THIS IS A LEGACY SPECIFICATION

RECOGNISING ACHIEVEMENT

ADVANCED GCE

PHYSICS B (ADVANCING PHYSICS) 2865/01

Advances in Physics

Candidates answer on the question paper

OCR Supplied Materials:
- Insert (Advance Notice Article for this question paper) (inserted)
- Data, Formulae and Relationships Booklet

Other Materials Required:
- Electronic calculator
- Ruler (cm/mm)

Tuesday 27 January 2009
Morning

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.
- Show clearly the working in all calculations, and give answers to only a justifiable number of significant figures.
- 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**.
- 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.
- There are four marks available 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.
- This document consists of **20** pages. Any blank pages are indicated.

For Examiner's Use		
Qu.	**Max**	**Mark**
1	6	
2	5	
3	10	
4	10	
5	12	
6	9	
7	6	
8	14	
9	14	
QWC	4	
Total	90	

Answer **all** the questions.

Section A

1 This question is about Rutherford's experiments with alpha particles (lines 3 – 7 in the article).

(a) In the experiment that Geiger, Marsden and Rutherford performed on alpha particle scattering, they found that some alpha particles were scattered through large angles, while most were not scattered at all.

What did Rutherford conclude, from this information, about the structure of the atom?

[2]

(b) Rutherford was the first to produce an artificial nuclear change, using nitrogen gas.
Complete the nuclear equation below showing the change produced.

$$^{14}_{7}\mathrm{N} + {}^{4}_{2}\mathrm{He} \longrightarrow {}^{\cdots\cdots}_{\cdots\cdots}\mathrm{O} + {}^{\cdots\cdots}_{\cdots\cdots}\mathrm{p}$$

[2]

(c) Rutherford's alpha particles could get close enough to a nitrogen nucleus to produce a nuclear change.

Nuclear changes are much less likely to happen when similar alpha particles bombard gold nuclei ($^{197}_{79}\mathrm{Au}$).
Explain why.

[2]

[Total: 6]

2 Particle accelerators were developed to produce more effective nuclear probes (lines 8 – 15 in the article).

(a) Cockcroft and Walton accelerated protons through a potential difference of 200 kV.

(i) Write down the energy gained by these protons, in eV.

energy = ... eV **[1]**

(ii) Calculate this energy in J.

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

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

(b) Cockcroft and Walton used the high-speed protons to disintegrate lithium into separate alpha particles. This occurs when lithium-7 nuclei are converted into beryllium-8 nuclei, which are unstable.

$$^{8}_{4}\text{Be} \longrightarrow 2\ ^{4}_{2}\text{He}$$

Use the data in the table to calculate the energy released in this reaction.

nucleus	**mass / u**
beryllium-8	8.003 108
helium-4	4.001 508

$u = 1.7 \times 10^{-27}$ kg
$c = 3.0 \times 10^{8}$ m s^{-1}

.... J **[3]**

[Total: 5]

3 This question is about using voltages to accelerate charged particles (lines 16 – 28 in the article).

(a) Particles are accelerated when they pass between electrodes (Fig. 3.1).

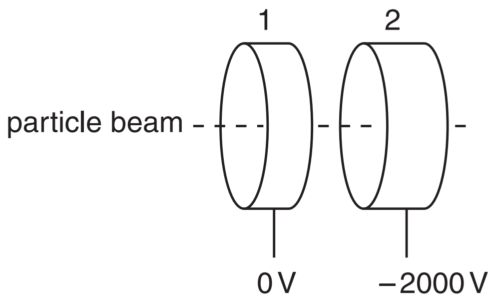

Fig. 3.1

Fig. 3.2 is a sectional view of the space between the two electrodes in Fig. 3.1 showing the electric field lines.

