BPhO
British Physics Olympiad

BRITISH PHYSICS OLYMPIAD 2013-14

Round 1

Section 2

15th November 2013

Instructions

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

Questions: Only TWO of the six questions in *Section 2* should be attempted.

Marks: The maximum mark for each of these questions is 20.

Solutions: Answers and calculations are to be written on loose paper or in examination booklets. Graph paper and formula sheets should also be made available. Students should ensure their **name** and **school** is clearly written on each page of their 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 hours 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}	$m\ s^{-1}$
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
Gravitational constant	G	6.67×10^{-11}	$N\ m^{2}\ kg^{-2}$
Acceleration of free fall	g	9.81	$m\ s^{-2}$
Permittivity of a vacuum	ε_0	8.85×10^{-12}	$F\ m^{-1}$
Avogadro constant	N_A	6.02×10^{23}	mol^{-1}

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Q1.

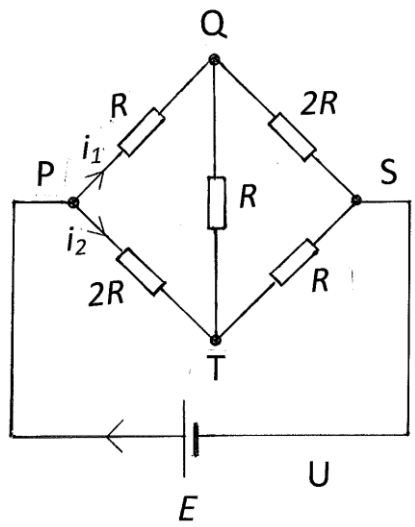

Figure 1.1

The above circuit, Figure 1.1, has resistors with resistance R and $2R$, a cell with emf E, and currents i_1 and i_2 along PQ and PT respectively.

(a) By reversing the cell's polarity determine the current in QS, i_Q, and in TS, i_T.

[2]

(b) Determine the currents, i_{QT} and i_{SUP}, in QT and SUP, respectively, using the result that the sum of the currents entering any junction is equal to the sum of the currents leaving the junction.

[2]

(c) The sum of the clockwise products of current and resistance around any closed path is equal to the source of emf in the closed path. Use this result for paths PQTP and PTSUP to obtain two independent equations.

[4]

(d) Hence determine the resistance, R_{PS}, across PS, in terms of R, and the currents i_1 and i_2 in terms of E and R. If the cell has resistance $3R$, how is R_{PS} altered?

[5]

(e) If the resistance across QT is replaced by a variable resistance, X, what is the possible range of values for R_{PS}?

[7]

Q2.

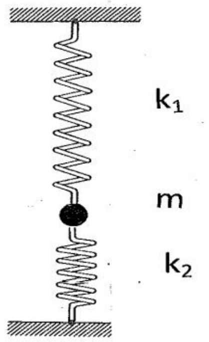

Figure 2.1

(a) A Hookian spring, with spring constant k_1, is cut into n identical springs, each with a spring constant k_2. Determine the relation between k_1 and k_2.

[4]

(b) A spring, with spring constant k_1, is attached to small sphere of mass m. The other end is hung from a rigid support. A spring, with spring constant k_2 as in part (a), is attached to the bottom of the sphere and the lower end of the spring is attached to a rigid base and has zero tension. The two springs and the mass lie in a vertical line, Figure 2.1.

Determine the equilibrium extension of the upper spring, x_{10}.

[1]

(c) If the mass is displaced vertically downwards from equilibrium, by a distance x, show that it will perform simple harmonic motion and determine its frequency, f.

[6]

(d) Derive an expression for the total energy, E, of the system in terms of the downward displacement, x of the mass , from its equilibrium position, and its velocity v. Show that E depends only on the variables v^2 and x^2.

[6]

(e) If the system is arranged horizontally on a smooth table, so that the sphere oscillates, in a straight line, along the direction of the springs, determine the frequency of oscillation, f_H.

[3]

Q3.

(a) What is an electrostatic (i) field line and (ii) equipotential surface?

[2]

(b) An electrostatic field is produced by a charge $+4Q$ at A and $-Q$ at B. The distance AB = a. Determine the position, C , of the neutral point/s, where the electrostatic field is zero.

[4]

(c) Write down, in its simplest form, an equation for a point on the equipotential surface, with potential V, in terms of the distances, r_A and r_B, respective from A and B.

