

Physics
Higher level
Paper 3

Monday 11 May 2015 (afternoon)

Candidate session number

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]**.

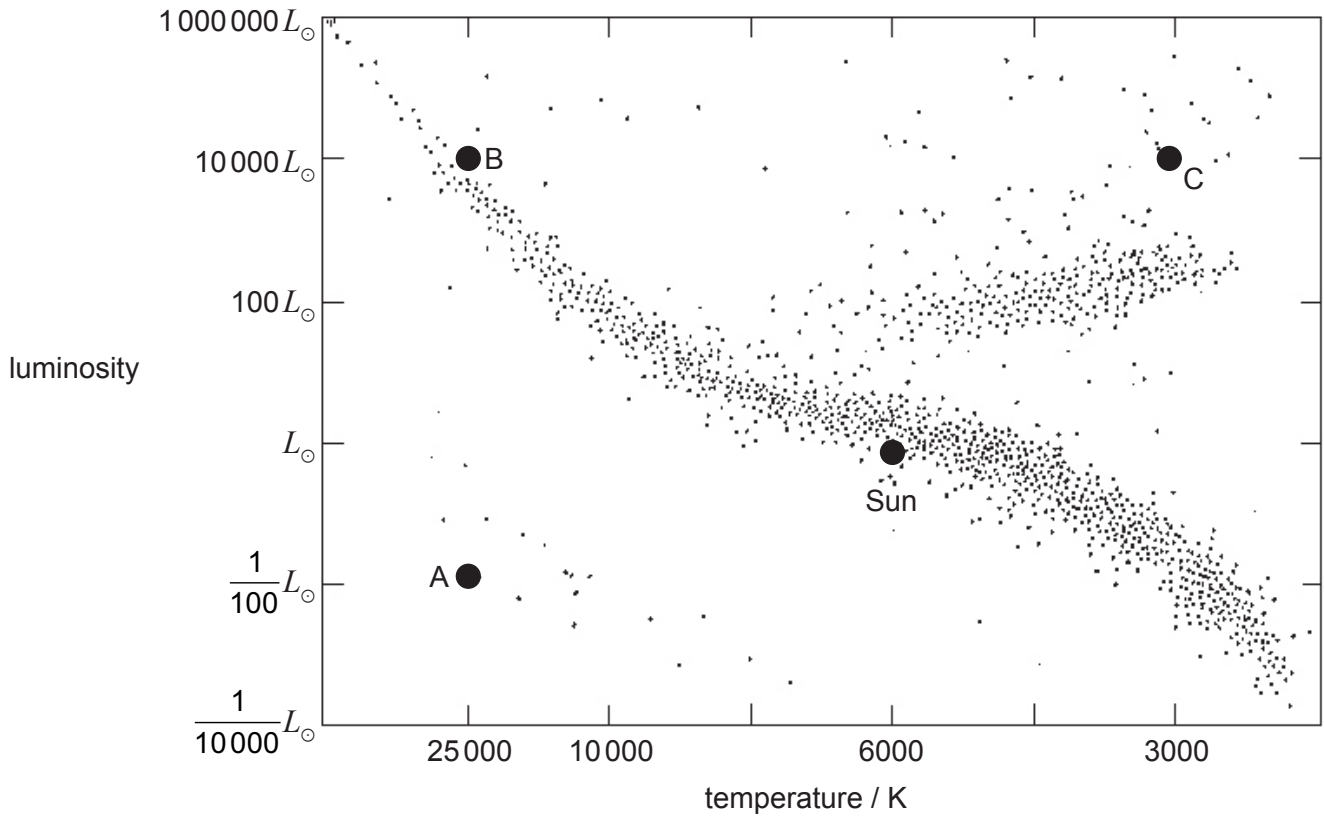
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Option E — Astrophysics

1. This question is about stars.

The Hertzsprung–Russell (HR) diagram shows the position of the Sun and three stars labelled A, B and C.



(a) State the star type for A, B and C. [3]

A:
B:
C:

(Option E continues on the following page)



(Option E, question 1 continued)

- (b) Determine the ratio $\frac{\text{radius of B}}{\text{radius of A}}$. [2]

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- (c) The apparent brightness of C is $3.8 \times 10^{-10} \text{ W m}^{-2}$. The luminosity of the Sun is $3.9 \times 10^{26} \text{ W}$.

- (i) State what is meant by apparent brightness and luminosity. [2]

Apparent brightness:
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Luminosity:
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- (ii) Determine the distance of C from Earth. [2]

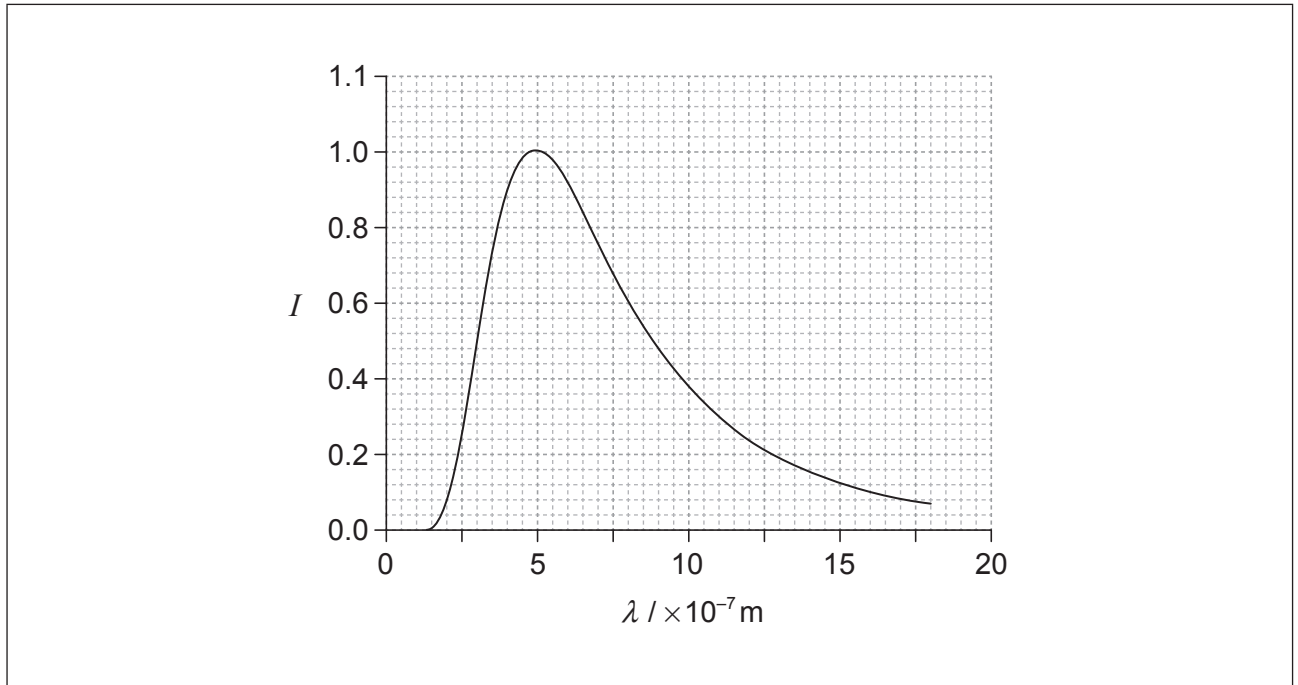
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(Option E, question 1 continued)

