931.5 MeV/c^2) [1]

(a) 0.304 u (b) 0.0304 u

(c) 0.0152 u (d) 0.0076 u

Answer: (b) $E_b = \Delta Mc^2$, so ΔM = 28.3 MeV ÷ 931.5 MeV/u = 0.0304 u. 0.0076 u is the mass defect per nucleon (÷ 4); 0.0152 u divides by 2; 0.304 u slips a decimal.

6. The SI unit of magnetisation M is [1]

(a) T m A^{-1} (b) A m^2

(c) T (d) A m^{-1}

Answer: (d) M is the net magnetic moment per unit volume: (A m^2)/m^3 = A m^{-1}, the same unit as H.

7. Equal point charges +Q are fixed at two vertices of an equilateral triangle of side a in vacuum. The magnitude of the electric field at the third vertex is ($k = 1/4\pi\varepsilon_0$) [1]

(a) $2kQ/a^2$ (b) $\sqrt{3}\,kQ/a^2$

(c) kQ/a^2 (d) zero

Answer: (b) Each charge gives kQ/a^2 along its own side, the two fields 60° apart. Resultant = $2(kQ/a^2)\cos 30° = \sqrt{3}\,kQ/a^2$, along the bisector, away from the two charges.

8. The SI unit of resistivity is [1]

(a) $S\ m^{-1}$ (b) $\Omega\ m^{-1}$

(c) $\Omega\ m^{-2}$ (d) Ω m

Answer: (d) From $R = \rho l/A$, $\rho = RA/l$, with unit $\Omega\ m^2 / m = \Omega$ m. $S\ m^{-1}$ is the unit of conductivity.

9. In a spark plug, electrons are pulled out of a metal electrode by an electric field of the order of $10^8\ V\ m^{-1}$. This process is called [1]

(a) thermionic emission (b) photoelectric emission

(c) secondary emission (d) field emission

Answer: (d) Energy supplied by a very strong electric field, of the order of $10^8\ V\ m^{-1}$, gives field emission. Thermionic emission needs heating; photoelectric emission needs light of suitable frequency.

10. An ac voltage is applied across an ideal inductor. The current in the inductor [1]

(a) lags the voltage by $\pi/2$ (b) leads the voltage by $\pi/2$

(c) is in phase with the voltage (d) lags the voltage by π

Answer: (a) For a pure inductor $i = i_m \sin(\omega t - \pi/2)$: the current reaches its maximum a quarter period after the voltage, so it lags by $\pi/2$. A lead of $\pi/2$ is the capacitor's case; in phase is the resistor's.

11. Infrared waves are often called heat waves because they [1]

(a) ionise the molecules they strike (b) travel faster than visible light in vacuum

(c) are produced only by the sun (d) set entire atoms and molecules vibrating, raising the internal energy of matter

Answer: (d) Infrared, of lower frequency than visible light, vibrates not only electrons but whole atoms and molecules (water in particular absorbs it readily), raising their internal energy and temperature. All electromagnetic waves travel at the same speed in vacuum; any hot body emits infrared.

12. An object on the axis of a concave mirror of focal length 10 cm is moved from 30 cm to 20 cm in front of the mirror. During this move the image shifts through [1]

(a) 5 cm, towards the mirror (b) 10 cm, away from the mirror

(c) 10 cm, towards the mirror (d) 5 cm, away from the mirror

Answer: (d) f = −10 cm. At u = −30 cm, 1/v = −1/10 + 1/30 = −1/15, v = −15 cm. At u = −20 cm, 1/v = −1/10 + 1/20 = −1/20, v = −20 cm. The image moves from 15 cm to 20 cm in front of the mirror: 5 cm away from it, as the object moves 10 cm towards it.

13. Assertion (A): The binding energy per nucleon is nearly constant for nuclei with $30 < A < 170$. [1] Reason (R): The nuclear force between two nucleons does not depend on their electric charge.

(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, but the near-constancy comes from the short range of the nuclear force (saturation): an interior nucleon feels only its near neighbours, however large the nucleus. Charge independence does not explain it.

14. Assertion (A): While a storage cell is being charged, the voltmeter across its terminals reads more than its emf. [1] Reason (R): During charging, the current flows through the cell from its positive terminal to its negative terminal, so $V = \varepsilon + Ir$.

(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 true. Driving the current against the cell's emf adds the drop Ir to ε, so the terminal voltage $V = \varepsilon + Ir$ exceeds ε; R explains A.