[2]

(d) Sketch, in a plane containing AB, (i) the field lines and (ii) the equipotentials.

[6]

(e) Three equal charges, each of charge $+Q$, are situated at the corners of a right angled triangle , with sides of length $3a$, $4a$ and $5a$.

Determine the potential and electric field vector at the mid-point, M, of the side of length $3a$.

[6]

Q4.

Two identical balls, A and B, each of mass m, undergo a collision. Initially B is stationary and A has velocity u_0. After the collision A has velocity v_A and B has velocity v_B.

(a) For an elastic collision along a straight line, determine the motion of the masses after impact.

[4]

(b) In an inelastic, two dimensional, collision, A has an initial kinetic energy of 8.00 J and 2.00 J is converted into heat on collision. After impact the directions of A and B make equal angles, Θ, with the direction of u_0.

Determine:

(i) the energy conservation equation

(ii) the momentum conservation equation/s

(iii) Θ

(iv) the change in momentum of A.

[16]

Q5.

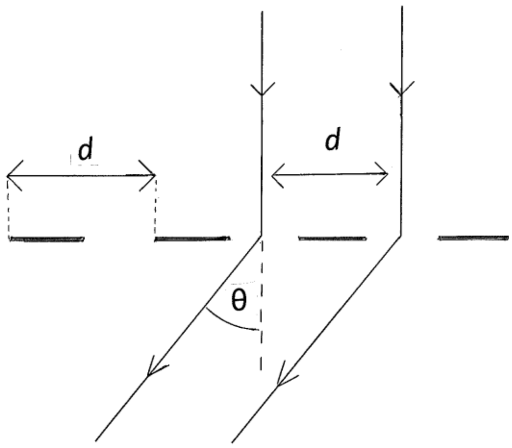

Figure 5.1

A diffraction grating, with period *d*, consists of slits, of equal width, Figure 5.1. Monochromatic light, wavelength λ , incident normally on the diffraction grating, is diffracted by an angle θ.

(a) Determine the condition for:

(i) constructive interference

(ii) destructive interference.

[3]

(b) When monochromatic red and monochromatic violet light are incident on the diffraction grating, it is found that the fourth line observed, not counting the undiffracted zero order line, is a superposition of red and violet light. Explain this observation and specify the first four lines.

[4]

(c) If the grating has 500 lines per mm, and the diffraction angle for the composite line is 43.6^{o}, determine the wavelengths of the red and violet lines.

[6]

(d) What is the fifth line in the spectrum and its associated diffraction angle?

[4]

(e) Indicate, graphically, how the intensity of the lines varies with order *n*.

[3]

Q6

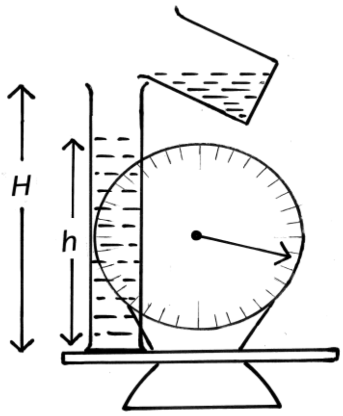

Figure 6.1

Liquid, density ρ , is slowly poured , beginning at time t = 0, from a beaker into a tall measuring cylinder of height H, cross-sectional area A and weight W_{MC}, that stands on weighing scales , Figure 6.1. The initial volume of liquid in the beaker will just fill the cylinder. The liquid is poured, at a volume rate of v, from a height H above the bottom of the cylinder.

(a) Derive an equation for the weight registered on the weighing scales, w, as a function of the height of liquid in the cylinder, h.

[4]

(b) Determine the maximum reading on the scales. (It may be helpful to express the result in (a) in terms of the variable y, where $y^2 = H - h$).

[6]

(c) Deduce the difference between the result in (b) and the weight of liquid in the cylinder plus W_{MC} at the time of the maximum reading.

[2]

(d) Express w as a function of time t, from $t = 0$ until the time when the liquid in the beaker is exhausted, $t_{E.}$

[4]

(e) Sketch a graph of the weighing scale reading, w , against time, t, from $t = 0$ until the beaker is empty.

[4]

$$[\ ax^2 + bx + c = a(x + b/2a)^2 + c - b^2/4a\ ]$$

End of Questions