BRITISH PHYSICS OLYMPIAD

British Physics Olympiad 2010

Paper 1

September/October 2009

Answer all the questions

Allow 1 hour Total 50 marks

$g = 9.8\ \text{ms}^{-2}$ or N kg^{-1}

$c = 3.0 \times 10^{8}\ \text{ms}^{-1}$

Q1.

(a) A long rowing boat, shown in Fig.1, has to be weighed using only a single bathroom scales. The boat will sag if it is supported only in the middle, and so the scales must be put first at position A with a wooden support at B, and then at position B with the wooden support at A. The readings on the scales are 45 kg and 52 kg respectively. What is the mass of the boat?

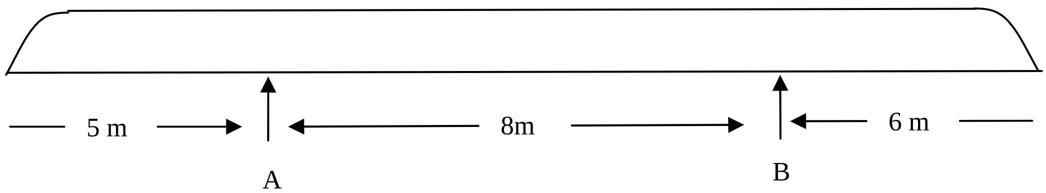

Fig. 1

(2 marks)

(b) The wires leading from the mains supply in the street into a building have a resistance R of 0.2 Ω. The electrical potential difference of the mains supply in the street is constant and equal to 230 V. The electrical potential difference at the sockets in the building is not to drop below 225 V when electrical power is consumed.

i) Sketch a circuit diagram with the given figures noted on it.
ii) Calculate the maximum current, and hence the maximum power that can be dissipated in the building so that the potential difference at the sockets does not drop below 225 V.

(4 marks)

(c) A pin dropped on a hard floor on the far side of a quiet room can be heard by the human ear.

i) If the pin has a mass of 0.2 g, and is dropped from a height of 1 m onto a hard floor, with 10% of the energy being converted into sound, calculate the sound energy released.
ii) If the eardrum (which we can assume is circular) has a diameter of 6 mm, and one human ear can detect the sound of the pin at a distance of 5 m, estimate the energy received by the ear. State any assumptions you make.

(4 marks)

(d) A cinema screen is a white painted surface designed to reflect light back into your eye. The more light that is reflected back the brighter the image will be. Why then can a mirror not be used instead?

(2 marks)

(e) A pair of plane circular metal plates are connected to a cell of emf V and supported in the position shown in Fig.2 below. The separation of the plates, d, is much less than their diameter so that the field strength between the plates, E, is uniform. The energy stored in the electric field is given by $\frac{1}{2}QV$, where Q is the magnitude of the charge on a plate. The field strength $E = V/d$ and E is proportional to the charge Q on the plates.

When the charged plates are moved apart then work is done on the system (as the charged plates attract each other). In the first case (a), the cell remains connected so that the potential between the plates remains at V as the plate separation is doubled. In the second case (b), the cell is disconnected before the plate separation is doubled. What is the ratio of the final energy stored in (a) to the final energy stored in situation (b)?

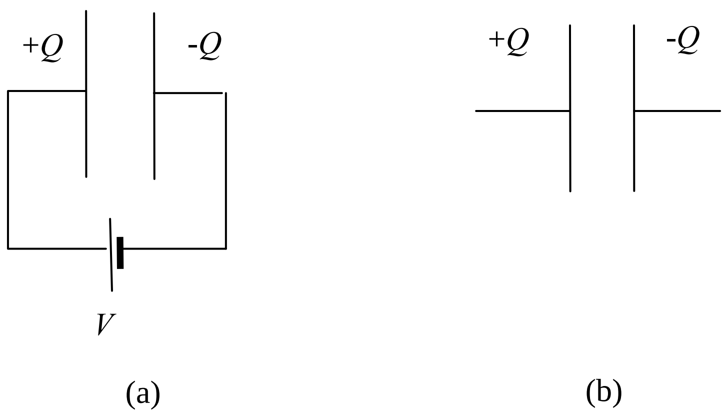

Fig. 2

(4 marks)

(f) A church bell is struck once and the sound energy dies away with a half life of 2.0 s. The energy of an oscillating system is proportional to the square of the amplitude of oscillation.
If the resonant frequency of the bell is 226 Hz, how many oscillations take place before the amplitude falls to ¼ of the initial amplitude?