15. Assertion (A): A convex lens of glass of refractive index 1.5 behaves as a diverging lens when immersed in a liquid of refractive index 1.7. [1] Reason (R): For a lens of index n_2 in a medium of index n_1, $1/f = (n_2/n_1 - 1)(1/R_1 - 1/R_2)$, and the factor $(n_2/n_1 - 1)$ is negative when $n_2 < n_1$.

(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) In air $(n_2/n_1 - 1) = 0.5 > 0$ and the convex shape gives $f > 0$. In the liquid, $1.5/1.7 - 1 < 0$ while $(1/R_1 - 1/R_2)$ is still positive, so $f < 0$: the lens diverges. R is the relation that makes A true.

16. Assertion (A): The average power supplied by an ac source to an ideal inductor over a complete cycle is zero. [1] Reason (R): In an ideal inductor the current lags the voltage by $\pi/2$, so the instantaneous power $p = -(i_m v_m/2) \sin 2\omega t$ is positive for half the time and negative for the other half.

(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. Because of the $\pi/2$ lag the product vi is a $\sin 2\omega t$ term, whose average over a cycle is zero: R is exactly why A holds.

Section B (5 × 2 marks)

17. On the wave picture of light, how long would one expect an electron to take to escape from a metal under very dim light? How does this compare with what is observed? [2]

Or *On the wave picture of light, how should the maximum kinetic energy of photoelectrons change when the intensity of light is increased? How does this compare with what is observed?*

In the wave picture the energy of the radiation is spread continuously over the whole wavefront and shared by a very large number of electrons, so each absorbs only a little per unit time; calculations estimate that an electron could take hours or more to gather the work function. Observed: above the threshold, emission starts instantaneously, in about 10^{-9} s or less, even for very dim light.

- wave picture: energy shared over the wavefront, time lag of hours or more (1)
- observed: no time lag, ~10^{-9} s or less (1)

Or:

In the wave picture a greater intensity means a greater amplitude of the electric and magnetic fields, so each electron absorbs more energy, and Kmax should increase with intensity. Observed: for a given frequency, the stopping potential, and so Kmax, is independent of intensity; only the photocurrent rises.

- wave picture: Kmax should rise with intensity (1)
- observed: Kmax independent of intensity (1)

18. Two coherent sources each produce an intensity I_0 at a point on a screen. Find the resultant intensity at points where the phase difference between the two waves is (i) π/2, (ii) 5π/3. [2]

Or *In a double-slit experiment, light of wavelength 600 nm falls on slits 0.30 mm apart and the screen is 1.5 m away. Each slit alone gives an intensity I_0 on the screen. Find the resultant intensity at points (i) 0.50 mm, (ii) 4.5 mm from the central bright fringe.*

$I = 4I_0 \cos^2(\phi/2)$. (i) $\phi = \pi/2$: $I = 4I_0 \cos^2(\pi/4) = 4I_0 \times 1/2 = 2I_0$. (ii) $\phi = 5\pi/3$: $I = 4I_0 \cos^2(5\pi/6) = 4I_0 \times 3/4 = 3I_0$.

- $I = 4I_0\cos^2(\phi/2)$; (i) $2I_0$ (1)
- (ii) $3I_0$ (1)

Or:

$\beta = \lambda D/d = (600 \times 10^{-9} \times 1.5)/(0.30 \times 10^{-3}) = 3.0$ mm. Moving one fringe width changes the path difference by λ, so the phase difference at distance x is $\phi = 2\pi x/\beta$, and $I = 4I_0 \cos^2(\phi/2)$. (i) x = 0.50 mm: $\phi = 2\pi/6 = \pi/3$, $I = 4I_0 \cos^2(\pi/6) = 4I_0 \times 3/4 = 3I_0$. (ii) $x = 4.5$ mm $= 1.5\beta$: $\phi = 3\pi$, $I = 4I_0 \cos^2(3\pi/2) = 0$, a dark point (the second dark fringe).

- $\beta = 3.0$ mm, $\phi = 2\pi x/\beta$; (i) $\phi = \pi/3$, $I = 3I_0$ (1)
- (ii) $\phi = 3\pi$, $I = 0$ (1)

19. A proton and an alpha particle (charge 2e, mass four times the proton's) enter the same uniform magnetic field with the same speed, perpendicular to the field. Find the ratio of the radius of the alpha particle's path to that of the proton's. [2]

$r = mv/qB$, so at the same v and B, $r \propto m/q$. $r_\alpha/r_p = (4m/2e)/(m/e) = 2$.

