



22146509

**PHYSICS  
HIGHER LEVEL  
PAPER 3**

Candidate session number

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Thursday 8 May 2014 (afternoon)

Examination code

1 hour 15 minutes

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**INSTRUCTIONS TO CANDIDATES**

- Write your session number in the boxes above.
- Do not open this examination paper until instructed to do so.
- Answer all of the questions from two of the Options.
- Write your answers in the boxes provided.
- A calculator is required for this paper.
- A clean copy of the *Physics Data Booklet* is required for this paper.
- The maximum mark for this examination paper is [60 marks].

Option	Questions
Option E — Astrophysics	1 – 5
Option F — Communications	6 – 9
Option G — Electromagnetic waves	10 – 14
Option H — Relativity	15 – 19
Option I — Medical physics	20 – 22
Option J — Particle physics	23 – 27



52EP01

**Option E — Astrophysics**

1. This question is about comets.

Outline the nature of a comet.

[2]

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2. This question is about the life history of stars.

(a) Outline, with reference to pressure, how a star on the main sequence maintains its stability.

[3]

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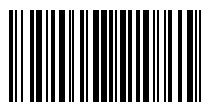
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*(Option E continues on the following page)*



*(Option E, question 2 continued)*

- (b) A star with a mass equal to that of the Sun moves off the main sequence. Outline the main processes of nucleosynthesis that occur in the core of this star before and after this change. [2]

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- (c) Compare the fate of the star in (b) with that of a star of much greater mass. [3]

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*(Option E continues on the following page)*



(Option E continued)

3. This question is about stellar distances.

Sirius A is a main sequence star of temperature 9900 K, absolute magnitude +1.42 and apparent magnitude –1.47.

(a) Show that Sirius A is about 3 pc from Earth. [3]

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(b) The apparent brightness of Sirius A is  $1.2 \times 10^{-7} \text{ W m}^{-2}$ . Use the result in (a) to determine the luminosity of Sirius A. [2]

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(c) The luminosity of the Sun is  $3.8 \times 10^{26} \text{ W}$ . Determine the mass of Sirius A relative to the mass of the Sun. (Assume that  $n = 3.5$  in the mass–luminosity relation.) [2]

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(Option E continues on the following page)



*(Option E, question 3 continued)*

- (d) State and outline another technique that will allow astronomers to confirm the distance estimate in (a). [4]

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*(Option E continues on the following page)*



52EP05

**Turn over**

*(Option E continued)*

4. This question is about the structure of the universe.

- (a) (i) State, in terms of the arrangement of galaxies, the present large-scale distribution of mass in the universe. [1]

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- (ii) State how the separation of distant galaxies is changing with time. [1]

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- (b) State and explain the observational evidence for your answer to (a)(ii). [3]

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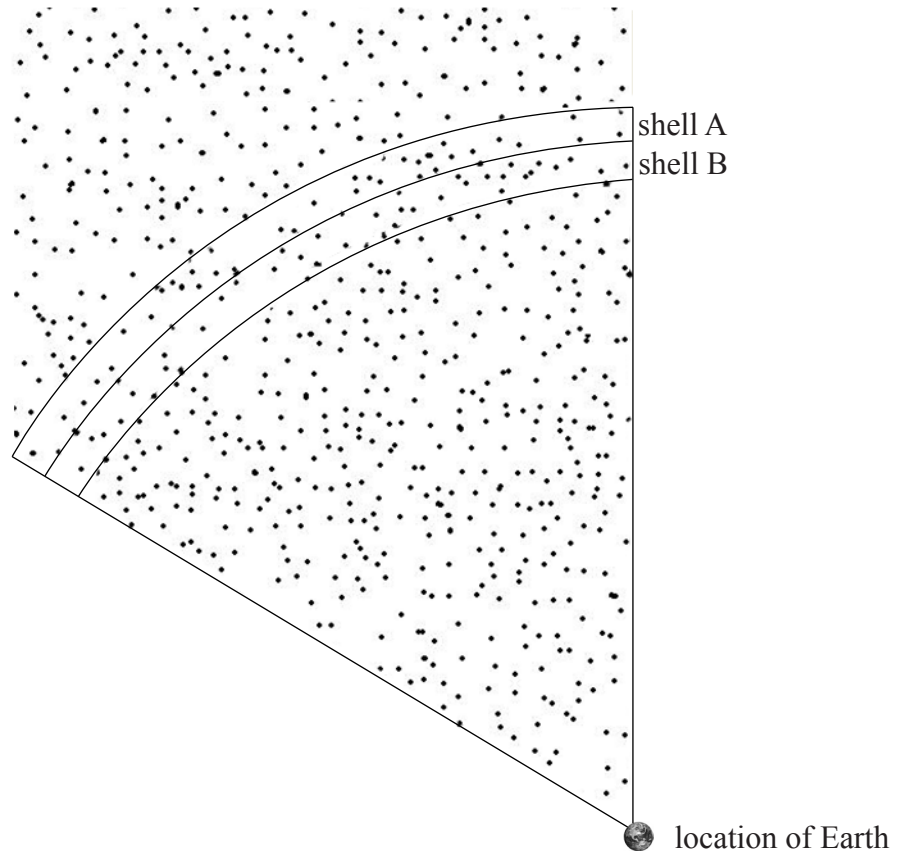
*(Option E continues on the following page)*



(Option E continued)

5. This question is about Newton's model of the universe.

The diagram below shows a part of a series of thin spherical shells of equal thickness with the Earth at their centre.



Explain quantitatively, with reference to the assumptions Newton made in his model of the universe, how Olbers' paradox arises.

[4]

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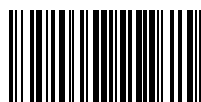
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**End of Option E**



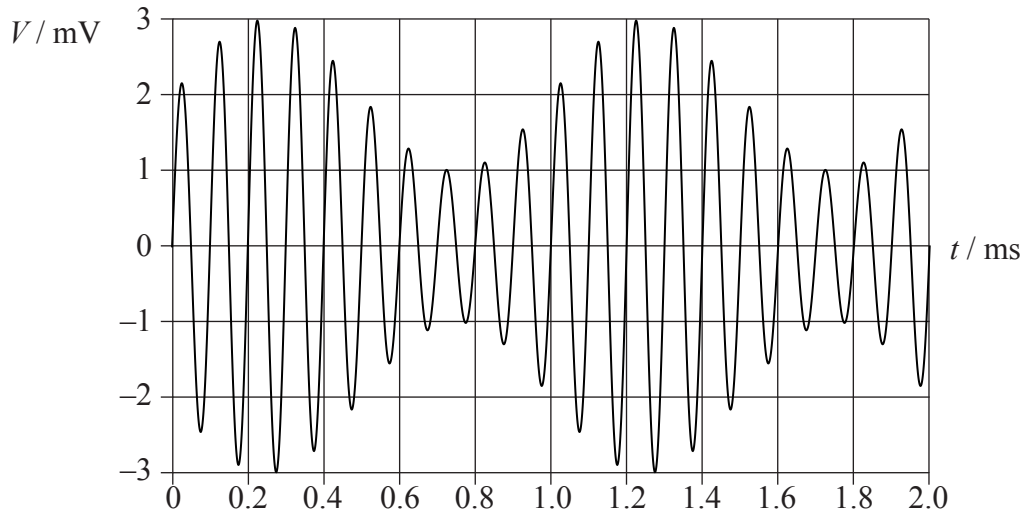
52EP07

Turn over

**Option F — Communications**

6. This question is about radio communication.

A signal wave is used to modulate a carrier wave. The amplitude of the carrier wave is 2 mV. The graph below shows how the amplitude  $V$  of the modulated wave varies with time  $t$ .



(a) State what type of modulation has been applied to the carrier wave. [1]

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*(Option F continues on the following page)*





(Option F, question 6 continued)

(b) Using the graph opposite, estimate

(i) the frequency of the carrier wave.