- (d) The graph shows the variation with wavelength λ of the intensity I of the radiation emitted by 1.0 m^2 of the surface of the Sun. The curve of the graph has been adjusted so that the maximum intensity is 1.



On the grid, draw a corresponding graph for star C. Your curve should have a maximum intensity of 1.

[2]

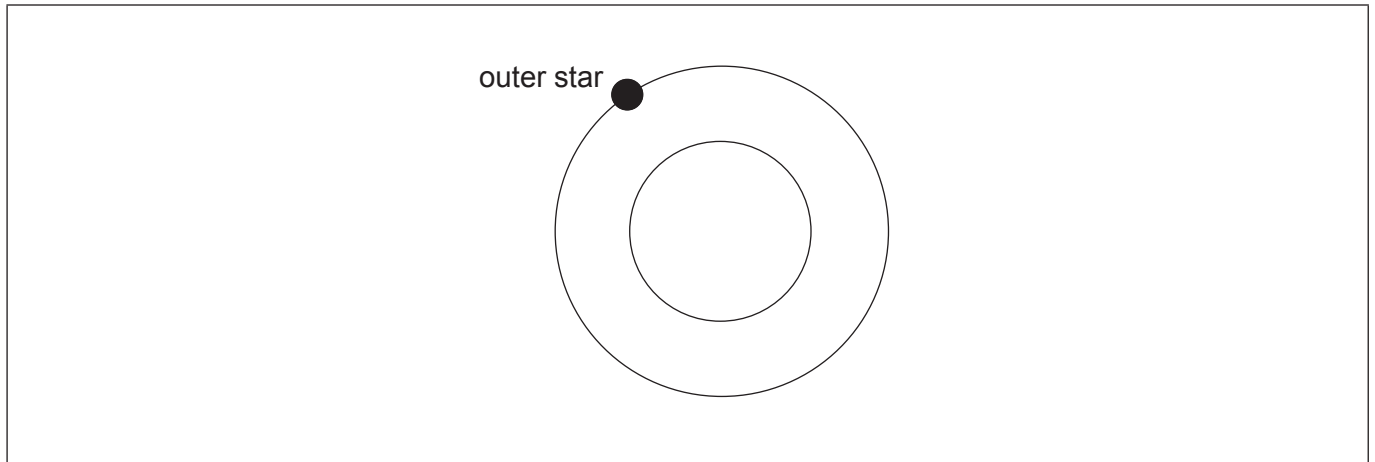
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(Option E continued)

2. This question is about eclipsing binary stars.

The two circles in the diagram represent the orbits of two stars in a binary star system. The position of the outer star is shown.

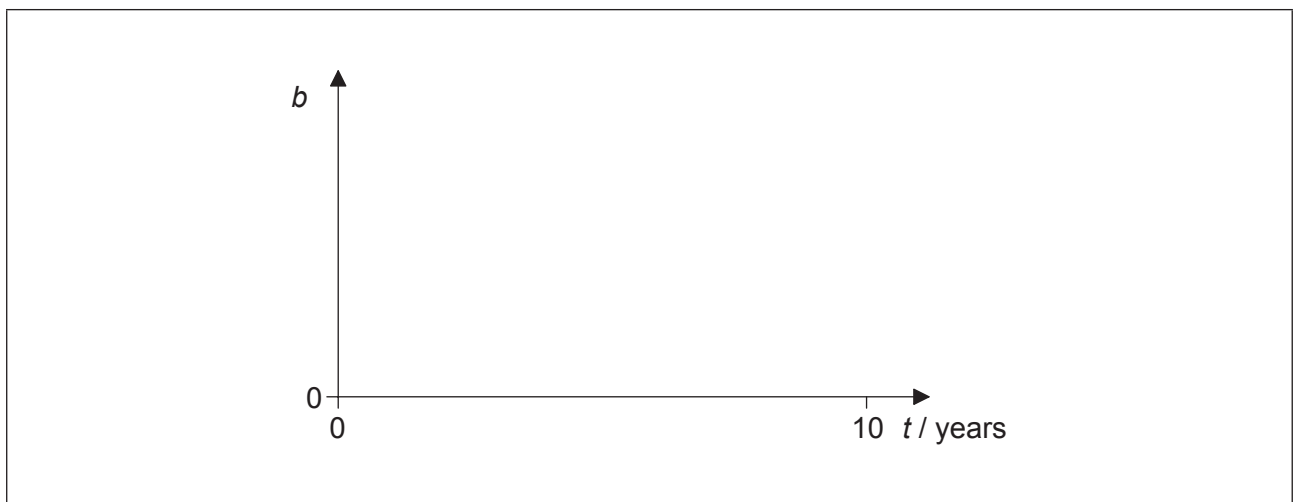


(a) On the diagram, draw a dot to indicate the position of the second star. Label this S. [1]

(b) State **one** condition that must be met for this system to be classified as an eclipsing binary star system. [1]

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(c) The two stars have the same radius but different apparent brightness. The period of revolution of the two stars is 10 years. On the axes, sketch a graph to show the variation with time t of the combined apparent brightness b of the two stars. [2]



(Option E continues on the following page)



48EP05

Turn over

(Option E continued)

3. This question is about the expanding universe.

Since 1929 it has been thought that the universe is expanding.