- $r = mv/qB$, so $r \propto m/q$ at the same v and B (1)
- ratio $r_\alpha : r_p = 2 : 1$ (1)

20. A plastic comb run through dry hair attracts small bits of neutral paper. Explain why. [2]

The charged comb produces a field that polarises the paper: it induces a dipole moment in the paper along the field. The comb's field is non-uniform, stronger nearer the comb, so the induced dipole feels a net force towards the stronger field, and the paper moves towards the comb.

- the comb's field polarises the paper, inducing a dipole along the field (1)
- field is non-uniform, so a net force acts towards the comb (1)

21. In a half-wave rectifier, why must the diode's reverse breakdown voltage be sufficiently higher than the peak of the ac voltage from the transformer? [2]

In the half-cycle when the diode is reverse biased it does not conduct, and the whole ac voltage of that half-cycle, up to its peak, appears across it. If the peak exceeded the breakdown voltage, the reverse current would rise sharply and the diode would conduct in the wrong half-cycle (and could be destroyed), spoiling the rectification.

- in the reverse half-cycle the full peak voltage appears across the diode (1)
- above breakdown it conducts sharply/is damaged, so rectification fails (1)

Section C (7 × 3 marks)

22. An iron nail is made of many magnetic domains, yet on its own it attracts nothing. (a) Explain why it shows no net magnetisation. (b) Explain how it becomes strongly magnetised when a magnet is brought near. (c) Why does it stay magnetised for only a short time after the magnet is removed, while a lodestone stays magnetised? [3]

Or *Describe the state of the domains in a ferromagnetic sample (a) with no external field, (b) in a strong external field B_0, and (c) after the field is removed, for a hard and for a soft ferromagnet.*

(a) Within each domain the atomic dipoles are aligned, but the magnetisation varies randomly from domain to domain, so the moments cancel and there is no bulk magnetisation. (b) In the magnet's field the domains turn towards the field and those already along it grow, so the field lines are highly concentrated; in the non-uniform field it moves towards high field, that is, it is attracted. (c) The nail is soft iron, a soft ferromagnet whose magnetisation disappears when the field is removed; lodestone is a hard ferromagnet whose magnetisation persists.

- domains randomly oriented, so moments cancel (1)
- domains align and grow in the field; attracted towards high field (1)
- soft ferromagnet loses magnetisation; lodestone is a hard ferromagnet (1)

Or:

(a) Each domain (about 1 mm, about 10^{11} atoms) is magnetised, but the directions vary randomly from domain to domain: no bulk magnetisation. (b) The domains orient along B_0 and those along B_0 grow, until they amalgamate into a single giant domain; the field lines are highly concentrated. (c) In a hard ferromagnet (Alnico, lodestone) the alignment and magnetisation persist: a permanent magnet. In a soft ferromagnet (soft iron) the magnetisation disappears.

- random domains, no net M (1)
- domains align along B_0 and grow into a giant domain (1)
- hard keeps, soft loses its magnetisation (1)

23. A coil of metal X (temperature coefficient of resistivity $5.0 \times 10^{-3}\ °C^{-1}$, referred to 20 °C) and a manganin coil Y each have a resistance of 10.0 Ω at 20 °C. Treat the resistance of Y as constant and ignore changes in dimensions. (a) At what temperature is the resistance of X 1.5 times that of Y? (b) What is the resistance of X and Y in parallel at that temperature? [3]

(a) $R_X = 10.0[1 + 5.0 \times 10^{-3}(T - 20)] = 15.0\ \Omega$ gives $T - 20 = 100$, so $T = 120$ °C. Y stays at 10.0 Ω because manganin's resistivity depends very little on temperature. (b) $15.0 \times 10.0/25.0 = 6.0\ \Omega$.

- $R_T = R_0[1 + \alpha(T - T_0)]$ set to 15.0 Ω (1)
- T = 120 °C (1)
- parallel resistance 6.0 Ω (1)

24. An aluminium ring rests on the top of a vertical coil wound on a soft-iron core. When the switch in the coil's circuit is closed, the ring jumps up. (a) Explain why. (b) Why does it fall back while the switch is kept closed? (c) What would happen if the ring had a narrow cut in it? [3]

(a) Closing the switch makes the coil's current, and the flux through the ring, rise sharply (the iron core makes the flux large). By Lenz's law the induced current in the ring opposes this rise: its field is opposite to the coil's, so the ring is repelled and jumps. (b) Once the current is steady the flux stops changing, the induced current dies away, there is no repulsion and gravity pulls the ring back. (c) With a cut the ring is an open circuit: an emf appears across the cut but no current flows, so there is no force and the ring does not jump.