[1]

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(ii) the amplitude of the signal wave.

[1]

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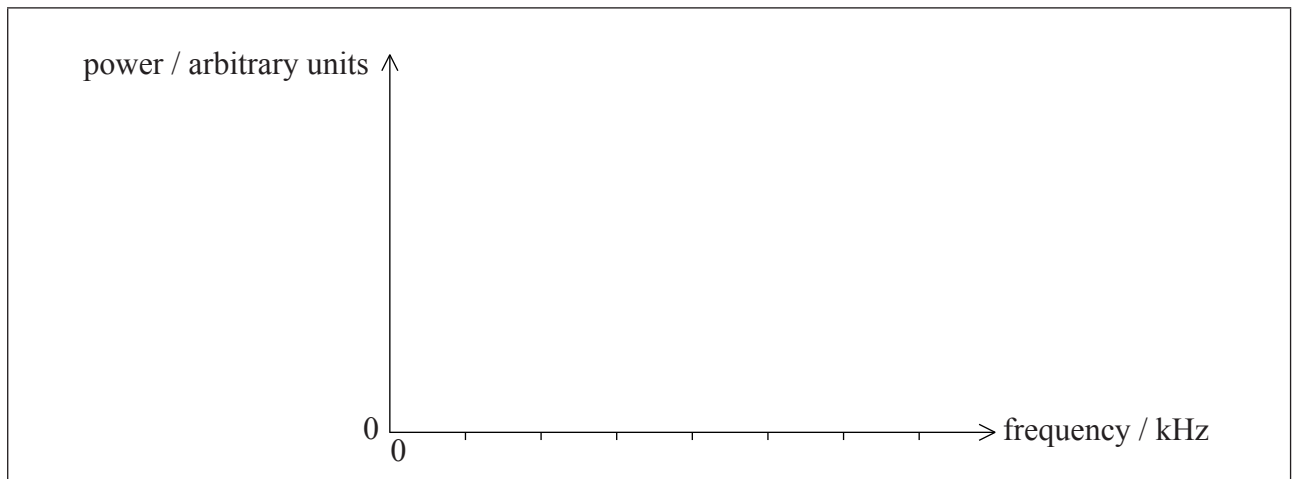
(iii) the frequency of the signal wave.

[1]

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(c) On the axes below, sketch the power spectrum of the modulated wave.

[3]



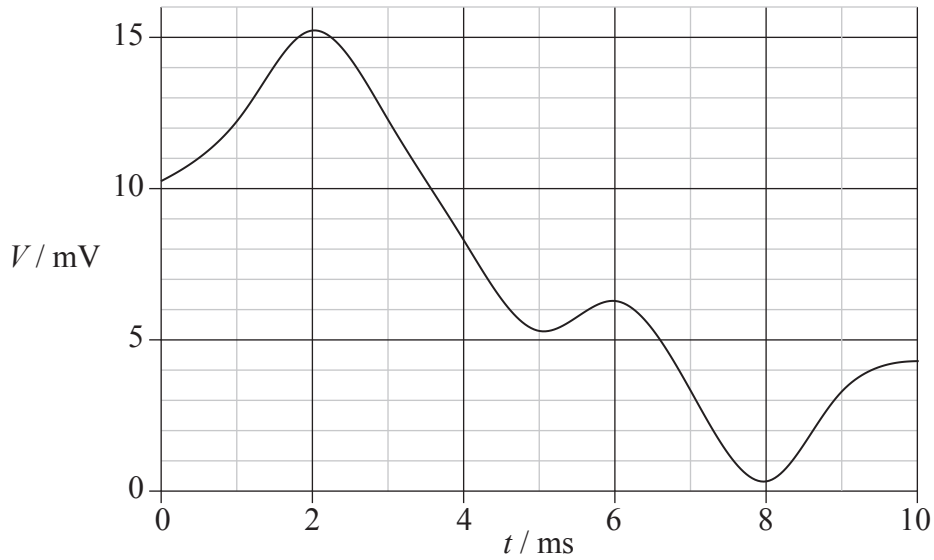
(Option F continues on the following page)



(Option F continued)

7. This question is about the transmission of digital signals.

A piece of music sung by a famous soprano is to be digitally recorded. Part of the variation of the output  $V$  of the microphone with time  $t$  is shown below.



A sound engineer samples the signal using an analogue-to-digital converter (ADC) that has 16 output levels.

(a) State the number of bits required for each sample.

[1]

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(Option F continues on the following page)



(Option F, question 7 continued)

- (b) The system rounds down each analogue sample to the nearest mV before each digital conversion (for example 0.8 mV becomes 0 mV and 15.1 mV becomes 15 mV).

The level of the signal at  $t=2$  ms is converted to the maximum digital output and the level of the signal at  $t=8$  ms is converted to a zero digital output.

The signal is sampled at a rate of 1000 Hz starting at  $t=0$ . Calculate the binary output for the first two samples. [2]

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- (c) With reference to sampling, suggest **two** reasons why the quality of the recording is poor. [2]

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- (d) The full song is digitally recorded on a computer, where it occupies about 120 kilobytes of memory (1 byte=8 bits). The soprano then sends the song to a friend by email. It takes 1.3 s for the file to reach the friend’s computer. Calculate, in  $\text{kbits s}^{-1}$ , the bit-rate of this transmission. [2]

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(Option F continues on the following page)

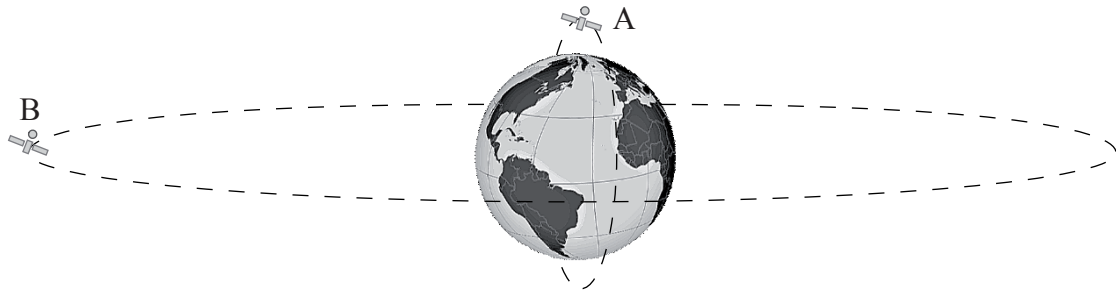


Turn over

(Option F continued)

8. This question is about satellite communication.

The diagram below shows two communications satellites, A and B.



(not to scale)

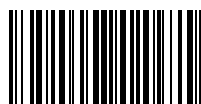
(a) Identify the type of orbit of each satellite. [2]

A: .....
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B: .....
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(b) Suggest whether type A or type B satellites are more suitable for unbroken communication. [2]

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(Option F continues on the following page)



*(Option F, question 8 continued)*

- (c) Explain why satellites require more than one frequency for two-way communication with a ground station. [2]

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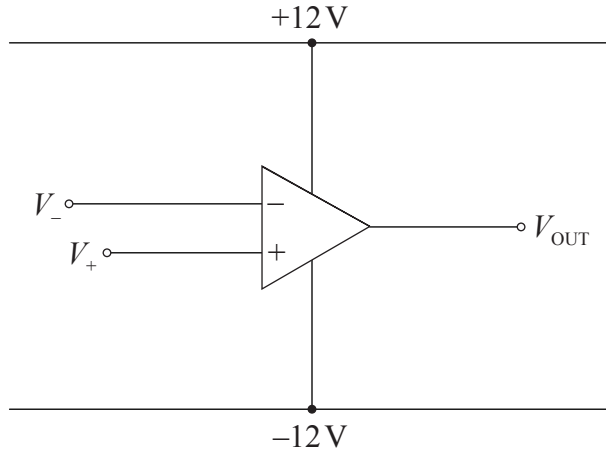
*(Option F continues on the following page)*



(Option F continued)

9. This question is about the operational amplifier (op-amp).

A non-ideal op-amp has a supply voltage of  $\pm 12\text{ V}$  and an open-loop gain of  $10^6$ . In the diagram, the non-inverting and inverting inputs are  $V_+$  and  $V_-$  respectively, and  $V_{\text{OUT}}$  is the output voltage.



