THIS IS A LEGACY SPECIFICATION

OCR
RECOGNISING ACHIEVEMENT

ADVANCED GCE

PHYSICS A

Nuclear and Particle Physics

2825/04

Candidates answer on the Question Paper

OCR Supplied Materials:
None

Other Materials Required:
- Electronic calculator

Thursday 28 January 2010
Afternoon

Duration: 1 hour 30 minutes

Candidate Forename		Candidate Surname	

Centre Number						Candidate Number				

INSTRUCTIONS TO CANDIDATES

- Write your name clearly in capital letters, your Centre Number and Candidate Number in the boxes above.
- Use black ink. Pencil may be used for graphs and diagrams only.
- Read each question carefully and make sure that you know what you have to do before starting your answer.
- Answer **all** the questions.
- Do **not** write in the bar codes.
- Write your answer to each question in the space provided, however additional paper may be used if necessary.

INFORMATION FOR CANDIDATES

- The number of marks is given in brackets **[ ]** at the end of each question or part question.
- The total number of marks for this 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.
- This document consists of **24** pages. Any blank pages are indicated.

Examiner's Use Only:			
1			
2			
3			
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5			
6			
7			
Total			

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,	$\mathrm{u} = 1.66 \times 10^{-27}\ \mathrm{kg}$
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, $\frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_2} + \dots$

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

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 composition of nuclei.

(a) (i) In the equation $r = r_0 A^{1/3}$, $r_0 = 1.41 \times 10^{-15}$ m.

State the meaning of

r ....

r_0 ....

A ....
[2]

(ii) On Fig. 1.1, sketch a graph to show how r varies with A.

[1]

Fig. 1.1

(b) (i) Calculate the radius of a cobalt-59 ($^{59}_{27}Co$) nucleus.
Give your answer to 3 significant figures.

radius = ... m **[2]**

(ii) The density of the nucleus of $^{59}_{27}Co$ is $1.44 \times 10^{17}\,kg\,m^{-3}$.
Show that the mass of a $^{59}_{27}Co$ nucleus is $9.98 \times 10^{-26}\,kg$.

[2]

(c) The $^{59}_{27}Co$ nucleus is composed of protons and neutrons.

proton mass = 1.673×10^{-27} kg
neutron mass = 1.675×10^{-27} kg

(i) State the number of protons and neutrons in the $^{59}_{27}Co$ nucleus.

protons ....

neutrons ....

[1]

(ii) Calculate the total mass of these protons and neutrons.

mass = ... kg **[1]**

(d) Use your answers to **(b)(ii)** and **(c)(ii)** to calculate the binding energy of the $^{59}_{27}Co$ nucleus.

binding energy = ... J **[3]**

[Total: 12]

2 This question is about the production and use of plutonium-239 ($^{239}_{94}Pu$).
In a uranium fission reactor, uranium-238 ($^{238}_{92}U$) is bombarded with neutrons.
A nucleus of $^{238}_{92}U$ can absorb a neutron.
The product of this reaction then undergoes two decay reactions to produce $^{239}_{94}Pu$.

(a) Write nuclear equations for these three reactions.
Use X to represent any intermediate nucleus.

(i) absorption of a neutron

(ii) first decay reaction

(iii) second decay reaction

[4]

(b) (i) State the half-life of plutonium-239.

half-life = ... y **[1]**

(ii) Calculate the decay constant λ of plutonium-239.

decay constant = ... s^{-1} **[2]**

(c) Plutonium-239 can be used with uranium-235 in a different kind of reactor. A particular fuel rod for such a reactor has a mass of 3.5 kg, of which 5.0% is plutonium-239.

(i) Show that the number of atoms of plutonium in this fuel rod is about 4×10^{23}.

[2]

(ii) Calculate the activity of the plutonium in this fuel rod.
State the unit of your answer.

activity = ... unit .... **[3]**

[Total: 12]

3 This question is about nuclear fusion reactions inside the Sun.

(a) Explain the importance of gravity in making fusion reactions possible inside the Sun.

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.... **[4]**

(b) Two hydrogen nuclei ^1_1H which are initially a long way apart, approach each other along the same straight line.

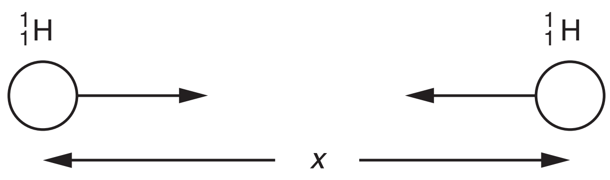

Fig. 3.1

The repulsive force F_e between them varies with their separation x as shown in Fig. 3.2.