- rising flux induces a current opposing it, so the ring is repelled (1)
- steady current, no change of flux, no induced current (1)
- cut ring: emf only, no current, so no jump (1)

25. Two germanium samples, X and Y, are doped with indium and kept at the same temperature: X at 1 atom in 10^7 and Y at 1 atom in 10^6. Taking every acceptor as ionised and $n_h \approx N_a$, (a) by what factor is the ratio n_h/n_e in Y larger than in X? (b) Find the ratio of the electron concentration in Y to that in X. (c) Explain why heavier doping lowers the minority concentration. [3]

(a) $N_a(Y) = 10\ N_a(X)$, so $n_h(Y) = 10\ n_h(X)$. Since $n_e n_h = n_i^2$ at a fixed temperature, $n_e = n_i^2/N_a$, so $n_h/n_e = N_a^2/n_i^2 \propto N_a^2$. Ten times the doping makes n_h/n_e larger by $10^2 = 100$. (b) $n_e \propto 1/N_a$, so $n_e(Y)/n_e(X) = 1/10$. (c) The abundant majority holes give each thermally produced electron more chance of meeting a hole and recombining, so the minority concentration falls as the majority rises ($n_e n_h = n_i^2$ stays fixed).

- $n_h \propto N_a$ and $n_e = n_i^2/N_a \propto 1/N_a$, so $n_h/n_e \propto N_a^2$: factor 100 (1)
- ratio 1/10 (1)
- more majority carriers, more recombination of minority carriers (1)

26. A parallel plate capacitor has plates of area A a distance d apart (d^2 much smaller than A), carrying charges +Q and −Q. Using the field of a large plane sheet of charge, find the field inside and outside the plates and show that $C = \varepsilon_0 A/d$. [3]

With $\sigma = Q/A$, each plate gives a field $\sigma/2\varepsilon_0$. Outside the plates the two fields are opposite: $E = \sigma/2\varepsilon_0 - \sigma/2\varepsilon_0 = 0$. Between the plates they add: $E = \sigma/\varepsilon_0 = Q/\varepsilon_0 A$, uniform, from the positive to the negative plate. Then $V = Ed = Qd/\varepsilon_0 A$, and $C = Q/V = \varepsilon_0 A/d$.

- outside E = 0 (fields cancel) (1)
- inside $E = \sigma/\varepsilon_0 = Q/\varepsilon_0 A$ (1)
- $V = Qd/\varepsilon_0 A$, so $C = \varepsilon_0 A/d$ (1)

27. A capacitor with circular plates of radius R is being charged by a current i, the electric field between the plates being uniform. Using the Ampere–Maxwell law, obtain the magnetic field at a distance r ($r \le R$) from the axis, between the plates. How does it vary from the axis to the rim? [3]

Take a circular loop of radius r coaxial with the plates. No conduction current crosses it; the displacement current through it is the fraction r^2/R^2 of the total i, since E is uniform over the plate area. So $B(2\pi r) = \mu_0 i\, r^2/R^2$, $B = \mu_0 i\, r/(2\pi R^2)$. B is zero on the axis and rises linearly with r to $\mu_0 i/(2\pi R)$ at the rim, equal to the field just outside the plates.

- displacement current through the loop = $i\, r^2/R^2$ (1)
- $B = \mu_0 i\, r/(2\pi R^2)$ (1)
- zero on the axis, linear rise to $\mu_0 i/(2\pi R)$ at the rim (1)

28. An α-particle (charge 2e) of kinetic energy K is aimed head-on at a nucleus of charge Ze. (a) Show that its distance of closest approach is $d = 2Ze^2/(4\pi\varepsilon_0 K)$, stating the assumption made about the nucleus. (b) The radius of a gold nucleus (Z = 79) is about 6 fm. Neglecting the size of the α-particle, find the least kinetic energy, in MeV, with which an α-particle must approach head-on to just reach the surface of the gold nucleus. ($1/4\pi\varepsilon_0 = 9 \times 10^9$ N m^2 C^{-2}, $e = 1.6 \times 10^{-19}$ C, 1 MeV = 1.6×10^{-13} J) [3]