(a) State what is meant by the expansion of the universe. [1]

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(b) Red-shift of light from distant galaxies provides evidence for an expanding universe.

(i) State **one** other piece of evidence in support of an expanding universe. [1]

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(ii) Explain how your answer in (b)(i) is evidence for the Big Bang model of the universe. [3]

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(Option E continues on the following page)



(Option E continued)

4. This question is about stellar evolution.

- (a) The mass of a main sequence star is two solar masses. Estimate, in terms of the solar luminosity, the range of possible values for the luminosity of this star. [2]

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- (b) The star in (a) will eventually leave the main sequence.

State

- (i) the condition that must be satisfied for this star to eventually become a white dwarf. [1]

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- (ii) the source of the energy that the white dwarf star radiates into space. [1]

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- (iii) **one** likely element, other than hydrogen and helium, that may be found in a white dwarf. [1]

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(Option E continues on the following page)



(Option E, question 4 continued)

- (c) Explain why a white dwarf maintains a constant radius. [2]

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5. This question is about Hubble's law.

- (a) A galaxy a distance d away emits light of wavelength λ . Show that the shift in wavelength $\Delta\lambda$, as measured on Earth, is given by

$$\Delta\lambda = \frac{H_0 d \lambda}{c}$$

where H_0 is the Hubble constant.

[1]

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- (b) Light of wavelength 620 nm is emitted from a distant galaxy. The shift in wavelength measured on Earth is 35 nm. Determine the distance to the galaxy using a Hubble constant of $68 \text{ km s}^{-1} \text{ Mpc}^{-1}$.

[2]

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End of Option E



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48EP09

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Option F — Communications

6. This question is about amplitude modulation (AM).

(a) Describe what is meant by amplitude modulation (AM). [2]

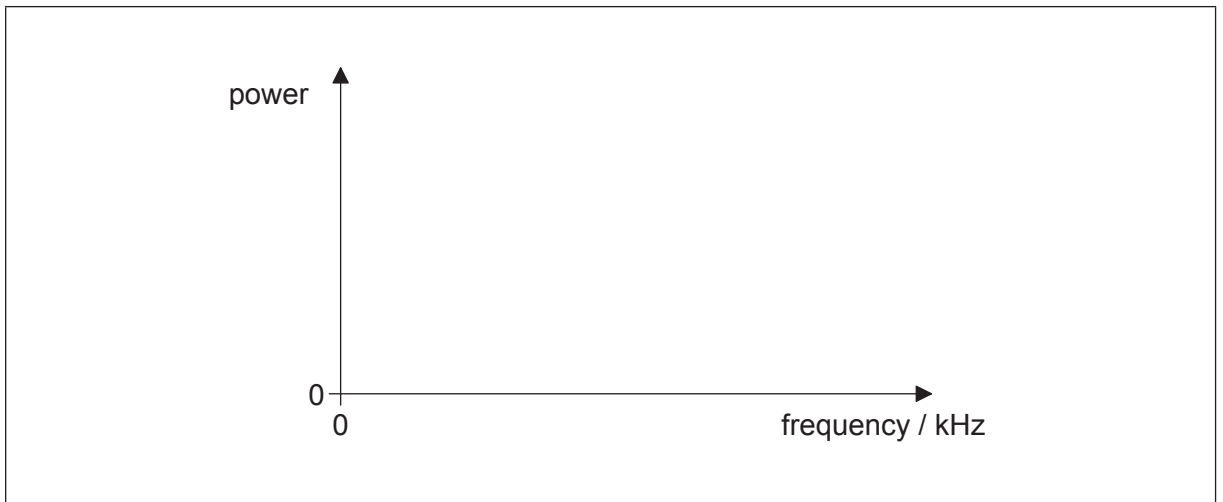
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(b) A carrier wave has a frequency of 540 kHz. It is amplitude-modulated by a signal wave of frequency 4.0 kHz.

(i) State the bandwidth of the modulated carrier wave. [1]

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(ii) On the axes, sketch the power spectrum of the modulated carrier wave. [2]

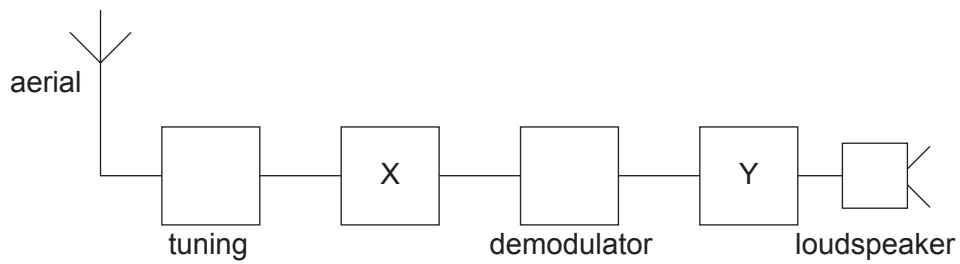


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(Option F, question 6 continued)

(c) The block diagram shows an AM radio receiver.



Identify the blocks labelled X and Y.

[2]

X:

Y:

7. This question is about digital signals.

(a) A two-channel (stereo) recording is made at a sampling frequency of 44.1 kHz, using 16-bit sampling in each channel.

(i) Determine the bit-rate during the recording.

[1]

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(ii) Determine the duration of **one** sample.

[2]

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(Option F continues on the following page)



48EP11

Turn over

(Option F, question 7 continued)

- (b) Explain **one** change to the process that could be used to improve the quality of the transmission.