(a) State the value of the resistance between the inverting and non-inverting input of an op-amp. [1]

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(b) In the table below, calculate the missing entries for the circuit in (a). The first row has been completed for you. [2]

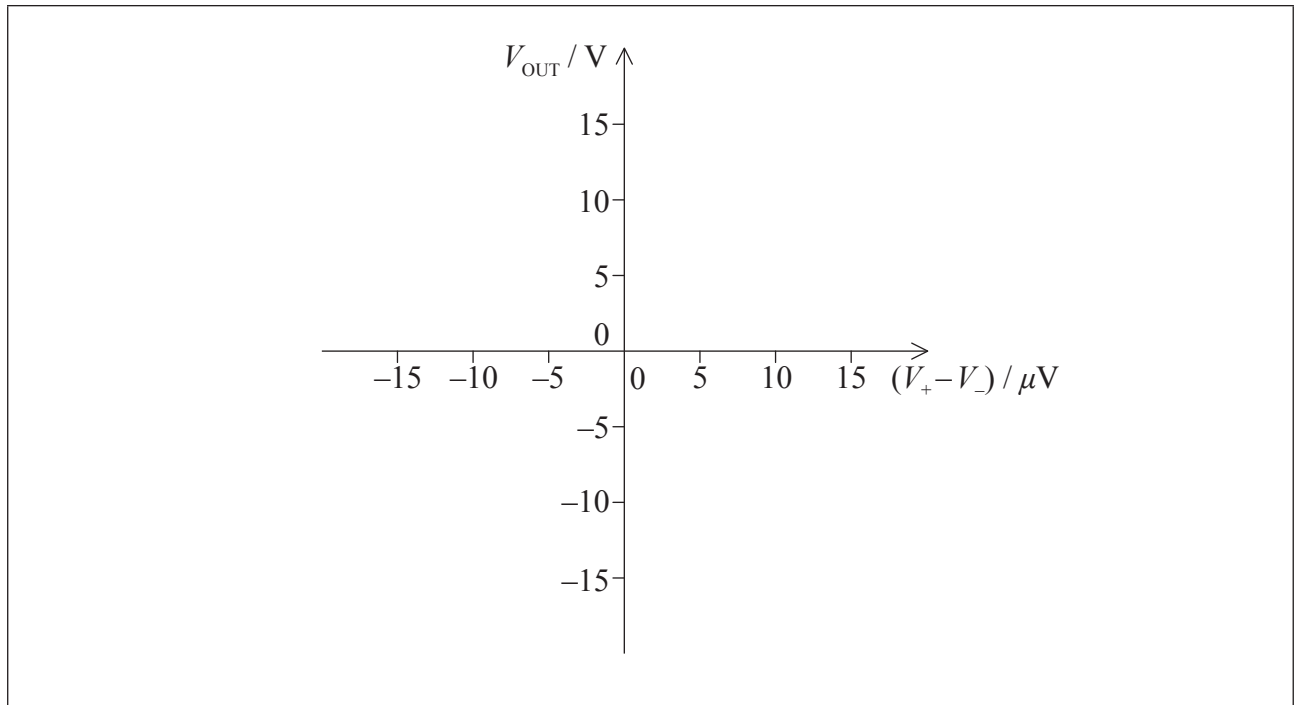
$V_+ - V_-$	$V_{\text{OUT}}$
$0\mu\text{V}$	$0\text{V}$
$8\mu\text{V}$	
$-15\mu\text{V}$	

(Option F continues on the following page)



(Option F, question 9 continued)

- (c) On the axes below, sketch the variation of the output voltage  $V_{\text{OUT}}$  with the input voltage  $(V_+ - V_-)$ . [3]

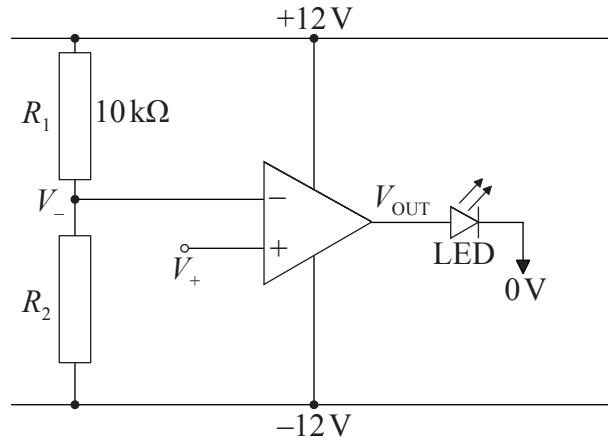


(Option F continues on the following page)



(Option F, question 9 continued)

- (d) Two resistors,  $R_1$  and  $R_2$ , and a light emitting diode (LED) are added to the circuit in (a) as shown below.



- (i) State the name of this configuration for the op-amp. [1]

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- (ii) The circuit in (d) is designed so that the LED turns on when  $V_+$  is greater than 6V. The resistance  $R_1 = 10\text{ k}\Omega$ . Determine the value of resistance  $R_2$ , assuming that the op-amp is ideal. [3]