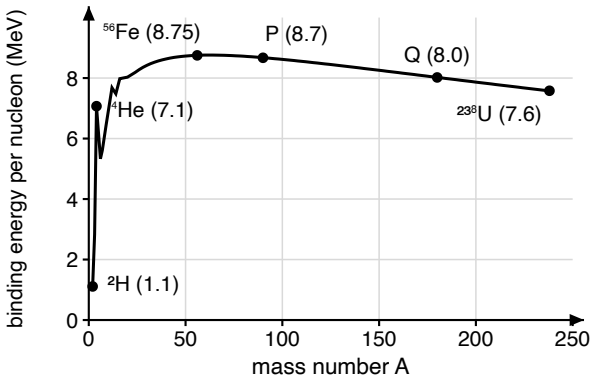
(a) The gold nucleus, much heavier than the α-particle, is taken as stationary. Mechanical energy is conserved: at the turning point the α-particle is momentarily at rest, so all of K has become electric potential energy: $K = (1/4\pi\varepsilon_0)(2e)(Ze)/d$, giving $d = 2Ze^2/(4\pi\varepsilon_0 K)$. (b) Setting $d = 6 \times 10^{-15}$ m: $K = 9 \times 10^9 \times 2 \times 79 \times (1.6 \times 10^{-19})^2/(6 \times 10^{-15})$ J $= 6.07 \times 10^{-12}$ J ≈ 37.9 MeV, about 38 MeV, roughly five times the energy of the α-particles that showed the nucleus to be smaller than 30 fm.

- nucleus stationary; K equals potential energy at turning point (1)
- $d = 2Ze^2/(4\pi\varepsilon_0 K)$ (1)
- K ≈ 38 MeV (1)

Section D (2 × 4 marks)

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

Ananya, a student in Kochi, plots the binding energy per nucleon E_{bn} of stable nuclei against mass number A from a table of data. Her graph is shown, with a few points marked and their E_{bn} values in MeV in brackets. P and Q are nuclei of mass numbers 90 and 180. She wants to compare the energy available from fusing very light nuclei with that from splitting heavy ones, reading the values from her graph.



(a) The curve is nearly flat between A = 30 and A = 170 because the nuclear force [1]

(a) is much stronger than the gravitational force
(b) is short-ranged, so an interior nucleon is bound only by its near neighbours
(c) does not depend on electric charge
(d) becomes repulsive below 0.8 fm

Answer: (b) Saturation: with a short-ranged force, an interior nucleon's binding does not grow with the size of the nucleus, and most nucleons are interior. Charge independence, strength and the repulsive core are true properties but do not explain the flat region.

(b) Using the marked values, the energy released per nucleon of fuel when two ^{2}H nuclei fuse into ^{4}He is about how many times that released per nucleon when nucleus Q splits into two nuclei like P? [1]

(a) 1.0
(b) 0.19
(c) 8.6
(d) 12

Answer: (c) Fusion: 4 × 7.1 − 2 × (2 × 1.1) = 24.0 MeV from 4 nucleons, 6.0 MeV per nucleon. Fission: 180 × (8.7 − 8.0) = 126 MeV from 180 nucleons, 0.70 MeV per nucleon. Ratio 6.0/0.70 ≈ 8.6. 0.19 compares the energies per reaction (24/126), not per nucleon.

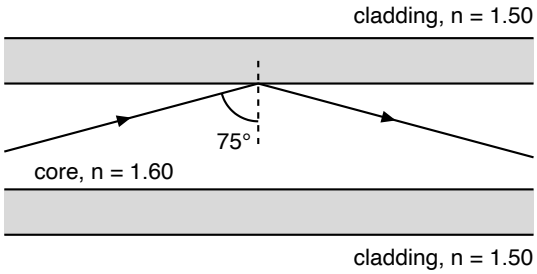
(c) Explain, using the graph, why neither the fission nor the fusion of nuclei near ^{56}Fe can release energy. [2]

^{56}Fe sits at the peak of the curve, $E_{bn} \approx 8.75$ MeV. Splitting it gives lighter nuclei with lower E_{bn}, and fusing two such nuclei gives a heavier one with lower E_{bn}. Either way the nucleons end up less tightly bound, the products have more mass than the reactants, the Q-value is negative, and energy has to be supplied.

