S6 Physics Practice Paper: Electric Field and Potential, Electromagnetic Induction and Transformers, Alternating Current, Photoelectric Effect and Atomic Models, Nuclear Decay and Half-life

Level: S6 | Subject: Physics | 75 minutes | 100 marks | 24 questions | answer key

Section A Electric Field and Electric Potential (18 marks)

Show all working. Give units and answers to three significant figures.

#	Question	Answer	Marks
1	Two point charges of +4.0 x 10^-6 C and -3.0 x 10^-6 C are placed 0.30 m apart in air. (a) Find the magnitude and direction of the electrostatic force between them. (b) Find the magnitude and direction of the resultant electric field at the midpoint between them.	(a) F = k Q1 Q2 / r^2 = 8.99 x 10^9 x 4.0 x 10^-6 x 3.0 x 10^-6 / 0.30^2 = 1.2 N. The charges are opposite, so the force is attractive and points towards the other charge. (b) Each charge is 0.15 m from the midpoint. The field from the positive charge is 8.99 x 10^9 x 4.0 x 10^-6 / 0.15^2 = 1.60 x 10^6 V/m away from it; from the negative charge it is 8.99 x 10^9 x 3.0 x 10^-6 / 0.15^2 = 1.20 x 10^6 V/m towards it. Both point from the positive to the negative charge, so the resultant is 2.8 x 10^6 V/m, directed from the +4.0 x 10^-6 C charge to the -3.0 x 10^-6 C charge.	5
2	Two parallel metal plates 5.0 mm apart are connected to a 250 V d.c. supply. (a) Find the uniform electric field between the plates. (b) Find the force on an electron between the plates. (c) How much work must an external agent do to move a proton from the negative plate to the positive plate? Give the answer in eV and in J.	(a) E = V / d = 250 / 5.0 x 10^-3 = 5.0 x 10^4 V/m. (b) F = e E = 1.6 x 10^-19 x 5.0 x 10^4 = 8.0 x 10^-15 N. (c) W = q V = 1 e x 250 V = 250 eV, which is 250 x 1.6 x 10^-19 = 4.0 x 10^-17 J.	4
3	A point charge of +6.0 x 10^-6 C is isolated in air. (a) Find the potential at points 0.20 m and 0.50 m from it. (b) How much work must an external agent do to move a second charge of +2.0 x 10^-6 C from 0.50 m to 0.20 m from the first charge?	(a) V = k Q / r. At 0.20 m, V = 8.99 x 10^9 x 6.0 x 10^-6 / 0.20 = 2.70 x 10^5 V; at 0.50 m, V = 8.99 x 10^9 x 6.0 x 10^-6 / 0.50 = 1.08 x 10^5 V. (b) The potential difference is 2.70 x 10^5 - 1.08 x 10^5 = 1.62 x 10^5 V, so W = q dV = 2.0 x 10^-6 x 1.62 x 10^5 = 0.32 J. The work is positive because the charge is pushed to a higher potential.	4
4	Two positive point charges of +9.0 x 10^-6 C and +4.0 x 10^-6 C are 0.50 m apart in air. (a) On the line joining them, how far from the +9.0 x 10^-6 C charge is the point where the electric field is zero? (b) Find the potential at that point.	(a) Let x be the distance from the +9.0 x 10^-6 C charge; the other distance is 0.50 - x. Equating field magnitudes, k x 9.0 x 10^-6 / x^2 = k x 4.0 x 10^-6 / (0.50 - x)^2, so 3.0 / x = 2.0 / (0.50 - x) and x = 0.30 m from the +9.0 x 10^-6 C charge, i.e. 0.20 m from the other charge. (b) V = k (9.0 x 10^-6 / 0.30 + 4.0 x 10^-6 / 0.20) = 8.99 x 10^9 x 5.0 x 10^-5 = 4.5 x 10^5 V. The fields cancel but the potentials add, so the potential is not zero.	5

Section B Electromagnetic Induction (17 marks)

State the formula used. Explain the direction of any induced current with Lenz law.