[2]

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- (c) The sample is digitized. Time-division multiplexing is used to send this digital signal to a radio transmitter. Describe what is meant by time-division multiplexing.

[2]

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(Option F continues on the following page)



(Option F continued)

8. This question is about optic fibre transmission.

(a) Explain, with reference to the critical angle, what is meant by total internal reflection. [3]

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(b) In an optic fibre the refractive index of the core is 1.62. The refractive index for the cladding is 1.50. Determine the critical angle for the boundary between the core and the cladding. [2]

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(c) State **one** effect of dispersion on a pulse that has travelled along an optic fibre. [1]

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(Option F continues on the following page)



48EP13

Turn over

(Option F continued)

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

(a) State **two** properties of an ideal operational amplifier (op-amp).

[2]

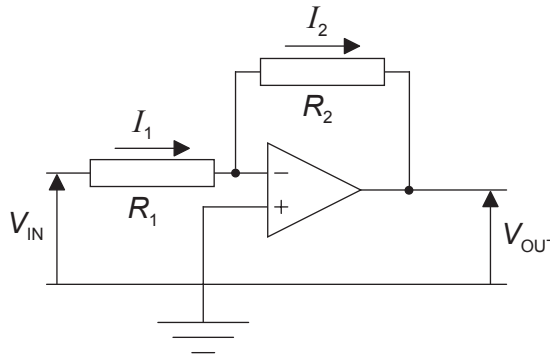
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(b) The diagram shows an op-amp connected as an inverting amplifier. The input voltage is V_{IN} and the output voltage is V_{OUT} .



Show that the gain of the amplifier is $\frac{V_{OUT}}{V_{IN}} = -\frac{R_2}{R_1}$.

[3]

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(Option F continues on the following page)



(Option F, question 9 continued)

(c) The op-amp in (b) is powered by a supply of $\pm 15\text{V}$. The resistance R_1 is $50\text{k}\Omega$ and the resistance R_2 is $600\text{k}\Omega$.

(i) Determine the output voltage V_{OUT} when the input voltage V_{IN} is 0.70V . [2]

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(ii) Estimate the output voltage V_{OUT} when the input voltage V_{IN} is 1.7V . [1]

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(iii) Outline the reasoning for your answer to (c)(ii). [2]

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End of Option F



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Option G — Electromagnetic waves

10. This question is about electromagnetic (EM) waves and lasers.

(a) Outline the nature of electromagnetic (EM) waves. [3]

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(b) Distinguish between absorption and scattering of EM radiation. [2]

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(c) State **one** application of laser technology. [1]

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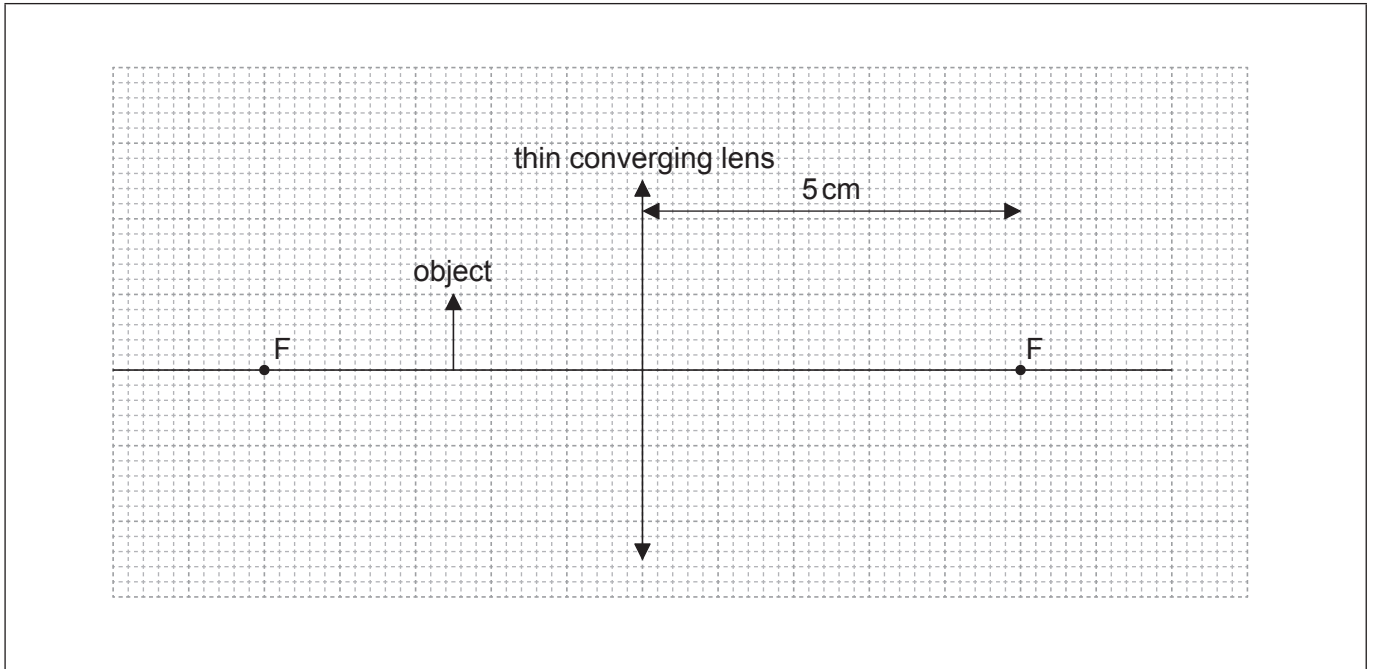
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(Option G continued)

11. This question is about a thin converging (convex) lens.

The diagram shows an object placed in front of a thin converging lens.



The focal points of the lens are labelled F.

(a) (i) Using the diagram, determine the power of the lens. [2]

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(ii) On the diagram, construct lines to show how the image of the object is formed by the lens. [3]

(Option G continues on the following page)



(Option G, question 11 continued)

- (iii) State and explain whether the image is a real image **or** a virtual image. [2]

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- (b) Argus uses an astronomical telescope to observe a telecommunications tower. The height of the tower is 82m and the distance from Argus to the tower is 4.0 km. The image formed by the telescope has an angular diameter of 0.10 rad and is formed at infinity.

