British Physics Olympiad

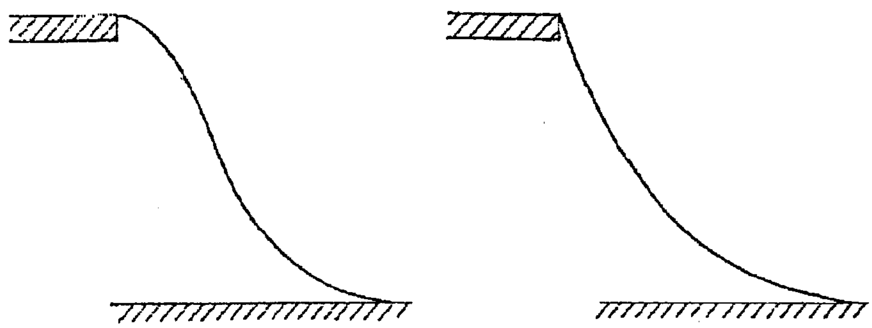
Paper 1, September/October 2008

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. A flexible track is fixed in two alternate arrangements, as shown in Fig. 1. The length of the track used is the same in each case, and the height through which it falls from the bench to the floor is the same. A toy car is released at rest and slides down the track. Air resistance can be ignored.



(i) (ii)

Fig. 1

(a) Explain how the speed of a given car at the bottom of track (i) would compare with the speed at the bottom of track (ii). Would it be faster, slower or the same? Give a reason for your answer.

(2 marks)

(b) Explain how the time taken for the car to slide down slope (i) would compare with the time taken on slope (ii). Give a reason for your answer.

(2 marks)

(c) Suppose a car of twice the mass is now used. How would the times compare for track (i) and track (ii) now? Give a reason for your answer.

(2 marks)

[6]

2. An object of mass 2.00 kg is suspended from two cables attached to the ceiling and the wall as shown in Fig.2.

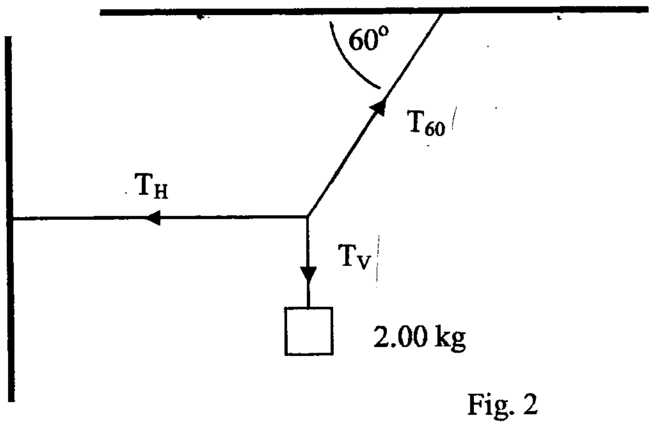


Fig. 2

(a) Calculate the tension in the horizontal string T_H, the tension T_{60} in the cable attached to the ceiling, and the tension T_V in the vertical cable supporting the weight.

(3 marks)

(b) Explain why, although the system is in equilibrium, adding the magnitudes of two of the forces together will not be equal to the third force, but adding the squares of two of the forces together will be equal to the square of the third force.

(2 marks)

(c) A large bird is perching on a massive wire which takes up a curved shape as shown in Fig. 3. The angle of sag, i.e. the angle from the horizontal at each support, θ is given. If without the bird the angle of sag of the wire is 12° and, with the bird perching on the wire, the angle is increased by 0.5°, calculate the mass of the bird. The mass of the wire alone is 20.0 kg

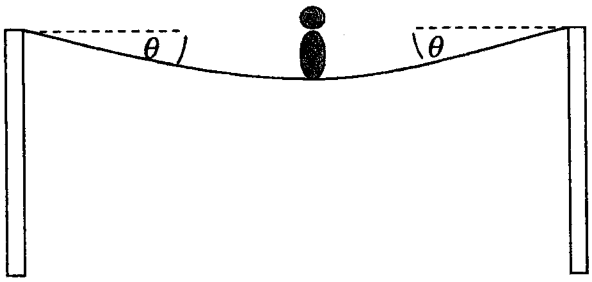


Fig. 3

(3 marks)

[8]

3. A man has a typical mass of 70 kg and the minimum cross sectional area of the bones in each leg is approximately 5.0×10^{-4} m^2. The compressive breaking stress of bone is approximately 1.0×10^7 Nm^{-2}. If the man stands with his weight equally supported by each leg, calculate the following:

(a) The maximum stress in his leg bones

(2 marks)

(b) The ratio of the maximum stress to the breaking stress

(1 marks)

If a giant grew to such a size that each of the linear dimensions of his body increased by a factor of nine calculate:

(c) The mass of the typical giant

(2 marks)

(d) The new ratio of the maximum stress to the breaking stress

(2 marks)

(e) Is the giant able to stand on one leg?

(1 marks)

[8]

4. The crews that race in the Oxford and Cambridge Boat Race row in a long narrow boat, called an "eight", as show in Fig. 4. In some conditions on the river, waves which do not have a large amplitude can cause the boat to break in two. The boat is 18 m long and the depth of the river is 2.4 m in one particular stretch.

