BRITISH PHYSICS OLYMPIAD 2007

COMPETITION

Paper 2

3rd November 2006

A three hour paper, plus 15 minutes reading time

There are SEVEN questions.
The marks for each question are given on the right hand side of the page.
Graph paper is available.

FOUR questions are to be attempted. Formulae sheets may be used.

QUESTION 1 IS COMPULSORY. It is expected that students will spend 75 minutes on this question. The total mark allocated is 81. Students can attempt any, or all, of the sections. However the maximum total mark awarded will be 40.

THREE of the remaining six questions should be attempted. Students are recommended to spend 35 minutes on each of these questions. The maximum mark for each of these questions is 20.

Important Constants

Speed of light	c	3.00×10^{8}	ms^{-1}
Planck constant	h	6.63×10^{-34}	Js
Electronic charge	e	1.60×10^{-19}	C
Mass of electron	m_e	9.11×10^{-31}	kg
Permittivity of a vacuum	ε_o	8.85×10^{-12}	Fm^{-1}
Gravitational constant	G	6.67×10^{-11}	$Nm^2\,kg^{-2}$
Acceleration of free fall	g	9.81	ms^{-2}

Q1 (a) How does the proton number, Z, and the nucleon number, A, of a nucleus change due to:

(i) the emission of an alpha particle ?
(ii) the emission of a beta particle ?
(iii) the fusion with a deuterium nucleus ?

[3]

(b) (i) A lorry is moving at a constant velocity along a road. It has rear wheel drive. Draw a diagram showing the forces exerted by the road on the wheels of the vehicle.

(ii) A jet plane, in level flight, is flying at constant velocity. Draw a diagram indicating the forces acting on the plane. State the nature of these forces and their relations.

[5]

(c) In the right angle triangle ABP, Figure 1.a, there is a charge of 100 nC at A and a charge of 576nC at B. AP = 50 mm, BP = 120 mm and AB = 130 mm.

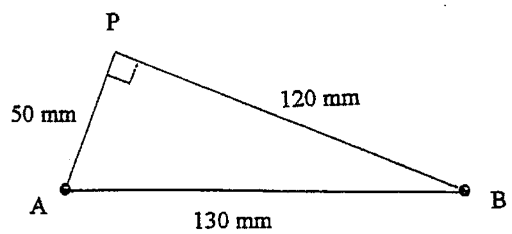

Figure 1.c

What is the magnitude and direction of the electric field, E, at P ? [5]

(d) The circuit in Figure 1.d consists of a cell of emf E and resistors, each with resistance R. Calculate the current I through the battery.

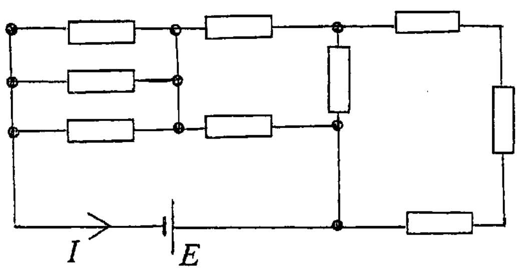

Figure 1.d [5]

(e) The potential difference between the target and the cathode of an X-ray tube is 50.0 kV. The current in the tube is 20.0 mA. Only 1.00% of the total energy is emitted as X-rays.

(i) What is the maximum frequency of the emitted radiation ?
(ii) At what rate must the heat be removed from the target in order to keep it at a constant temperature?

[3]

(f) A lead bullet at 320K is stopped by a sheet of steel so that it reaches its melting point of 600K and completely melts. If 80% of the kinetic energy of the bullet is converted into its internal energy, calculate the speed with which the bullet hit the steel sheet. The specific heat capacity of lead is 0.12 kJ $kg^{-1}K^{-1}$ and its specific latent heat of fusion is 21 $kJkg^{-1}$.

[4]

(g) A uranium bearing rock contains 9 uranium atoms to every 8 helium atoms. Assuming the decay process, which converts a uranium atom into a lead atom, involves the emission of 8 alpha particles, calculate the age of the rock. The half life of uranium is 4.5×10^9 years.

[5]

(h) Estimate, making reasonable assumptions where necessary :

(i) the pressure excess in a champagne bottle if the cork can be projected vertically 6 m. Assume the cork experiences a constant force for the first 2 cm of its flight.

(ii) the mean thickness of a layer of rubber left on the road by a car tyre which, during 50,000 km of travelling, loses 5 mm of tread.

[8]

(j) A large tank contains water to a depth of 1.00 m and stands on the floor. Water spurts from a small hole in the side of the tank 20 cm below the level of the surface. Calculate :

(i) the speed, v, with which the water emerges from the hole

(ii) the distance, d, measured from the base of the tank at which the water strikes the floor.

(iii) the height, h, above the floor at which a second hole should be drilled so that water ejected hits the floor at the same point as in (ii).

[10]

(k) Calculate the *mass* of electrons, M_e, in terms of the fraction of the Earth's mass, M_E, that is required to be taken from the Earth to the Moon in order to double the force of attraction between these two bodies. Assume M_e is much less than M_E. The mass of the Moon is 0.0123 M_E.