#	Question	Answer	Marks
5	A coil of area 0.015 m2 is placed in a uniform magnetic field of 0.40 T. (a) What is the magnetic flux through the coil when its plane is perpendicular to the field? (b) What is the flux when the normal to the plane makes 60 degrees with the field?	Flux is given by PHI = B A cos(theta), where theta is the angle between the normal to the plane and the field. (a) theta = 0, cos 0 = 1, so PHI = 0.40 x 0.015 x 1 = 6.0 x 10^-3 Wb. (b) theta = 60 degrees, cos 60 = 0.50, so PHI = 0.40 x 0.015 x 0.50 = 3.0 x 10^-3 Wb.	4
6	A 200-turn coil of total area 2.0 x 10^-3 m2 and resistance 4.0 ohm has its plane perpendicular to a uniform magnetic field. The field increases uniformly from 0.10 T to 0.50 T in 0.20 s. (a) Find the induced e.m.f. (b) Find the induced current. (c) Find the power dissipated in the coil. (d) Find the charge that passes any cross-section of the wire in this time.	(a) dPHI = 2.0 x 10^-3 x (0.50 - 0.10) = 8.0 x 10^-4 Wb, so e.m.f. = N dPHI / dt = 200 x 8.0 x 10^-4 / 0.20 = 0.80 V. (b) I = e.m.f. / R = 0.80 / 4.0 = 0.20 A. (c) P = I^2 R = 0.20^2 x 4.0 = 0.16 W. (d) Q = I dt = N dPHI / R = 200 x 8.0 x 10^-4 / 4.0 = 0.040 C.	5
7	A metal rod 0.50 m long slides at a steady 4.0 m/s on two parallel rails. Its velocity is perpendicular to a uniform field of 0.60 T, and the total circuit resistance is 3.0 ohm. (a) Find the motional e.m.f. (b) Find the induced current. (c) Find the force needed to keep the speed constant. (d) Find the mechanical power of this force and compare it with the electrical power.	(a) e.m.f. = B L v = 0.60 x 0.50 x 4.0 = 1.2 V. (b) I = e.m.f. / R = 1.2 / 3.0 = 0.40 A. (c) F = B I L = 0.60 x 0.40 x 0.50 = 0.12 N, applied in the direction of motion to overcome the magnetic force. (d) P = F v = 0.12 x 4.0 = 0.48 W, and the electrical power I^2 R = 0.40^2 x 3.0 = 0.48 W; they agree, as required by conservation of energy.	4
8	A coil has a self-inductance of 0.20 H. The current through it increases uniformly from zero to 2.0 A in 0.050 s. (a) Find the induced e.m.f. across the coil. (b) Find the magnetic energy stored. (c) Explain why the self-induced e.m.f. always opposes the change in current.	(a) e.m.f. = L dI / dt = 0.20 x 2.0 / 0.050 = 8.0 V, opposing the rise of current. (b) Energy = 0.5 L I^2 = 0.5 x 0.20 x 2.0^2 = 0.40 J. (c) The current sets up flux through the coil itself; a changing current changes that flux and so induces an e.m.f. By Lenz law the induced current creates a field that opposes the change of flux that produced it, so the self-induced e.m.f. always opposes the change in current.	4

Section C Transformers and High-voltage Transmission (17 marks)

Assume ideal transformers unless stated otherwise.

#	Question	Answer	Marks
9	An ideal transformer has 2000 turns in the primary and 100 turns in the secondary. The primary is connected to a 220 V a.c. supply and the secondary drives a load drawing 5.0 A. (a) Find the secondary voltage. (b) Find the output power. (c) Find the primary current. (d) Is this a step-up or a step-down transformer?	(a) Vs / Vp = Ns / Np, so Vs = 220 x 100 / 2000 = 11 V. (b) Ps = Vs Is = 11 x 5.0 = 55 W. (c) For an ideal transformer input power equals output power, so Ip = 55 / 220 = 0.25 A (the same result follows from Ip / Is = Ns / Np). (d) The secondary voltage is lower, so it is a step-down transformer.	5
10	A transformer has an efficiency of 90%. Its input power is 500 W at 250 V and its secondary voltage is 25 V. (a) Find the output power. (b) Find the secondary current. (c) Find the primary current.	(a) Efficiency = output / input, so output = 0.90 x 500 = 450 W. (b) Ps = Vs Is gives Is = 450 / 25 = 18 A. (c) Input power = Vp Ip, so Ip = 500 / 250 = 2.0 A. The primary current must be found from the input power, not the output power, because of the losses.	4