- (i) Determine the angular magnification of the telescope. [2]

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- (ii) The focal length of the eyepiece is 15 cm. Calculate the focal length of the objective lens. [1]

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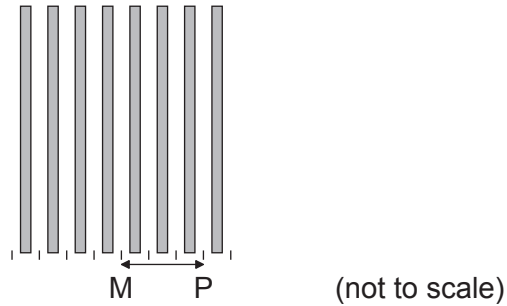
(Option G continues on the following page)



(Option G continued)

12. This question is about a double-slit experiment.

Coherent monochromatic light is incident on two narrow rectangular slits. The diagram shows the fringes produced on a screen that is some distance from the slits. M is the middle of the central bright fringe and P is the middle of the third bright fringe.



(a) Explain why an interference pattern is produced on the screen.

[2]

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(b) The two slits are separated by 2.2 mm and the distance from the slits to the screen is 1.8 m. The wavelength of the light is 650 nm. Calculate the distance MP.

[2]

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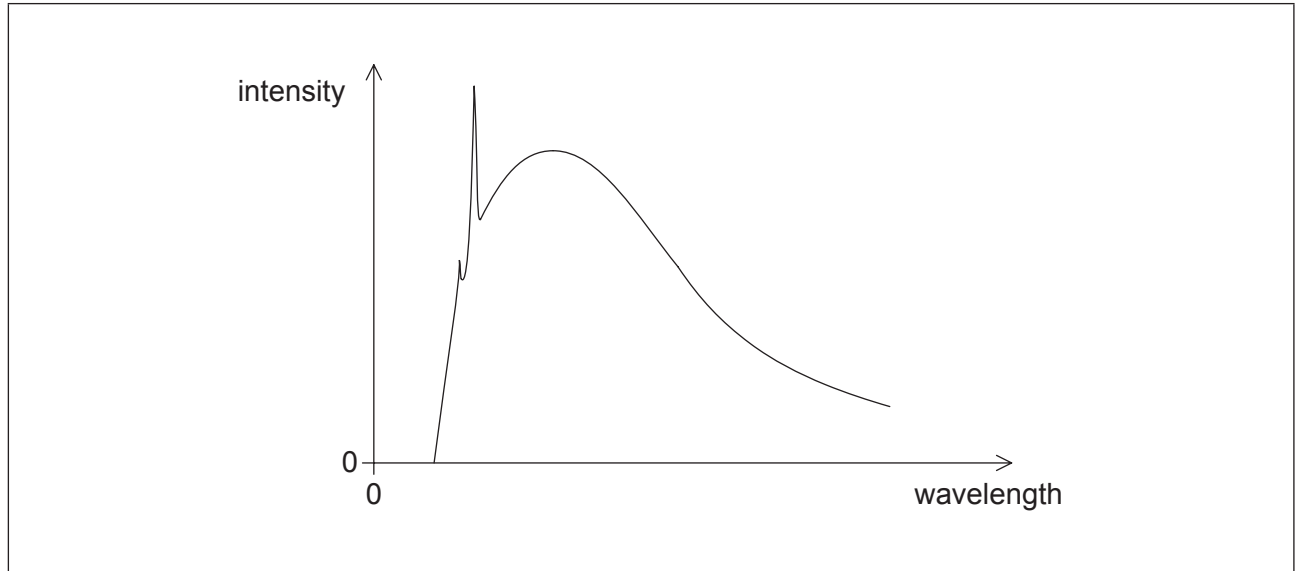
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(Option G continued)

13. This question is about X-rays.

(a) The graph shows an X-ray spectrum.



On the graph,

- (i) annotate the main features of this spectrum. [3]
- (ii) sketch the spectrum that would be observed if the accelerating potential difference is increased. [2]
- (b) A medical imaging X-ray machine accelerates electrons to a kinetic energy of 40 keV. Show that the minimum wavelength λ_{\min} of the produced X-rays is 3.1×10^{-11} m. [2]

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(Option G continues on the following page)



(Option G, question 13 continued)

- (c) X-rays of wavelength 3.1×10^{-11} m are directed normally at a crystal of lattice spacing $d = 8.9 \times 10^{-11}$ m. Calculate the difference between the angles at which the first and third maxima of the scattered X-rays are observed. [3]

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End of Option G



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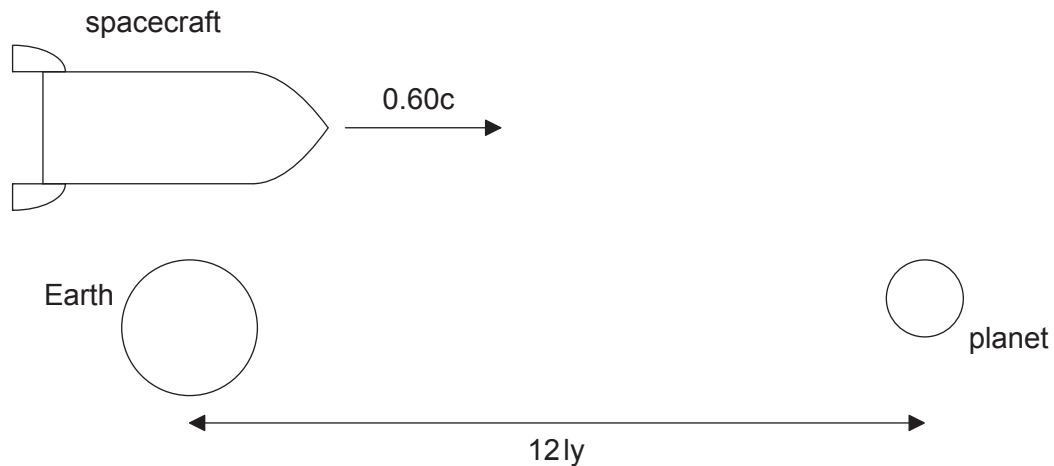
48EP23

Turn over

Option H — Relativity

14. This question is about relativistic kinematics.

A spacecraft leaves Earth and moves towards a planet. The spacecraft moves at a speed $0.60c$ relative to the Earth. The planet is a distance of 12 ly away according to the observer on Earth.