[4]

(l) When monochromatic light, wavelength λ, is reflected almost normally from two glass plates, one on top of the other with a very small angle, θ, between them, bright and dark interference fringes are observed.

(i) Explain how these fringes arise.
(ii) How does the separation of the fringes depend on θ ?
(iii) What is the effect of filling the volume between the plates with water ?

[8]

(m) A 0.20 kg mass is attached to the lower end of a helical spring which is fixed at its upper end. The vertical spring is extended by 0.16 m when in equilibrium. Determine :

(i) the change in gravitational potential energy of the mass due to the spring's extension
(ii) the elastic energy stored in the spring
(iii) Why do the magnitudes of (i) and (ii) differ ?

The mass is pulled down a further distance of 0.08 m and released.

(iv) What is its kinetic energy when passing through the equilibrium position ?
(v) What is its period of oscillation ?
(vi) If the upper end of the spring is released, describe the motion of the mass and the spring.

[10].

(n) A bicycle tyre has a volume of 1.2×10^{-3} m^3 when fully inflated. The barrel of a bicycle pump has a working volume of 9.0×10^{-5} m^3 . How many strokes of the pump are needed to inflate the, initially , completely flat tyre to a total pressure of 3.0×10^5 Pa ? The atmospheric pressure is 1.0×10^5 Pa. Assume the air is pumped slowly so that the temperature does not change.

Explain why, in practice, the barrel of the bicycle pump increases in temperature when the pumping is not slow.

[5]

(o) A uniform plank, AB, mass m, of length $2l$ is supported at each end by vertical forces, S_A and S_B respectively. A man of mass M walks across the plank. Determine S_A and S_B when the man is a distance x from B. Plot ,on a single graph, the variation of S_A and S_B with x .

[6]

Q2 The circuit in Figure 2.1 has currents i_1 to i_{12} in the arms indicated due to a potential difference V across AB. Each arm has a resistor of resistance R.

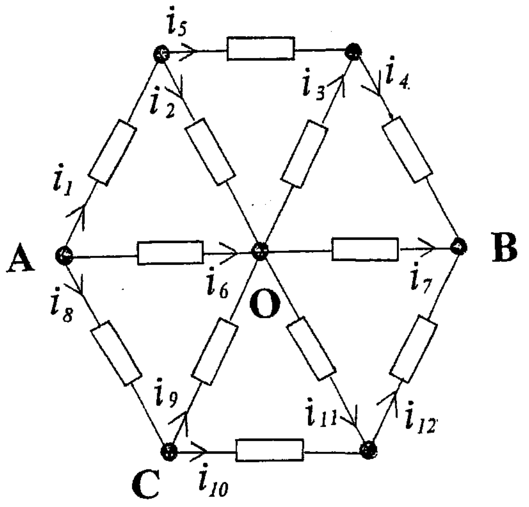

Figure 2.1

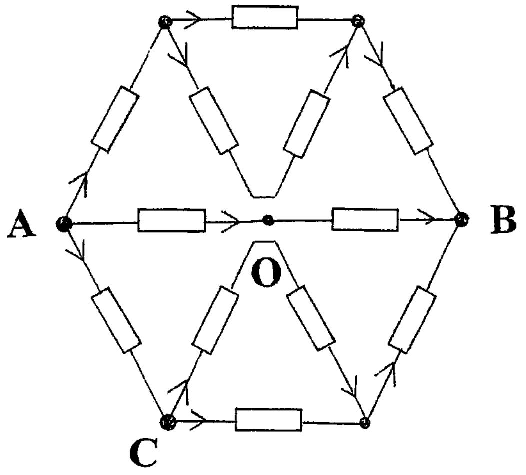

Figure 2.2

(a) (i) From the symmetry of the circuit, deduce the relationships between the currents in the lower arms and those in the upper arms.

(ii) If V is reversed, what can be deduced , using symmetry, about :

(x) the directions of the currents ?
(xi) the magnitudes of the currents ?

(iii) How do the currents in the arms change if the connections at O are altered in the way indicated in Figure 2.2 ?

(iv) Deduce the resistance, R_{AB} , across AB.

[10]

(b) Using the methods applied in (a)(ii) and (a)(iii), determine the resistance across AC when V is applied across AC.

[10]

Q3 (a) Derive the frequency, f, detected by an observer from a sound source of frequency f_0, indicating if it increases or decreases with respect to f_0, when:

(i) the source is stationary and the observer is moving with velocity v directly towards it.

(ii) the source is moving with velocity u directly towards the stationary observer.

(iii) the source and observer are moving towards each other ,along the same straight line, with speeds ,respectively, of v and u.

The speed of sound is c_S.

[8]

(b) A stationary source emits a note of frequency f_0. An observer who is moving with constant velocity v, in a straight line , initially towards the source, but not directly towards it, detects a frequency f that varies with time t. Table 3.1 gives the measurements of f against t. The speed of sound is 330 ms^{-1}.

f / Hz	t / s
210.4	0
210.4	30.0
210.0	60.0
208.0	70.0
199.5	75.0
185.8	80.0
182.1	90.0
181.6	120.0
181.6	150.0

Table 3.1

(i) Why does the frequency f, in Table 3.1, decrease with t ?
(ii) Using the data at large and small times determine f_0 and v .
(iii) Determine the time at which the observer is closest to the source .

