RECOGNISING ACHIEVEMENT

OXFORD CAMBRIDGE AND RSA EXAMINATIONS
Advanced GCE

PHYSICS B (ADVANCING PHYSICS)

2865/01

Advances in Physics

Monday **28 JUNE 2004** Afternoon 1 hour 30 minutes

Candidates answer on the question paper.
Additional materials:
Insert (Advance Notice Article for this question paper)
Data, Formulae and Relationships Booklet
Electronic calculator

Candidate Name	Centre Number	Candidate Number

TIME 1 hour 30 minutes

INSTRUCTIONS TO CANDIDATES

- Write your name in the space above.
- Write your Centre number and Candidate number in the boxes above.
- Answer **all** the questions.
- Write your answers in the spaces provided on the question paper.
- Read each question carefully and make sure you know what you have to do before starting your answer.
- Show clearly the working in all calculations, and give answers to only a justifiable number of significant figures.

INFORMATION FOR CANDIDATES

- Section A (questions 1–7) is based on the Advance Notice article, a copy of which is included as an insert. You are advised to spend about 60 minutes on Section A.
- The number of marks is given in brackets [ ] at the end of each question or part question.
- There are four marks for the quality of written communication on this paper.
- The values of standard physical constants are given in the Data, Formulae and Relationships booklet. Any additional data required are given in the appropriate question.

FOR EXAMINER'S USE		
Qu	**Max.**	**Mark**
1	9	
2	6	
3	6	
4	12	
5	7	
6	10	
7	6	
8	16	
9	14	
QWC	4	
TOTAL	90	

This question paper consists of 22 printed pages, 2 blank pages and an insert.

SP (NF/GR) S51788/6

Registered Charity Number: 1066969

[Turn over

Answer **all** the questions.

Section A

The questions in this section are based on the Advance Notice article.
You are advised not to spend more than 60 minutes on this section.

1 This question is about the energy and momentum of alpha particles. (Lines 9–13 in the article.)

(a) **(i)** Show that the kinetic energy of 5.4 MeV alpha particles is about 9×10^{-13} J per particle.

$e = 1.6 \times 10^{-19}$ C

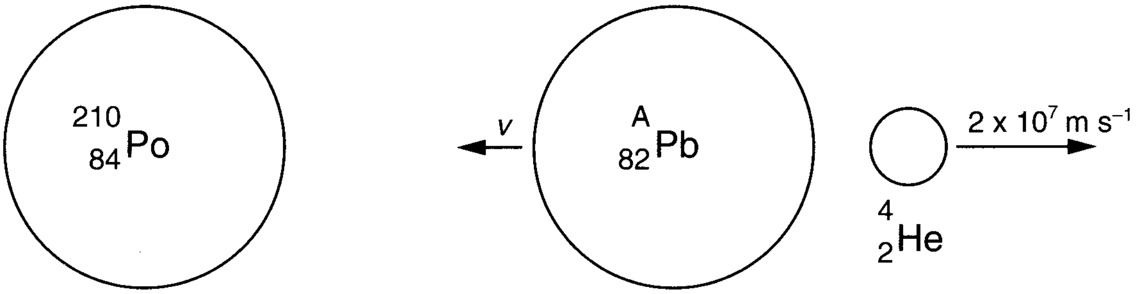
[2]

(ii) Show that these 5.4 MeV alpha particles are travelling at a speed of about 2×10^{7} m s^{-1}.

mass of alpha particle = 6.6×10^{-27} kg

[2]

(b) Fig. 1.1 shows an alpha particle being emitted at 2×10^7 m s^{-1} from a nucleus of $^{210}_{84}$Po.



before emission

after emission

Fig. 1.1

(i) Write down the nucleon number A of the lead (Pb) nucleus produced in the decay.

nucleon number = ... [1]

(ii) Show that the lead nucleus in Fig. 1.1 is recoiling at a speed *v* of about 3×10^5 m s^{-1}.

[2]

(iii) Explain why the article is justified in stating (line 12 in the article) that nearly all the energy is given to the alpha particle.

[2]

[Total: 9]

2 This question is about the changes during beta decay. (Lines 14–20 in the article.)
An example of beta decay is the decay of bismuth-210 to polonium-210, as shown below.

$$^{210}_{83}\text{Bi} \rightarrow {}^{210}_{84}\text{Po} + {}^{0}_{-1}\text{e} + \bar{\nu}$$

(a) How does this equation show that the anti-neutrino $\bar{\nu}$ is uncharged?

[1]

(b) Explain why uncharged particles such as neutrons are harder to detect than charged particles such as beta particles.