(a) Determine the time, in years, that it takes the spacecraft to reach the planet according to the

(i) observer on Earth.

[1]

<p>.....</p> <p>.....</p>

(ii) observer in the spacecraft.

[2]

<p>.....</p> <p>.....</p> <p>.....</p> <p>.....</p>

(Option H continues on the following page)



(Option H, question 14 continued)

(b) The spacecraft passes a space station that is at rest relative to the Earth. The proper length of the space station is 310 m.

(i) State what is meant by proper length. [1]

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(ii) Calculate the length of the space station according to the observer in the spacecraft. [2]

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(Option H continues on the following page)

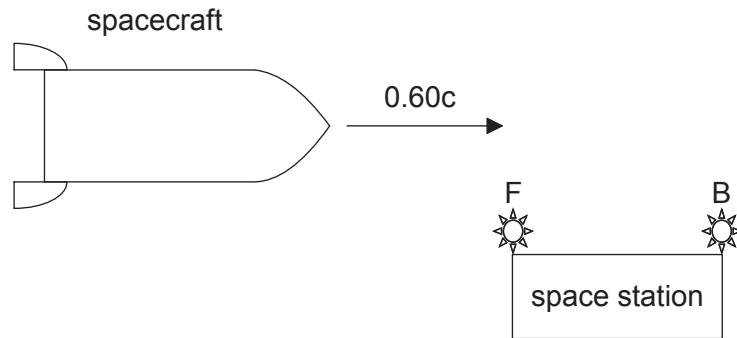


48EP25

Turn over

(Option H, question 14 continued)

- (c) F and B are two flashing lights located at the ends of the space station, as shown. As the spacecraft approaches the space station in (b), F and B turn on. The lights turn on simultaneously according to the observer on the space station who is midway between the lights.



State and explain which light, F or B, turns on first according to the observer in the **spacecraft**.

[4]

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(Option H continues on the following page)



(Option H continued)

15. This question about the Michelson–Morley experiment.

- (a) (i) State the purpose of the Michelson–Morley experiment. [1]

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- (ii) Outline why the experimental apparatus was rotated by 90° as part of the experiment. [2]

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- (b) Outline the relevance of the Michelson–Morley experiment to the theory of special relativity. [2]

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(Option H continues on the following page)



(Option H continued)

16. This question is about relativistic mechanics.

A proton is accelerated from rest through a potential difference of 1.5 GV.

Calculate, for the accelerated proton, the

(a) total energy. [2]

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(b) momentum. [2]

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(c) speed. [2]

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(Option H continues on the following page)



(Option H continued)

17. This question is about gravitation.

Planets move in orbits around the Sun. Explain this observation according to

(a) Newton's universal law of gravitation.

[2]

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(b) Einstein's theory of general relativity.

[2]

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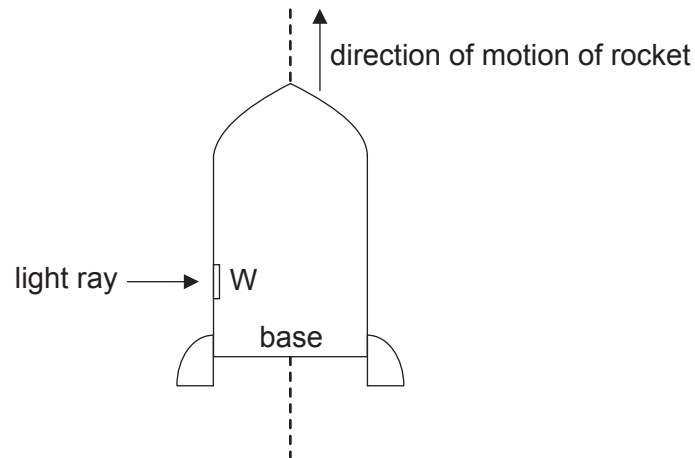
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(Option H continued)

18. This question is about general relativity.

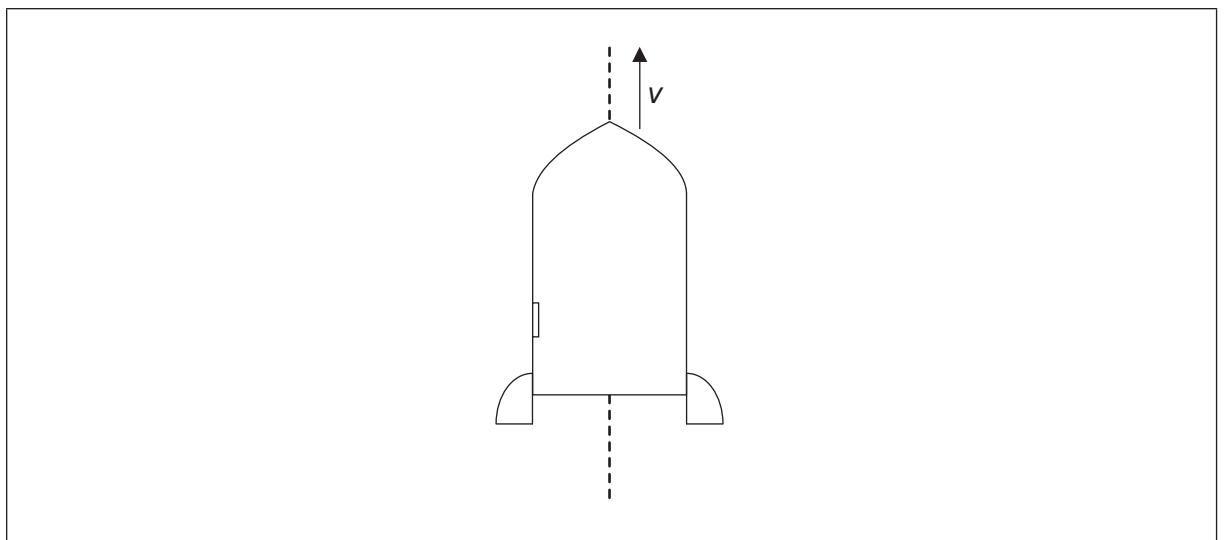
A rocket is in outer space far from all masses. It moves along the dotted line according to an inertial observer located outside the rocket.