- ^{56}Fe at the peak: the products of either process have lower E_{bn} (1)
- less binding means more mass: negative Q-value, energy must be supplied (1)

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

A doctor in a Chennai hospital examines a patient's stomach with an endoscope, a bundle of thin optical fibres. Each fibre has a glass core of refractive index 1.60 inside a cladding of refractive index 1.50 (see figure). Light sent into one end meets the core–cladding boundary again and again, and travels along the fibre even where the bundle bends. In good silica fibres more than 95% of the light comes through a kilometre of fibre, which is why such fibres also carry telephone and video signals between cities.



(a) The critical angle at the core–cladding boundary is about [1]

(a) 38.7° (b) 41.8°
(c) 69.6° (d) 20.4°

Answer: (c) sin i_c = n(cladding)/n(core) = 1.50/1.60 = 0.9375, $i_c \approx 69.6°$. 38.7° would be the core–air value, and 20.4° is 90° − 69.6°.

(b) If the cladding were replaced by glass of refractive index 1.60, the same as the core, light would [1]

(a) pass into the cladding, since total internal reflection at the boundary could not occur (b) still be totally reflected, since the core is glass
(c) be totally reflected only where the fibre bends (d) travel faster in the core than in the cladding

Answer: (a) Total internal reflection needs light going from a denser to a rarer medium. With equal indices there is no boundary for refraction at all: light goes straight into the cladding.

(c) In the figure a ray meets the boundary at 75°. Is it totally reflected? What happens to a ray that meets the boundary at 60°? [2]

75° is greater than the critical angle 69.6°, so the ray is totally reflected and stays in the core. 60° is less than 69.6°, so that ray is partly reflected and partly refracted into the cladding; at each such meeting some light leaves the core and is lost.

- 75° > 69.6°: totally reflected (1)
- 60° < 69.6°: partly refracted into the cladding, light lost (1)

Section E (3 × 5 marks)

31. (a) What is a polaroid? Describe an experiment with two polaroids which shows that light is a transverse wave. (b) Unpolarised light of intensity 64 W m^{-2} passes through three polaroids P_1, P_2, P_3 in turn. The pass-axis of P_2 is at 30° to that of P_1, and the pass-axis of P_3 is at a further 30° beyond P_2, that is at 60° to P_1. Find the intensity emerging from P_3. Then find the intensity when P_2 is removed, and comment on the result. [5]

Or *(a) Light polarised by a polaroid P_1 falls on a polaroid P_2 whose pass-axis makes an angle θ with that of P_1. Show that the intensity transmitted by P_2 is $I = I_0 \cos^2\theta$, where I_0 is the intensity between them, and state between what limits two polaroids can control the intensity of unpolarised light. (b) Unpolarised light of intensity 48 W m^{-2} falls on P_1. (i) Find θ for which the light emerging from P_2 is one-eighth of the incident intensity. (ii) With P_2 at this angle, a third polaroid P_3 is placed after P_2 with its pass-axis parallel to that of P_1. Find the intensity emerging from P_3. (iii) Would the light from P_2 change if P_3 were placed instead between P_1 and P_2, still parallel to P_1? Give a reason.*

(a) A polaroid is a sheet whose long-chain molecules are aligned in one direction; it absorbs the electric vector along them and passes the component along the pass-axis, perpendicular to the molecules. Light through one polaroid P_1 is halved and does not change as P_1 turns; viewed through a second polaroid P_2, rotating one of them makes the light nearly vanish at one position and reach full brightness 90° from it. This happens only if the electric field is at right angles to the propagation: light is transverse. (b) After P_1: 32 W m^{-2}. After P_2: 32 $\cos^2 30°$ = 24 W m^{-2}. After P_3: 24 $\cos^2 30°$ = 18 W m^{-2}. Without P_2: 32 $\cos^2 60°$ = 8 W m^{-2}. Inserting a polaroid between the other two increases the light that gets through, because P_2 passes a component that has a larger projection on P_3's pass-axis.

