RECOGNISING ACHIEVEMENT

ADVANCED GCE UNIT

2825/03

PHYSICS A

Materials

FRIDAY 26 JANUARY 2007

Morning

Time: 1 hour 30 minutes

Additional materials: Electronic calculator

Candidate Name

Centre Number

Candidate Number

INSTRUCTIONS TO CANDIDATES

- Write your name, Centre Number and Candidate number in the boxes above.
- Answer **all** the questions.
- Use blue or black ink. Pencil may be used for graphs and diagrams only.
- Read each question carefully and make sure you know what you have to do before starting your answer.
- Do **not** write in the bar code.
- Do **not** write outside the box bordering each page.
- WRITE YOUR ANSWER TO EACH QUESTION IN THE SPACE PROVIDED. ANSWERS WRITTEN ELSEWHERE WILL NOT BE MARKED.

INFORMATION FOR CANDIDATES

- The number of marks for each question is given in brackets [ ] at the end of each question or part question.
- The total number of marks for this question paper is 90.
- You may use an electronic calculator.
- You are advised to show all the steps in any calculations.
- The first six questions concern Materials. The last question concerns general physics.

FOR EXAMINER'S USE

Qu.	Max.	Mark
1	11	
2	13	
3	12	
4	10	
5	14	
6	10	
7	20	
TOTAL	90	

This document consists of **19** printed pages and **1** blank page.

Data

speed of light in free space,	$c = 3.00 \times 10^{8}\ \mathrm{m\,s^{-1}}$
permeability of free space,	$\mu_0 = 4\pi \times 10^{-7}\ \mathrm{H\,m^{-1}}$
permittivity of free space,	$\epsilon_0 = 8.85 \times 10^{-12}\ \mathrm{F\,m^{-1}}$
elementary charge,	$e = 1.60 \times 10^{-19}\ \mathrm{C}$
the Planck constant,	$h = 6.63 \times 10^{-34}\ \mathrm{J\,s}$
unified atomic mass constant,	$u = 1.66 \times 10^{-27}\ \mathrm{kg}$
rest mass of electron,	$m_e = 9.11 \times 10^{-31}\ \mathrm{kg}$
rest mass of proton,	$m_p = 1.67 \times 10^{-27}\ \mathrm{kg}$
molar gas constant,	$R = 8.31\ \mathrm{J\,K^{-1}\,mol^{-1}}$
the Avogadro constant,	$N_A = 6.02 \times 10^{23}\ \mathrm{mol^{-1}}$
gravitational constant,	$G = 6.67 \times 10^{-11}\ \mathrm{N\,m^{2}\,kg^{-2}}$
acceleration of free fall,	$g = 9.81\ \mathrm{m\,s^{-2}}$

Formulae

uniformly accelerated motion, $s = ut + \frac{1}{2}at^2$

$v^2 = u^2 + 2as$

refractive index, $n = \frac{1}{\sin C}$

capacitors in series, $\frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_2} + \ldots$

capacitors in parallel, $C = C_1 + C_2 + \ldots$

capacitor discharge, $x = x_0 e^{-t/CR}$

pressure of an ideal gas, $p = \frac{1}{3}\frac{Nm}{V}<c^2>$

radioactive decay, $x = x_0 e^{-\lambda t}$

$t_{\frac{1}{2}} = \frac{0.693}{\lambda}$

critical density of matter in the Universe, $\rho_0 = \frac{3H_0^{\,2}}{8\pi G}$

relativity factor, $= \sqrt{(1 - \frac{v^2}{c^2})}$

current, $I = nAve$

nuclear radius, $r = r_0 A^{1/3}$

sound intensity level, $= 10 \lg \left(\frac{I}{I_0}\right)$

Answer **all** the questions.

1 **(a)** State, giving a scientific or technical application, an example of

(i) a single-crystal solid ....

application ....

(ii) an amorphous solid ....

application ....[4]

(b) A bubble raft on the surface of a liquid is used to represent the arrangement of atoms in a crystal plane of a solid. Fig. 1.1 shows a photograph of a bubble raft.