(a) A ray of light is moving at right angles to the direction of the rocket according to the same inertial observer. The ray of light enters the rocket through a window W. Draw the path of the light ray according to an observer at rest inside the rocket,

(i) when the rocket is moving at constant speed v .

[1]



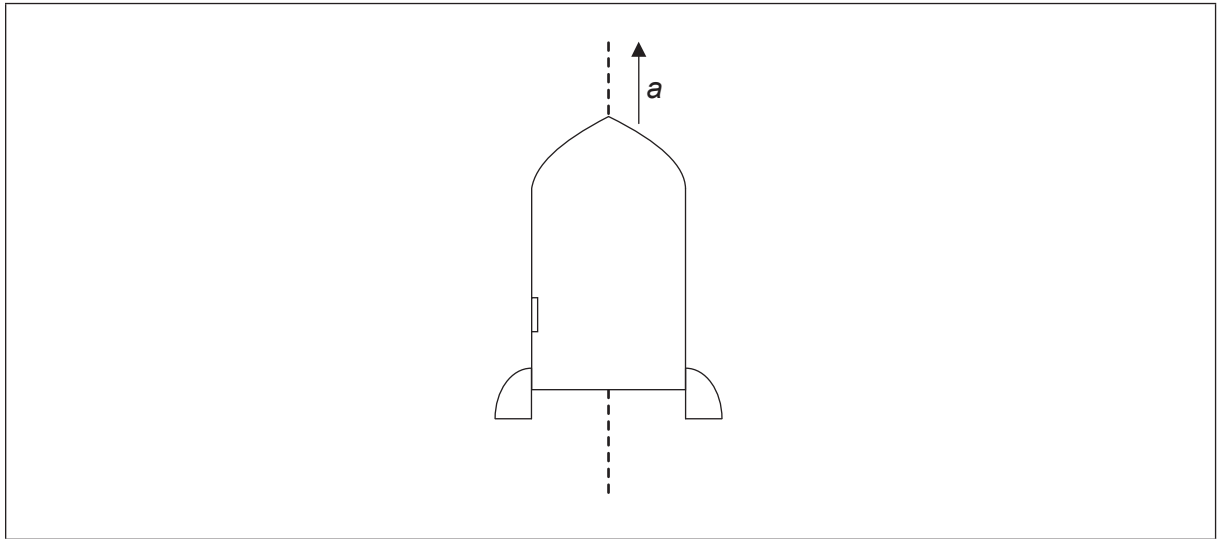
(Option H continues on the following page)



(Option H, question 18 continued)

(ii) when the rocket is moving at constant positive acceleration a .

[1]



(b) The acceleration of the rocket in (a)(ii) is 12 m s^{-2} . A gamma ray is emitted from the base of the rocket. The frequency at the base is $f_{\text{base}} = 3.4 \times 10^{18} \text{ Hz}$. A detector in the rocket is at a distance of 25 m above the base. The frequency measured by the detector is f_{detector} . Determine the frequency shift $f_{\text{detector}} - f_{\text{base}}$.

[3]

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End of Option H



48EP31

Turn over

Option I — Medical physics

19. This question is about the ear.

- (a) Sound is incident on a student's ear drum. He is a young, healthy adult. Describe the physical processes which lead to the sensation of hearing in his brain. [4]

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- (b) The student is listening to music through headphones connected to an amplifier. The power of the sound at his ear drum is $0.12\mu\text{W}$. The area of his ear drum is 65mm^2 . Calculate, for the student's ear, the

- (i) intensity of sound. [1]

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- (ii) intensity level (IL). [2]

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(Option I continues on the following page)



(Option I, question 19 continued)

- (c) The student then increases the power in two stages: from $0.12 \mu\text{W}$ to $0.60 \mu\text{W}$ and then from $0.60 \mu\text{W}$ to $3.0 \mu\text{W}$. Explain why the change in the observed loudness at each stage will be the same. [2]

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(Option I continues on the following page)



48EP33

Turn over

(Option I continued)

20. This question is about X-rays.

- (a) (i) X-rays travelling in a medium experience attenuation. State what is meant by attenuation. [1]

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- (ii) Show that the half-value thickness $x_{\frac{1}{2}}$ is related to the attenuation coefficient μ by

$$\mu x_{\frac{1}{2}} = \ln 2 . \quad [2]$$

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- (iii) Estimate the fraction of the incident intensity of an X-ray beam that has travelled through 2.0 cm of muscle. The half-value thickness of muscle is 0.73 cm. [2]

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(Option I continues on the following page)



(Option I, question 20 continued)

(b) Compare standard X-ray imaging to computed tomography (CT). [3]

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(Option I continues on the following page)



48EP35

Turn over

(Option I continued)

21. This question is about ultrasound.

(a) Define *acoustic impedance* of a medium.