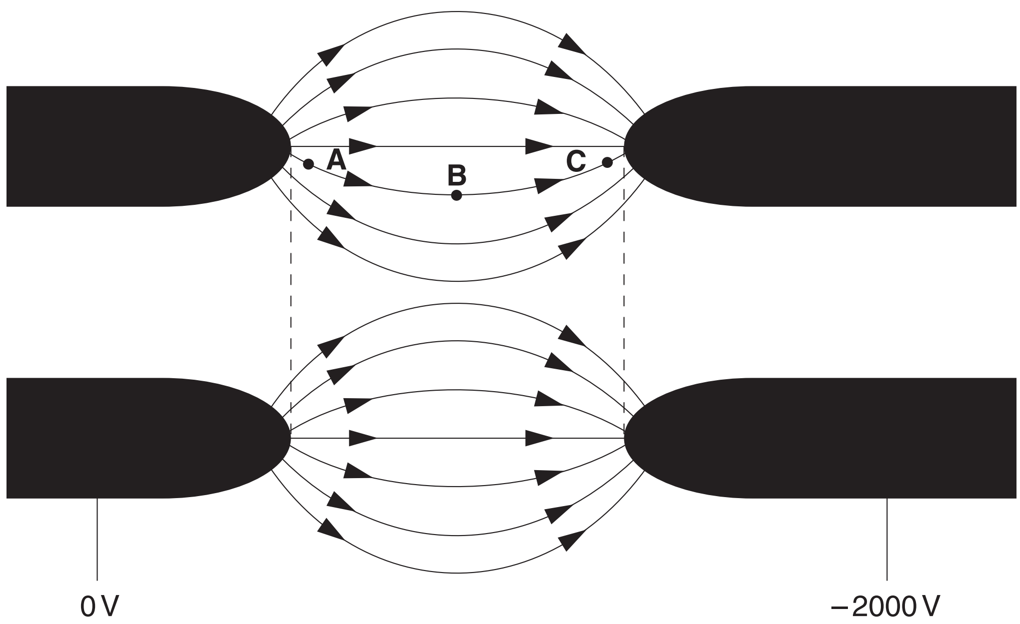

Fig. 3.2

(i) State how Fig. 3.2 shows that the electric field at **A** is stronger than the field at **B**.

[1]

(ii) State the potential at the point marked **B**, which is midway between the electrodes.

potential .... unit .... **[2]**

(iii) Draw three equipotentials in the space between the two electrodes, passing through the points marked **A**, **B** and **C**.

[2]

(b) Fig. 3.3 below shows a proton moving in the space between the two electrodes. The velocity of the proton is indicated by the arrow - - - - ►.

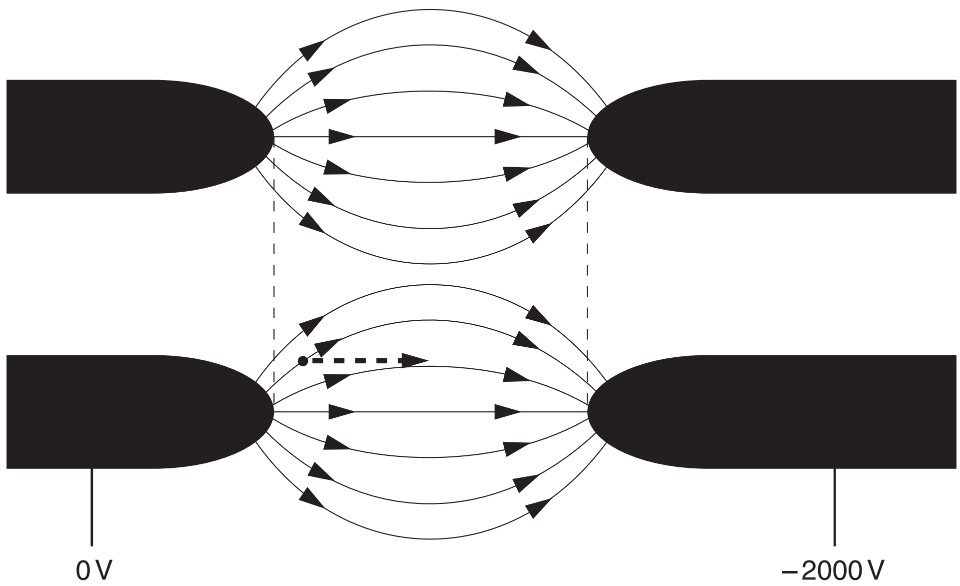

Fig. 3.3

(i) Draw an arrow on Fig. 3.3 to show the **force** acting on the proton due to the electric field.