11	A power station delivers 50 kW at 400 V. The total resistance of the transmission cable is 0.50 ohm. (a) Find the transmission current. (b) Find the power lost in the cable. (c) Find the loss as a percentage of the power delivered.	(a) P = V I, so I = 50 000 / 400 = 125 A. (b) P_loss = I^2 R = 125^2 x 0.50 = 7 812.5 W, about 7.8 x 10^3 W. (c) The percentage is 7 812.5 / 50 000 x 100% = 15.6%, so about one sixth of the power is wasted. The voltage drop along the cable is I R = 125 x 0.50 = 62.5 V.	4
12	The same station now transmits the same 50 kW through the same cable using 20 kV. (a) Find the new transmission current. (b) Find the new power loss. (c) Find the ratio of the loss at low voltage to the loss at high voltage, and explain why high-voltage transmission is more efficient.	(a) I = 50 000 / 20 000 = 2.5 A. (b) P_loss = I^2 R = 2.5^2 x 0.50 = 3.125 W, about 3.1 W. (c) The ratio is 7 812.5 / 3.125 = 2 500. For a fixed power, current is inversely proportional to voltage; since the loss is I^2 R, reducing the current to one fiftieth reduces the loss to one two thousand five hundredth, so high-voltage transmission is far more efficient.	4

Section D Alternating Current (16 marks)

All r.m.s. values and powers refer to averages over a complete cycle.

#	Question	Answer	Marks
13	The voltage of an a.c. supply varies with time as V = 340 sin(100 pi t), with V in volts and t in seconds. (a) Find the peak voltage. (b) Find the r.m.s. voltage. (c) Find the frequency. (d) Find the period.	(a) The peak voltage is 340 V. (b) The r.m.s. voltage is 340 / 1.414 = 240 V (exactly 340 / sqrt 2). (c) The angular frequency is omega = 100 pi = 2 pi f, so f = 50 Hz. (d) The period is T = 1 / f = 1 / 50 = 0.020 s.	4
14	A 100 ohm resistor is connected to an a.c. supply of r.m.s. voltage 220 V. (a) Find the r.m.s. current. (b) Find the average power dissipated. (c) Find the peak current. (d) Find the peak power.	(a) I_rms = 220 / 100 = 2.2 A. (b) P = V_rms I_rms = 220 x 2.2 = 484 W, the same as V_rms^2 / R. (c) The peak current is 1.414 x 2.2 = 3.1 A. (d) The peak power is I0^2 R = 3.1^2 x 100 = 968 W, twice the average power.	4
15	A 20 x 10^-6 F capacitor is connected to a 50 Hz a.c. supply of r.m.s. voltage 220 V; the resistance of the circuit is negligible. (a) Find the capacitive reactance. (b) Find the r.m.s. current. (c) Explain why the reactance falls as the frequency rises.	(a) Xc = 1 / (2 pi f C) = 1 / (2 x 3.14 x 50 x 20 x 10^-6) = 159 ohm. (b) I_rms = 220 / 159 = 1.38 A. (c) The reactance is proportional to 1 / (f C): at higher frequency the capacitor is charged and discharged more often per second, so more charge flows for the same voltage change and the effective impedance is smaller.	4
16	An electric water heater is marked 2000 W, 220 V (r.m.s.). (a) Find the resistance of its heating element. (b) Find the peak current through it. (c) How many kW h of energy does it use in 3 hours of continuous operation? (d) If the supply frequency were doubled at the same voltage, would the average power change? Explain.	(a) P = V^2 / R, so R = 220^2 / 2000 = 48 400 / 2000 = 24.2 ohm. (b) I0 = 1.414 x (2000 / 220) = 1.414 x 9.09 = 12.9 A. (c) Energy = 2.0 kW x 3 h = 6.0 kW h. (d) No. For a pure resistor the impedance does not depend on frequency, and the average power is V_rms^2 / R, which depends only on the r.m.s. voltage and the resistance.	4

Section E Photoelectric Effect and Atomic Models (16 marks)

Take hc = 1240 eV nm, c = 3.0 x 10^8 m/s and 1 eV = 1.6 x 10^-19 J.

#	Question	Answer	Marks
17	Light of wavelength 400 nm falls on a metal surface of work function 2.3 eV. (a) Find the energy of each photon in eV. (b) Find the maximum kinetic energy of the emitted	(a) E = hc / wavelength = 1240 / 400 = 3.1 eV. (b) By the photoelectric equation the maximum kinetic energy is E - work function = 3.1 - 2.3 =	4

