BRITISH PHYSICS OLYMPIAD

British Physics Olympiad 2012

11th November 2011

Round 1

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*.

Important Constants

Speed of light	c	3.00×10^{8}	m s^{-1}
Planck constant	h	6.63×10^{-34}	J s
Electronic charge	e	1.60×10^{-19}	C
Mass of electron	m_e	9.11×10^{-31}	kg
Mass of proton	m_p	1.67×10^{-27}	kg
Acceleration due to free fall	g	9.81	m s^{-2}
Gravitational constant	G	6.67×10^{-11}	N m^{2} kg^{-2}
Radius of Earth	R_E	6.38×10^{6}	m
Mass of Earth	M_E	5.97×10^{24}	kg
Mass of the Sun	M_S	1.99×10^{30}	kg
Mass of Moon	M_M	7.35×10^{22}	kg
Radius of the Moon	R_M	1.74×10^{6}	m
Density of water	ρ	1.00×10^{3}	kg m^{-3}

Q2

(a) In Figure 2.a a battery of emf 12.6 V and internal resistance 0.10 ohms is being charged from a solar panel of emf 24.0 V and internal resistance 1.00 ohms. V_1 and V_2 are voltmeters, that give the value and sign of the voltage, and R is a fixed resistor.

(i) If the charging current is 5.00 A, determine the value of R.
(ii) If R is changed to 0.90 ohms, what would be the readings on the voltmeters?

[5]

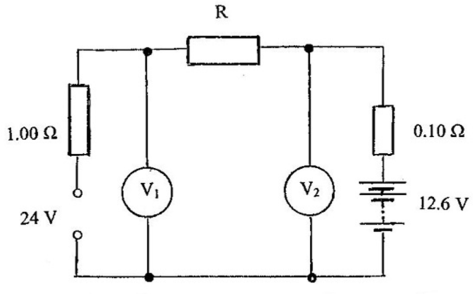

Figure 2.a

(b) In the circuit in Figure 2.b, determine the resistance R_1 if there is no current flowing through E_2.

[3]

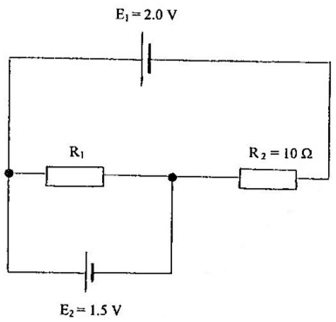

Figure 2.b

(c) In Figure 2.c all resistors have resistance R. If a pd V is applied across AB:

(i) Explain why the potentials at C and D are equal.
(ii) What is the outcome of joining C and D by a conducting wire?
(iii) Keeping C and D connected, draw a simplified circuit by combining those resistors which are in parallel.
(iv) What is the pd across CO?
(v) Determine the resistance across AB, R_{AB}.

[7]

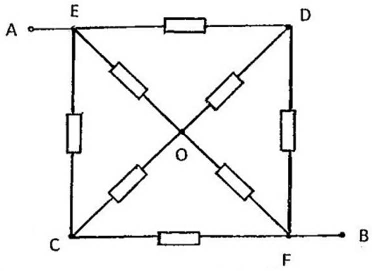

Figure 2.c

(d) Determine the resistance across AO, R_{AO}, in Figure 2.c.

[5]

Q3

(a) A train is travelling along a straight section of railway line at a constant speed u. It sounds its whistle, of frequency f_o, continuously. It passes under a low bridge. Obtain an expression for the frequency heard by an observer on the bridge as it approaches and recedes. The velocity of sound is v_s.

[6]

(b) The frequency f of a vibrating violin string, constant tension F, fixed at both ends, of length l and mass per unit length μ, is given by

$$f = \frac{1}{2l}\sqrt{\frac{F}{\mu}}$$

When a tuning fork of frequency f_{o} is struck, and the wire plucked, beats are heard. For three different increasing values of F which are, F_1, F_2 , and F_3, the number of beats heard in a second is, respectively, b_1, b_2 and b_3, where $b_1 > b_2 > b_3$. F_1, F_2, F_3 are expressed in terms of a constant tension, T.

$$F_1 = 0.99\,T, \qquad b_1 = 3.30,$$
$$F_2 = 1.00\,T, \qquad b_2 = 2.00,$$
$$F_3 = 1.02\,T, \qquad b_3 = 0.58.$$

(i) Sketch a graph of f against F indicating qualitatively, with an explanation from the data, the possible region(s) where f_{o} is located.

