OCR
RECOGNISING ACHIEVEMENT

ADVANCED GCE UNIT **2825/04**

PHYSICS A

Nuclear and Particle Physics

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 Nuclear and Particle Physics. The last question concerns general physics.

FOR EXAMINER'S USE		
Qu.	**Max.**	**Mark**
1	**10**	
2	**14**	
3	**11**	
4	**12**	
5	**11**	
6	**12**	
7	**20**	
TOTAL	**90**	

This document consists of **21** printed pages and **3** blank pages.

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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 This question is about the strong interaction within the nucleus.

(a) **(i)** On Fig. 1.1, sketch a graph to show the variation with nucleon separation of the strong interaction between two neutrons.

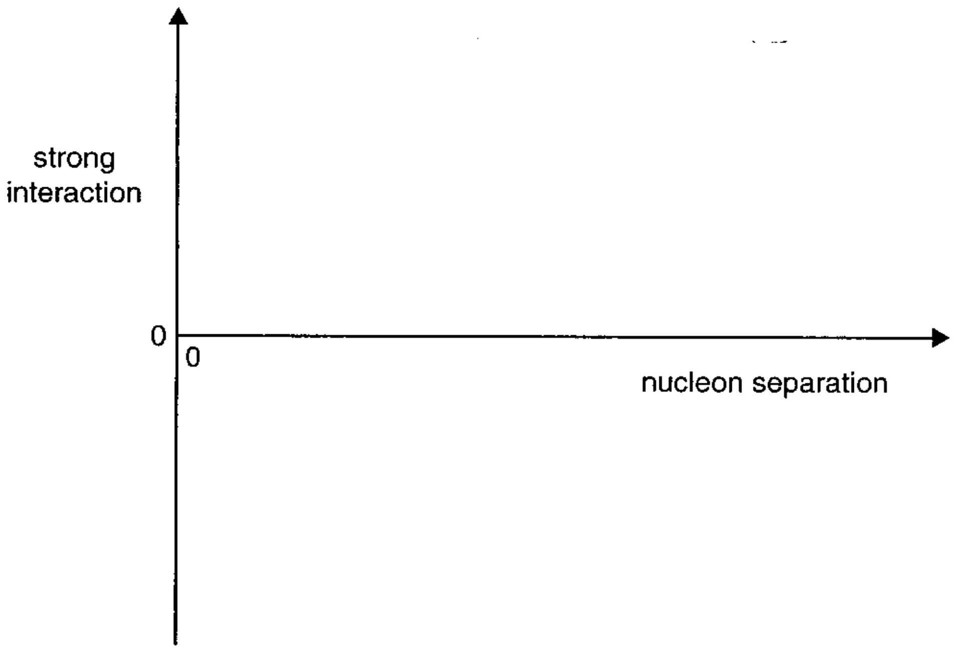

Fig. 1.1 [2]

(ii) Mark on Fig. 1.1 the parts of the graph where the force is attractive and where it is repulsive. [1]

(iii) Mark on Fig.1.1 the equilibrium separation of two neutrons. Label this point X. [1]

(b) By considering small displacements on either side of X, explain why two neutrons are stable at this separation.

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(c) Explain what is meant by the statement that the strong interaction is a short-range force and explain what this implies about the densities of nuclei of various sizes.

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.... [3]

[Total: 10]

2 A fuel rod inside a nuclear reactor contains uranium-238. When a $^{238}_{92}U$ nucleus is exposed to free neutrons it can absorb a neutron. The resulting nucleus decays, first to neptunium-239 $^{239}_{93}Np$ (**decay 1**) and then to plutonium-239 $^{239}_{94}Pu$ (**decay 2**).

(a) Write nuclear equations for these two decay reactions.

decay 1 ....

decay 2 .... [2]

(b) In the fuel rod, $^{239}_{93}Np$ nuclei are produced at a constant rate of $1.80 \times 10^7 s^{-1}$.