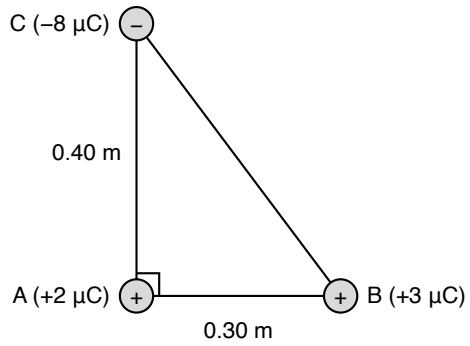
- polaroid: aligned molecules, passes E along the pass-axis (1)
- two-polaroid experiment: zero and maximum 90° apart, so transverse (1)
- 32 → 24 W m^{-2} after P_2 (1)
- 18 W m^{-2} after P_3 (1)
- without P_2: 8 W m^{-2}, so inserting P_2 increases the output (1)

Or:

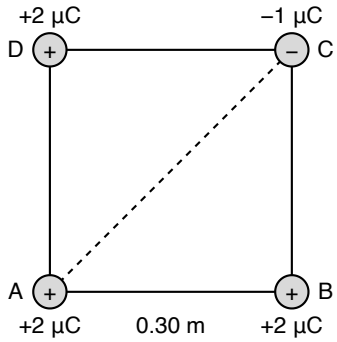
(a) Let the electric field amplitude after P_1 be E, along P_1's pass-axis. P_2 passes only its component along its own pass-axis, E cos θ. Intensity is proportional to the square of the amplitude, so $I = I_0 \cos^2\theta$ (Malus' law). With unpolarised light, P_1 passes 50%; P_2 then reduces it from that 50% (θ = 0) to zero (θ = 90°). (b) (i) After P_1: 24 W m^{-2}. One-eighth of 48 is 6 W m^{-2}, so $\cos^2\theta = 6/24 = 1/4$, $\cos\theta = 1/2$, θ = 60°. (ii) P_3 is at 60° to P_2: 6 $\cos^2 60° = 6 \times 1/4 = 1.5$ W m^{-2}. (iii) No. Light from P_1 is already polarised along P_1's pass-axis, so a polaroid parallel to P_1 passes all 24 W m^{-2} and P_2 still gives 24 $\cos^2 60° = 6$ W m^{-2}.

- component E cos θ passes; $I \propto \text{amplitude}^2$, so $I = I_0\cos^2\theta$ (1)
- limits 50% to zero of the incident intensity (1)
- 24 W m^{-2} after P_1; $\cos^2\theta = 1/4$, θ = 60° (1)
- 1.5 W m^{-2} from P_3 (1)
- no change: light from P_1 already polarised along P_1, so 6 W m^{-2} (1)

32. Point charges +2 μC, +3 μC and −8 μC are placed in vacuum at the vertices A, B and C of a right-angled triangle, with the right angle at A, AB = 0.30 m and AC = 0.40 m (see figure). (a) Find the force on the +2 μC charge due to each of the other two. (b) Find the magnitude and direction of the net force on it. (c) Find the electric field at A due to the charges at B and C. (Take $1/4\pi\varepsilon_0 = 9 \times 10^9$ N m^2 C^{-2}.) [5]



Or *Charges +2 μC are placed at three corners A, B and D of a square ABCD of side 0.30 m, and −1 μC at the fourth corner C (see figure). (a) Find the force on the −1 μC charge due to each of the other three. (b) Find the magnitude and direction of the net force on it. (c) Find the electric field at C due to the three +2 μC charges. (Take $1/4\pi\varepsilon_0 = 9 \times 10^9$ N m^2 C^{-2}.)*



(a) Due to B: $F_B = 9 \times 10^9 \times 2 \times 10^{-6} \times 3 \times 10^{-6}/(0.30)^2 = 0.60$ N, repulsive, along BA (away from B). Due to C: $F_C = 9 \times 10^9 \times 2 \times 10^{-6} \times 8 \times 10^{-6}/(0.40)^2 = 0.90$ N, attractive, along AC (towards C). (b) The two forces are at right angles: $F = \sqrt{(0.60^2 + 0.90^2)} = 1.08$ N ≈ 1.1 N, at $\tan^{-1}(0.90/0.60) = 56°$ to the direction BA (extended beyond A), on the side of C. (c) $E = F/q = 1.08/(2 \times 10^{-6}) = 5.4 \times 10^5$ N C^{-1}, in the direction of the net force, since the charge at A is positive.