(ii) Express f in terms of f_{o} for the first two sets of results.

(iii) Deduce the value of f_{o}.

(iv) Express f in terms of f_{o} for the third set of results.

(v) For the second set of results, (F_2, b_2), with no change in tension, what percentage change in l is necessary for the string and tuning fork to sound in unison?

[14]

Q4

A simple pendulum in a 19th century Swiss clock has a period of oscillation T = 1.000 s, a bob of mass m and suspension wire of length l. It is located on the surface of the Earth at a temperature of 15° C.

(a) If the temperature is kept at 20° C, over a period of a week, by how much will the pendulum lose or gain time? The coefficient of thermal expansion of the suspension $\alpha = 1.9 \times 10^{-5}$ K^{-1}.
(α is the fractional increase in length of the pendulum per unit temperature rise)

[5]

(b) If the pendulum is taken to a height of 20.0 m, by how much will it lose or gain time in the period of a week? Assume the temperature remains at 15°C.

[4]

(c) Explain why the tension, F, in the suspension of a simple pendulum is not constant. If θ is the angle the suspension makes with the vertical, determine the tension in it and compare it with the weight of the bob when it is at:

(i) maximum amplitude, θ_M
(ii) $\theta = 0$

[5]

(d) Some sand is sprinkled on a loud speaker lying on its back which can be made to vibrate vertically with simple harmonic motion. When the amplitude is 0.015 cm the sand begins to loose contact with the membrane. Calculate the frequency of vibration at which this occurs.

[6]

Q5

A technician is measuring the quality of rectangular medical thin glass plates by looking at the interference of light between two plates. One plate has a straight length of wire, diameter 0.0050 cm, resting on it parallel to an edge at one end. Another identical glass plate is supported by the wire at one end, with the other end resting on the horizontal plate, forming an air wedge of angle θ. Interference fringes are produced by monochromatic light of wavelength λ, incident normally on the plates.

(a) Explain, with a diagram, how the interference arises assuming the incident and reflected light is normal to the horizontal plate, and derive the conditions for constructive and destructive interference when the air gap is of thickness t. If 200 fringes are observed across the glass plate, what is the wavelength λ of the light?

[6]

(b) What would be observed if white light replaced the monochromatic light? How would the conditions for monochromatic interference alter if a transparent liquid of refractive index μ replaced the air in the wedge?

[4]

(c) If you had an optically flat glass slide of thickness t and a similar one that was defective in this respect, containing areas with thickness less than t, how would you determine the extent of its deviation from an optical flat and produce a contour map of its surface deviation from a plane surface?

[4]

(d) If you were provided with two monochromatic sources, of different wavelengths, one of which was known, how could you determine the wavelength of the unknown source?

[6]

Q6

(a) A block of wood, mass M, rests on a smooth horizontal table. A gun is fired horizontally at the block and the bullet, mass m, passes through it, emerging with half its initial speed. Determine the fraction of the initial kinetic energy that is lost in the collusion.

[5]

(b) A particle, mass m, is placed at the top of a smooth sphere of radius a. The particle is disturbed and slides down the side gaining speed v at a vertical height z above the centre of the sphere. At what value of z will it leave the surface of the sphere?

[6]

(c) Figure 6.c shows two 45° wedges, the smaller wedge w has a horizontal top face. It can slide down the larger wedge W, which is on a horizontal table. All the surfaces are smooth. A mass m sits on the top face of the upper wedge. Describe qualitatively the motion of the system once it is released from rest.