[1]

(ii) By considering the horizontal and vertical components of the force on the proton, explain why the field shown above tends to produce a narrow parallel beam down the centre of the electrodes.

[2]

(c) The energy that can be obtained with two electrodes is limited.
Suggest and explain one reason why particles with energies of several GeV, as produced by modern accelerators, cannot be produced by two electrodes as above.

[2]

[Total: 10]

4 This question is about a linear accelerator (LINACs) accelerating a beam of protons (lines 16 – 28 in the article).

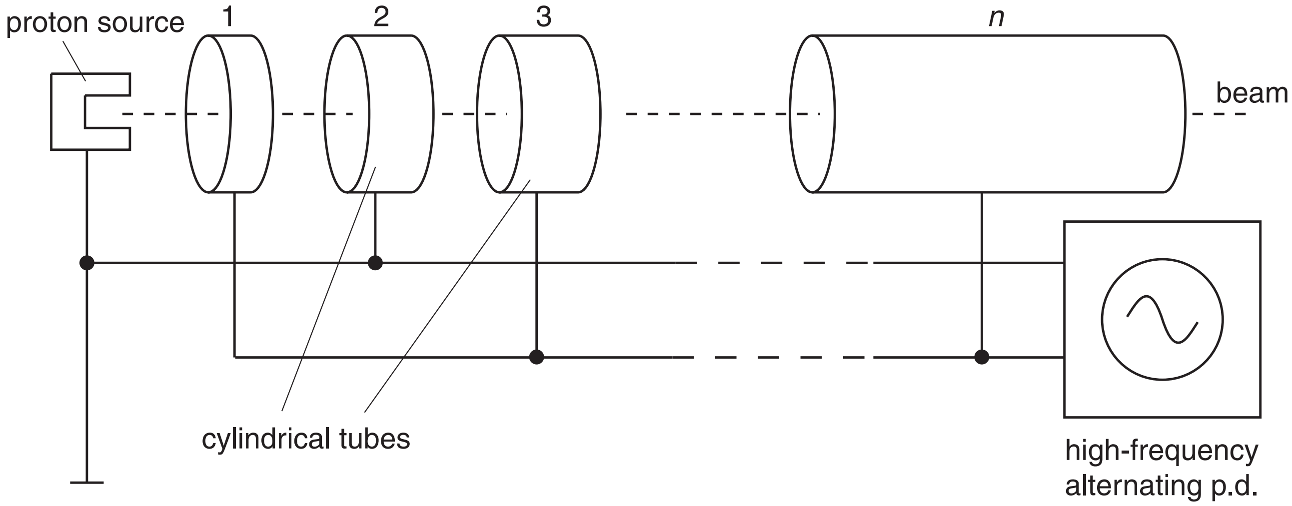

Fig. 4.1

(a) (i) Explain why tube 2 must be at a **more negative** potential than tube 1 to accelerate the protons leaving tube 1.

[1]

(ii) As the protons pass through tube 2, it is necessary that the potential of tube 2 changes polarity.
Explain why.

[1]

(b) Fig. 4.1 above shows that a linear accelerator consists of a large number *n* of accelerating stages.
Calculate the number *n* of accelerating stages required to produce protons of kinetic energy 1.6 MeV with an applied alternating p.d. of amplitude 40 kV.
State any assumption made.

n = ... **[2]**

(c) The diagram of Fig. 4.2 shows the graph of energy against time for a proton moving down part of the centre of the linear accelerator.

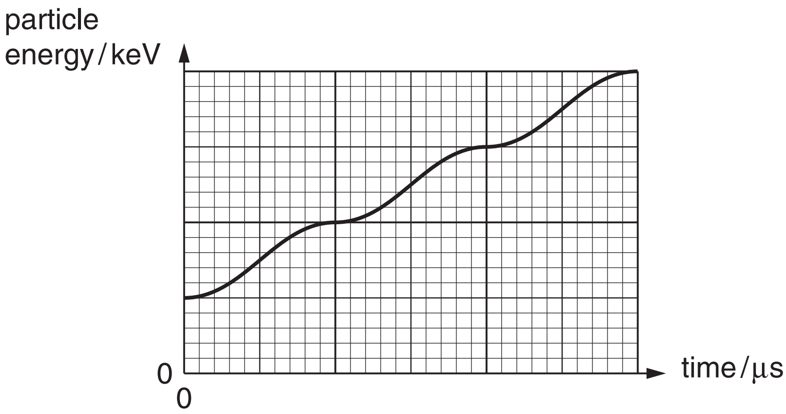

Fig. 4.2

(i) Label with the letter **P** a point on the graph where the proton was midway **between** two adjacent tubes.