[1]

(c) The table below shows the masses of particles involved in the beta decay of bismuth-210 to polonium-210.

particle	mass / u
bismuth-210 nucleus	209.938 45
polonium-210 nucleus	209.936 66
electron	0.000 55
anti-neutrino	zero

(i) Show that the overall mass loss when one bismuth-210 nucleus decays is about 2×10^{-30} kg.

$u = 1.7 \times 10^{-27}$ kg

[2]

(ii) Calculate the energy released during the decay.

$c = 3.0 \times 10^{8}\ \mathrm{m\,s^{-1}}$

energy released = ... J [2]

[Total: 6]

[Turn over

3 This question is about the detection of neutrinos.
In Reines & Cowan's experiment (lines 37–51 in the article), the positron created in the reaction $\bar{\nu} + {}^{1}_{1}\mathrm{p} \rightarrow {}^{1}_{0}\mathrm{n} + {}^{\ 0}_{+1}\mathrm{e}$ annihilates with an electron to produce a pair of gamma photons as shown in Fig. 3.1.

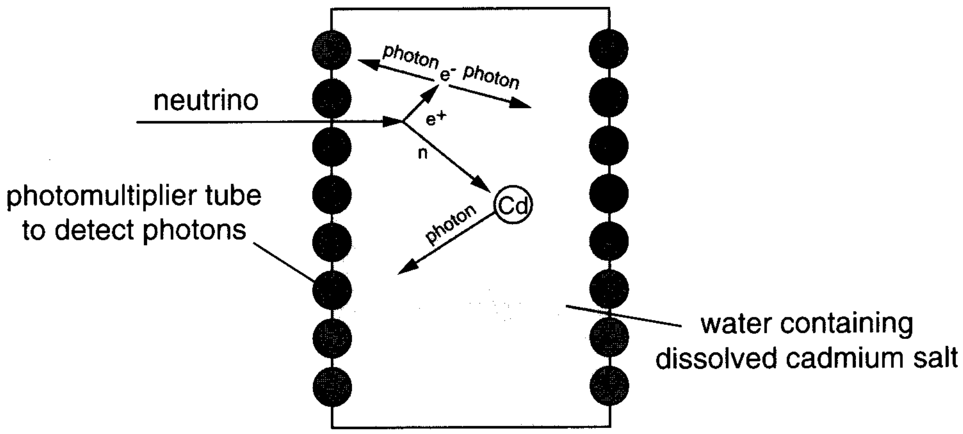


Fig. 3.1

(a) Explain why the detector uses **two** banks of photomultiplier tubes to detect the photons produced by the positron annihilation.

[2]

(b) The positron and neutron are produced at the same time. The photon produced when the neutron is absorbed by the cadmium nucleus is emitted a few microseconds after the positron annihilates.

Suggest **one** reason for this time delay.

[1]

(c) The difficulties in Reines & Cowan's experiment were explained in terms of 'signal to noise ratio'. (Line 56 in the article.)

(i) State what the **signal** is in this experiment.

[1]

(ii) State what the **noise** is in this experiment.

[1]

(d) Give the reason why today's neutrino observatories are very deep underground.

[1]

[Total: 6]

[Turn over

4 This question is about the Sun's output of neutrinos.

(a) **(i)** Explain the meaning of the expression 'neutrino flux.' (Lines 43–46 in the article.)

[2]

(ii) At the Earth's distance from the Sun (1.5×10^{11} m), the 2×10^{38} neutrinos produced by the Sun each second pass through the surface of a sphere of area 2.8×10^{23} m^2, as shown in Fig. 4.1.