On Fig. 2.1, draw a graph to show how the number of $^{239}_{93}Np$ nuclei **produced** varies with time. Label this graph X. Assume that initially there are no $^{239}_{93}Np$ nuclei. [1]

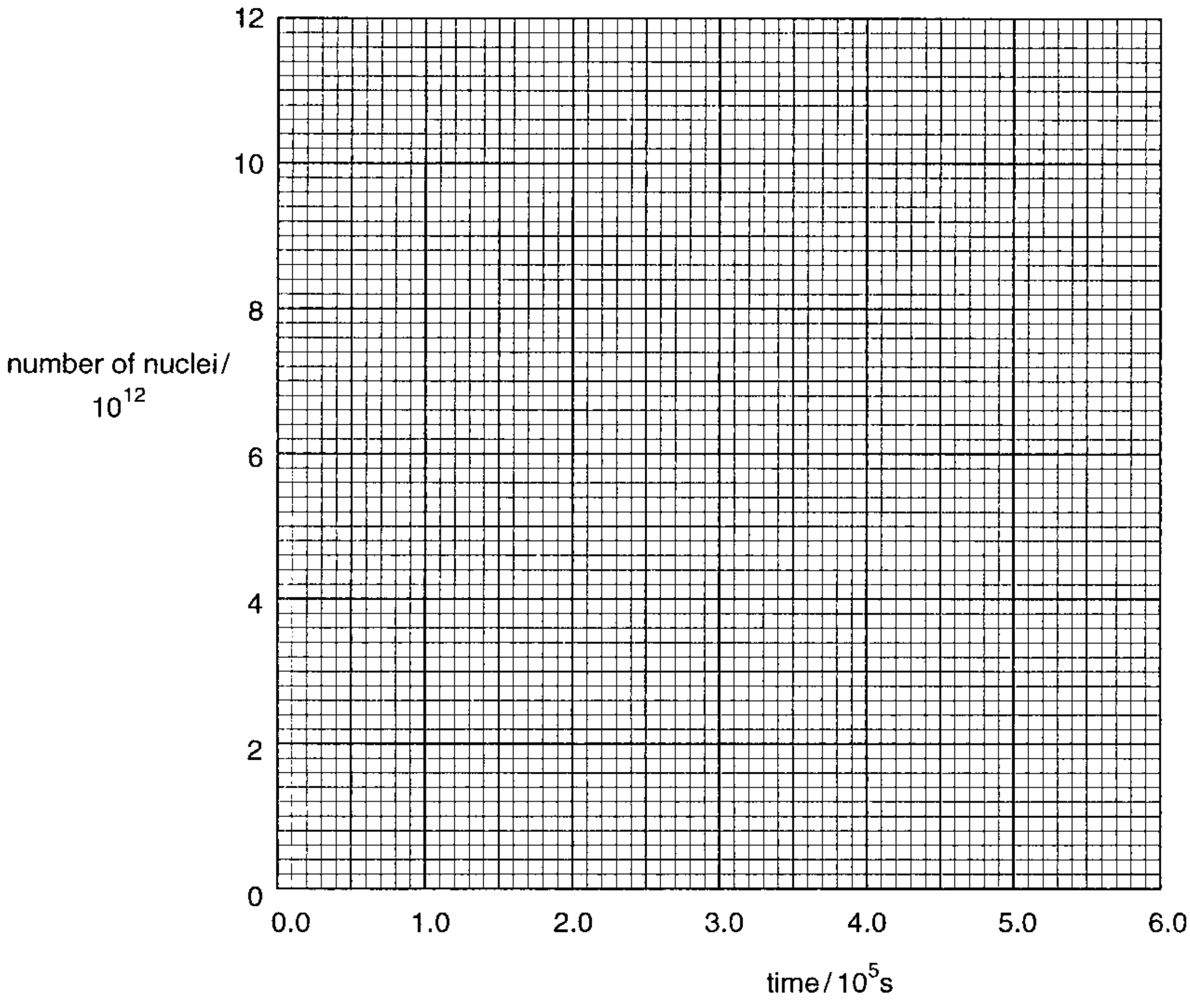

Fig. 2.1

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(c) **(i)** State and explain, without calculation, how the number of $^{239}_{93}Np$ nuclei **decaying** per second varies with time.