[1]

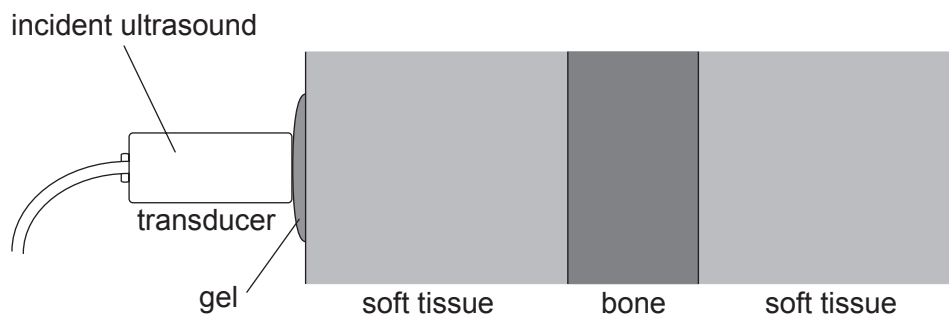
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(b) The acoustic impedances for various media are shown in the table.

Medium	Acoustic impedance / $\text{kg m}^{-2} \text{s}^{-1}$
soft tissue	1.6×10^6
gel	1.6×10^6
bone	6.1×10^6

Ultrasound is incident normally on a layer of soft tissue. Gel is placed between the skin and the transducer.



The fraction of the intensity of ultrasound that is reflected (reflection coefficient) at the boundary of two media of impedances Z_1 and Z_2 is given by the following equation.

$$\left(\frac{Z_2 - Z_1}{Z_2 + Z_1} \right)^2$$

(Option I continues on the following page)



(Option I, question 21 continued)

- (i) Suggest why the gel allows the ultrasound to enter the soft tissue without any reflection. [2]

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- (ii) Calculate the reflection coefficient at the soft tissue–bone boundary. [1]

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- (iii) The soft tissue between the skin and the bone absorbs 60% of the intensity of ultrasound travelling through it. The intensity of ultrasound leaving the transducer is I_0 . Determine, in terms of I_0 , the intensity of the ultrasound that is reflected back into the transducer from the bone. [3]

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(Option I continues on the following page)



(Option I continued)

22. This question is about radiation.

(a) Define

(i) *absorbed dose*. [1]

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(ii) *dose equivalent*. [1]

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(b) A radio-isotope, which emits gamma rays, is injected into a tumour in a patient. The effective half-life of the radio-isotope is 8.0 hours.

(i) State what is meant by effective half-life. [1]

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(ii) The tumour has mass 18 g. The energy of the emitted gamma rays is 3.1 MeV and the quality factor is 1. Determine the dose equivalent received by the patient during **one** effective half-life, assuming an average activity of 0.25 MBq. [3]

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End of Option I



Option J — Particle physics

23. This question is about particles and interactions.

(a) (i) State what is meant by an antiparticle. [1]

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(ii) Some particles are identical to their antiparticles. Discuss whether the neutron and the antineutron are identical. [2]

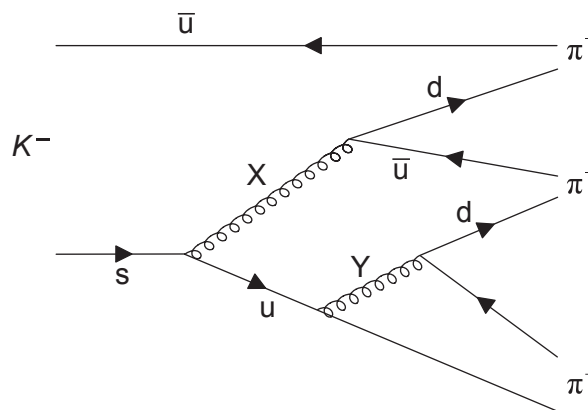
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(Option J, question 23 continued)

(b) The Feynman diagram represents the decay $K^- \rightarrow \pi^+ + \pi^- + \pi^-$.



Particles X and Y are exchange particles.

(i) Explain what is meant by an exchange particle. [2]

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(ii) Identify X. [1]

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(iii) Determine the electric charge of Y. [1]

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(iv) Calculate the change in strangeness in the decay of the K^- . [1]

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(Option J continues on the following page)



(Option J, question 23 continued)

- (c) It was once believed that the exchange particle of the strong interaction was the pion. The range of the strong interaction between hadrons is about 10^{-15} m. Estimate the mass of the pion. [2]

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(Option J continues on the following page)



48EP41

Turn over

(Option J continued)

24. This question is about particle production in a linear accelerator.

- (a) State **one** advantage and **one** disadvantage of a linear accelerator compared to a synchrotron. [2]

Advantage:

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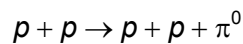
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Disadvantage:

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- (b) In a linear accelerator, protons that have been accelerated to a kinetic energy E_k collide with stationary protons according to the following reaction.



Determine the minimum E_k for which this reaction is possible. The mass of the proton is $938 \text{ MeV } c^{-2}$ and that of the pion is $135 \text{ MeV } c^{-2}$. [3]

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- (c) The linear accelerator in (b) must, in fact, provide more energy to each proton than the calculated energy E_k . Explain this observation. [1]

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(Option J continues on the following page)



(Option J continued)

25. This question is about the standard model and the Pauli exclusion principle.

- (a) State **one** conservation law that would be violated, if the following reactions were to occur.

(i) $\pi^0 \rightarrow e^+ + \mu^-$ [1]

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(ii) $p^+ + \bar{n} \rightarrow e^+ + e^- + \bar{\nu}_e + \nu_e$ [1]

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- (b) The reaction $\bar{\nu}_\mu + e^- \rightarrow \bar{\nu}_\mu + e^-$ is an example of a neutral current reaction. Draw a Feynman diagram for this reaction labelling all the particles involved. The arrow provided indicates the direction of time. [3]

time →

(Option J continues on the following page)



(Option J, question 25 continued)

- (c) (i) State the Pauli exclusion principle. [1]

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- (ii) Explain why the spin $\frac{3}{2}$ baryon uuu does **not** violate the Pauli exclusion principle. [1]

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- (iii) Discuss whether it is possible for the three quarks in the baryon uds to have the same colour. [2]

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(Option J continues on the following page)



(Option J continued)

26. This question is about the early universe.

- (a) Estimate the temperature at which an electron–positron pair could be produced by thermal fluctuations in the vacuum. [2]

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- (b) Outline why there is more matter than antimatter in today’s universe. [3]

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End of Option J



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48EP46

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