(3 marks)

(g) A solid cone with a uniform density ρ_c floats with its apex downwards in a liquid of density ρ_w. The cone is of height h and a height ℓ is submerged in the liquid.

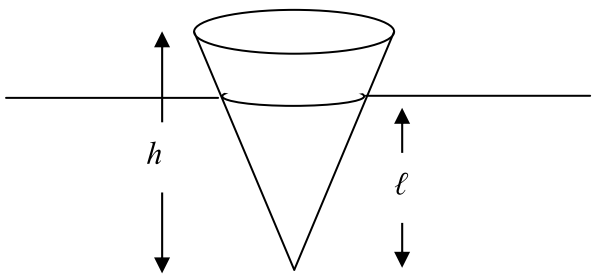

Fig. 3

i) Explain what force keeps the cone from sinking.
ii) Sketch a diagram of the forces acting on the cone.
iii) The radius of the circular cross section of the cone at the top of the diagram is R and the radius at the level of the liquid is r. Write down the relation between R, r, h and ℓ.
iv) From the forces acting on the cone in its equilibrium position, show that

$$\frac{\rho_c}{\rho_w} = \left(\frac{\ell}{h}\right)^3$$

The volume of a cone of height h and radius of base, r, is $\frac{1}{3}\pi r^2 h$

(6 marks)

(h) A fisherman listens to the radio as he sits on the bank waiting for a fish to bite. The sound is also heard by the fish and the path of the sound waves entering the water is shown below in Fig. 4.

i) Describe what happens to the frequency, wavelength, and the speed of sound as it moves from air to water.

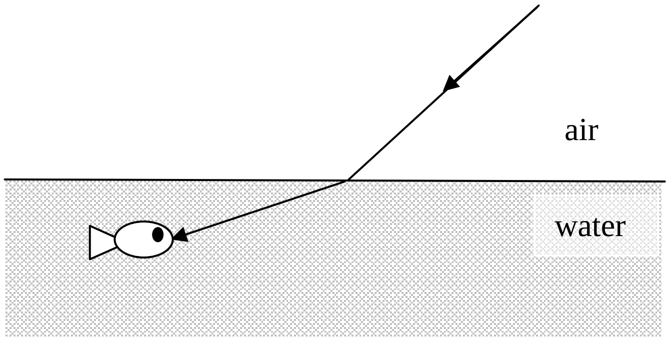

Fig. 4

ii) The fisherman's radio has two speakers, as shown in Fig. 5. Sketch a diagram illustrating how destructive interference between sounds from the two speakers can occur when the radio is playing a note of a single frequency, assuming that the waves from the two speakers start in phase.

iii) For a note of a single frequency and for a given separation of the two speakers, *d*, what must be the maximum wavelength *l* and orientation of the radio for complete destructive interference to occur?

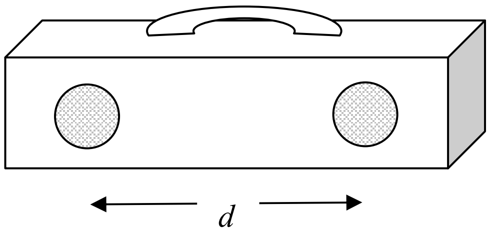

Fig. 5

(6 marks)

(i) A glass prism with an apex angle of 30º has a monochromatic beam of light passing through it, as shown in Fig. 6. The critical angle for the glass of the prism is 42°. (The critical angle is the largest angle of incidence within the glass for which the light can just escape from the glass or the smallest angle of incidence at which Total Internal Reflection can occur).

The normals for the incident and emergent rays are shown. The ray of light emerges at angle q_e for a ray incident on the prism at angle q_i. As angle q_i increases to 90º, which side of its normal does the emerging ray appear? (You do not need to calculate angle q_e but you DO NEED to give the angles of the rays inside the glass). You may draw a diagram with all the angles within the glass marked.