[1]

(ii) The acceleration was provided by a 40 kV, 10 MHz alternating source.
Use this information to add scales of energy and time to the axes of the graph.

[2]

(d) In Fig. 4.3 the velocity-time graph for the protons has been added to the energy-time graph of Fig. 4.2.

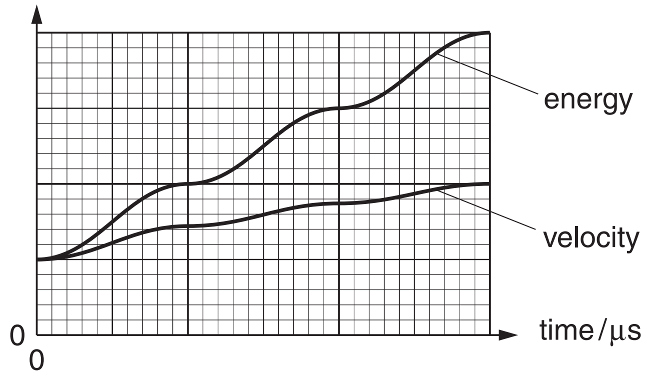

Fig. 4.3

Explain, in as much detail as you can, the shape of the velocity-time graph.

[3]

[Total: 10]

5 This question is about synchrotrons accelerating protons (lines 55 – 94 in the article).
The diagram in Fig. 5.1 shows a simple synchrotron viewed from above and from the side. The arrows show the direction of movement of the protons.

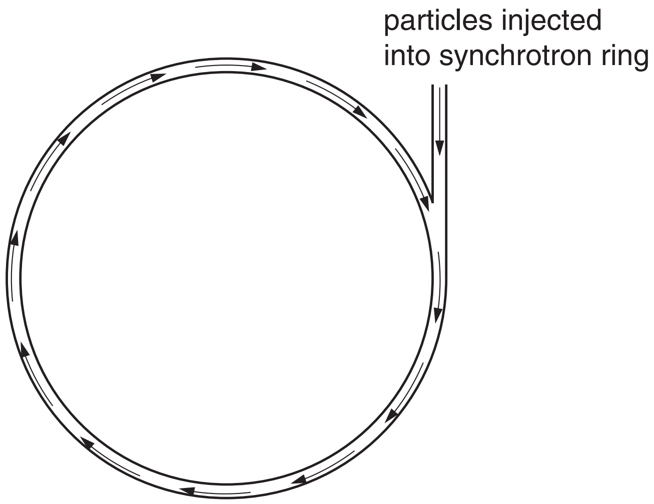

Fig. 5.1a View from above

Fig. 5.1b View from side

Fig. 5.1

(a) On **one** of the above diagrams, draw four lines to show the direction of the magnetic field B. **[1]**

(b) The magnetic force acting on a proton produces centripetal acceleration.
Use this fact to show that the momentum p of the protons is given by the equation

$$p = eRB$$

where R is the radius of the synchrotron and e is the proton charge.

[3]

(c) At very high energies, the momentum is given by γmv where γ is the ratio of the total particle energy to its rest energy (lines 56 – 70 in the article).

(i) Calculate the magnetic field strength B required in a synchrotron of radius 100 m

1 at a proton speed of $3.0 \times 10^{7}\,\mathrm{m\,s^{-1}}$, when γ is very close to 1
$u = 1.7 \times 10^{-27}\,\mathrm{kg}$
$e = 1.6 \times 10^{-19}\,\mathrm{C}$

B = ... T **[2]**

2 at a proton speed of 99.999% of the speed of light, when $\gamma = 220$.
$c = 3.0 \times 10^{8}\,\mathrm{m\,s^{-1}}$

B = ... T **[1]**

(ii) Calculate the total energy E of a proton moving at 99.999% of the speed of light with $\gamma = 220$.

rest energy of proton = 940 MeV

E = ... GeV **[1]**

(iii) Explain why protons with $\gamma = 220$ can be used to create other particles of much greater mass.