	photoelectrons. (c) Find the stopping potential.	0.80 eV. (c) The stopping potential satisfies e Vs = maximum kinetic energy, so Vs = 0.80 V.	
18	The work function of a metal is 2.3 eV. (a) Find the longest wavelength (threshold wavelength) that can cause photoemission, in nm. (b) Find the corresponding threshold frequency. (c) What happens if the incident wavelength is longer than this threshold?	(a) At threshold, hc / wavelength equals the work function, so the wavelength is 1240 / 2.3 = 539 nm, about 5.4 x 10^-7 m. (b) The frequency is 3.0 x 10^8 / 5.39 x 10^-7 = 5.6 x 10^14 Hz. (c) The photon energy is below the work function, so no photoelectrons are emitted however intense the light or however long it shines: a single photon does not carry enough energy.	4
19	Light of wavelength 500 nm falls on a metal of work function 1.9 eV. (a) Find the photon energy in eV. (b) Find the maximum kinetic energy of the photoelectrons in eV. (c) If light of 700 nm were used instead, would photoelectrons be emitted? Justify with a calculation.	(a) E = 1240 / 500 = 2.48 eV. (b) The maximum kinetic energy is 2.48 - 1.90 = 0.58 eV. (c) A 700 nm photon has energy 1240 / 700 = 1.77 eV, which is less than the 1.9 eV work function, so no photoelectrons are emitted.	4
20	The energy levels of the hydrogen atom are E1 = -13.6 eV, E2 = -3.40 eV and E3 = -1.51 eV. (a) Find the energy and wavelength (nm) of the photon emitted when the electron falls from n = 3 to n = 2. (b) Find the wavelength (nm) of the photon emitted in the n = 2 to n = 1 transition. (c) To which series does each line belong?	(a) The photon energy is E3 - E2 = -1.51 - (-3.40) = 1.89 eV, so the wavelength is 1240 / 1.89 = 656 nm (red, the Balmer H-alpha line). (b) The photon energy is E2 - E1 = -3.40 - (-13.6) = 10.2 eV, so the wavelength is 1240 / 10.2 = 122 nm (ultraviolet, Lyman series). (c) The 3 to 2 line belongs to the Balmer series (final level n = 2); the 2 to 1 line belongs to the Lyman series (final level n = 1).	4

Section F Nuclear Decay and Half-life (16 marks)

Take 1 u = 931.5 MeV/c^2, 1 day = 86 400 s and ln 2 = 0.693.

#	Question	Answer	Marks
21	A radioisotope has a half-life of 6.0 hours. A sample has an activity of 8 000 Bq now. (a) What is the activity after 18 hours? (b) What percentage of the nuclei remain undecayed then? (c) What will the activity be after a further 6.0 hours?	(a) 18 hours is 18 / 6.0 = 3 half-lives, so the activity is 8 000 / 2^3 = 8 000 / 8 = 1 000 Bq. (b) The fraction remaining is 1 / 2^3 = 1 / 8 = 12.5%. (c) One more half-life halves the activity to 500 Bq.	4
22	The half-life of carbon-14 is 5 730 years. An archaeological sample originally contained 8.0 g of carbon-14. (a) How much carbon-14 remains after 11 460 years? (b) What percentage has decayed? (c) Why is carbon-14 dating not suitable for fossils millions of years old?	(a) 11 460 years is 11 460 / 5 730 = 2 half-lives, so 8.0 / 2^2 = 8.0 / 4 = 2.0 g remains. (b) The fraction decayed is 1 - 1/4 = 3/4, i.e. 75%. (c) After millions of years very many half-lives have passed, so almost nothing is left (after ten half-lives less than one thousandth remains); the activity is then too low to measure reliably against background radiation.	4
23	A sample contains 2.0 x 10^20 radioactive nuclei; the half-life is 5.0 days. (a) Find the decay constant in s^-1. (b) Find the present activity of the sample. (c) If the number of nuclei were doubled with the same half-life, how would the activity change?	(a) The decay constant is lambda = ln 2 / T = 0.693 / (5.0 x 86 400) = 0.693 / 432 000 = 1.6 x 10^-6 s^-1. (b) A = lambda N = 1.6 x 10^-6 x 2.0 x 10^20 = 3.2 x 10^14 Bq. (c) Since A = lambda N and lambda is unchanged, doubling N doubles the activity to 6.4 x 10^14 Bq.	4

24	Uranium-238 decays by alpha emission to thorium-234, which then decays by beta emission. (a) Write the two nuclear equations. (b) A nuclear reaction has a mass defect of 0.0030 u; find the energy released in MeV and in J. (c) Explain why the electron energy spectrum in beta decay is continuous.	(a) Alpha decay: 238/92 U -> 234/90 Th + 4/2 He (2 protons and 4 nucleons leave). Beta decay: 234/90 Th -> 234/91 Pa + electron + antineutrino, with the mass number unchanged and the atomic number raised by one. (b) E = 0.0030 x 931.5 = 2.79 MeV, which is 2.79 x 10^6 x 1.6 x 10^-19 = 4.5 x 10^-13 J. (c) The energy released is shared between the electron and the antineutrino, and the antineutrino can carry any share, so the electron energies form a continuous spectrum rather than a single peak.	4