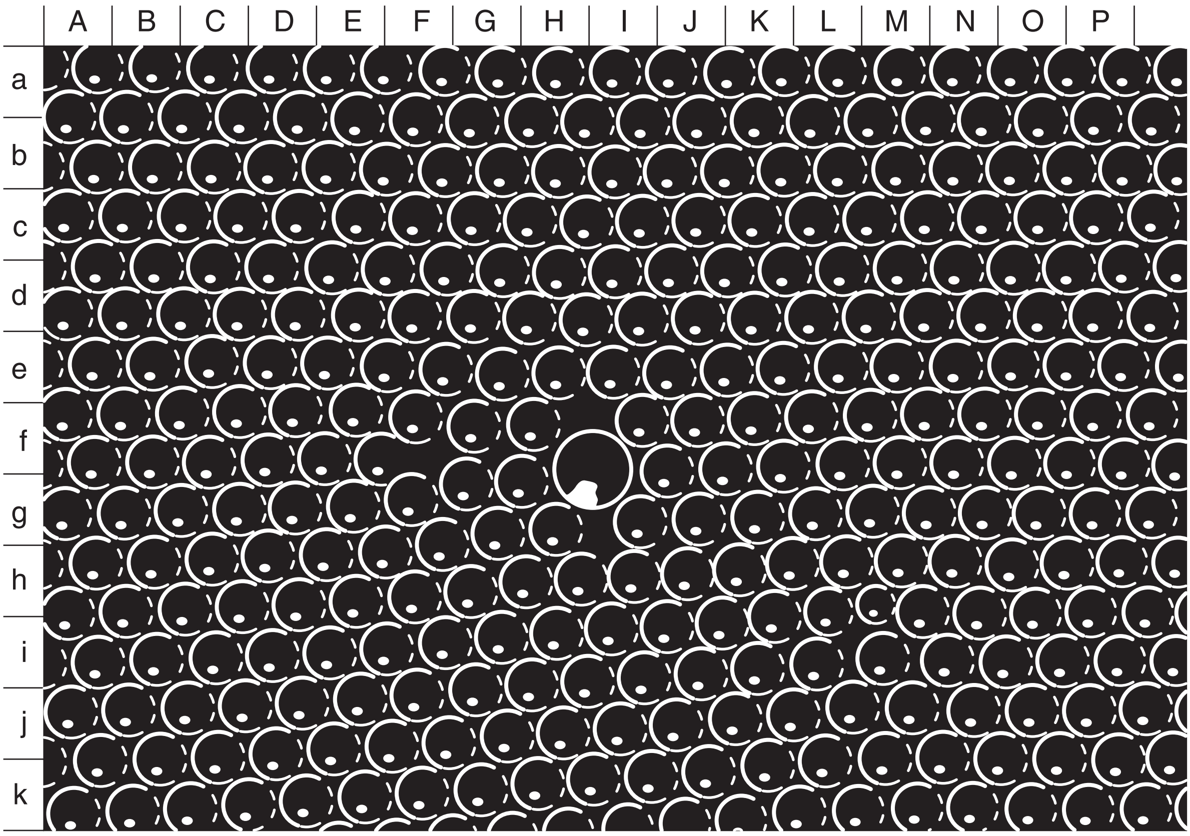

Fig. 1.1

(i) Explain why the crystal plane shown is part of a close-packed structure.

....

....[1]

(ii) By careful observation of Fig. 1.1 locate **two** different types of imperfections in the crystal plane. Use the letters above and to the left of the photograph (e.g. Dh) to indicate the position of these faults.
For each position state the type of imperfection.

Position of fault 1 .... Type of imperfection ....

Position of fault 2 .... Type of imperfection ....[4]

(c) Models made with polystyrene balls may also be used to represent crystal structures. State **one** advantage of the use of

(i) a ball model rather than a bubble raft

....

....

(ii) a bubble raft rather than a ball model.

....

....[2]

[Total: 11]

2 A specimen of semiconductor has a square cross-section, as shown in Fig. 2.1. The length of the specimen is 18 mm. The side of the square is 7.5 mm. At 25 °C the charge carrier density in the specimen is $2.1 \times 10^{16}\,\text{m}^{-3}$. A potential difference of 6.0 V, applied to the ends of the specimen, causes a current of 8.2 μA.