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.... [2]

(ii) State why the number of $^{239}_{93}Np$ nuclei **present** eventually becomes constant.

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.... [1]

(iii) Calculate this constant number of $^{239}_{93}Np$ nuclei.

half-life of $^{239}_{93}Np = 2.04 \times 10^5$ s

number = ... [3]

(iv) Sketch a graph on Fig. 2.1 to show how the number of $^{239}_{93}Np$ nuclei present varies with time. Label this graph Y. [1]

(d) **(i)** What is the half-life of plutonium-239 in seconds?

1 year = 3.16×10^7 s

half-life = ... s [2]

(ii) On Fig. 2.1, sketch a graph to show how the number of $^{239}_{94}Pu$ nuclei varies with time. Label this graph Z. [2]

[Total: 14]

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3 This question is about the possibility of fusion between a tritium nucleus and a deuterium nucleus.

A tritium nucleus ${}^{3}_{1}H$ and a deuterium nucleus ${}^{2}_{1}H$ approach each other along the same line with the **same** speed *u*.

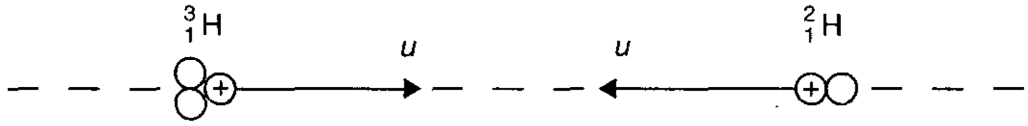

Fig. 3.1

Each nucleus decelerates, comes to rest and then accelerates in the reverse direction.

(a) **(i)** By considering conservation of momentum, explain why both nuclei cannot come to rest at the same time.

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.... [1]

(ii) When the nuclei are closest together they have the same **velocity**. Show that this velocity is *u*/5.

[2]

(b) **(i)** Energy is conserved during the interaction.

Write a word equation relating the initial energy of the two nuclei when they are far apart, to their energy when they are closest together. Your equation should make clear the kind(s) of energy involved.

....

.... [1]

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(ii) Show that the total **initial** kinetic energy of the two nuclei is equal to $4.18 \times 10^{-27} u^2$ joule where u is in m s^{-1}.

[3]

(iii) The potential energy E of two charges Q_1 and Q_2, separated by a distance r is given by

$$E = \frac{Q_1 Q_2}{4\pi \epsilon_0 r}. \qquad \epsilon_0 = \text{permittivity of free space}$$

For ^3_1H and ^2_1H to fuse, their separation must be no more than 1.50×10^{-15} m.

Calculate the minimum value of u for fusion to take place.

minimum value of u = ... m s^{-1} [4]

[Total: 11]

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4 **(a)** Give a brief account of the principles of operation of the JET fusion experiment.

Your account should refer to

- the energy-generating nuclear reaction
- confinement of the reacting materials
- **two** methods of supplying energy to the reactants
- the reason why high temperatures are important.

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(b) State and explain **two** possible advantages of using nuclear fusion rather than nuclear fission for generating useful energy on a large scale.

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.... [4]

[Total: 12]

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5 A particular cyclotron accelerates protons to an energy of 750 keV, using an accelerating potential difference of 15.0 kV. The protons move along a spiral path, reaching a maximum orbital radius of 0.382 m. The principle of the cyclotron is illustrated in Fig. 5.1.

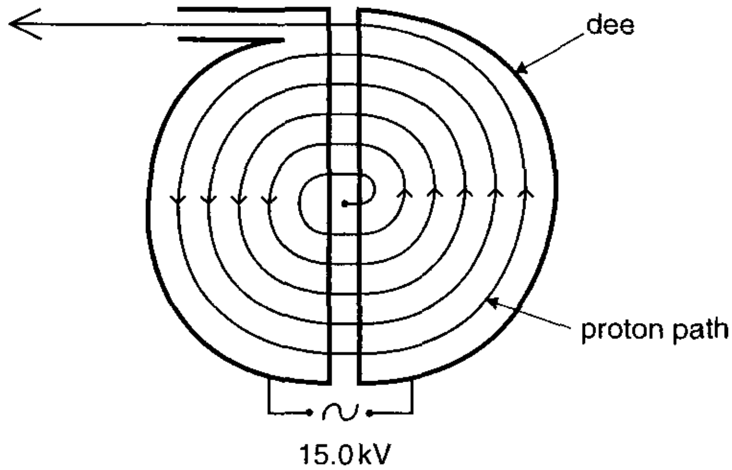

Fig. 5.1

(a) Calculate the final speed of the protons.