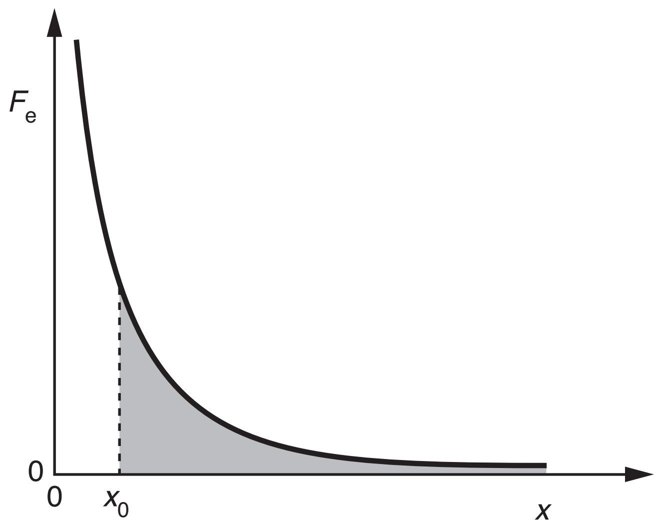

Fig. 3.2

The nuclei fuse if their separation becomes equal to or less than a critical separation x_0. What is the physical significance of the shaded area?

....

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....

.... **[2]**

(c) The average kinetic energy in joule, E_k of a ^1_1H nucleus inside a star is given by the equation

$$E_k = 2.07 \times 10^{-23}\ T.$$

The temperature T of the Sun's interior is 15×10^6 K.
Calculate the average kinetic energy of a ^1_1H nucleus inside the Sun.

kinetic energy = ... J **[1]**

(d) The interior of the Sun is mainly composed of ^1_1H nuclei and these nuclei collide continually. Two nuclei will fuse if their combined energy exceeds 8×10^{-14} J. Use your answer from **(c)** to explain why only a very small proportion of the head-on collisions between ^1_1H nuclei result in a fusion reaction.

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.... **[3]**

(e) The hydrogen cycle of fusion reactions is responsible for most of the energy generated inside the Sun. In one of these reactions two ${}^{1}_{1}H$ nuclei fuse to make a deuterium nucleus ${}^{2}_{1}H$ thus:

$$ {}^{1}_{1}H + {}^{1}_{1}H \rightarrow {}^{2}_{1}H + {}^{0}_{1}e + {}^{0}_{0}\nu $$

(i) Calculate the energy in joule generated by this reaction.

	mass / u
${}^{1}_{1}H$ nucleus	1.007 276
${}^{2}_{1}H$ nucleus	2.013 553
${}^{0}_{1}e$	0.000 549

energy = ... J **[2]**

(ii) State how the positron ${}^{0}_{1}e$ created in the reaction will result in **further** generation of energy.

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.... **[1]**

[Total: 13]

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4 **(a)** The cyclotron can be used to accelerate protons.
Explain why there is a limit to the energy which these protons may gain in a cyclotron.

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.... **[2]**

(b) A particular cyclotron accelerates protons to an energy of 800 keV, using an accelerating potential difference of 10.0 kV. The protons move along a spiral path, reaching a maximum orbital radius of 0.394 m. The principle of the cyclotron is illustrated in Fig. 4.1.

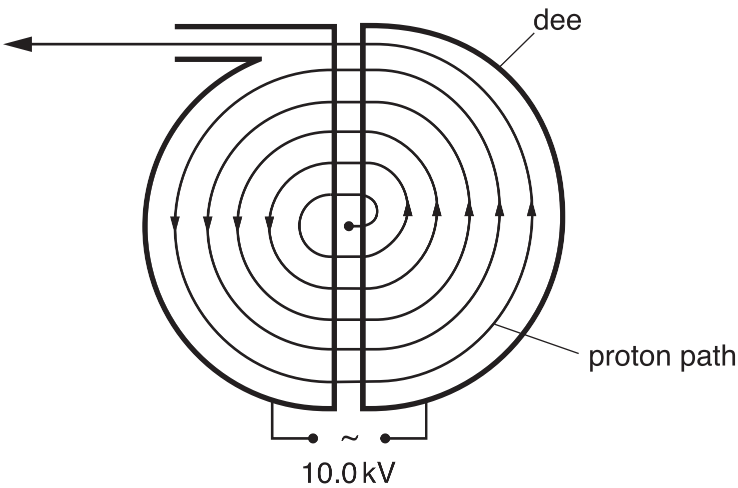

Fig. 4.1

(i) Calculate the final speed of the protons.