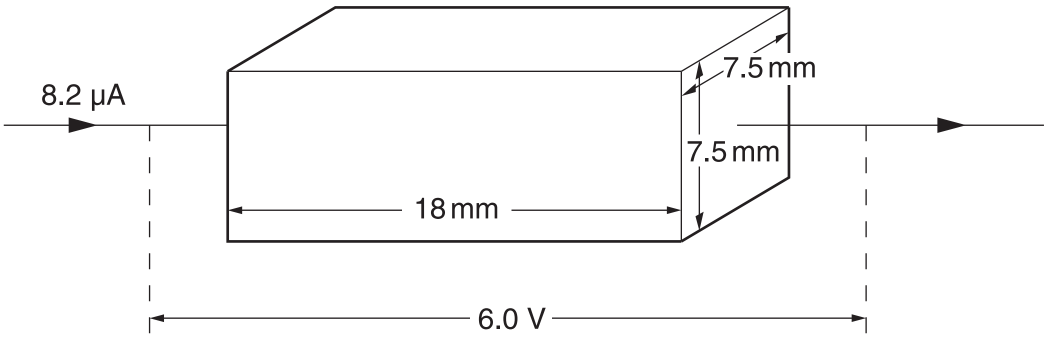

Fig. 2.1

(a) Calculate

(i) the conductivity of the semiconductor

conductivity = ... $\Omega^{-1}\,\text{m}^{-1}$ [4]

(ii) the drift velocity of the charge carriers.

drift velocity = ... $\text{m}\,\text{s}^{-1}$ [2]

(b) The temperature of the specimen in Fig. 2.1 is now raised to 30 °C.

(i) Explain, using band theory, why the charge carrier density in the specimen increases.

....

....

....[2]

(ii) The equation relating charge carrier density and **absolute** temperature is

$$\ln\left(\frac{n_2}{n_1}\right) = 1.28 \times 10^4 \left(\frac{1}{T_1} - \frac{1}{T_2}\right)$$

where n_1 and n_2 are the charge carrier densities in the specimen at **absolute** temperatures T_1 and T_2 respectively.
Show that the charge carrier density at 30 °C is about $4.3 \times 10^{16}\,\mathrm{m^{-3}}$.

[3]

(iii) Calculate the potential difference needed to give a current of 8.2 μA through the specimen at 30 °C. Assume that the change from 25 °C to 30 °C causes negligible change in the mean drift velocity.

potential difference = ... V [2]

[Total: 13]

[Turn over

3 **(a)** **(i)** In terms of forces between atoms, explain what is meant by the *equilibrium* separation of a pair of atoms in a solid.

....

....[2]

(ii) Suggest why, when the solid is not subject to stress and not at absolute zero, the actual separation of the atoms varies rapidly with time.

....[1]

(b) The graph in Fig. 3.1 shows the variation with separation *x* of the resultant force *F* between a pair of neighbouring atoms.