speed = ... $m\,s^{-1}$ [3]

(b) Show that the protons cross the gap between the dees at intervals of approximately 1.0×10^{-7} s.

[2]

(c) Calculate how many times a proton crosses the gap between the dees as it gains energy.

number = ... [1]

(d) At a particular instant during the acceleration process, a proton enters a dee with an energy of 60.0 keV. On Fig. 5.2, show how the energy of the proton varies during the next 5.0×10^{-7} s. [3]

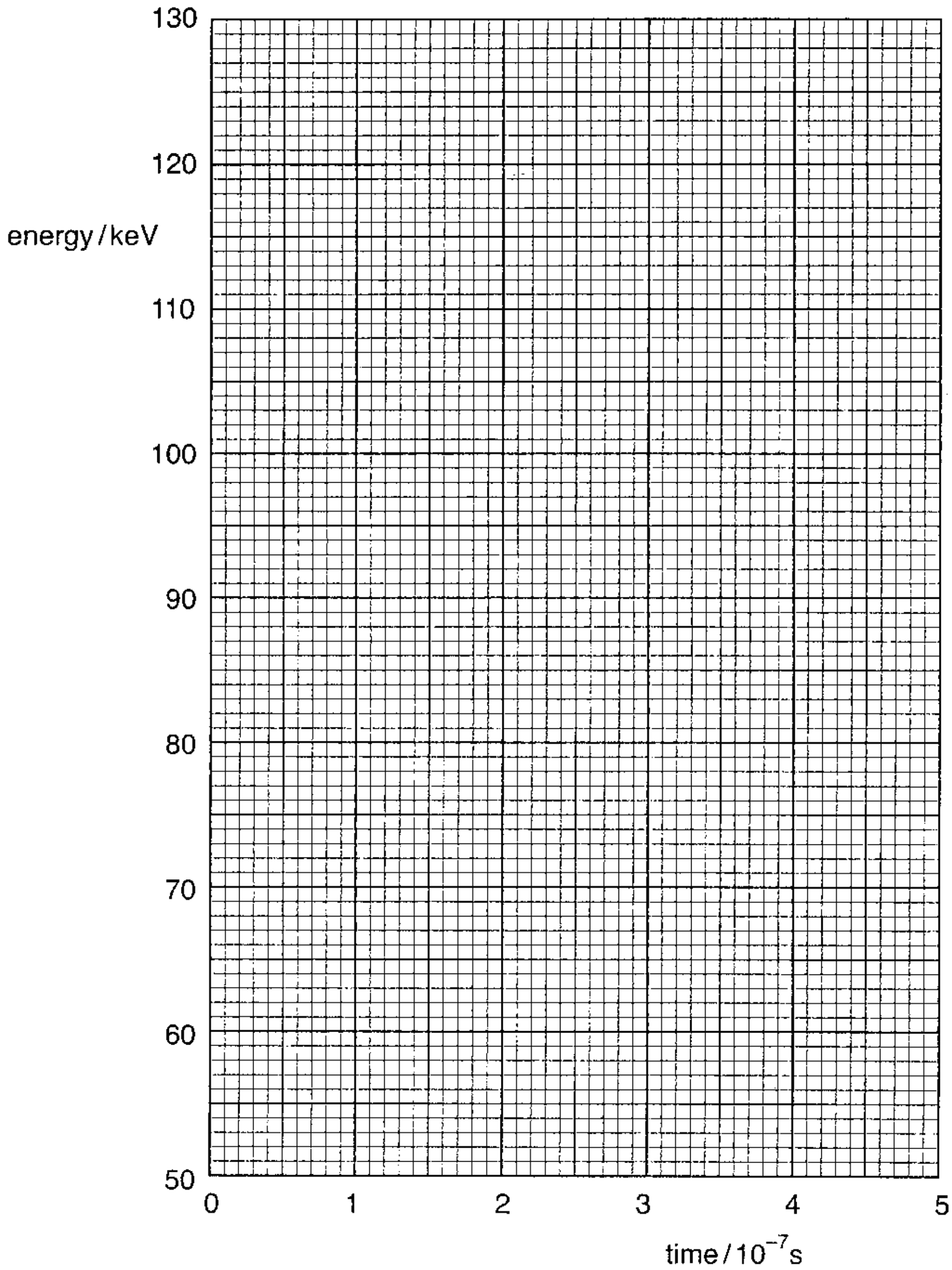

Fig. 5.2

(e) A student decides to plot the **speed** of the proton against time. Without detailed calculation, explain how the general shape of this graph would differ from that in Fig. 5.2.

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.... [2]

[Total: 11]

6 A uranium-236 nucleus, $^{236}_{92}U$, undergoes fission, producing nuclei of zirconium-100, $^{100}_{40}Zr$, and tellurium-131, $^{131}_{52}Te$.

(a) Write a nuclear equation to represent this fission reaction.

.... [1]

(b) Each of the product nuclei is a β^- emitter.

(i) State the change, if any, in the nucleon number and the proton number caused by a β^- emission.

nucleon number ....

proton number .... [1]

(ii) The β^- decay of zirconium-100 is followed by three more β^- decays before the product nucleus is stable.

State the nucleon number and the proton number of the resulting stable nucleus.

nucleon number ....

proton number .... [1]

(iii) On Fig. 6.1, use crosses to represent each of the nuclei involved in the series of decays by which zirconium-100 changes to a stable nucleus. Add arrows to show the direction of each reaction. [2]