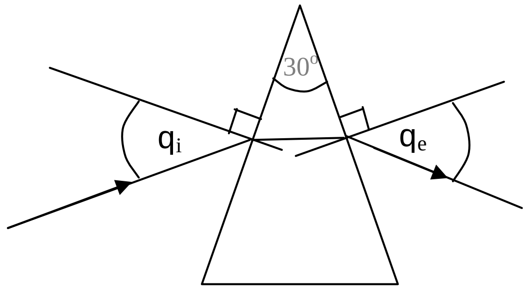

Fig. 6

(3 marks)

(j) A star with a diameter larger than that of the Sun can collapse to form a neutron star which has a diameter of only a few kilometres. As the core collapses to form a neutron star, its electrical conductivity becomes very high. This results in the magnetic field lines being trapped in the collapsing matter so that the field lines become denser and the field strength increases.

If the magnetic field pattern is similar to that of a bar magnet, as shown in Fig. 7 below, then as the star radius *r* decreases, its cross sectional area decreases, and the density of the field lines at the equator changes as $1/r^2$.

If the radius decreases from 1.4 x 10^6 km to 10 km, and the initial magnetic field strength of the star at the equator is 10^{-2} T, calculate the magnetic field strength of the neutron star at the equator.

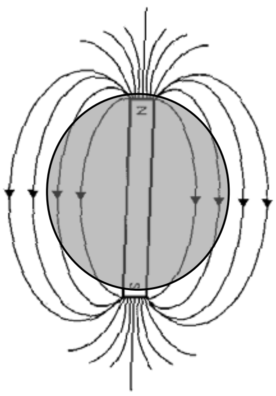

Fig. 7

(4 marks)

[Q1: 38 marks]

Q2. An insight into the solution of a problem can often be made by looking at the dimensions of the relevant physical quantities.

An example is the simple pendulum, in which a mass at the end of a light inextensible string swings from side to side. The period of the swing, *T*, could be determined by resolving the forces acting on the mass. Alternatively, if we suggest that the relevant factors affecting the period are the length of the string, *l*, the mass, *m*, and the strength of the gravitational field, *g*, then *T* must depend upon the product of powers of the quantities *l*, *m* and *g*.

$$\text{i.e } T = const \times l^a \times m^b \times g^c \qquad (1)$$

The dimensions of *l*, *m*, *g* are given by

$$[l] = \mathrm{L}, \quad [m] = \mathrm{M}, \quad [g] = \mathrm{LT}^{-2} \text{ and } [T] = \mathrm{T}. \qquad (2)$$

So then we can write the equation in terms of dimensions as

$$\mathrm{T} = \mathrm{L}^a \times \mathrm{M}^b \times (\mathrm{LT}^{-2})^c \qquad (3)$$

The powers of T, L, M on each side of the equation must be the same.

For T: $\mathrm{T}^1 = \mathrm{T}^{-2c}$ so that c = -½ .
For M: $\mathrm{M}^0 = \mathrm{M}^b$ so b = 0.
For L: $\mathrm{L}^0 = \mathrm{L}^{a+c}$, so that a = ½ .

This results in the equation $T = const \times \sqrt{\dfrac{l}{g}}$. A full analysis of the forces will enable you to deduce that *const* = 2p.

Now solve the following example in the same manner: when a river floods, large boulders can be left behind on the riverbed, and yet the speed of the river does not change very much (the slope remains the same). Assume that the mass of boulders swept along by the river, *m*, depends upon the speed of the river, *v*, the gravitational field strength, *g*, and the density of the boulder, *ρ*.

Write down:

i) The form of the equation relating *m* to *v*, *g*, *ρ* as exemplified in equation (1)

(1 mark)

ii) The dimensions of each of the quantities *m*, *v*, *g*, *ρ*, as in the set of equations in (2).

(4 marks)

iii) The dimensional equation for these quantities, as in (3) and solve to obtain the powers *a*, *b*, *c*.

(4 marks)

iv) The final equation for *m* in terms of the variables.

(2 marks)

v) From your solution, explain why a flooding river which has a small change of speed has a significant effect on the size of the boulders that are swept along.

(1 mark)

[Q2: 12 marks]

[End of Questions]