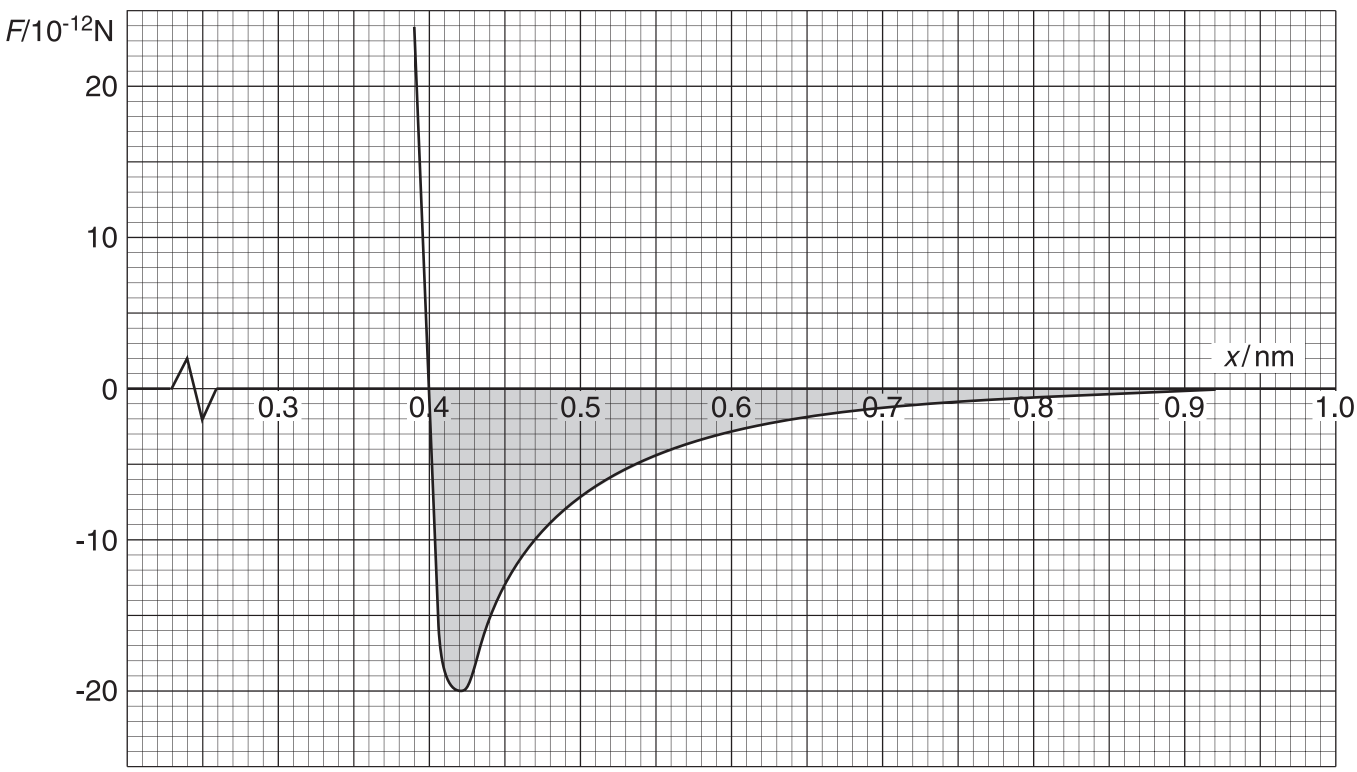

Fig. 3.1

(i) State

1 the range of values of *x* over which the resultant force is attractive

....[1]

2 the equilibrium separation of the two atoms.

....[1]

(ii) Explain why the shaded area in Fig. 3.1 represents the energy required to separate the pair of atoms.

....

....

....[2]

(iii) Estimate the energy represented by the shaded area.

energy = ... J [3]

(iv) The process of atoms leaving the surface of a solid to form a vapour without any melting occurring is called sublimation. The energy needed for 1 kg of material to sublime is called the specific latent heat of sublimation. Suggest how this is related to the energy calculated in **(iii)**.

....

....

....[2]

[Total: 12]

4 **(a)** Explain what is meant by the *transition temperature* of a superconductor.

....

....[1]

(b) Below the transition temperature, a material ceases to be a superconductor if placed in a magnetic field of flux density greater than a critical value B_c. This critical value of flux density B_c at which the transition occurs depends on the absolute temperature T and is given by the relationship

$$B_c = B_0 - aT^2$$

where B_0 is the value of B_c when T is 0 K and a is a constant. The table below gives values of T and B_c for the element niobium.

T (kelvin)	B_c (tesla)	T^2 (kelvin^2)
2.0	0.185	
4.0	0.155	
6.0	0.115	
8.0	0.055	

(i) Complete the table and plot T^2 against B_c on Fig. 4.1. Draw the best straight line through the points. [3]

(ii) Using the graph, determine

1 the value of B_0

B_0 = ... T

2 the transition temperature of niobium, when $B_c = 0$.

transition temperature = ... K
[3]

(c) The compound YBCO is described as a high-temperature superconductor. Suggest what is meant by a *high-temperature superconductor* and why such a material is economically important.

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....[3]

[Total: 10]