[2]

(iv) Suggest and explain one technical difficulty presented by the use of superconducting magnets in large synchrotrons.

[2]

[Total: 12]

6 This question is about the medical use of particle accelerators (lines 44 – 54 in the article).

(a) X-ray and gamma photons are both used to treat tumours. The quality factor for both is 1.

(i) Explain why you would expect X-ray and gamma photons to have the same quality factor.

[1]

(ii) Give one advantage and one disadvantage of using radiation of quality factor 1 to destroy tumours by irradiation.

advantage:

disadvantage:

[2]

(b) High energy protons have a quality factor which depends upon their energy.
A typical value is 10.

(i) State and explain **one** reason why protons have a higher quality factor than gamma photons or X-rays.

[2]

(ii) An accelerator produces a 0.1 μA beam of protons. Show that a 3 second dose from this beam contains about 2×10^{12} protons.

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

[2]

(iii) Calculate the dose equivalent in sievert received by a tumour of mass 0.1 kg when it absorbs 2×10^{12} protons of energy 2 MeV.

dose equivalent = ... Sv **[2]**

[Total: 9]

7 This question is about synchrotron radiation (lines 96 – 136 in the article).

(a) Synchrotron radiation is highly polarised.

Explain clearly how you could demonstrate this for a component of synchrotron radiation in the visible region.

[2]

(b) Radiation from the synchrotron ring passes into an optics 'hutch', where a diffraction grating is used to select a single wavelength (Fig. 7.1).

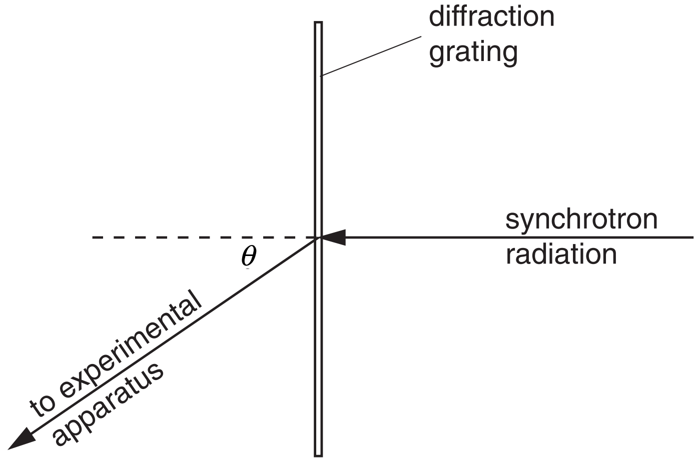

Fig. 7.1

(i) For a grating of 1000 lines mm^{-1}, show that the wavelength of the radiation that has a first-order maximum in the direction $\theta = 35°$ is in the visible region of the spectrum.

[2]

(ii) In the direction $\theta = 35°$, radiation in the ultraviolet region is observed as well as the visible wavelength of part (i).

Explain why there is also an ultraviolet maximum at this angle, and suggest how it can be removed from the beam.

[2]

[Total: 6]

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Section B

8 This question is about some aspects of biometrics, the science of measuring human attributes to establish a person's identity.

(a) Fingerprints are the most widely used biometric data. Fig. 8.1 shows a typical fingerprint.

actual size

Fig. 8.1

(i) Estimate the area that needs to be imaged to capture the fingerprint shown in Fig. 8.1.

width = ... height = ...

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

(ii) Calculate the number of pixels in the image if its resolution is 2.5×10^{-5} m pixel^{-1}.

number of pixels = ... **[2]**

(iii) Explain why a single bit per pixel is sufficient to encode a fingerprint image.

[2]

(b) Eye recognition is another biometric technique. Fig. 8.2 shows an iris.

Fig. 8.2

The complex structure of the iris is thought to be unique to each individual.

A person stands in front of an iris recognition camera. His eye is 30 cm from the camera lens. A sharp image of the iris is produced on a CCD sensor placed 3 cm behind the lens (Fig. 8.3).
Fig. 8.3 shows some rays reflected **from** the eye towards the camera lens.
XY represents the extent of the image of the eye on the CCD.