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

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

[2]

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

number = ... **[1]**

(iv) At a particular instant during the acceleration process, a proton enters a dee at time $t = 0$ with an energy of 20.0 keV. On Fig. 4.2, show how the energy of the proton varies during the next 6.0×10^{-7} s. **[3]**

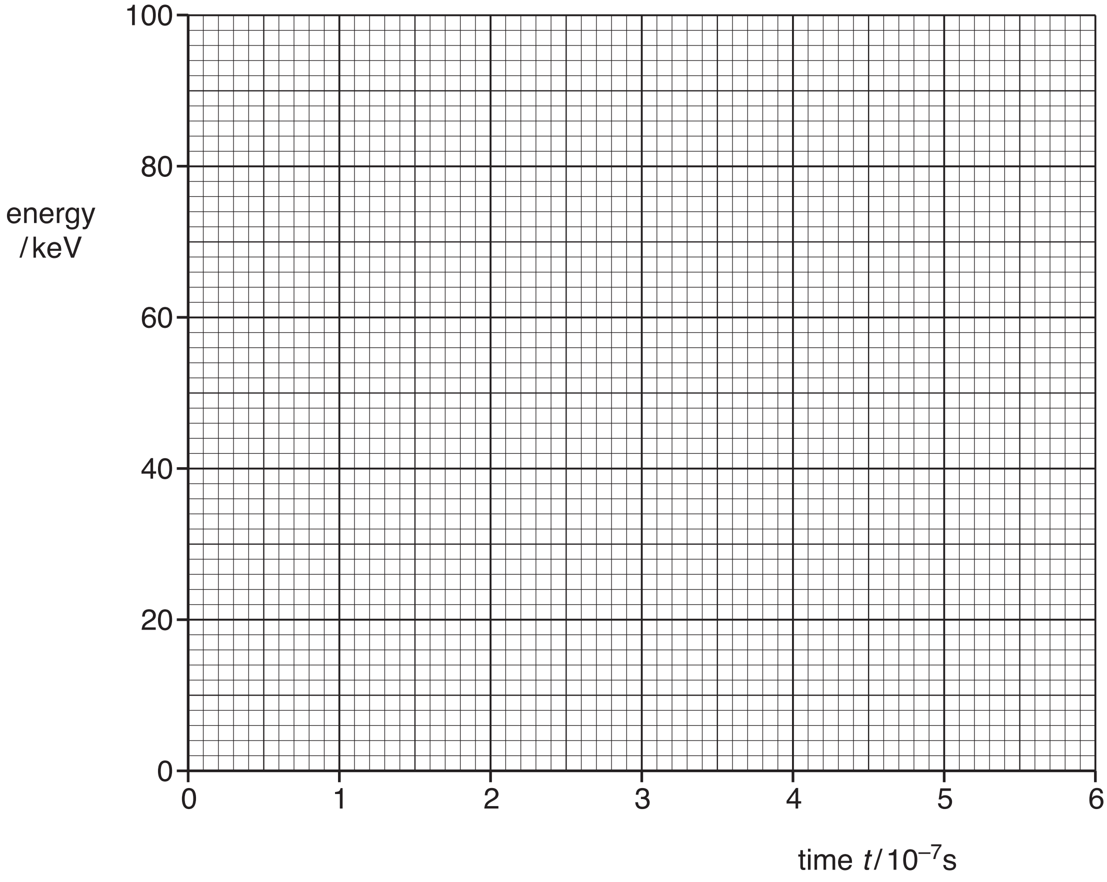

Fig. 4.2

[Total: 11]

5 **(a)** Describe what is meant by **fixed target** and **colliding beam** experiments.
Discuss the relative advantages of each.

description ....

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advantages ....

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.... **[7]**

(b) A high-energy positron collides with a stationary electron, creating a ${}^{0}_{0}Z$ particle. The reaction may be represented thus:

$${}^{0}_{1}e + {}^{0}_{-1}e \rightarrow {}^{0}_{0}Z$$

The incoming positron and the outgoing ${}^{0}_{0}Z$ particle both move at **approximately** the speed of light.

(i) Use the principle of conservation of momentum to compare the masses of the positron and the ${}^{0}_{0}Z$ particle.

....

....

