2008 BRITISH PHYSICS OLYMPIAD PAPER 1

September / October 2007

Answer all the Questions

Allow 1 hour Total 50 marks

$g = 9.81\ ms^{-2}$ or $N\ kg^{-1}$
$c = 3.0 \times 10^{8}\ ms^{-1}$
$h = 6.6 \times 10^{-34}\ Js$

1. What must be the speed of a lead bullet if it melts when it strikes a steel slab? The initial temperature of the bullet is 27 °C. The melting point of lead is 327 °C, its latent heat of melting is $2.1 \times 10^{4}\ J\ kg^{-1}$ and its specific heat capacity is $126\ J\ kg^{-1}\ °C^{-1}$. Assume that all of the kinetic energy is converted to heat energy in the bullet.

(4 marks)

2. A fish rests at the bottom of a bucket of water whilst the bucket is being weighed on a balance. When the fish begins to swim around, does the reading on the balance change?

(2 marks)

3. Would you expect the centre of mass and the centre of gravity of the Empire State Building (a tall skyscraper) to coincide precisely? Explain.

(2 marks)

4. A juggler tossing juggling balls can handle two balls per second; i.e. it takes at least 0.5 seconds to catch a ball with one hand and start it upwards again with the other hand. If he is juggling five balls altogether, to what minimum height must he throw them?

(4 marks)

5. When water is heated from 0 °C its density increases initially, and then decreases as the temperature continues to rise.
   (a) Explain how the fact that water at its freezing point is less dense than water a few degrees warmer prevents a pond from freezing solid overnight when the air temperature drops to below zero.

   (b) A unit volume of water at 0°C has a volume V at temperature T°C given by

$$V = 1 + aT + bT^{2},$$

where $a = -6.105 \times 10^{-5}\ °C^{-1}$
$b = 7.733 \times 10^{-6}\ °C^{-2}$

i. If water was used as the expanding liquid in a glass thermometer, describe the behaviour of the length of the water column (or thread) as the thermometer was warmed up from 0 °C to 10 °C.

ii. Sketch a graph (no values are required) of the length of the water column against temperature

(c) Calculate the temperature range over which the thermometer will give readings that could represent either of two temperatures.

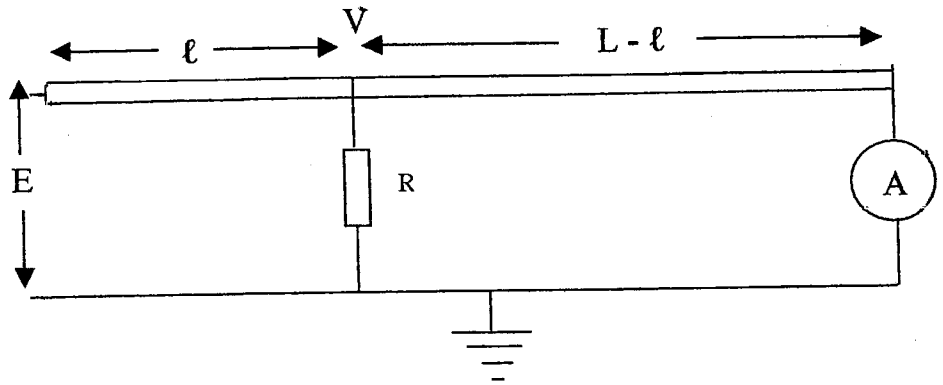
(d) At what temperature is the water column in the thermometer at its shortest?

(10 marks)

6. Cosmic rays are charged particles that move randomly in the galaxy as a result of being scattered by interstellar magnetic fields. The process resembles diffusion. In such situations, if a particle travels an average distance between collisions of λ (known as the mean free path) and it makes N collisions, each time going in a random direction, then the distance travelled is on average given by $R = \sqrt{N}\,\lambda$. Given the dimension of the galaxy as 5×10^{20} m and the mean free path for a cosmic ray as 3×10^{18} m, then estimate how long it takes for a cosmic ray to traverse the galaxy. Assume that it travels at the speed of light.

(4 marks)

7. The arrangement of resistances shown in the diagram below, is attached to a constant source of emf E, The resistor at the top consists of a wire of length L and resistance per unit length ρ. The top end of the fixed resistor R can be slid along the wire L. The earthed horizontal wire at the bottom is of negligible resistance and the resistance of the ammeter can also be neglected. V is the potential at the point where resistor R is connected.



You are required to determine the length ℓ for which the current through the ammeter is a maximum.

(a) If the resistance of length ℓ is R_1 and that of L-ℓ is R_2, determine the ratio V/E in terms of R, R_1 and R_2.

(b) The current I through the ammeter is given by V/R_2. Since we want the minimum value of I, we can look for the maximum value of 1/I. Determine an expression for 1/I.

(c) Substitute for R_1 and R_2 in terms of the lengths of the wire and write down an expression for 1/I in terms of L, ℓ, ρ, R and E.

(d) What is the value of ℓ that maximises 1/I?

(10 marks)

8. (a) The average wavelength of light emitted from an incandescent torch bulb with a metal filament is 120 nm. Calculate the number of photons emitted by a 20 W torch bulb in one hour.

(b) A photon has a momentum given by E/c where E is the energy of the photon and c is the speed of light. If the torch bulb emits a parallel beam of light, then calculate the force on the torch.

(c) Calculate the initial acceleration of the torch if it was in empty space and it had a mass of 200g.

(d) If the spectrum of the light remained the same, and the mass of the torch remained unchanged, what power of torch bulb would be needed in order for it to levitate in the earth's gravitational field?

(6 marks)

9. (a) In a two source interference experiment (double slits), monochromatic light is used to produce light and dark fringes on a screen. The maxima of the fringe pattern, symmetric about the beam of light at normal incidence, is given by

$$n\lambda = d \sin(\theta),$$

where n is the order of the fringe, λ is the wavelength of the light, d is the separation of the slits and θ is the inclination of the light rays to the horizontal.

If d = 0.2 mm and a wavelength of 450 nm is incident on the two slits, what is the angular separation of the 9^{th} and 10^{th} order fringes? If a different wavelength of 495 nm is incident, what would be the angular separation of the 9^{th} and 10^{th} order fringes now?

(b) The change in wavelength was a 10% increase. Using your calculated angles, state clearly which of your angles have increased by 10%.
Why should a 10% increase in the wavelength change the fringes by 10% almost exactly?

(8 marks)