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**End of Option F**

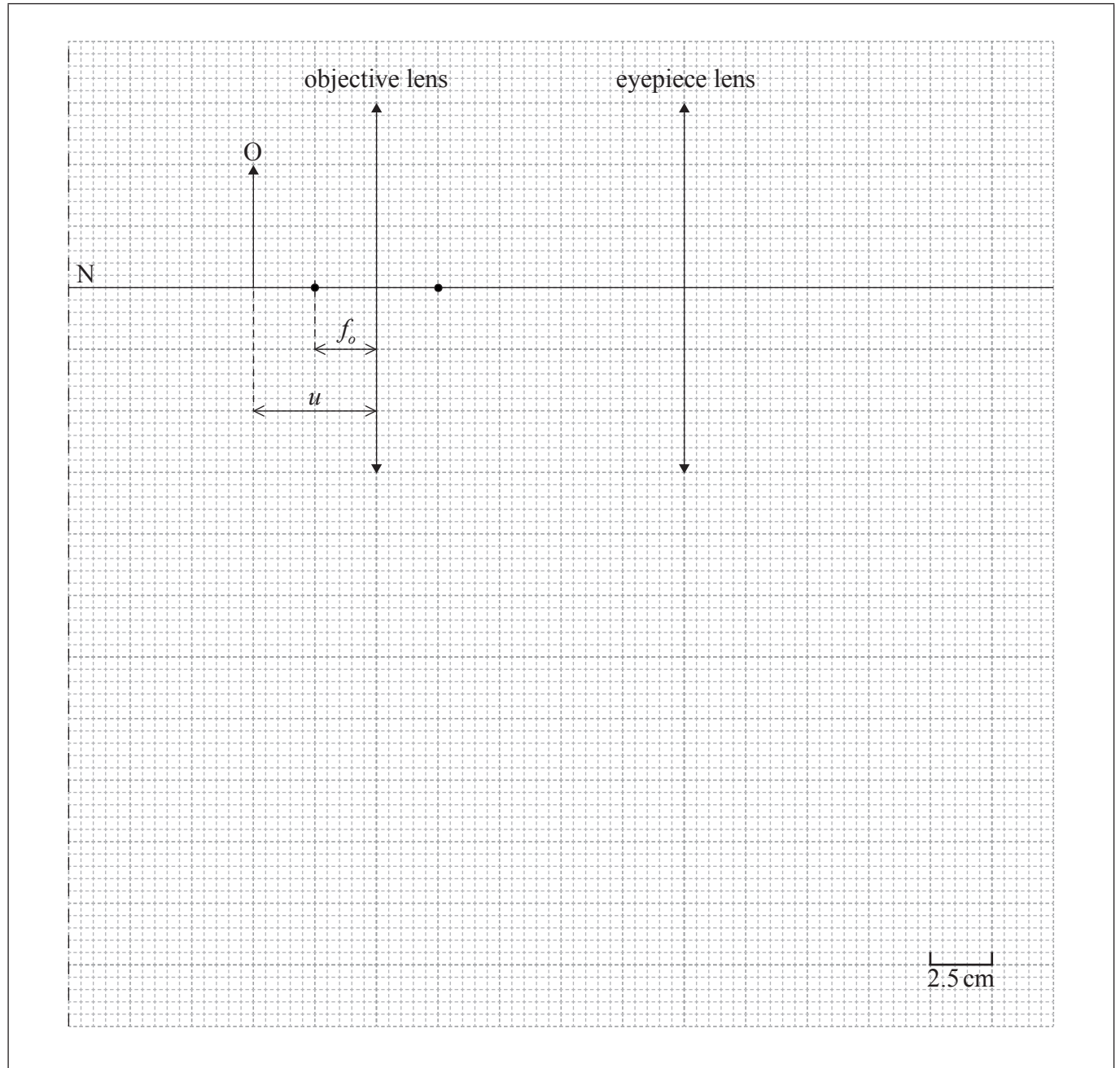




**Option G — Electromagnetic waves**

10. This question is about a compound microscope.

The diagram below shows two thin converging lenses in a compound microscope. The focal length of the objective lens is  $f_o$ . The object  $O$  is placed at a distance  $u$  from the objective lens.



- (a) (i) On the diagram above, construct a ray diagram to locate the position of the image formed by the objective lens. Label this image I. [2]

*(Option G continues on the following page)*



(Option G, question 10 continued)

- (ii) Outline whether the image I is real. [1]

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- (b) The compound microscope in (a) is in normal adjustment so that the final image is formed at the near point of an unaided eye. The position of the near point of the eye is located at N.

- (i) Define *near point*. [1]

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- (ii) Deduce that the focal length of the eyepiece is around 10.7 cm. [3]

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- (iii) Estimate the total linear magnification of the microscope. [2]

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(Option G continues on the following page)



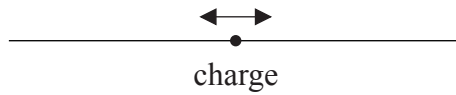
(Option G continued)

11. This question is about the nature and properties of electromagnetic waves.

- (a) Electromagnetic waves propagating in a medium suffer dispersion. Describe what is meant by dispersion. [2]

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- (b) A charge moves backwards and forwards along a wire, as shown in the diagram below.



Outline, with reference to the motion of the charge, why electromagnetic radiation is produced by the moving charge. [2]

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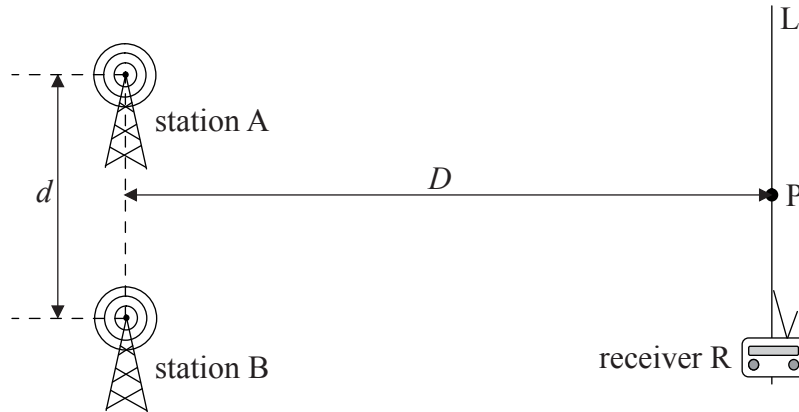
(Option G continues on the following page)



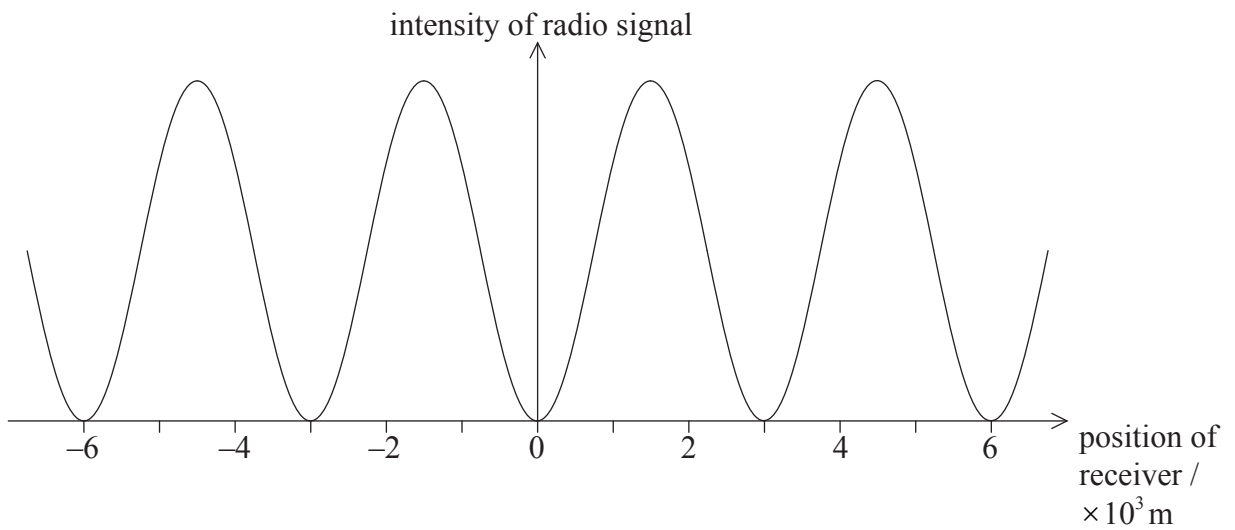
(Option G continued)

12. This question is about interference.

- (a) Two radio stations, A and B, broadcast two coherent signals. The separation  $d$  between A and B is much less than the distance  $D$  from the stations to the receiver R. Point P is at the same distance from A and B.



The graph shows how the intensity of the radio signal varies with position as the receiver is moved along line L. The position of the receiver is zero when the receiver is at P.



(Option G continues on the following page)



*(Option G, question 12 continued)*

- (i) Deduce that the two sources A and B are 180° out-of-phase. [3]

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- (ii) The wavelength of the radio signal is 40 m. Calculate the ratio  $\frac{D}{d}$ . [2]

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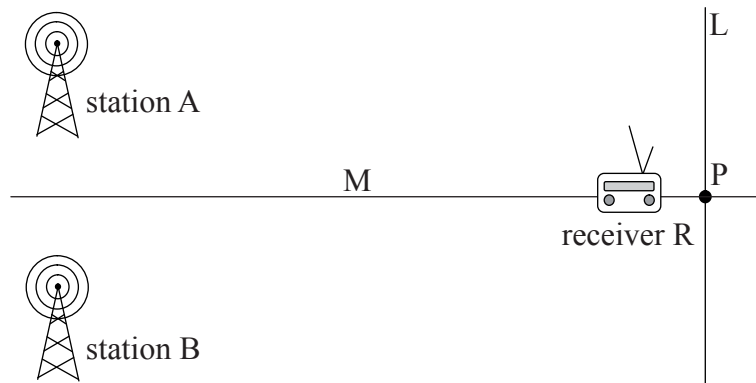
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*(Option G continues on the following page)*



(Option G, question 12 continued)

(b) The receiver R then moves along a different line M which is at  $90^\circ$  to line L.



