Diploma Programme
Programme du diplôme
Programa del Diploma

# Physics
# Standard level
# Paper 3

Monday 11 May 2015 (afternoon)

1 hour

Candidate session number

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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 **[40 marks]**.

| Option | Questions |
|---|---|
| Option A — Sight and wave phenomena | 1 – 4 |
| Option B — Quantum physics and nuclear physics | 5 – 7 |
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2215–6518

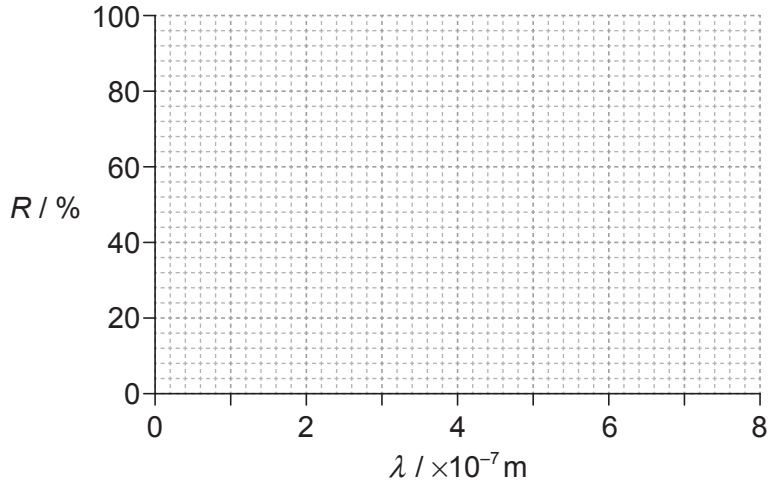
Please **do not** write on this page.

Answers written on this page
will not be marked.

**Option A — Sight and wave phenomena**

**1.** This question is about rod cells.

(a) On the axes, sketch a graph to show the variation with wavelength $\lambda$ of the spectral response $R$ of rod cells in the human eye. [2]




(b) Some flowers appear bright red during the day and dull red immediately after sunset. Explain, with reference to your sketch graph in (a), this observation. [2]

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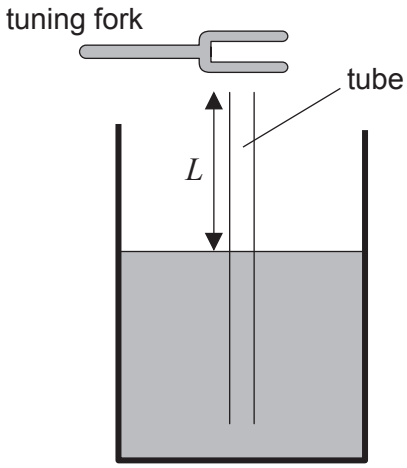
**(Option A continues on the following page)**

**(Option A continued)**

**2.** This question is about standing (stationary) waves in a tube.

(a) A thin tube is immersed in a container of water. A length $L$ of the tube extends above the surface of water.




A tuning fork is sounded above the tube. For particular values of $L$, a standing wave is established in the tube.

(i) Explain how a standing wave is formed in this tube. [2]

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(ii) The frequency of the tuning fork is 256 Hz. The smallest length $L$ for which a standing wave is established in the tube is 33.0 cm. Estimate the speed of sound in the tube. [2]

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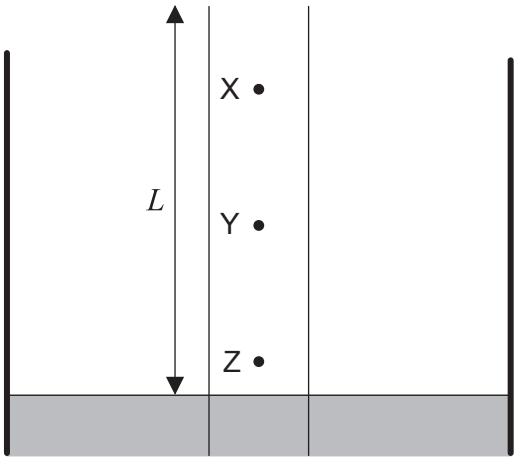
**(Option A continues on the following page)**

**(Option A, question 2 continued)**

(b) The diagram shows an enlarged view of the tube shown in (a). X, Y and Z are three molecules of air in the tube.