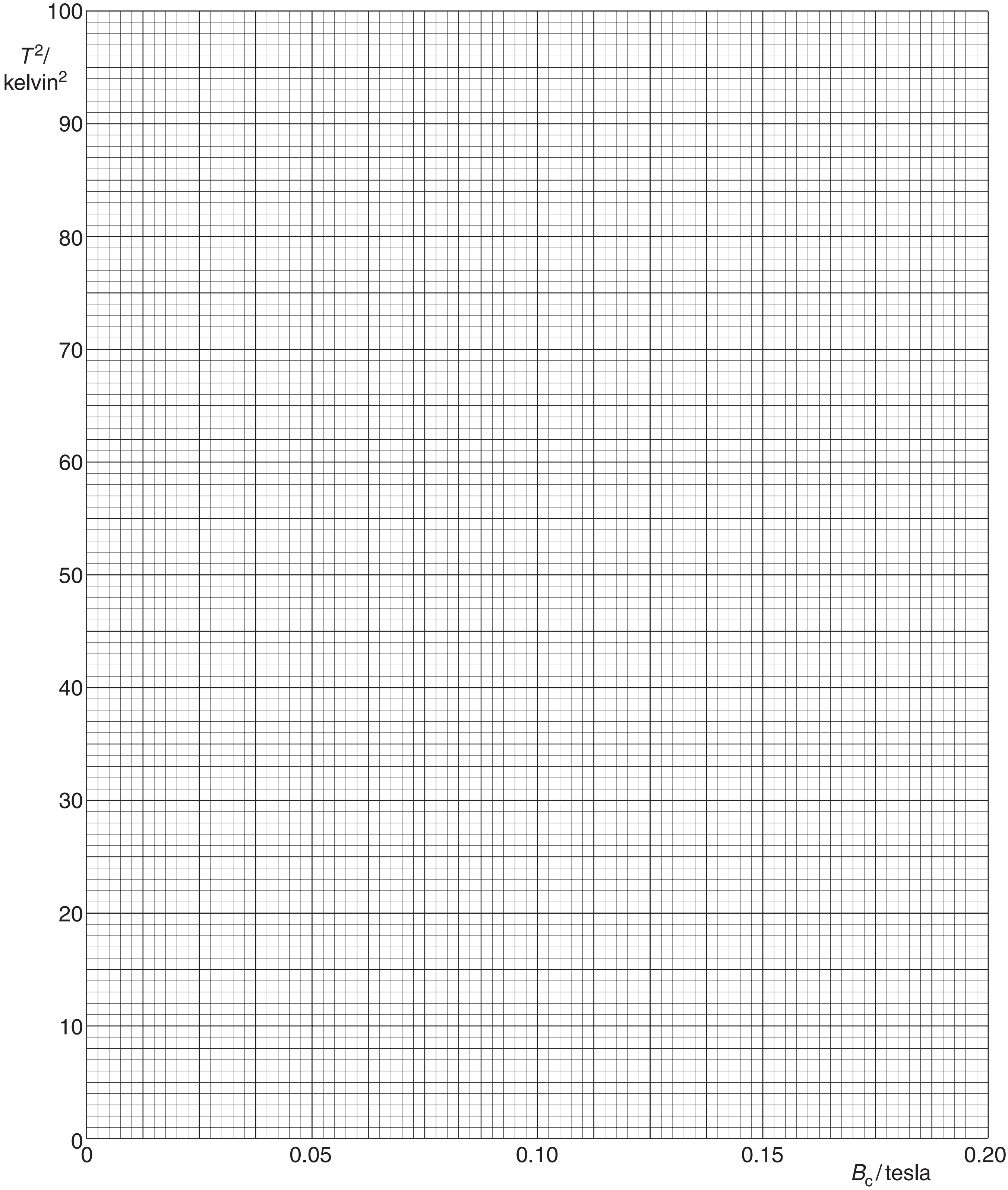
100
T^2/
kelvin^2
90
80
70
60
50
40
30
20
10
0
0
0.05
0.10
0.15
0.20
B_c / tesla

Fig. 4.1

5 **(a)** A student makes a transformer by winding coils of copper wire around a solid hard iron core. He carries out an experiment to show how the efficiency of the transformer varies with the frequency of the supply. Describe the experiment, including the following aspects in your answer

- a sketch of the apparatus
- the quantities which are kept constant
- the procedure followed
- the readings taken
- how the efficiency is calculated.

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....[10]

(b) The student concludes that the efficiency of the transformer decreases with increasing frequency. Explain why this decrease takes place.

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....[4]

[Total: 14]

6 **(a)** As light and infra-red radiation pass through glass their intensities decrease. With reference to the different processes causing this decrease, explain why a wavelength of 1.5 μm is preferred for optic-fibre communication systems.

