BRITISH PHYSICS OLYMPIAD 2012-13

BPhO Round 1

Section 2

16th November 2012

Instructions

Time: 1 hour 20 minutes (approximately 40 minutes on each question).

Questions: Only TWO of the eight questions in *Section 2* should be attempted.
Marks: The maximum mark for each of the questions is 20.

Solutions: Answers and calculations are to be written on loose paper or examination booklets. Graph paper and formula sheets should also be made available. Students should ensure their name and school is clearly written on all answer sheets.

Setting the paper: There are two options for setting BPhO Round 1:

- *Section 1* and *Section 2* may be sat in one session of 2 hour 40 minutes.
- *Section 1* and *Section 2* may be sat in two sessions on separate occasions; with 1 hour 20 minutes allocated for each section. If the paper is taken in two sessions on separate occasions, *Section 1* must be collected in after the first session and *Section 2* handed out at the beginning of the second session.

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
Gravitational constant	G	6.67×10^{-11}	$Nm^{2}kg^{-2}$
Acceleration of free fall	g	9.81	ms^{-2}
Permittivity of a vacuum	ε_0	8.85×10^{-12}	Fm^{-1}

Q2.

(a) The circuit in Figure 2.a consists of a DC voltage *E*, a 1.0 ohm load , a 12 V battery with a 0.40 ohm and a 0.20 ohm resistor.

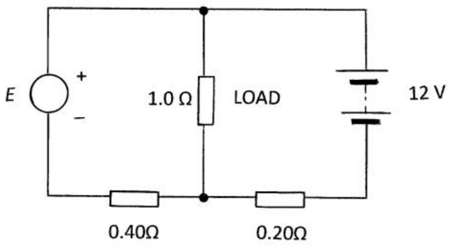

Figure 2.a

(i) At what value of *E* does the battery begin to charge?

(ii) What fraction of the power is delivered to the load by the voltage supply E when the charging current is zero?

(iii) What is the current through the battery when *E* = 20 V?

[8]

(b) In the circuit in Figure 2.b, with the specified resistors and currents, i_1,... i_6 , and with a pd of *V* across AB:

(i) Determine relations between the currents by reversing V and using symmetry considerations, or otherwise.

(ii) Deduce the total resistance across AB.

(iii) Determine the magnitudes of the currents in terms of V.

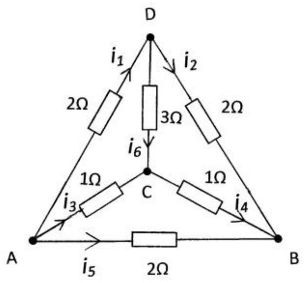

Figure 2.b

(iv) If the voltage is now applied across CD determine, by redrawing the circuit in a similar form to Figure 2.b, with CD as the base, the resistance across CD.

(v) Redraw the circuit with AC as the base. Explain why the resistance across AC cannot be calculated in terms of resistances in series and/or parallel.

[12]

Q3.

(a) The Earth can be approximated by a perfect homogeneous stationary solid sphere, radius R_E. A straight smooth tunnel is drilled along a diameter. Show that a particle, mass *m*, released from the entrance, will perform simple harmonic motion. Determine its period, T_1, in terms of RE and *g.* Hence evaluate T_1.

$$R_E = 6.38 \text{ x } 10^3 \text{ km}$$

[8]

(b) A straight smooth tunnel is drilled through the Earth, in any direction, from any point on the Earth's surface, not passing through the centre of the Earth. Determine the motion of a particle released from the entrance and obtain its period of oscillation, T_2.

[5]

(c) Compare the period of a satellite orbit, T_S, in very close Earth orbit, with T_2.

[5]

(d) If the particle is given an increased velocity, when in the middle of the tunnel, what can be deduced about its trajectory when it emerges from the tunnel into space?

[2]

Q4.

(a) An oil drop of mass 3.3×10^{-15} kg falls vertically, with uniform velocity, through the air between two vertical parallel plates with zero potential difference that are 3.0 cm apart. Explain this motion.

[2]

(b) When a potential difference of 2.0×10^{3} V is applied between the plates, the drop is observed to move with uniform velocity at an angle of 45^{o} to the vertical. Explain this result, with a diagram, indicating the forces acting on the drop, and calculate the charge on the drop.

[5]

(c) The path of the drop suddenly changes, becoming inclined at 18.43^{o} to the vertical. Subsequently the path changes again and is inclined at 33.70^{o} to the vertical. Explain these results.

Deduce from these observations the best estimate of the elementary unit of charge.

[6]

(d) The plates are now arranged horizontally, 12 mm apart, with no potential difference. A drop of oil, mass 10^{-14} kg, is observed to fall vertically with constant velocity of 4.0×10^{-4} ms^{-1}. When a pd of 1.5 kV is applied to the plates the drop rises vertically with a velocity of 8.0×10^{-5} ms^{-1}. How many electrons are present in the drop?

[7]

The drop experiences air resistance proportional to its velocity

Q5.

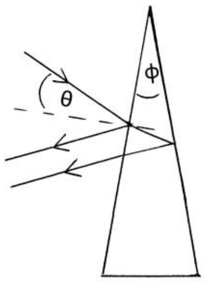

Figure 5.1

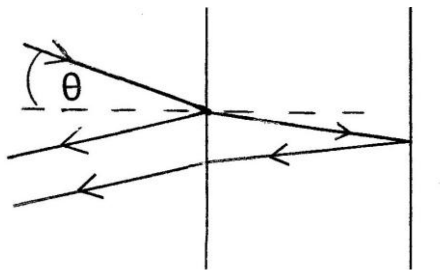

Figure 5.2

A soap film, with constant refractive index $\mu = 1.45$, is contained within a vertical rectangular wire frame and has a wedge shaped profile, small wedge angle ϕ, Figure 5.1. The film drains under gravity, being thicker at the bottom than at the top, where the thickness can be considered to be zero. The film is viewed, by reflection, with red and violet light at near normal incidence; the angle of incidence being exceedingly small. Interference results from light reflected from the outer surface and that emerging after reflection at the inner surface of the film. The optical path difference between the two rays can be determined, to a good approximation, by assuming the film is of constant thickness, t , in the region of these two reflections, Figure 5.2; t will increase with position down the film. The first violet, wavelength 420 nm, constructive interference band is observed at a distance $x_V = 3.0$ cm from the top edge of the film. The wavelength of the red light is 680 nm.