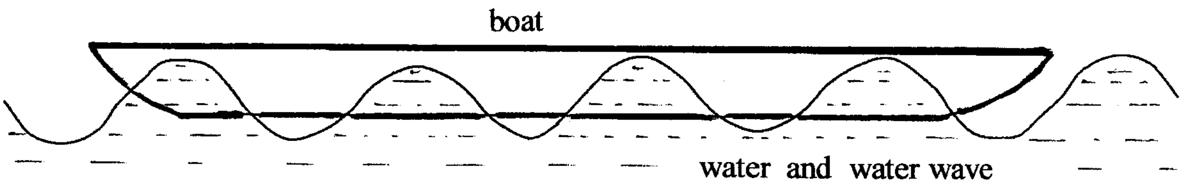


Fig. 4

(a) Sketch a diagram to show what particular wavelength is likely to produce the greatest strain on the boat so that it could break in two. What is the value of the wavelength?

(2 marks)

(b) If the speed of the waves, c, is given by $c = \sqrt{gd}$ where d is the depth of the water, calculate the frequency of the waves in still water which will produce the destructive wavelength.

(3 marks)

[5]

5. In order to probe the structure of a nucleus, whose radius is about 10^{-15} m, a beam of electrons from a particle accelerator is fired at a solid target containing a high density of nuclei. If the wavelength of the electrons is similar to the size of the nucleus, then a diffraction effect will occur and the size of the nucleus can be determined.

(a) Calculate the momentum of the electron beam which is needed to make the wavelength equal to the nuclear diameter.

(2 marks)

(b) Calculate the energy of the electron beam, both in joules and in electron volts. Assume that the electrons are moving at almost the speed of light, and use $E = mc^2$ with the momentum, $p = mc$, where m is the mass of the electron.

(2 marks)

(c) If the beam current is 10^{-8} A, calculate the number of the electrons hitting the target each second.

(2 marks)

(d) A copper target of thickness 0.1 cm intercepts the electron beam in part (b). The beam has a cross sectional area of 9 mm^2 when it hits the copper target. What is the volume of copper through which the beam passes? Show that the number of target nuclei lying in the beam is approximately 8×10^{20}.

(3 marks)

(e) If the cross sectional area of the nuclei are very small and they do not lie behind each other, then calculate the ratio of the total area of the nuclei lying in the beam path to the cross sectional area of the beam.

(2 marks)

(f) The ratio in part (e) can be taken as the probability that an electron will collide with a target nucleus. From your answer in part (c) calculate the number of interactions in the target per second.

(2 marks)

[13]

$e = 1.6 \times 10^{-19}$ C
mass of electron = 9.1×10^{-31} kg
Density of copper is 8900 kg m^{-3}
Relative atomic mass of copper is 63.5
Avogadro's number, $N_A = 6.02 \times 10^{23}$ atoms/mol

6. When a parallel beam of light passes through a narrow aperture, the beam spreads out so that it is no longer parallel. When diffraction occurs through a circular aperture, the majority of the energy is confined to a beam whose angular spread is given by

$2\theta = 2\times1.2\dfrac{\lambda}{d}$ where d is the diameter of the aperture and λ is the wavelength, and θ is indicated in Fig. 5. (θ is measured in radians)

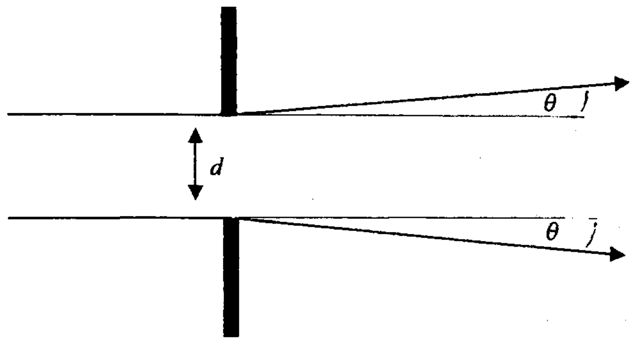


Fig. 5

(a) Light is emitted from a laser with a circular beam of diameter of 1.0 cm, at a wavelength of 530 nm and with a power of 10.0 W. If it is shone at the moon, calculate the area of the moon which is illuminated by the beam (the area of the moon which is illuminated can be taken to be a flat surface)

(3 marks)

(b) If the parallel beam from the laser of part (a) is focussed down by a lens to a spot on a screen, calculate the average intensity (power per unit area) of the spot. The width of the spot is determined by the angular spread of the beam and the focal length (the distance away from the lens that the spot is focussed), such that the width of the spot is the focal length multiplied by the angular spread. The focal length of the lens is 15 cm.

(3 marks)

For a dish aerial shown in Fig. 6, a source of radio waves placed at the focus will also suffer from diffraction with the angle of diffraction also given by $2\theta = 2\times 1.2\frac{\lambda}{d}$,where the angle θ is given in Fig. 6.

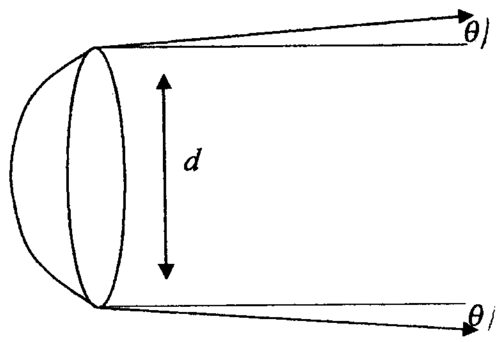


Fig. 6

(c) A satellite carrying a dish aerial of 10 m diameter is placed in orbit at a height of 44,000 km above the earth, transmitting at a frequency of 1.5 GHz. The dish is aimed vertically downwards. Show that the area of the earth illuminated with the signal is approximately 3×10^{12} m^2.

(4 marks)

Distance between earth and moon is 4.0×10^8 m

[10]