- $F_B = 0.60$ N along BA (repulsion) (1)
- $F_C = 0.90$ N along AC (attraction) (1)
- vector sum: F = 1.08 N (1)
- direction: 56° from BA, towards the side of C (1)
- $E = F/q = 5.4 \times 10^5$ N C^{-1} along the net force (1)

Or:

(a) B and D are 0.30 m from C: each force = $9 \times 10^9 \times 2 \times 10^{-6} \times 1 \times 10^{-6}/(0.30)^2$ = 0.20 N, attractive, along CB and CD. A is $0.30\sqrt{2}$ m away: force = $9 \times 10^9 \times 2 \times 10^{-12}/0.18$ = 0.10 N, along CA. (b) The forces along CB and CD are perpendicular and equal; their resultant is $0.20\sqrt{2}$ = 0.283 N along CA. Adding the 0.10 N along CA: F = 0.38 N, along the diagonal CA, towards A. (c) E = F/q in magnitude = $0.383/(1 \times 10^{-6}) = 3.8 \times 10^5$ N C^{-1}; since the test charge is negative, E points opposite to the force, along AC, away from A.

- 0.20 N each due to B and D, towards them (1)
- 0.10 N due to A, at distance $0.30\sqrt{2}$ m (1)
- B and D combine to 0.28 N along CA (1)
- net 0.38 N along CA, towards A (1)
- E = 3.8×10^5 N C^{-1}, along AC, away from A (1)

33. (a) A series LCR circuit is connected to an ac source $v = v_m \sin \omega t$. Draw its phasor diagram for $X_L > X_C$, and use it to obtain the impedance of the circuit and the phase angle between the current and the source voltage. (b) A circuit with R = 50 Ω, X_L = 150 Ω and X_C = 30 Ω is connected to a 130 V (rms) supply. Find the rms current and the power factor. [5]

Or *(a) In a series LCR circuit the source voltage is $v = v_m \sin \omega t$ and the current is $i = i_m \sin(\omega t + \phi)$. Show that the average power over a cycle is P = VI cos ϕ, V and I being rms values. (b) A circuit with R = 50 Ω, X_L = 40 Ω and X_C = 160 Ω is connected to a 260 V (rms) supply. Find the average power and state whether the current leads or lags.*

(a) The same current $i = i_m \sin(\omega t + \phi)$ flows through R, L and C. Take I as reference: V_R (length $i_m R$) along I, V_L ($i_m X_L$) π/2 ahead of I, V_C ($i_m X_C$) π/2 behind I. V_L and V_C are opposite, combining to $i_m(X_L - X_C)$ along V_L. The source phasor V is the hypotenuse of the right triangle with sides V_R and ($V_L + V_C$): $v_m^2 = (i_m R)^2 + [i_m(X_L - X_C)]^2$, so $i_m = v_m/Z$ with $Z = \sqrt{[R^2 + (X_C - X_L)^2]}$. The angle between V and I gives $\tan \phi = (X_C - X_L)/R$. (b) $Z = \sqrt{[50^2 + (150 - 30)^2]} = \sqrt{(2500 + 14\,400)} = 130\ \Omega$, $I = 130/130 = 1.0$ A, $\cos \phi = R/Z = 50/130 \approx 0.38$ (the current lags, since $X_L > X_C$).

- phasor diagram: V_R along I, V_L ahead and V_C behind by π/2 (1)
- $v_m^2 = (i_m R)^2 + [i_m(X_L - X_C)]^2$ (1)
- $Z = \sqrt{[R^2 + (X_C - X_L)^2]}$ and $\tan \phi = (X_C - X_L)/R$ (1)
- Z = 130 Ω, I = 1.0 A (1)
- $\cos \phi \approx 0.38$ (1)

Or:

(a) $p = vi = v_m i_m \sin \omega t \sin(\omega t + \phi) = (v_m i_m/2)[\cos \phi - \cos(2\omega t + \phi)]$. Over a cycle the average of $\cos(2\omega t + \phi)$ is zero, so $P = (v_m i_m/2) \cos \phi = (v_m/\sqrt{2})(i_m/\sqrt{2}) \cos \phi = VI \cos \phi$. (b) $Z = \sqrt{[50^2 + (160 - 40)^2]} = 130\ \Omega$, $I = 260/130 = 2.0$ A, $P = I^2R = 4.0 \times 50 = 200$ W. $X_C > X_L$, so $\phi > 0$ and the current leads.

- $p = vi$ expanded to $(v_m i_m/2)[\cos \phi - \cos(2\omega t + \phi)]$ (1)
- average of $\cos(2\omega t + \phi)$ is zero (1)
- $P = (v_m i_m/2) \cos \phi = VI \cos \phi$ (1)
- Z = 130 Ω, I = 2.0 A, P = 200 W (1)
- current leads (1)