Determine:

(i) the thickness of the film at the lowest order constructive violet interference band, t_V.

[4]

(ii) the film wedge angle ϕ in degrees.

[3]

(iii) for the red light, the lowest order constructive interference film thickness, t_R, and distance, x_R from the top of the film.

[3]

(iv) The soap film drains so that the rate of change of decreases in angle by 8.3 x 10^{-5} degrees in one minute. Determine the initial speed, ($\Delta x_V/\Delta t$) , in cm per minute, of the observed violet interference fringe by considering a small time interval, Δt, in which ϕ changes by $\Delta\phi$ and x_V changes by Δx_V, by first showing

$$x_V\Delta\phi + \phi\Delta x_V = 0 \text{ , or otherwise.}$$

[10]

Q6.

Three small identical steel balls A, B, and C are suspended by vertical threads of equal length from a horizontal support, with their centres in a horizontal line and separated by a small gap. A is raised by a height *h*, with the thread taut, and released. All subsequent collisions are elastic.

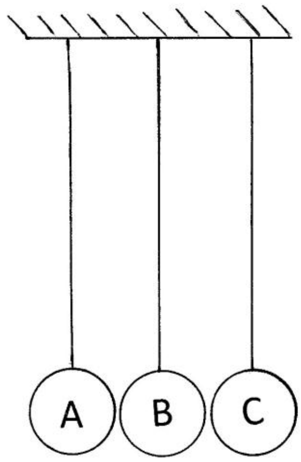

Figure 6.1

(i) When all the balls have mass M, determine the subsequent motion of the system and the height to which the centre of C is raised following its first collision.

[8]

(ii) When A has mass M, B has mass 2M and C has mass 3M, determine the height to which the centre of C is raised after its first collision.

[12]

Q7.

(a) If the radius of the Earth R_E = 6.38 x 10^3 km and g = 9.81 ms^{-2} is the acceleration of free fall, obtain an expression for the minimum launch speed required to put a satellite into polar orbit, over the poles, and calculate its magnitude.

[4]

(b) What is the ratio of the minimum launch speed required to put a satellite into polar orbit, over the poles, to the minimum launch speed for an equatorial orbit, around the equator, when they are in close Earth orbits?

[4]

(c) What minimum initial speed must a space probe have if it is to leave the gravitational field of the Earth?

[4]

(d) What minimum launch speed is required for a probe to hit the Sun? Neglect the Earth's gravitational field.

[4]

(e) Ignoring the Earth's gravitational field, what minimum launch speed is required for a probe to leave the solar system?

[4]

Distance of the Earth from the Sun, R_{ES} = 1.50 x 10^8 km

Mass of the Sun, M_S = 1.99 x 10^{30} kg

Mass of the Earth, M_E = 5.98 x 10^{24} kg

Q8.

(a) A glass prism in the shape of a quarter- cylinder, Figure 8.a, radius R = 5.00 cm and refractive index μ = 1.50, lies on a horizontal table. A uniform horizontal beam of light is incident, from the left, on its vertical plane face.

(i) Where, beyond the cylinder, will the table be illuminated?

(ii) If the horizontal beam is incident from the right, *verify* that for angles of incidence, on the circular surface, greater than 83.27^{o}, no light will emerge directly from the vertical face of the prism.

[10]

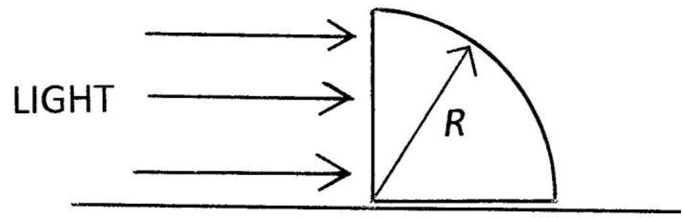

Figure 8.a

(b) Geophysical exploration is being carried out below a horizontal land area, Figure 8.b. The rock directly below ground has depth h and sound travels through it with velocity V_1. Below this layer of rock is another layer of rock in which the velocity of sound is V_2, with V_2 being greater than V_1. Sound is reflected and refracted in a similar manner to light.

An explosion on the surface at E is detected by a microphone M on the surface, which is a distance x from E. Sound waves from E can travel directly along the surface rock to M, and also down into the upper region of the lower rock layer as indicated in Figure 8.b, before final refraction and subsequent detection by M. Determine x, in terms of h, V_1 and V_2, if these two waves are to arrive at M simultaneously.

[10]

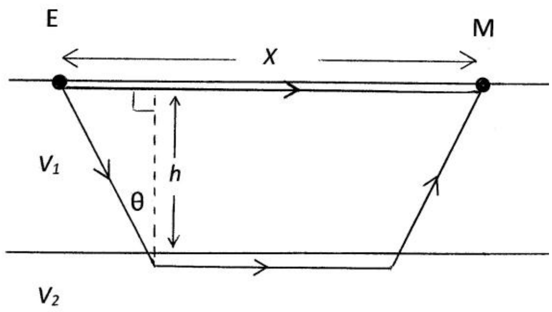

Figure 8.b

End of Questions