.... **[2]**

(ii) The rest mass of the ${}^{0}_{0}Z$ particle is 1.6×10^{-25} kg.
Calculate the ratio of the rest mass of the ${}^{0}_{0}Z$ particle to the rest mass of the positron.

ratio = ... **[1]**

(iii) Explain why your answers to **(i)** and **(ii)** are **not** contradictory.

....

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.... **[2]**

(c) State why the method of creating a ${}^{0}_{0}Z$ particle described in **(b)** is not very efficient.

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.... **[1]**

[Total: 13]

6 (a) Describe briefly the quark model of hadrons.

- Illustrate your answer by referring to the composition of **one** hadron.
- Include in your answer the names of **all** the known quarks.
- Give as much information as you can about **one** particular quark.

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.... **[5]**

(b) A proton (p^+) can interact with a π^- particle to produce the three particles shown and an unknown particle **X**. The equation for the reaction is

$$p^+ + \pi^- \rightarrow n^0 + \pi^0 + \pi^- + \mathbf{X}.$$

The charge, baryon number and strangeness of the π^- and π^0 particles are shown in Fig. 6.1.

	charge	baryon number	strangeness
π^-	–1	0	0
π^0	0	0	0

Fig. 6.1

(i) Assuming that strangeness is conserved in this reaction, find the charge, baryon number and strangeness of particle **X**.

charge ....

....

baryon number ....

....

strangeness ....

.... **[3]**

(ii) Suggest what particle **X** is.

....

.... **[1]**

[Total: 9]

7 A householder wants to reduce the amount of mains energy used in his home, in order to combat global warming. He plans to install a device which is powered by a renewable energy source. He considers three options:

A an array of photoelectric cells mounted on his house roof

B a solar panel mounted on the house roof for heating water by solar radiation

C an aerogenerator attached by a short pole to the house chimney.

Option A: Photoelectric cells

Photoelectric cells consist of two layers of different semiconductor materials in contact with each other. When a cell is exposed to solar radiation an e.m.f. is created. See Fig. 7.1. The cells are arranged in an array as shown in Fig. 7.2.

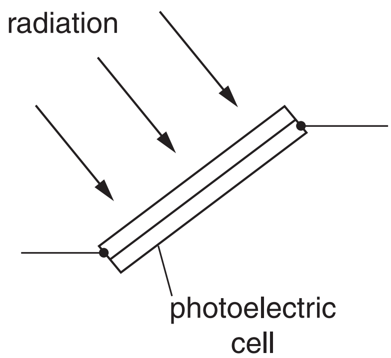

Fig. 7.1

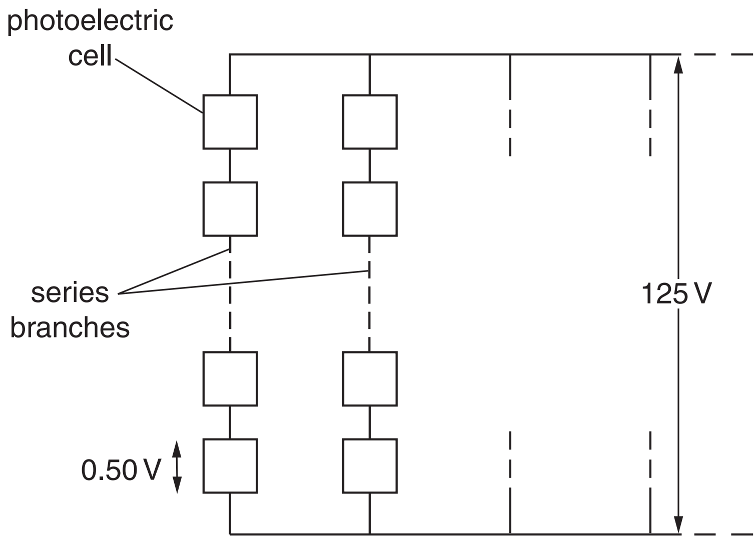

Fig. 7.2

intensity of solar radiation falling on the house	=	800 W m^{-2}
voltage output of each cell for this intensity	=	0.50 V
efficiency of each photoelectric cell	=	10 %
surface area of each photoelectric cell	=	5.0 cm^2
required output from photoelectric cell array	=	125 V

(a) **(i)** Calculate the total area of photoelectric cells needed to generate 1000 W of electrical power.

area = ... m^2 **[2]**

(ii) Show that the number of photoelectric cells needed is 25 000.

[1]

(iii) The photoelectric cells are arranged as in Fig. 7.2.