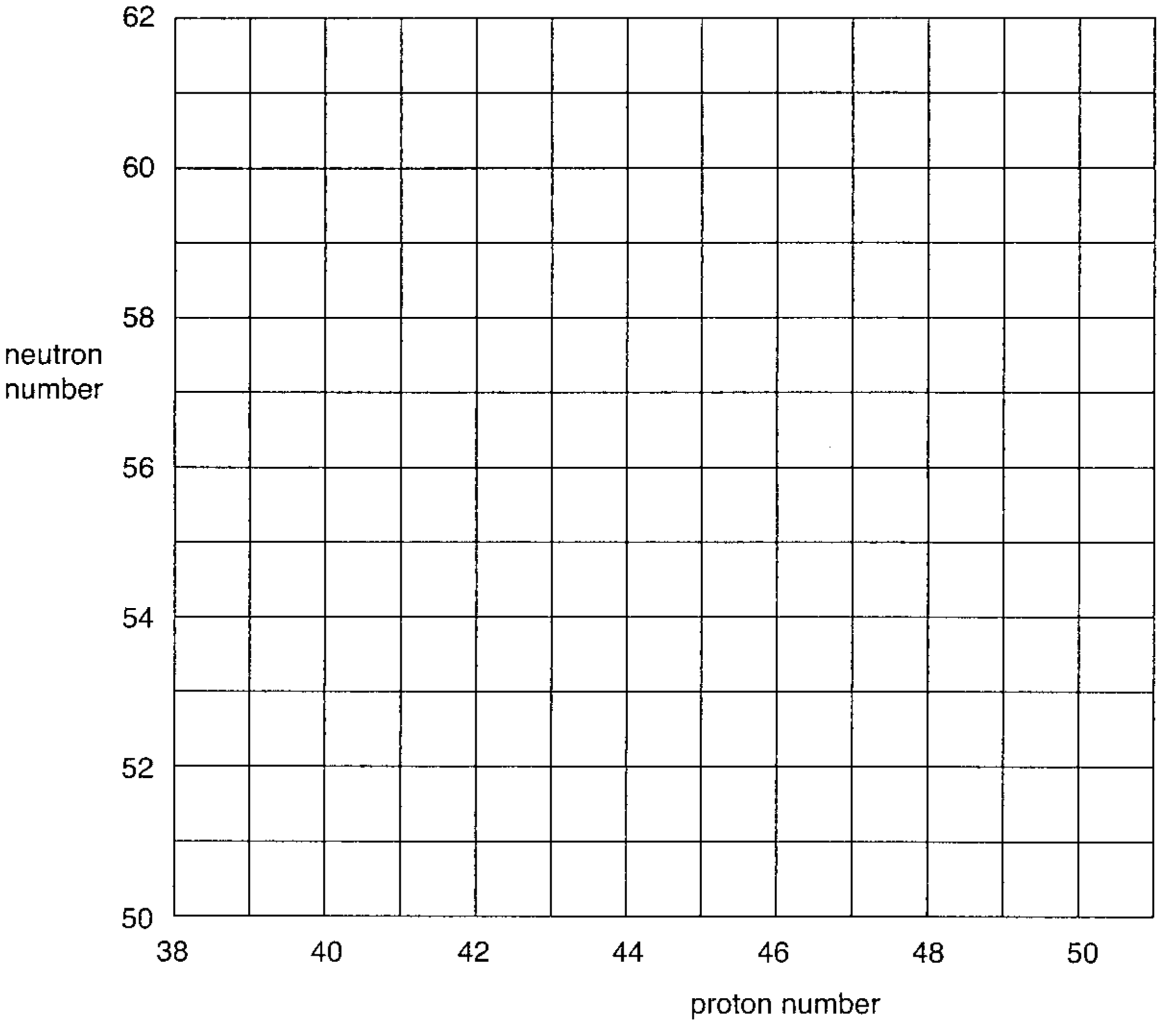

Fig. 6.1

(iv) On a graph of neutron number against proton number, stable nuclei all lie close to a line. On Fig. 6.1, sketch this line. [1]

(c) Zirconium-100 decays initially to niobium-100.

data:	nuclear masses:	zirconium-100	99.895 808 u
		niobium-100	99.891 679 u
		electron mass	0.000 549 u

(i) Calculate the mass defect for this decay reaction.

mass defect = ... u [2]

(ii) Show that this mass defect is equivalent to about 5×10^{-13} J.

[2]

(iii) When a particular zirconium-100 nucleus decays, the emitted β^- particle has only about 2×10^{-13} J. Suggest why this is less than the energy calculated in **(ii)**.

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.... [2]

[Total: 12]

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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.

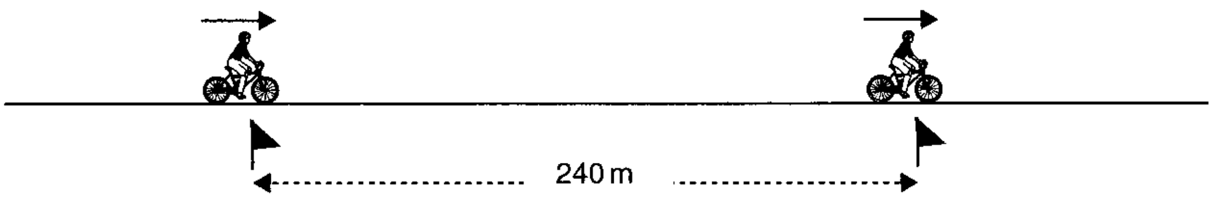

Fig. 7.1

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.