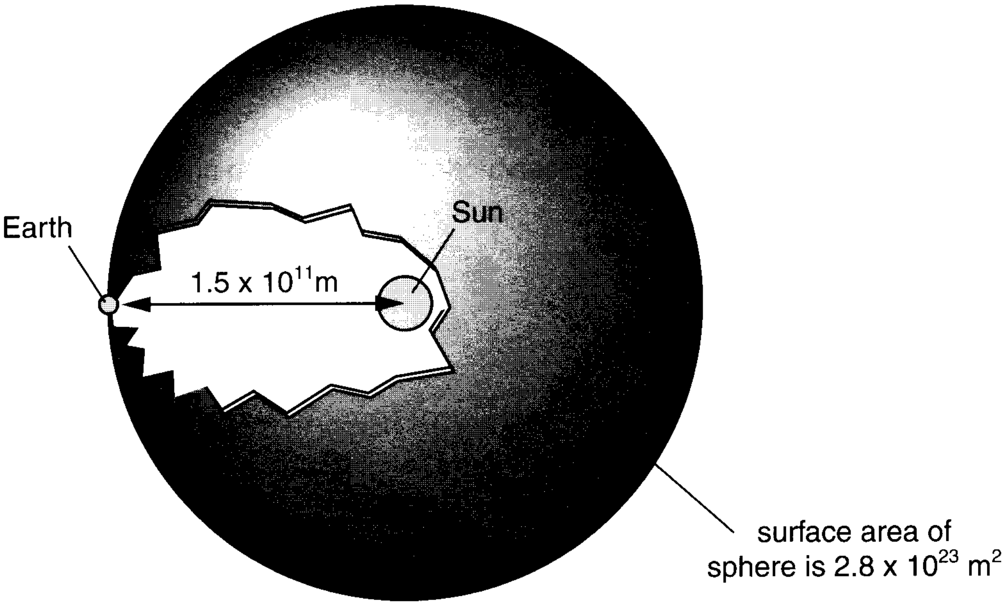


Fig. 4.1

Show that the neutrino flux at the Earth is about 7×10^{14} neutrinos m^{-2} s^{-1}.

[2]

(b) **(i)** Estimate the cross-sectional area of your body facing the Sun when you are lying sunbathing on the beach.

area = ... m^2 [1]

(ii) Calculate the number of neutrinos passing though your body each second while you are on the beach.

number per second = ... [2]

(iii) For each neutrino that passes through you, there is about 1 in 10^{18} chance of it being absorbed. If each neutrino has an energy of 1.6×10^{-13} J, estimate the absorbed dose received from neutrinos each year by a person of mass 65 kg.

1 year = 3.2×10^7 s

absorbed dose per year = ... unit .... [4]

(iv) Suggest **one** reason why neutrinos do **not** provide a significant radiation health hazard. (Lines 65–67 in the article.)

[1]

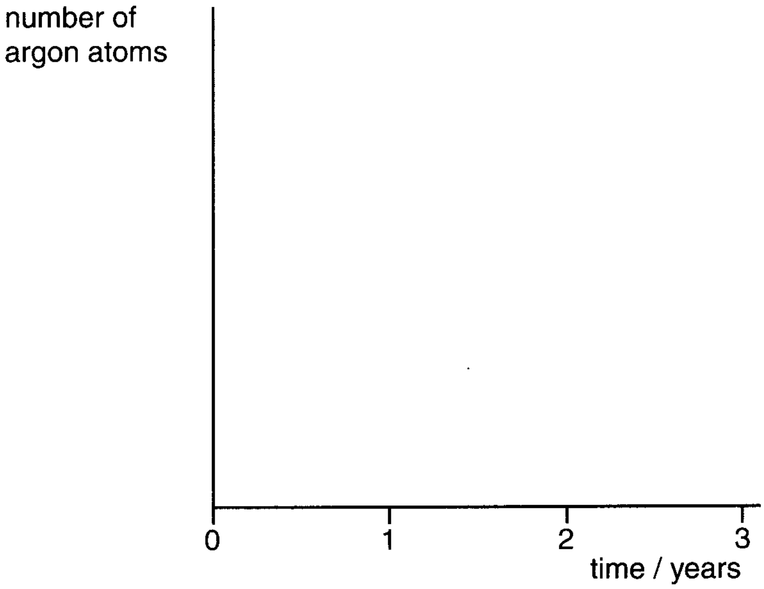
[Total: 12]

[Turn over

5 This question is about radioactive argon-37. (Lines 72–75 in the article.)

(a) Argon atoms were created in the Homestake neutrino detector at a steady rate of about 12 per month for many years.

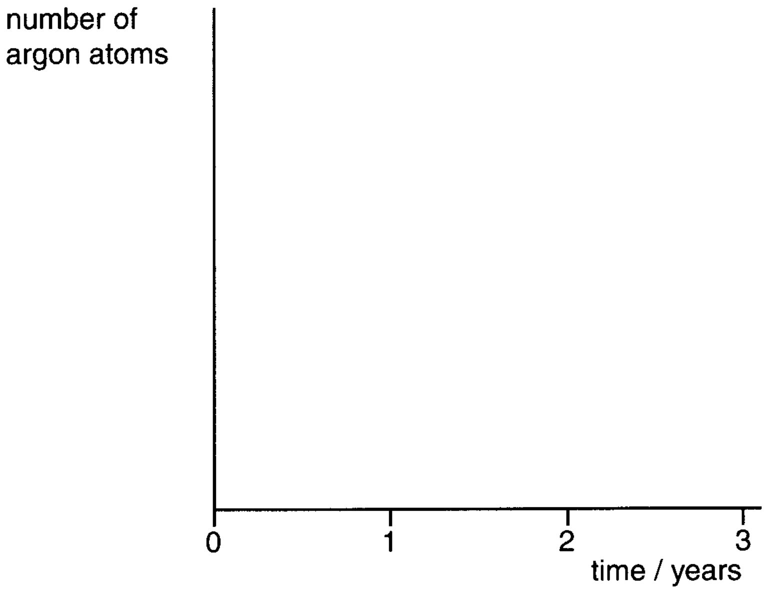
(i) Sketch a graph on the axes of Fig. 5.1 below to show how the number of argon atoms present would change from the time the detector started if the argon isotope produced had a very long half-life (hundreds of years).