Discuss the variation of the intensity of the radio signal with position as the receiver is moved along line M. [2]

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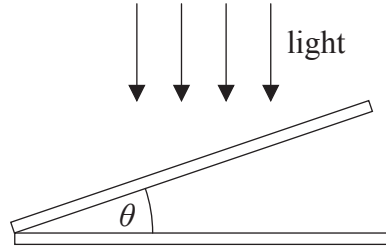
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(Option G continued)

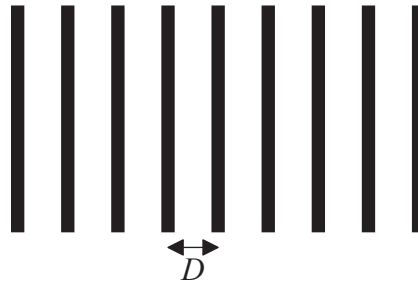
13. This question is about thin-film interference.

A thin air wedge consists of two flat glass plates that form an angle  $\theta$  of  $1.0 \times 10^{-3}$  rad.



(not to scale)

When illuminated with monochromatic light from above, the fringe pattern below is observed in the reflected light. The distance  $D$  between two consecutive fringes is 0.30 mm.



(not to scale)

(a) Calculate the wavelength of the light.

[2]

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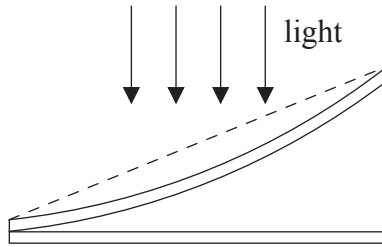
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(Option G continues on the following page)



(Option G, question 13 continued)

- (b) The upper glass plate is now replaced with a curved glass plate. The dotted line represents the upper glass plate used in (a).



Sketch the new fringe pattern in the space below. The fringe pattern of (a) is given for comparison. [2]

A rectangular box containing a fringe pattern for comparison. The pattern consists of a series of vertical black bars of equal height and width, spaced evenly across the width of the box. Below the bars is a white rectangular area, representing the original fringe pattern from part (a).

(Option G continues on the following page)

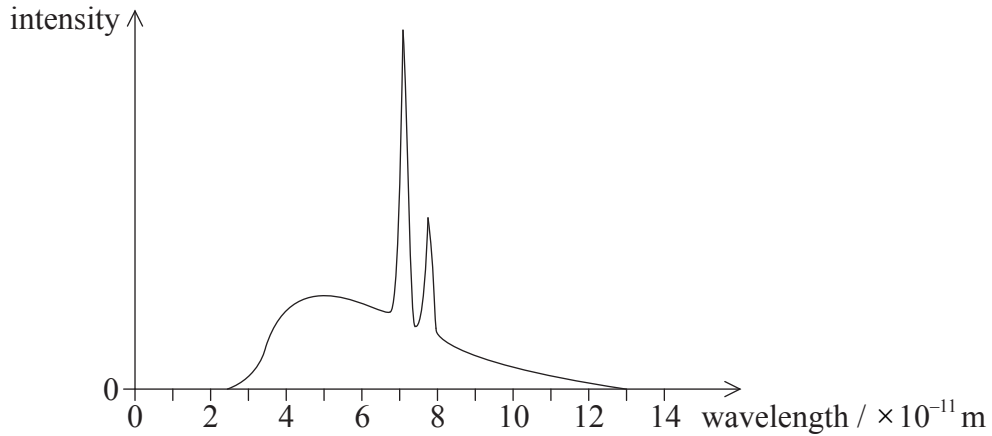




(Option G continued)

14. This question is about X-ray spectra.

The graph shows the spectrum obtained when accelerated electrons collide with a molybdenum target in an X-ray tube.



(a) Using the graph, calculate the accelerating potential difference of the X-ray tube. [2]

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(b) State and explain **one** way in which the intensity of the X-ray beam may be controlled. [2]

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(Option G continues on the following page)



52EP25

Turn over

*(Option G, question 14 continued)*

(c) Explain the origins of the characteristic X-ray spectrum.

[2]

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**End of Option G**



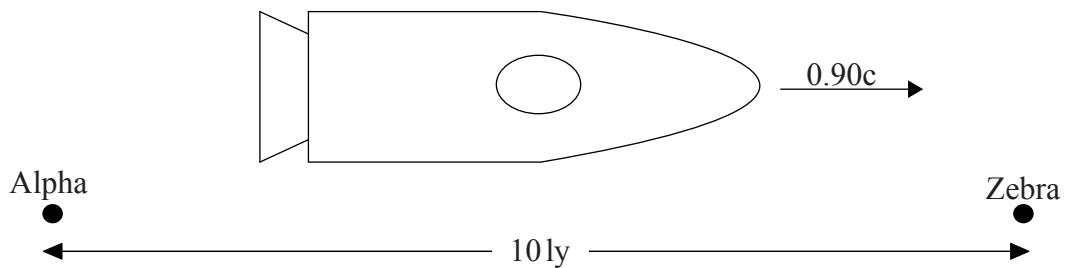
**Option H — Relativity**

15. This question is about relativistic kinematics.

- (a) State what is meant by an inertial frame of reference. [2]

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- (b) A spaceship travels from space station Alpha to space station Zebra at a constant speed of  $0.90c$  relative to the space stations. The distance from Alpha to Zebra is  $10\text{ ly}$  according to space station observers. At this speed  $\gamma = 2.3$ .



Calculate the time taken to travel between Alpha and Zebra in the frame of reference of an observer

- (i) on the Alpha space station. [1]

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- (ii) on the spaceship. [2]

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(Option H continues on the following page)



(Option H, question 15 continued)

- (c) Explain which of the time measurements in (b)(i) and (b)(ii) is a proper time interval. [2]

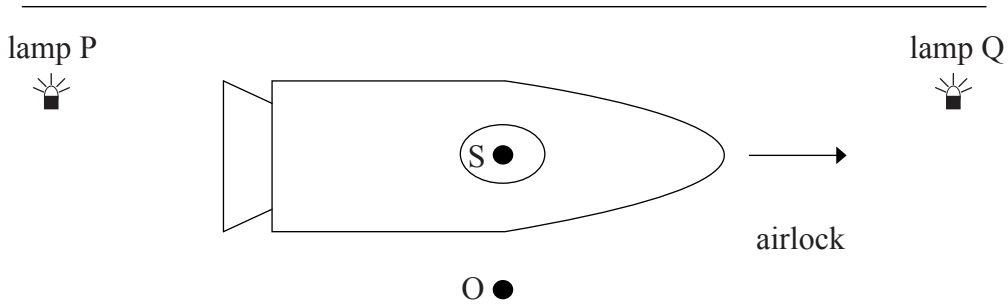
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- (d) The spaceship arrives at Zebra and enters an airlock at constant speed. O is an observer at rest relative to the airlock. Two lamps P and Q emit a flash simultaneously according to the observer S in the spaceship. At that instant, O and S are opposite each other and midway between the lamps.



Discuss whether the lamps flash simultaneously according to observer O. [3]

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(Option H continues on the following page)



*(Option H continued)*

**16.** This question is about relativistic dynamics.

A proton is accelerated from rest through a potential difference of 2.5 GV. Determine the momentum of the proton after acceleration.