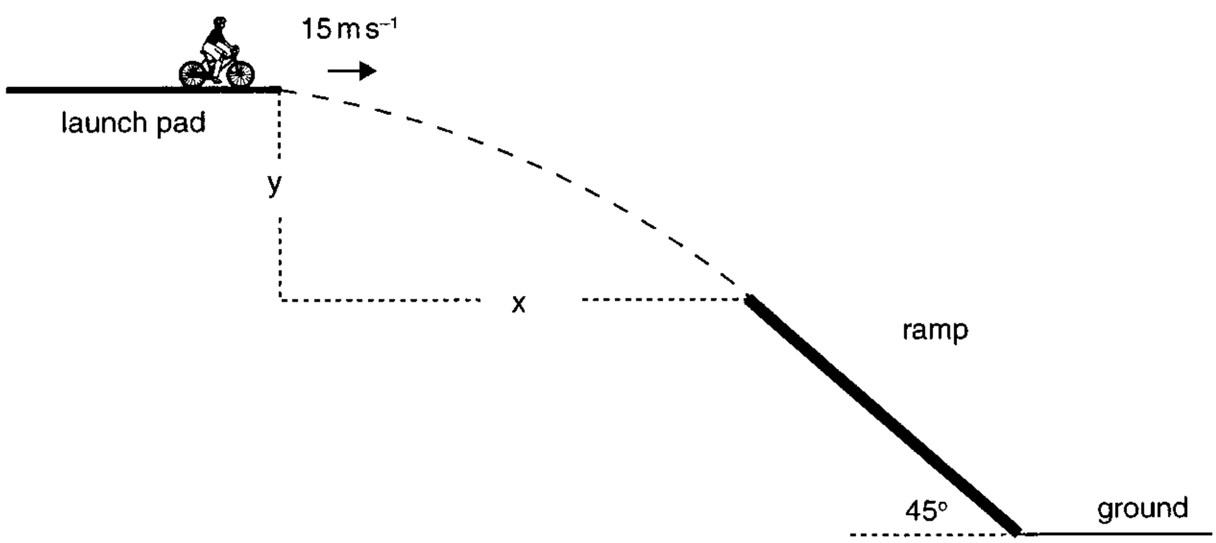

Fig. 7.2

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 $15\,m\,s^{-1}$.

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.... [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 $15\,m\,s^{-1}$ speed in order to exit from it smoothly.

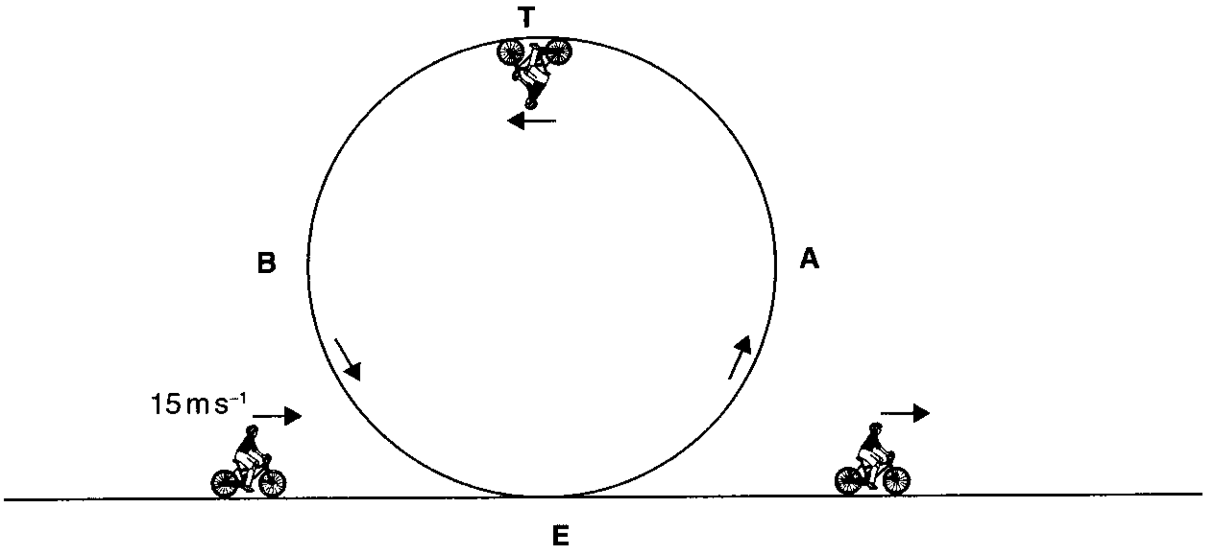

Fig. 7.3

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 $6.7\,m\,s^{-1}$.

[3]

(ii) The total mass of the cyclist and bike 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 respond to this suggestion? Explain your reasoning.

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.... [2]

[Total: 20]

END OF QUESTION PAPER

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