[1]

very long half-life
Fig. 5.1

(ii) Sketch a graph on the axes of Fig. 5.2 below to show how the number of argon atoms present would change from the time the detector started if the argon isotope produced had a half-life of a few months.



[1]

half-life of a few months
Fig. 5.2

(b) The decay constant of argon-37 is $2.3 \times 10^{-7}\ \text{s}^{-1}$.
Show that its half-life is about a month (2.6×10^{6} s).

[2]

(c) Suggest **one** reason why observing the low count rate of decaying argon-37 atoms in the Homestake detector is extremely difficult. (Lines 73–75 in the article.)

[1]

(d) The Sun's neutrino flux is fairly constant.
Suggest why the rate of neutrino detection by the Homestake detector varies from month to month.

[2]

[Total: 7]

6 This question is about movement of photons in the Sun's core. (Lines 84–99 in the article.)

(a) Show that a photon travels a total distance of about 4×10^{20} m in 40 000 years.

$c = 3.0 \times 10^{8}\ \mathrm{m\,s^{-1}}$, 1 year = 3.2×10^{7} s

[2]

(b) Explain why it may take 40 000 years for photons created at the Sun's centre to reach the edge of the core, a displacement of 2.0×10^{8} m. No calculations are necessary.

[2]

(c) The temperature at the core of the Sun is about 6 000 000 K, while that at the Sun's surface is 5 800 K. Show that the frequency of a photon emitted in the core is about 1000 times higher than that of a photon emitted from the surface.

$k = 1.4 \times 10^{-23}\ \mathrm{J\,K^{-1}}$, $h = 6.6 \times 10^{-34}$ J s

[3]

(d) Suppose a single photon undergoes a 'random walk', like a diffusing gas molecule, as it escapes from the Sun. The displacement after N steps of mean length L is only $\sqrt{N} \times L$, as shown in Fig. 6.1.

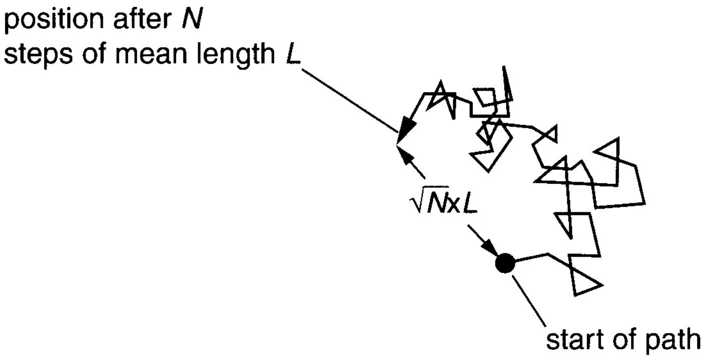


Fig. 6.1

For escape from the Sun, as in **(a)** and **(b)** opposite,

total travel $N \times L = 4.0 \times 10^{20}$ m

displacement $\sqrt{N} \times L = 2.0 \times 10^{8}$ m

Use these values to calculate the mean step length L of photons in the Sun's core.

mean step length = ... m [3]

[Total: 10]

7 This question is about the supernova observed in 1987. (Lines 103–108 in the article.)

(a) Explain why fusion in a massive star stops when its core has been converted to iron.

[2]

(b) The supernova detected in 1987 had happened in a nearby galaxy, a distance of 170 000 light years away.

(i) Explain why radar methods could **not** be used to measure this distance.

[1]

(ii) Explain why cosmological redshift (Hubble's Law) could **not** be used to measure this distance.

[2]

(c) The photons produced in the supernova were detected only a few hours after the neutrinos produced at the same time. Photons from our Sun emerge thousands of years after the neutrinos produced at the same time. Suggest a reason for this difference.

