BRITISH PHYSICS OLYMPIAD

British Physics Olympiad 2011

12th November 2010

Paper 2

Section 2

Instructions

Questions: Only THREE of the eight questions in *Section 2* should be attempted.
Time: It is recommended that students spend 1 hour 45 minutes on this section (approximately 30 minutes on each question with 15 minutes reading time).
Marks: The maximum mark for each of these questions is 20.

Question answers
Answers can be written on loose paper or examination booklets. Graph paper and formula sheet should be available.
Students should ensure their name and school is clearly written on their answer sheets.

Sittings
Section 1 and *Section 2* of *Paper 2* may be sat in one session of three hours. Alternatively, the paper may be sat in two sessions, 1 hour 15 minutes for *Section 1* and 1 hour 45 minutes for *Section 2*. If the paper is taken in two sessions, students should not receive *Section 2* until the start of the second session, and should not be allowed to return to their answers to *Section 1*.

BRITISH PHYSICS OLYMPIAD

British Physics Olympiad 2011

12th November 2010

Paper 2

Section 2

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_0	8.85×10^{-12}	Fm^{-1}
Acceleration due to free fall	g	9.81	ms^{-2}
Gravitational constant	G	6.67×10^{-11}	Nm^2kg^{-2}
Avogadro's number	N	6.02×10^{23}	Mol
Mass of Earth	M_E	5.9700×10^{24}	kg
Mass of Moon	M_M	7.35×10^{22}	kg
Radius of Earth	R_E	6.38×10^{3}	km
Radius of the Moon	R_M	1.74×10^{6}	m
Earth – Moon distance	R_{EM}	3.84×10^{8}	m

Q2

a) In the circuit below, determine the potential difference V_{AB} between A and B in *Figure 2.a.*

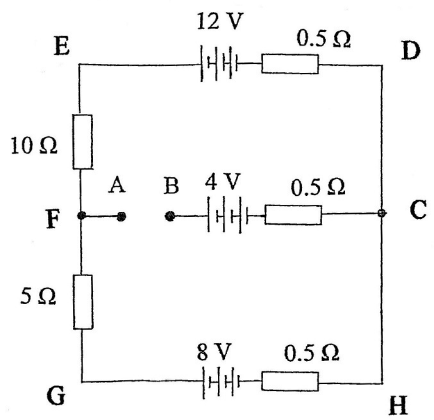

Figure 2.a

[6]

b) The network in *Figure 2.b* consists of eight 3.00 Ω resistors. The currents , i_1,… i_8 , in the arms of the circuit are indicated. A and B are connected to a voltage source.

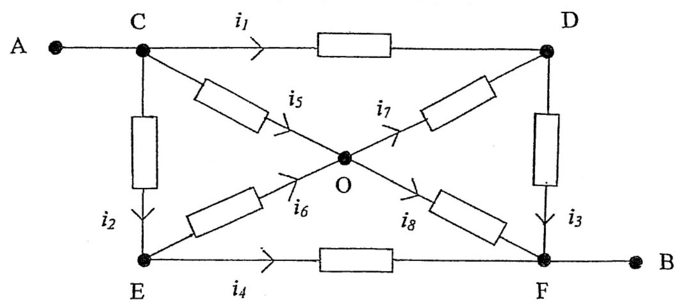

Figure 2.b

Determine:

(i) Using symmetry, the relations between currents.
(ii) By reversing the pd across AB, further relations between the currents.
(iii)Which points in the circuit are at the same potential.
(iv)The resistance, R_{AB}, between AB.
(v) What can be deduced about the potential at O?

[14]

Q3

a) A calorimeter, heat capacity $H = 42.7\ \mathrm{J\,K^{-1}}$, contains 0.80 kg of water at 15 C. 0.40 kg of molten lead, specific heat capacity c = $157\ \mathrm{J\,kg^{-1}\,K^{-1}}$ and latent heat of fusion $L = 2.31 \times 10^4\ \mathrm{J\,kg^{-1}}$, is poured into the calorimeter. The final temperature of the system is 25.0 C. What was the initial temperature of the lead?