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....[7]

(b) Two beams of infra-red radiation, A and B, enter a 1 km length of fibre-optic cable. Due to Rayleigh scattering, the intensity of A is reduced by 5.0%, and the intensity of B is reduced by 10%. The wavelength of A is 1.5 μm. Calculate the wavelength of B.

wavelength = ... μm [3]

[Total: 10]

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7 A champion BMX cyclist wishes to become a professional and seeks help from an A-level Physics student in creating an act. The student suggests two stunts; one involving a horizontal take-off on to a sloping ramp and the other involving a loop-the-loop manoeuvre.

(a) The student begins by finding out the maximum speed the cyclist can produce on level ground. Two flags are positioned 240 m apart on a flat road. The cyclist is told to accelerate to the first flag and to pedal as hard as he can until the second flag is passed. This is shown in Fig. 7.1

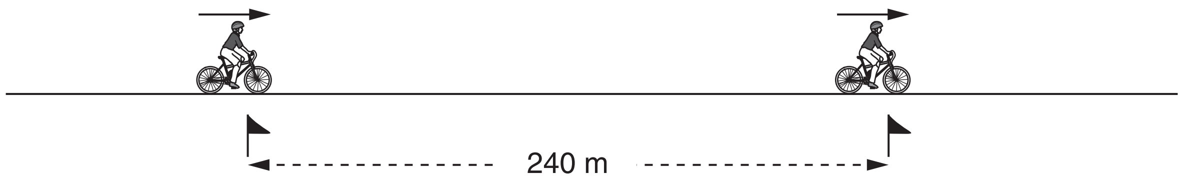

Fig. 7.1

The student gets the cyclist to repeat the test three times and records the following results :

14.8 s　　　17.2 s　　　15.6 s

Show that the mean speed the cyclist can maintain over the 240 m is about 15 m s^{-1}.

[2]

(b) The student designs the stunt shown in Fig. 7.2 where the cyclist must take off at 15 m s^{-1} from a horizontal launch pad and land smoothly just at the edge of a sloping ramp.

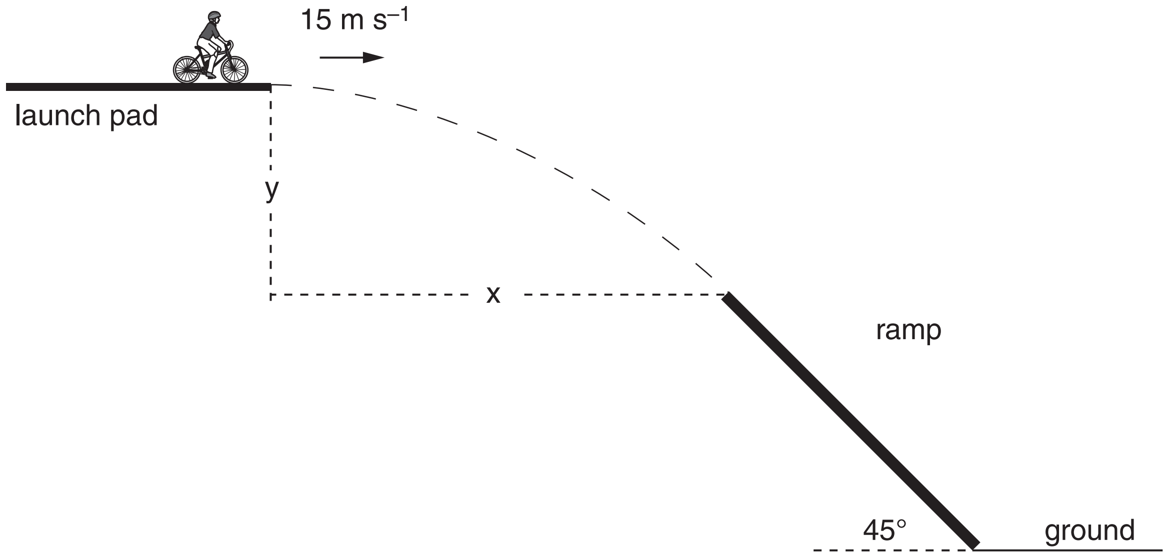

Fig. 7.2

The student reasons that in order to land smoothly, the direction of the velocity of the cyclist on reaching the edge of the ramp must be at the same 45° angle as the ramp itself.
Ignore air resistance in all calculations.

(i) Explain why the vertical component of velocity on reaching the ramp must be 15 m s^{-1}.

....