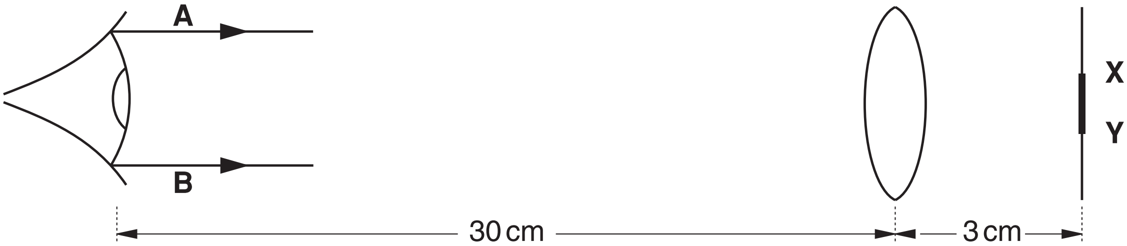

Fig. 8.3

[3]

(i) Complete the ray diagram showing the paths of the two rays **A** and **B** through the lens to the CCD.

(ii) Mark on the ray diagram, with the letter **F**, the focal point of the lens. **[1]**

(iii) Calculate the power of the lens in the iris scanner.

power = ... D **[3]**

(iv) Calculate the size of the image on the CCD sensor, given that the iris scanned is 10 mm across.

size of image = ... mm **[1]**

[Total: 14]

9 This question is about the Spitzer telescope shown in Fig. 9.1.

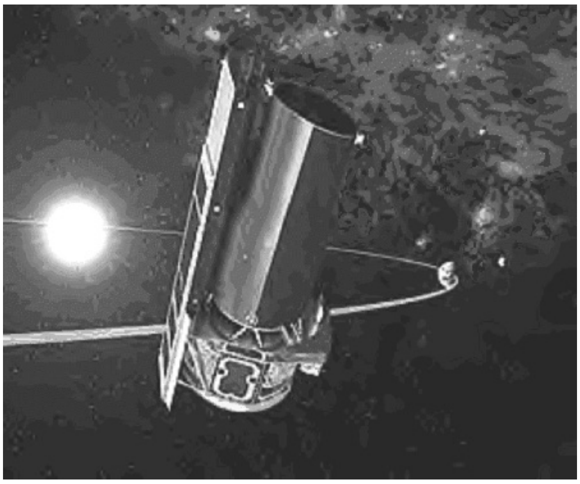

Fig. 9.1

Spitzer is a space telescope designed to operate at infrared wavelengths.

(a) The electromagnetic spectrum is divided into several broad wavelength bands listed below in **alphabetical order**.

gamma infrared microwave radio ultraviolet visible X-ray

Which **one** of these bands contains waves with wavelengths only **slightly shorter** than in the infrared band?

[1]

(b) Spitzer orbits the Sun at the same orbital radius as the Earth, but lagging behind by some distance.

(i) Show that the gravitational force acting on Spitzer due to the Sun alone is about 6 N.

$G = 6.7 \times 10^{-11}\,\text{N m}^2\,\text{kg}^{-2}$
mass of Sun = 2.0×10^{30} kg
mass of Spitzer = 950 kg
radius of Earth's orbit = 1.5×10^{11} m

[3]

(ii) Spitzer is about 7 x 10^{10} m away from the Earth. Explain why the gravitational attraction due to the Earth can be neglected compared with that due to the Sun.

mass of Earth = 6.0×10^{24} kg

[3]

(c) (i) Explain why the gravitational potential energy of Spitzer is negative.

[2]

(ii) Explain how the presence of the Earth influences the gravitational potential energy of Spitzer.

[2]

QUESTION 9 IS CONTINUED OVER THE PAGE

(d) The infrared sensors in Spitzer absorb energy from their surroundings. The sensors are mounted on a container of liquid helium at a temperature of 2 K. Evaporation of the liquid helium maintains the sensor at this temperature.

(i) By considering the energy of helium molecules which are able to leave the liquid, explain how evaporation keeps the sensor at 2 K.

[2]

(ii) Suggest why the evaporation method used to cool the sensors gives Spitzer a limited lifetime.

[1]

[Total: 14]

Quality of Written Communication [4]

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