The specific heat capacity of water is $4182\ \mathrm{J\,kg^{-1}\,K^{-1}}$.
The melting temperature of lead is 327 C.
The specific heat capacity of solid lead is $136\ \mathrm{J\,kg^{-1}\,K^{-1}}$.

[6]

b) A stream of particles, each of mass *m* and kinetic energy *E*, is collimated into a parallel beam of cross-sectional area *A*. The particles are incident, at a rate of *n* per second, on a smooth plane surface and rebound elastically.

(i) Derive an expression for the pressure on the surface.
(ii) Why would the pressure differ if the surface were rough?

[6]

c) A photon of wavelength λ has momentum *p* and energy E_λ .

(i) Determine the relation between *p* and E_λ .
An electric light bulb emits 20 W of radiation uniformly in all directions.
(ii) What is the maximum radiation pressure on a surface placed 2.0 m away from the bulb?
(iii)State the conditions under which this occurs.

[8]

Q4

a) A stone is projected with a speed u at a small angle α to the horizontal ground. It impacts on the ground at a distance d, having reached a maximum height h. At time t its velocity makes an angle θ with the horizontal.

Determine in terms of u and α:

(i) The time taken, T_g, to reach the ground and the distance d.
(ii) The maximum height, h, reached.
(iii) An expression for the radius of curvature of the trajectory, R , at height h.
(iv) Express R in terms of d and h.
(v) Sketch a graph of tanθ against t , indicating the key points on the graph.
(vi) Deduce, from (v), that there are no pair of points on the stone's trajectory, with velocities that are perpendicular if α less than 45^{o}.

[16]

b) A car, mass m , travels across a parabolic bridge of horizontal length d and maximum height h , the same values as in (a), at a constant speed v. Determine the reaction force, N, exerted by the bridge on the car at height h for any value of v. What advantage could be obtained by adding a spoiler to the car?

[4]

Q5

a) A taut horizontal wire, with zero tension, has length 2L and elastic constant k. A mass M is attached to its mid point O and the system is allowed to come to equilibrium. The wire is stretched by an amount $2y_e$, much less than $2L$, O is displaced vertically by an amount x_e, and the wire is at an angle θ (*Figure 5*.a).

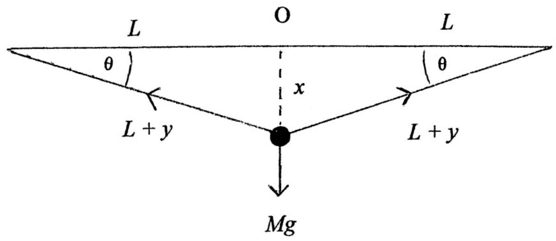

Figure 5.a

(i) Derive, using Pythagoras's theorem, the approximate relation

$$(x_e/L)^2 = 2(y_e/L).$$

(ii) Determine the equilibrium displacement x_e, in terms of M, L and k.

[10]

b) If mass M is released from its initial rest position, with the wire horizontal:

(i) Give its equation of motion in terms of the vertical coordinate, x.
(ii) Write down an expression for the kinetic energy of the mass in terms of x
(iii) Deduce the maximum value of x, x_m.

[10]

For z much smaller than unity the approximation,

$$(1 + z)^n = 1 + nz + \dots \text{ can be applied.}$$

Q6

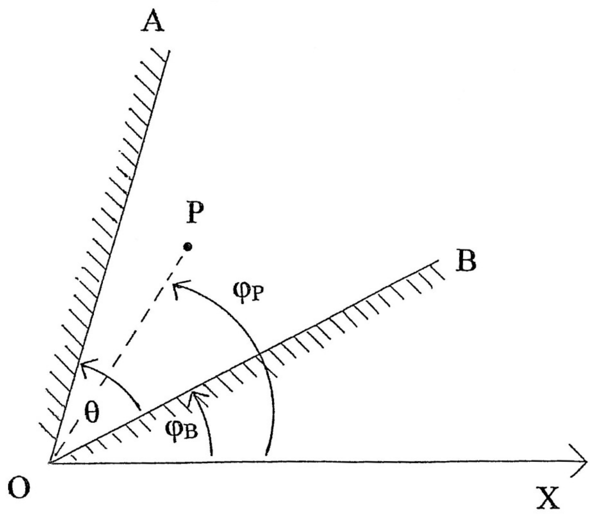

Figure 6.1

Two mirrors, OA and OB, (*Figure 6.1*), are rigidly set at a constant fixed angle θ, but can rotate about O. A fixed point P is situated between the mirrors. OP makes an angle φ_P with the fixed axis OX.

a) Draw , using graph paper , an accurate diagram showing two light rays from P that are first reflected from mirror OA and then reflected from mirror OB, indicating any real or virtual images, I_{AP} in mirror OA, and I_{BP} in mirror OB.