[1]

[Total: 6]

[Turn over

Section B

8 This question is about the physics involved in the design of a 'halogen kettle', where a halogen lamp replaces the usual kettle element. Such a kettle featured on the *Tomorrow's World* design awards a few years ago.

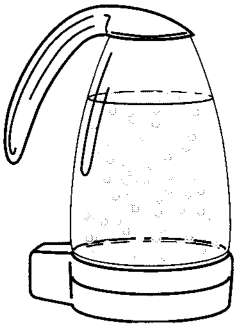


Fig. 8.1

(a) A conventional kettle draws a current of 10 A from the 230 V mains supply and takes 3 minutes to bring 1 kg of water to the boil from 20 °C.

(i) Show that the electrical energy drawn from the supply is about 4×10^5 J.

[2]

(ii) Show that the rise in internal energy of the water is about 3×10^5 J.

specific thermal capacity of water = 4200 J kg^{-1} °C^{-1}

[2]

(b) An ordinary kettle element is similar to the filament in an electric fire. The filament in a halogen lamp runs at a much higher temperature.

Describe how this will influence the spectrum of electromagnetic radiation that it produces.

[2]

(c) The halogen lamp in the new kettle has a power rating of 1000 W and emits light of average frequency 4.0×10^{14} Hz.

(i) Show that the average photon energy is about 3×10^{-19} J.

$h = 6.6 \times 10^{-34}$ J s

[2]

(ii) Assuming that all the energy is transferred as 3×10^{-19} J photons, calculate the number of photons emitted each second.

number = ... s^{-1} [2]

(d) As the water boils, illuminated bubbles seen through the transparent case are interesting to watch, but in practice the kettle takes more than 10 minutes to boil. Suggest why it is so inefficient.

[2]

[Turn over

(e) The use of plastic materials for the manufacture of kettles has improved their efficiency considerably over their metal predecessors.

List two useful physical properties for the plastic body of the kettle. Explain your choice.

1. Property

Explanation

[2]

2. Property

Explanation

[2]

[Total: 16]

BLANK PAGE

PLEASE TURN OVER FOR QUESTION 9

[Turn over

9 This question is about possible satellite observations of the Moon.

Use the data below to answer the following questions.

$G = 6.7 \times 10^{-11}$ N kg^{-2} m^{-2}
mass of the Moon = 7.3×10^{22} kg
mean radius of the Moon = 1700 km

(a) **(i)** Show that the gravitational field strength on the surface of the Moon is about 1.7 N kg^{-1}.

[3]

(ii) **Estimate** the change in gravitational potential that occurs from the surface to a point 10 km vertically above the surface. Assume that the gravitational field strength is constant.

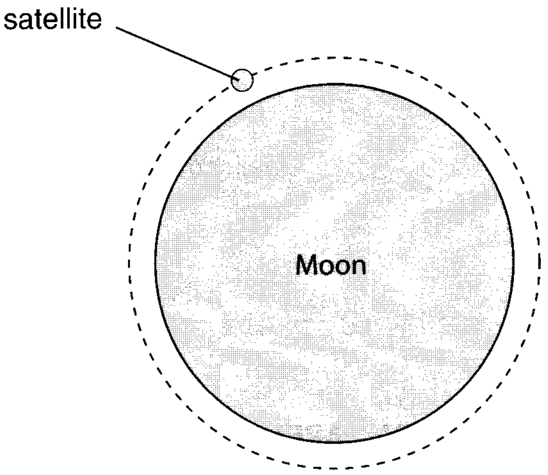
[2]

(iii) Explain why the actual change in gravitational potential is smaller than your estimate in **(ii)**.

[2]

(b) A satellite at an altitude of 10 km should clear the highest mountains on the surface of the Moon.

(i) Draw on Fig. 9.1 an arrow indicating the direction of the resultant force acting on the satellite as it orbits the Moon.



(not to scale)

[1]

Fig. 9.1

(ii) Explain why such low orbits are impossible around the Earth.

[2]

(c) A digital camera in the satellite is to be used to survey the surface in detail. The camera has a lens of focal length 5 cm in front of a charge coupled device. The image contains 1024 × 1024 pixels.

(i) Calculate the power of the lens required for this camera.

power = ... dioptre [1]

(ii) If each image corresponds to an 8 km × 8 km area of lunar surface, calculate the resolution of the images.

resolution = ... m pixel^{-1} [2]

(iii) Suggest **one disadvantage** of using such a low orbit.

[1]

[Total: 14]

Quality of Written Communication [4]

END OF QUESTION PAPER