[4]

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*(Option H continues on the following page)*



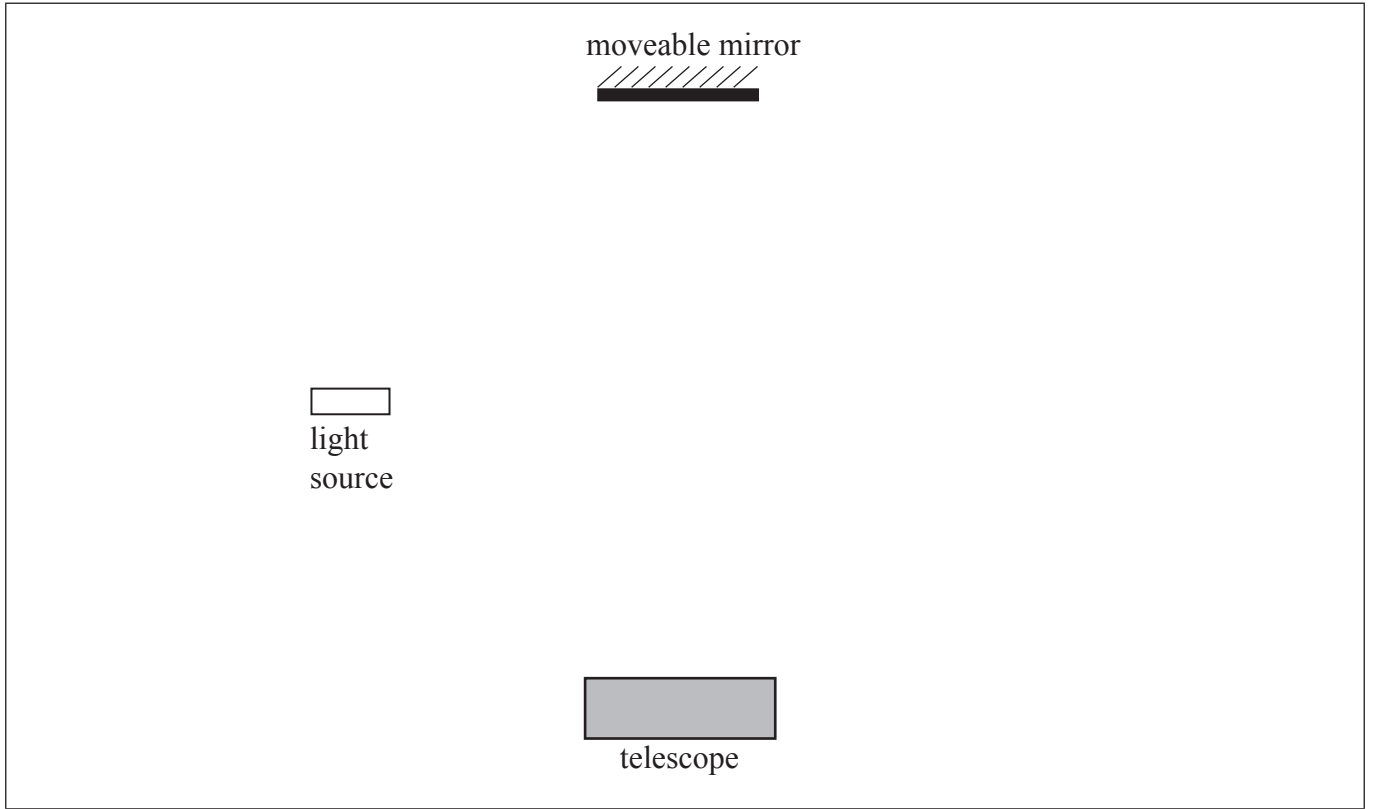
52EP29

**Turn over**

(Option H continued)

17. This question is about the Michelson-Morley experiment.

The diagram shows some features of the apparatus used in the Michelson-Morley experiment.



- (a) Draw and label the **two** missing components in the arrangement used by Michelson and Morley. [2]
  
- (b) Outline how Michelson and Morley used the apparatus in an attempt to detect the presence of an absolute frame of reference. [3]

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(Option H continues on the following page)



*(Option H, question 17 continued)*

- (c) Discuss the result and conclusion that Michelson and Morley obtained using this apparatus. [2]

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18. This question is about general relativity.

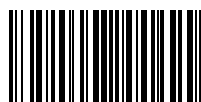
- (a) State the principle of equivalence. [1]

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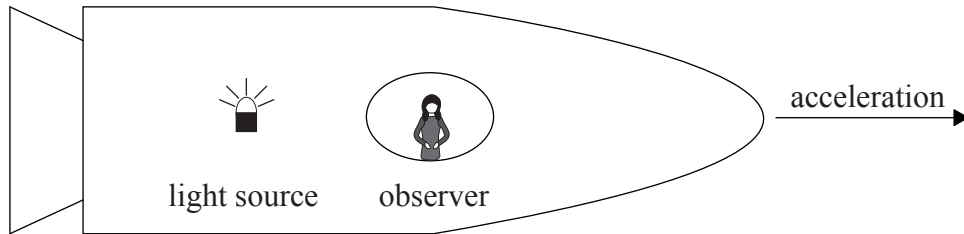
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*(Option H continues on the following page)*



(Option H, question 18 continued)

- (b) An observer in a spaceship moving at constant speed measures the frequency  $f_0$  of light emitted by a source. The spaceship now accelerates to the right.



The observed frequency changes to  $f$ .

- (i) Outline why, during the acceleration,  $f$  is less than  $f_0$ . [2]

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- (ii) Explain how the result outlined in (b)(i) leads to the deduction that time dilates near a planet. [3]

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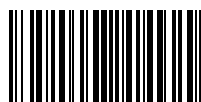
(Option H continues on page 34)





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Answers written on this page  
will not be marked.



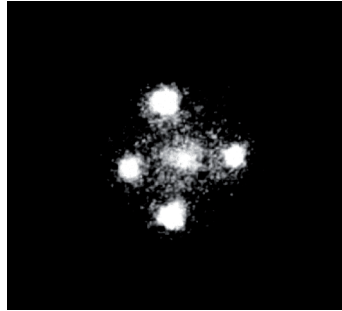
52EP33

Turn over

*(Option H continued)*

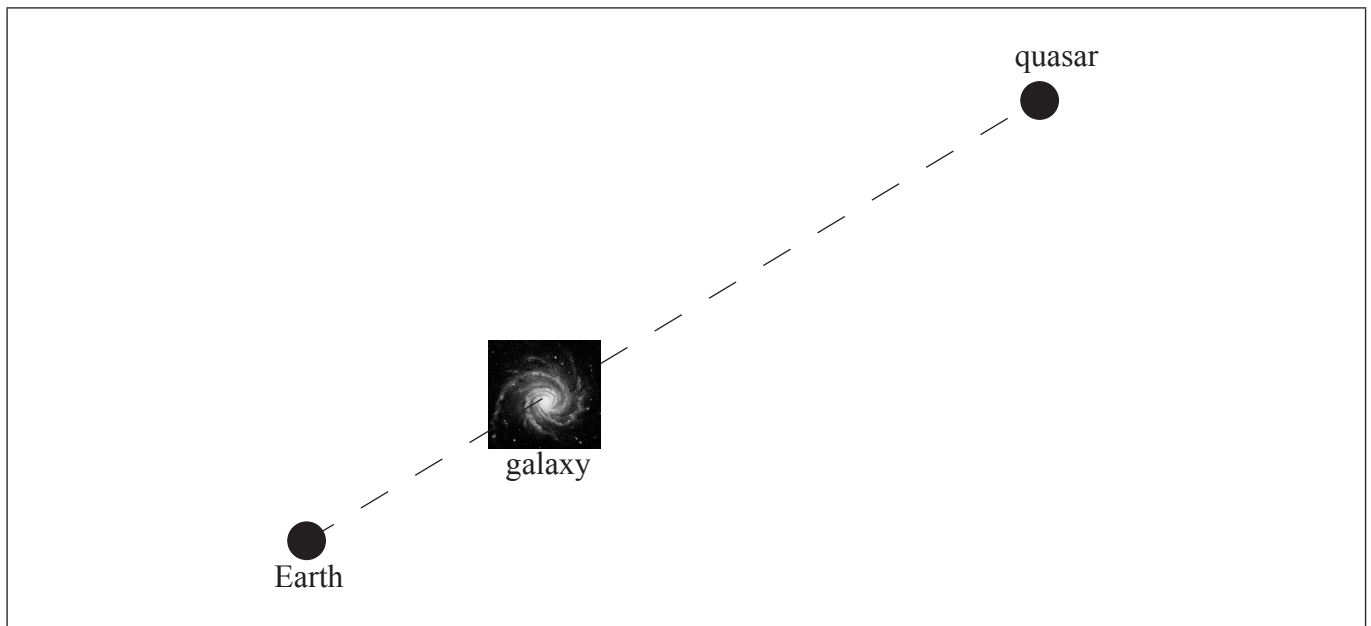
19. This question is about evidence that supports general relativity.