[4]

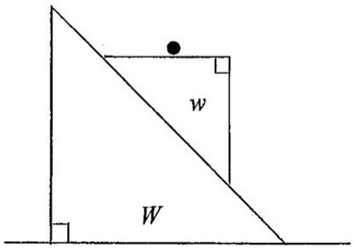

Figure 6.c

(d) Two trains are travelling away from a common station at speeds of u and $2u$, in directions that are at an angle 60° to each other. What is the *velocity* of the train with speed $2u$ relative to an observer in the other train?

[5]

Q7

In order to send a space vehicle to the Moon, the vehicle is first placed in a 'parking orbit' near the Earth.

(a) Calculate the speed v of the vehicle when it is in the parking orbit close to the Earth (you may neglect the height of the orbit compared to the radius of the earth).

[3]

(b) Explain how the rotation of the Earth affects the initial energy required to launch the vehicle from the surface of the Earth.

[3]

(c) When the vehicle is in the parking orbit close to the Earth, in the outer layers of the Earth's atmosphere, friction causes a gradual reduction in its total energy. However it is observed that the vehicle increases its speed. How is this explained using Newtonian mechanics?

[7]

(d) A star, with mass equal to that of our Sun, is located near the outer edge of a spherical galaxy, 3×10^4 ly from the centre. (1 ly is the distance light travels in 1 year.). Its orbital speed around the centre of the galaxy is 250 km s^{-1}.

Estimate, stating any assumptions made, the order of magnitude of:

(i) the mass of the galaxy.
(ii) the number of stars in the galaxy.

[7]

Q8

The scattering of photons (Compton scattering) can be used to identify the composition of materials by the intensity of the scattered radiation. The scattered radiation is at a different frequency and in this problem you are asked to find out what happens when a photon is scattered off at an angle.

An incident photon, frequency f, momentum (hf/c), is scattered by a stationary electron producing a scattered photon of frequency ($f - \Delta f$) , where Δf is small compared with f. This photon travels in a direction that makes an angle θ with the direction of the incident photon. The electron, mass m_e , acquires a non-relativistic speed v.

(a) Draw a labelled vector triangle of the momenta of the particles.

[3]

(b) Write down the equation relating the magnitude of the momentum of the electron to that of the photons.

[4]

(c) Obtain the equation for energy conservation.

[2]

(d) Deduce an equation for Δf . When Δf is much less than f and hf much less than $m_e c^2$, obtain the approximation,

$$\Delta f = \frac{hf^2(1 - \cos\theta)}{m_e c^2}$$

[7]

(e) Sketch graphs of:
(i) Δf against f for constant θ
(ii) Δf against θ for constant f.

For what angle(s) is Δf greatest? State the value(s) of Δf.

[4]

Q9

The charge distribution along a complex molecule can be simplified to the following arrangement of charges.

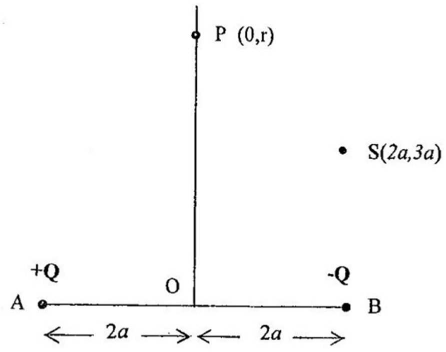

Figure 9.a

Two charges of magnitude, +Q and –Q, are separated by a distance 4*a*, and located at A and B respectively. O is the mid-point of AB, Figure 9.a.

(a) Determine the potential V_1 and field strength $\mathbf{E_1}$ along the perpendicular bisector of AB through O, at a point P a distance *r* from O.

[5]

(b) Determine the potential, V_2, and the field strength, $\mathbf{E_2}$, at the point S with coordinates (2*a*, 3*a*).

[10]

(c) A circular wire, radius 3*a*, centre C, has a charge +Q uniformly distributed around it. An insulating rod of length 4*a* and mass *m* is initially at rest and situated along the axis of the circle. It has a point charge of +Q at one end and –Q at the other end, -Q being 4*a* from C and +Q being 8*a* from C. Determine the velocity of the of the charges when –Q reaches C.

[5]

End of Paper