[12]

Q4 A hard steel ball, mass m, falls vertically a distance h_1 onto the horizontal surface of a soft steel anvil. It rebounds a distance h_2 after producing a small circular indentation of diameter d. For small h_1 theory predicts

$$3mg\,h_2 = P\,d^3,$$

where P is a constant.

Experiments were performed with $m = 4.00 \times 10^{-3}$ kg. The data obtained are given in Table 4.1. The accuracy of the measurements is correct to the last significant figure.

h_1/mm	h_2/ mm	d / mm
1000	290	1.22
500	162	1.01
100	41	0.64
2.0	1.3	

Table 4.1

(i) Graphically investigate the range of validity of the theory. State your conclusions.
(ii) What is the value and accuracy of P ?
(iii) Plot a graph of the variation of the coefficient of restitution, α, the ratio of the rebound speed, v_R, to the impact speed, v_I, as a function of v_I.
(iv) If a ball is dropped from 900 mm, how long will elapse before the second bounce ?
(v) How is the energy dissipated by the ball ?

[20]

Q5 (a) Two uncharged capacitors, C_1 and C_2, with capacitances C_1 and C_2, are connected in series with a battery and a switch S. When the switch is closed there is a charge Q_1 on C_1 and Q_2 on C_2.

(i) What is the relation between Q_1 and Q_2?
(ii) Give an expression for the potential difference across each capacitor.
(iii) Derive an expression for the capacitance, C, of a single capacitor equivalent to C_1 in series with C_2.
(iv) Calculate the total energy stored in the capacitors.

[7]

(b) An a.c. source of voltage V and frequency f is in series with a diode and a resistor, resistance R.

(i) Sketch a graph of the p.d., V_R, across the resistor as a function of time t.

(ii) Capacitors can be used to 'smooth' rectified a.c. voltages. A capacitor, capacitance C, is connected in parallel with the resistor, Figure 5.1. Explain, with a graph, how the modified p.d., V_R, varies with t.

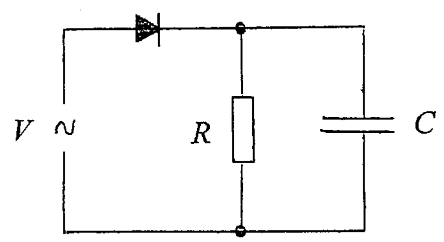

Figure 5.1

(iii) If the input voltage has a peak value of 10.000 V, $f = 100.000$ Hz, $C = 400.000$ μF and $R = 100.000\ \Omega$, calculate the time t_S for the p.d. across R to fall to its smallest value of 7.99049 V.

(iv) Verify that, to four significant figures, the input voltage also has this value at this time.

(v) The voltage across R can be approximated by the sum of a d.c. component, V_d, and an a.c. component with amplitude V_a and frequency f_a. Estimate the values of V_d, V_a, and f_a.

[13]

Q6 (a) Faraday's law of electromagnetic induction can be expressed as

$$E = - \text{ RATE OF INCREASE OF } (\Phi) .$$

Explain the symbols and the significance of the negative sign. [3]

(b) The wing span of a jumbo jet is 80m, its length is 60m and its depth is 8.0m. Estimate the magnitude of the electric potential differences that exist over the surface of the jet when it flies horizontally at 720 kmh^{-1}:

(i) over the North Pole
(ii) northwards over the equator
(iii) eastwards along the equator
(iv) northwards over London

The Earth's magnetic field density is 3×10^{-5} T at the equator, 5×10^{-5} T over London and 6×10^{-5} T at the North Pole. The angle between the horizontal and the Earth's magnetic field at London, the angle of dip, is 66°.

[11]

(c) A copper rod of length L is pivoted at its mid point and rotates about a horizontal axis perpendicular to its length, in a vertical plane, with a constant angular frequency ω . A uniform magnetic field flux density B exists parallel to the axis.

What is the magnitude of the emf developed between:

(i) the centre and one end of the rod ?
(ii) the ends of the rod ?
(iii) the ends of the rod when the pivot is moved to a point a distance x from one end ?

[6]

Q7 (a) Assuming the planets are in circular motion around the Sun, with radius R and period T, use the data in Table 7.1 to test, graphically, the hypothesis that T is proportional to R^{α} , where α is a constant. Obtain from the graph:

(i) a value for α and give its accuracy

(ii) the constant of proportionality in SI units

[10]

PLANET	R / 10^8 km	T / days
Earth	1.49	365
Mars	2.28	687
Jupiter	7.78	4333
Uranus	28.7	30690

Table 7.1

(b) (i) Derive, using mechanics, the relation between T and R in terms of the mass of the Sun, M_S.

(ii) Determine M_S using the data in (a).

(iii) The distance of the Moon from the Earth is 3.8×10^5 km and its period is 27.3 days. Deduce the ratio (M_S/M_E), where M_E is the mass of the Earth.

[10]