The astronomical photograph taken from Earth shows four separate images of a single distant quasar that appear to surround a galaxy. The galaxy is closer to Earth than the quasar.



[Source: [www.hubblesite.org/newscenter/archive/releases/1990/20/image/a/](http://www.hubblesite.org/newscenter/archive/releases/1990/20/image/a/)]

Outline how one image of the quasar is formed. You may draw on the diagram below that shows the arrangement of the Earth, the galaxy and the quasar to support your answer. [3]



[Source: adapted from [www.sciencephoto.com/media/332699/enlarge](http://www.sciencephoto.com/media/332699/enlarge)]

*(Option H continues on the following page)*



*(Option H, question 19 continued)*

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**End of Option H**



52EP35

**Turn over**

**Option I — Medical physics**

20. This question is about the ear and hearing.

(a) State the range of audible frequencies for a person with normal hearing. [1]

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(b) Distinguish between intensity of sound and sound intensity level. [2]

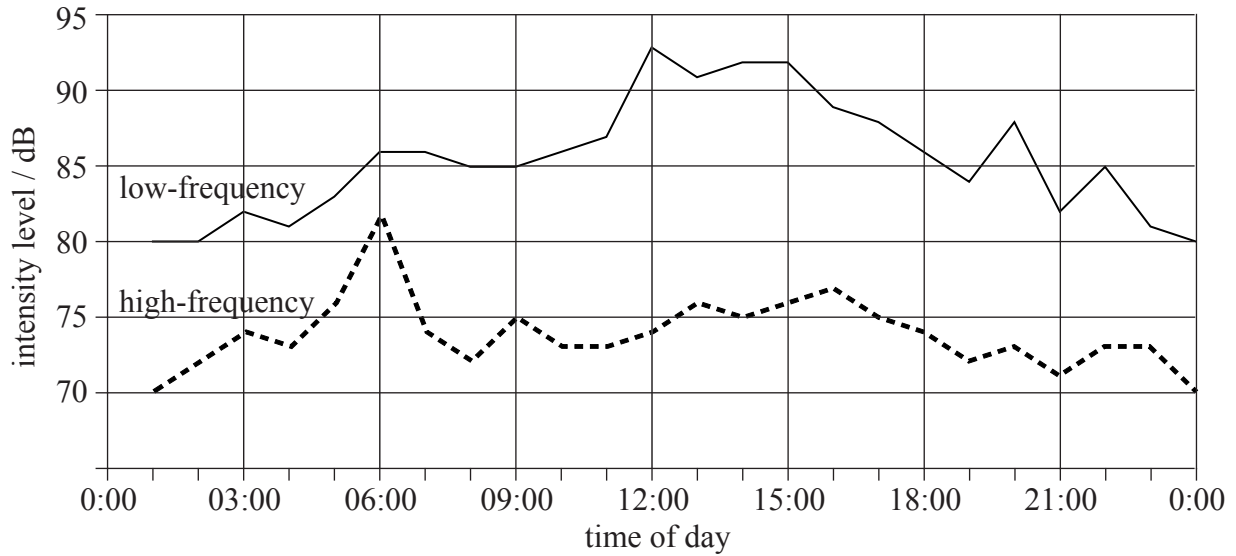
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*(Option I continues on the following page)*



(Option I, question 20 continued)

- (c) A survey on traffic noise was conducted to measure the sound intensity levels in a street during the day. The graphs for low-frequency noise and high-frequency noise are shown below.



Determine the total intensity of sound of noise at 09:00.

[3]

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- (d) Describe the effects on hearing due to long-term exposure to noise.

[2]

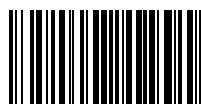
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(Option I continues on the following page)



52EP37

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(Option I continued)

21. This question is about X-rays.

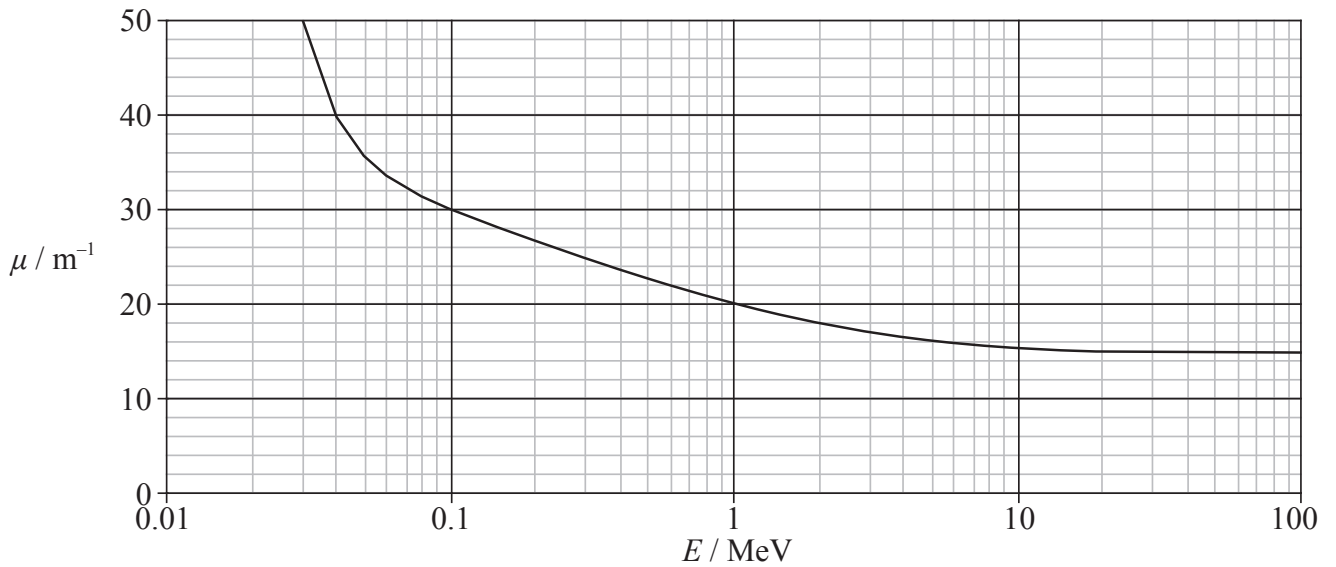
(a) Define *attenuation coefficient*.

[1]

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(b) The graph below shows the variation of attenuation coefficient  $\mu$  with photon energy  $E$  for X-rays in an absorbing medium.



(Option I continues on the following page)



(Option I, question 21 continued)

A beam of X-rays is incident on a sample of the medium with intensity  $I_0$ . Using the graph,

- (i) determine how far X-rays with energy equal to 0.1 MeV travel inside the sample before their intensity reduces to  $0.1 I_0$ . [4]

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- (ii) predict whether X-rays of energy 10 MeV are more penetrating than X-rays of energy 0.1 MeV in this medium. [2]

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(Option I continues on the following page)



*(Option I, question 21 continued)*

- (c) Outline how the use of intensifying screens improves the contrast in an X-ray image. [2]

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- (d) State **one** advantage and **one** disadvantage of conducting a computed tomography (CT) X-ray scan compared with taking a single X-ray image. [2]

advantage: .....  
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disadvantage: .....  
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*(Option I continues on the following page)*





*(Option I continued)*

22. This question is about radiation in medicine.

(a) Distinguish between absorbed dose and dose equivalent.