1 State the number of cells in **one** series branch. ....

2 State the number of branches in parallel. ....
[2]

(iv) Calculate the current through each photoelectric cell.

current = ... A **[2]**

Option B: Solar Panel

Solar radiation passes through a layer of glass and is absorbed by tubes of water. Cool water flows into the tubes and is heated. Hot water flows out and is led to an insulated storage tank.

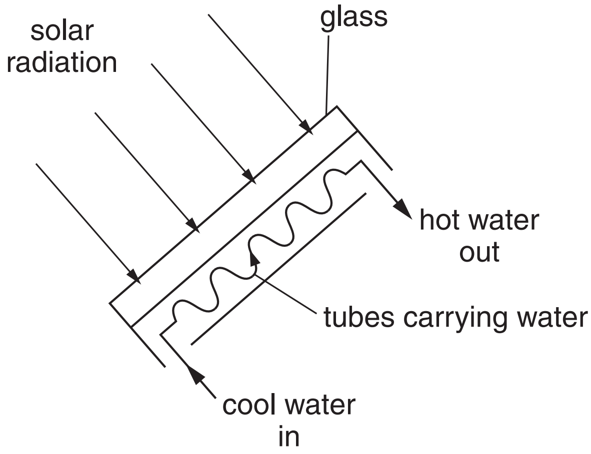

Fig. 7.3

intensity of solar radiation falling on the house	=	$800\,W\,m^{-2}$
efficiency of solar panel	=	70 %
incoming water temperature	=	20 °C
outgoing water temperature	=	75 °C
specific heat capacity of water	=	$4200\,J\,kg^{-1}\,K^{-1}$

(b) (i) Calculate the area of the solar panel needed for the water to gain 1000 J of heat energy per second.

area = ... m^2 **[2]**

(ii) Calculate the rate in $kg\,s^{-1}$ at which water must flow through the tubes in order to emerge at 75 °C.

rate = ... $kg\,s^{-1}$ **[3]**

Option C: Aerogenerator

This consists of a fan that rotates in the wind, and an electrical generator.

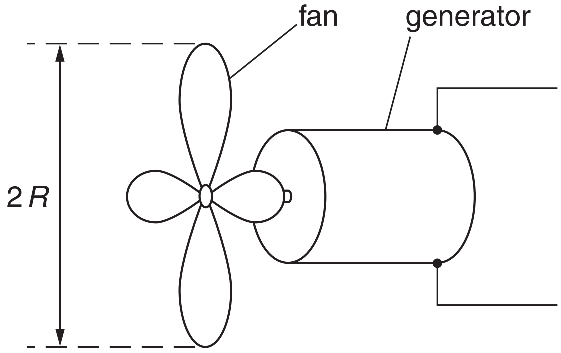

Fig. 7.4

efficiency of aerogenerator	=	40 %
wind speed	=	$5.0\,\mathrm{m\,s^{-1}}$
density of air	=	$1.3\,\mathrm{kg\,m^{-3}}$

(c) The air flowing through the fan in 1 second is a body of air having a cylindrical shape, of diameter $2R$ and length v where v is the speed of the air. See Fig. 7.5.

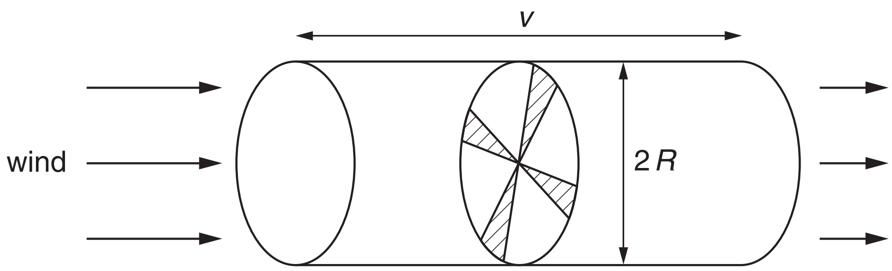

Fig. 7.5

The aerogenerator supplies 1000 J of electrical energy from this air in 1.0 second. This is 40 % of the initial kinetic energy of the air.

(i) Show that the initial kinetic energy of the cylinder of air is 2500 J.

[1]

(ii) Calculate the mass of this cylinder of air.

mass = ... kg **[2]**

(iii) Calculate the radius R of the aerogenerator fan.

R = ... m **[2]**

(d) The householder needs to make a choice.
Comment on the appropriateness or otherwise of **one** of these energy-generating processes for the house.

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.... **[3]**

[Total: 20]

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