The length $L$ is 33.0 cm.

(i) State the direction of oscillation of molecule Y. [1]

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(ii) Identify the molecule that has the greatest amplitude. [1]

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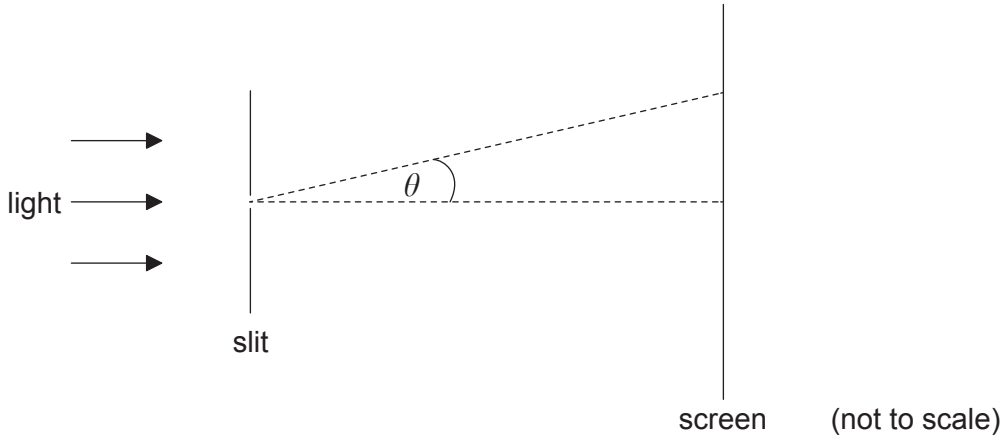
**(Option A continues on the following page)**

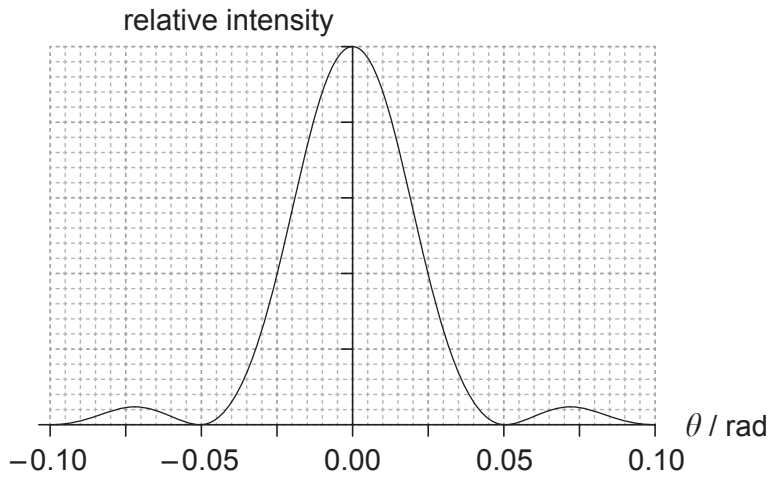
**(Option A continued)**

**3.** This question is about diffraction and resolution.

Monochromatic light is incident on a narrow rectangular slit.




The light is observed on a screen far from the slit. The graph shows the variation with angle $\theta$ of the relative intensity for light of wavelength $7.0 \times 10^{-7}$ m.




(a) Estimate the width of the slit. [2]

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**(Option A continues on the following page)**

**(Option A, question 3 continued)**

(b) On the graph, sketch the variation of the relative intensity with $\theta$ when the wavelength of the light is reduced. [1]

(c) State and explain, with reference to your sketch in (b), whether it is easier to resolve two objects in blue light **or** in red light. [2]

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**4.** This question is about polarization.