....

....[1]

(ii) The student calculated the vertical fall y to the ramp to be about 11 m. Show how he arrived at this result.

[2]

(iii) The student calculated the horizontal jump x to the ramp to be about 23 m. Show how he arrived at this result.

[1]

(iv) The total mass of the cyclist and bike is 86 kg. Show that the kinetic energy of the cyclist on reaching the ramp is about 19 kJ.

[3]

(c) The student next designs a loop-the-loop stunt shown in Fig. 7.3. The cyclist must enter the circular runway at the same $15\,\text{m}\,\text{s}^{-1}$ speed in order to exit from it smoothly.

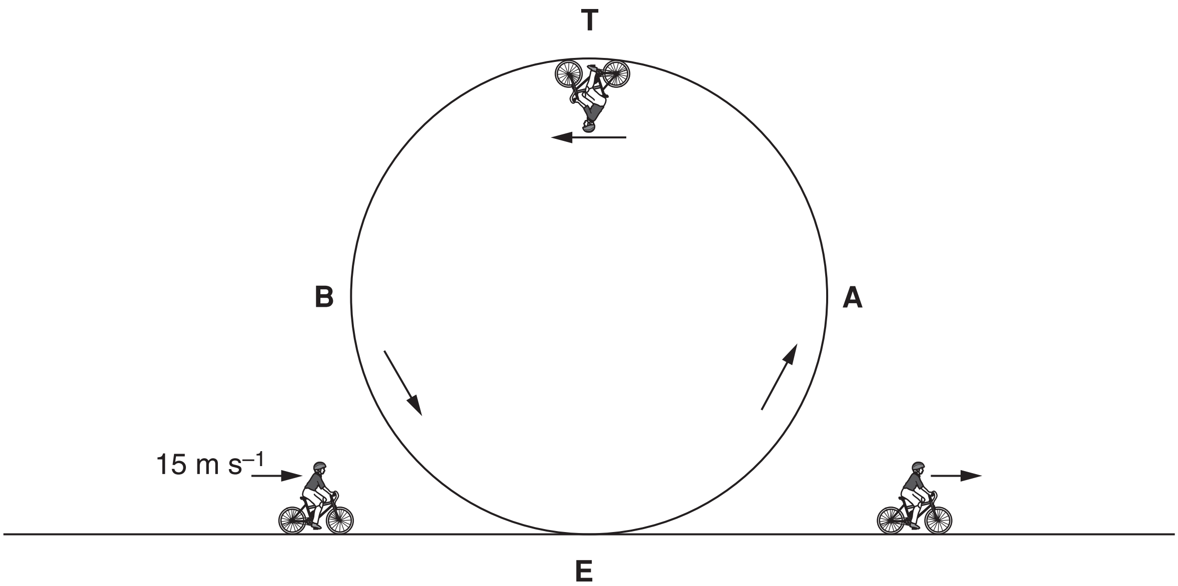

Fig. 7.3

In order to calculate the maximum diameter of loop in which the cyclist can safely execute the manoeuvre, the student makes the following assumptions

- the cyclist stops pedalling once he enters the loop at **E**
- the normal reaction of the runway on the tyre just becomes zero at the top of the loop **T**
- therefore the centripetal force at the top **T** is provided by the force of gravity only
- air resistance and runway friction can be ignored.

As a result, the student calculates the diameter of the track to be 9.17 m.

(i) Show that the speed of the cyclist at the top **T** of the loop should be $6.7\,\text{m}\,\text{s}^{-1}$.

[3]

(ii) The total mass of the cyclist and bike is 86 kg. Calculate

1 the kinetic energy of the cyclist at the top **T**

kinetic energy = ... J [2]

2 the gravitational potential energy of the cyclist at the top **T**. Take the gravitational potential energy at **E** to be zero.

potential energy = ... J [2]

(iii) Show that the sum of the kinetic and potential energies at the top **T** of the loop is equal to the kinetic energy of the cyclist as he enters the loop at **E**.

[2]

(iv) The cyclist suggests that removing the top half or semicircle of the loop from **A** to **B** would allow him to fly in a semi-circular arc through the air and thus make a more spectacular stunt. How should the student should respond to this suggestion? Explain your reasoning.

....

....

....

....[2]

[Total: 20]

END OF QUESTION PAPER

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