[2]

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(b) The following data refer to a patient of mass 75 kg exposed to radiation.

absorbed energy	0.65 J
dose equivalent	55 mSv

Type of radiation	Quality factor
X-rays	1
Protons	2
Neutrons	3–10
Alpha particles	20

Using the data above, suggest the likely nature of the radiation used.

[3]

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*(Option I continues on the following page)*



(Option I, question 22 continued)

- (c) Two isotopes of a radioactive nuclide are used in cancer therapy. Isotope X has a physical half-life of 0.7 days and isotope Y has a physical half-life of 7 days. Both X and Y have a biological half-life of 4 days.

- (i) Distinguish between physical half-life and biological half-life. [2]

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- (ii) Calculate the effective half-life for isotope X. [2]

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- (iii) Using the information in (c), suggest which isotope is likely to be better for cancer treatment. [2]

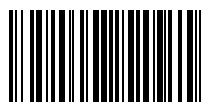
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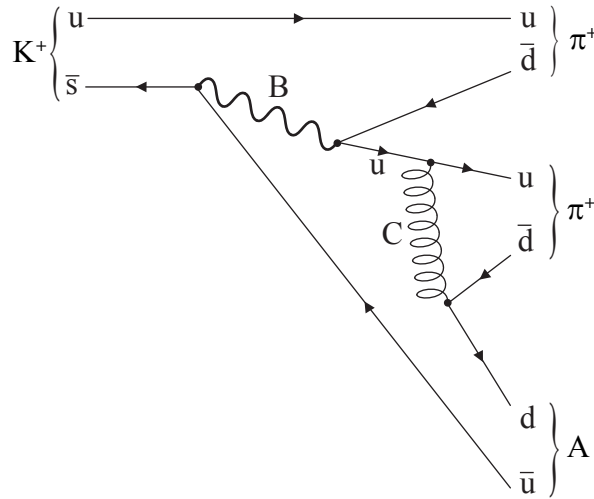
**End of Option I**



**Option J — Particle physics**

23. This question is about fundamental interactions.

The Feynman diagram shows the decay of a  $K^+$  meson into three other particles.



(a) Identify particle A. [1]

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(b) (i) Identify the interaction whose exchange particle is represented by B. [1]

.....

(ii) Identify the exchange particle labelled C. [1]

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*(Option J continues on the following page)*



*(Option J, question 23 continued)*

- (c) Outline, with reference to the conservation of strangeness, whether the decay process shown in the Feynman diagram is possible. [2]

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*(Option J continues on the following page)*



*(Option J continued)*

24. This question is about mesons.

The  $\pi^0$  meson has a mass of about  $135 \text{ MeV c}^{-2}$ .

- (a) The  $\pi^0$  meson is considered to be the exchange particle of the strong interaction. Show that the range of the strong interaction is approximately equal to the diameter of a proton. [2]

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- (b) Energy is supplied to a meson in order to separate the quark from the antiquark. With reference to quark confinement, predict the likely outcome of this experiment. [2]

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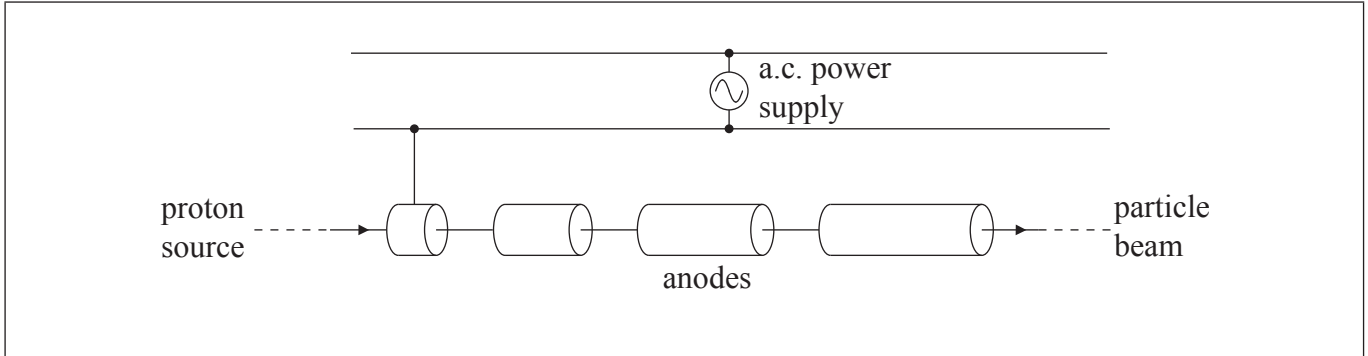
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(Option J continued)

25. This question is about particle accelerators.

The diagram shows part of a linear accelerator used to produce high-energy protons.



(a) Draw suitable power supply connections to the anodes to complete the diagram. The first anode connection has already been drawn for you. [1]

(b) (i) Outline how the protons are accelerated. [3]

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(ii) Explain why the length of the anodes in the machine is not constant. [3]

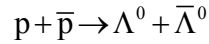
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(Option J, question 25 continued)

- (c) A particle and its antiparticle ( $\Lambda^0$  and  $\bar{\Lambda}^0$ ) can be produced in an accelerator when a proton and anti-proton pair collide in the following reaction.



The minimum energy required to produce the  $\Lambda$  pair is 2230 MeV.

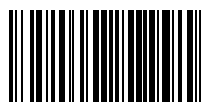
- (i) Show that the minimum kinetic energy of a proton required to produce the  $\Lambda$  pair in a collision with a stationary antiproton is about 770 MeV. [2]

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- (ii) In a synchrotron, the same collision takes place with proton and antiproton beams moving in opposite directions. Explain, using a calculation, the advantage that synchrotrons have over linear accelerators for production of the  $\Lambda$  pairs. [2]

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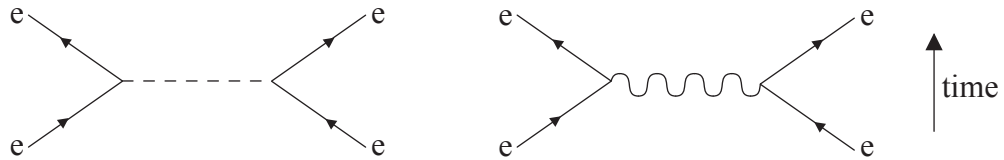
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(Option J continued)

26. This question is about the standard model.

The Feynman diagrams show two electroweak interactions between electrons. The particle represented by the wavy line is a photon.



(a) State

(i) the name of the exchange particle represented by the dotted line. [1]

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(ii) one difference between the two exchange particles. [1]

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(b) Outline how the observation of the interaction represented by the diagram with the dotted line provides evidence for the standard model. [2]

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(Option J continues on the following page)





*(Option J, question 26 continued)*

- (c) String theory provides an alternative explanation for the behaviour of particles. State **two** differences between string theory and the standard model. [2]

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2	.....
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*(Option J continues on the following page)*



(Option J continued)

27. This question is about particle-antiparticle production in the early universe.

It is suggested that about 100 s after the Big Bang the temperature of the universe was  $10^9$  K.

(a) State the value of the ratio

$$\frac{\text{temperature of the universe } 10^{-43} \text{ s after the Big Bang}}{\text{temperature of the universe 100s after the Big Bang}} \quad [1]$$

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(b) Determine whether electron–positron pair production on a large-scale was likely in the universe 100 s after the Big Bang. [3]

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**End of Option J**



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