(a) State what is meant by polarized light. [1]

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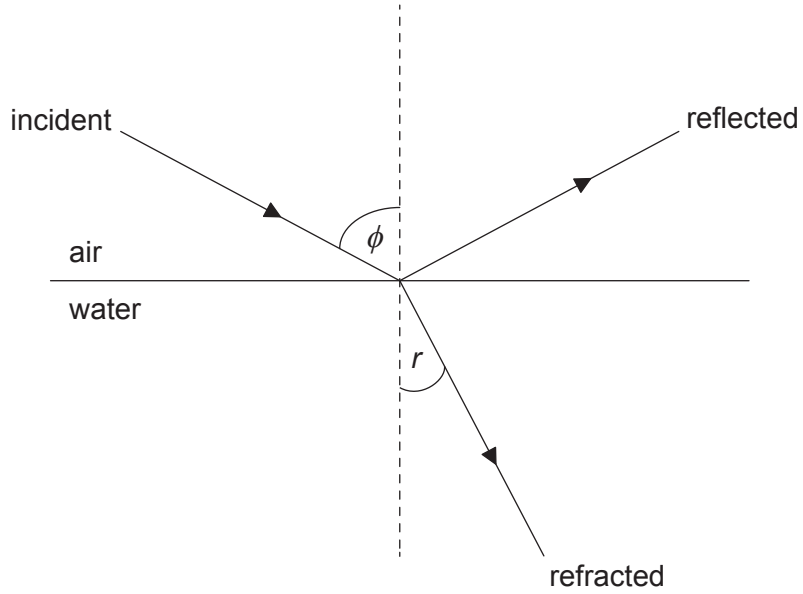
**(Option A continues on the following page)**

**(Option A, question 4 continued)**

(b) The diagram shows the incident ray, reflected ray and refracted ray at a horizontal air–water boundary. The angle of incidence is equal to the Brewster angle $\phi$.




(i) Describe the state of polarization of the reflected ray. [1]

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(ii) The Brewster angle is 53°. Calculate the angle of refraction $r$. [1]

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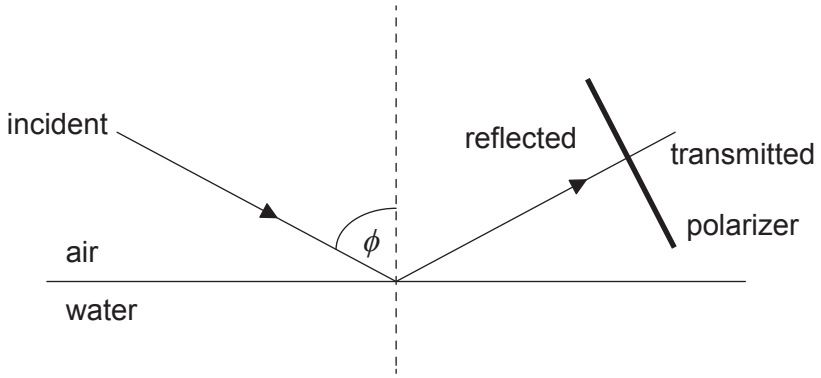
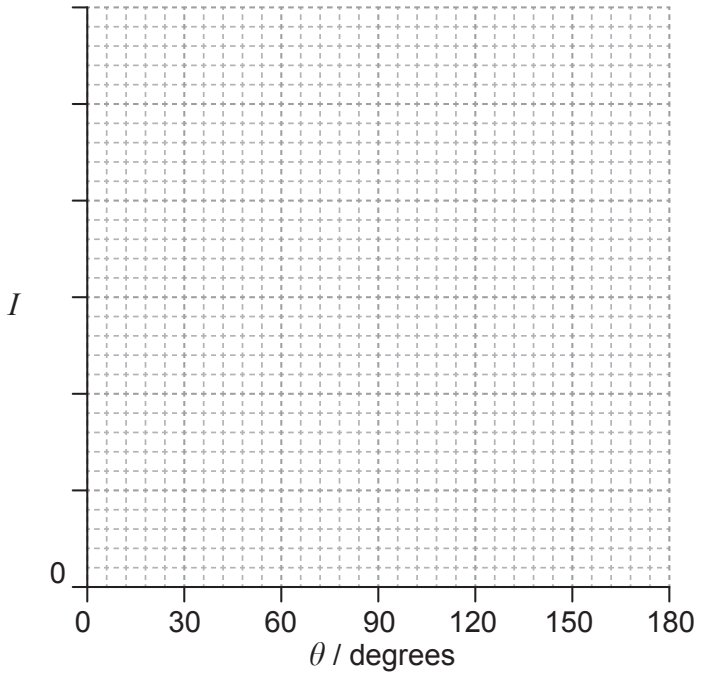
**(Option A continues on the following page)**