[6]

b) OB makes an angle φ_B with the fixed axis OX. If the mirrors are rotated, by changing φ_B , show:

(i) That P and the images of P remain at a fixed distance from O.
(ii) How the angle IAPOX varies with φB.
(iii)How the angle I_{BP}OX varies with φ_B , providing P remains within AOB.

[9]

c) Explain qualitatively how a rainbow is produced by spherical water droplets.

[5]

Q7

a)

(i) Explain the photoelectric effect.

(ii) Derive a relation between the incident photon frequency, v, and the electron kinetic energy for a photocathode with work function φ.

(iii) How does the classical explanation of this phenomenon differ from the quantum explanation?

(iv) Sketch a graph of current, I, against voltage, V, from anode to cathode, for positive and negative V, in the presence of a constant beam of photons in a photoelectric experiment.

(v) How could one graphically determine φ from measurements of photon wavelength and electron velocity?

[12]

(b) In a photoelectric experiment the measurements of stopping potential, V_s , against frequency, f, were obtained and are contained in the table below.

V_s / V	0.60	1.0	1.4	1.8	2.2
f / 10^{14} Hz	6.0	7.0	8.0	9.0	10

Plot a graph and deduce:

(i) The threshold frequency f_0.

(ii) The value of h.

[8]

Q8

a) A satellite of mass $m = 500$ kg is in a circular orbit at an altitude of $l = 600$ km above the Earth's surface . The satellite returns to Earth as a result of the frictional forces and impacts with a speed of $v = 2.00$ kms^{-1}. How much energy was absorbed by the atmosphere?

[6]

b) A rocket, mass M_R , is launched from the Earth. Its motors are used only near the Earth's surface in order to give the rocket *just* sufficient energy to reach the Moon. Once the fuel is exhausted the rocket has initial velocity v. Assume no relative motion of the Earth – Moon system.

Determine:

(i) the distance from the Earth's centre, d_E , at which the velocity of the rocket is least.

(ii) the initial velocity of the rocket, v, justifying any approximations you may make.

[14]

Mass of the Earth	$M_E = 5.97 \times 10^{24}$	kg
Mass of the Moon	$M_M = 7.35 \times 10^{22}$	kg
Radius of the Earth	$R_E = 6.38 \times 10^{3}$	km
Radius of the Moon	$R_M = 1.74 \times 10^{3}$	km
Earth – Moon distance, measured from their centres	$R_{EM} = 3.84 \times 10^{5}$	km

Q9

a) A rock sample has 1.0×10^{23} uranium nuclei which are in radioactive equilibrium with radium nuclei. How many radium nuclei are present? The half lives of uranium and radium are respectively 1.4×10^{17}s and 5.1×10^{10}s.

[3]

b) The window of a gamma-ray detector, area of 4.0×10^{-4} m^2 , is situated horizontally so that it lies 2.0 m vertically above a point source of gamma rays . The detector records 60 photons per min. A sheet of a gamma-ray absorber is introduced between the source and the detector. The count rate can only be maintained by moving the gamma- ray detector vertically down by 0.2 m.

Calculate:

(i) The rate of emission of gamma-rays from the source.
(ii) The percentage of gamma-rays absorbed.

[5]

Living wood takes in radioactive carbon 14 from the atmosphere during the process of photosynthesis; the proportion of carbon 14 to carbon 12 being 1.25×10^{-12} . When the wood dies the carbon 14 decays, its half life being 5600 years. 4.00 g of carbon from a piece of dead wood gave a total count of 20.0 disintegrations per minute, with an uncertainty of 0.4 in the value.

Determine:

(i) The age of the wood.
(ii) The uncertainty in the age.

[12]

End of Paper