**(Option A, question 4 continued)**

(iii) The reflected light is transmitted through a polarizer. The plane of the polarizer is at right angles to the reflected ray.




The transmission axis of the polarizer is initially horizontal. The polarizer is then rotated by an angle $\theta$ about the reflected ray. On the axes, sketch a graph to show the variation with $\theta$ of the transmitted intensity $I$. [2]




## End of Option A

**Option B — Quantum physics and nuclear physics**

**5.** This question is about the photoelectric effect.

In a photoelectric experiment, light of wavelength 450 nm is incident on a sodium surface. The work function for sodium is 2.4 eV.

(a) (i) Calculate, in eV, the maximum kinetic energy of the emitted electrons. [3]

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(ii) The number of electrons leaving the sodium surface per second is $2 \times 10^{15}$. Calculate the current leaving the sodium surface. [2]

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(b) The wavelength of the light incident on the sodium surface is decreased without changing its intensity. Explain why the number of electrons emitted from the sodium will decrease. [4]

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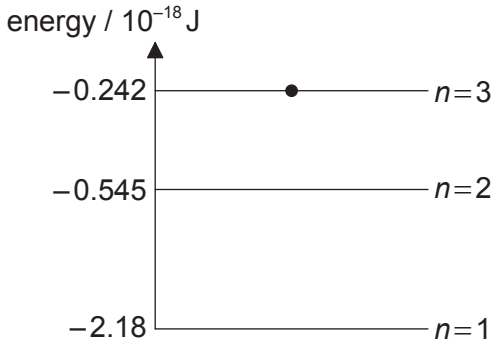
**(Option B continues on the following page)**

**(Option B continued)**

**6.** This question is about the hydrogen atom.

The diagram shows the three lowest energy levels of a hydrogen atom.




(a) An electron is excited to the $n=3$ energy level. On the diagram, draw arrows to show the possible electron transitions that can lead to the emission of a photon. [2]

(b) Show that a photon of wavelength 656 nm can be emitted from a hydrogen atom. [2]

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**(Option B continues on the following page)**

**(Option B continued)**

**7.** This question is about radioactive decay.

Nuclide X has a half-life that is estimated to be in the thousands of years.

(a) Outline how the half-life of X can be determined experimentally. [4]

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(b) A pure sample of X has a mass of 1.8 kg. The half-life of X is 9000 years. Determine the mass of X remaining after 25 000 years. [3]

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## End of Option B

**Option C — Digital technology**

**8.** This question is about digital signals.

(a) For the binary number 11010,

(i) state the least-significant bit (LSB). [1]

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(ii) show that the decimal equivalent is 26. [1]

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(b) A two-channel (stereo) recording is made at a sampling rate of 44.1 kHz, using 16-bit sampling. The recording is then stored onto a mini-CD as 210 MB (1 byte = 8 bits) of data. Estimate the playing time of the mini-CD. [3]

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**(Option C continues on the following page)**

**(Option C continued)**

**9.** This question is about a charge-coupled device (CCD).

A charge-coupled device (CCD) sensor has $1.6 \times 10^7$ pixels and is connected to a portable telescope. The magnification of the system is $2.08 \times 10^{-3}$. The area of the CCD is 866 mm$^2$.

(a) (i) Calculate the length of the side of one pixel on the CCD. [2]

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(ii) A student uses the telescope to observe a distant object. Determine the smallest distance between two points on the object that can be resolved. [2]

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(b) Explain how the incident light on a CCD causes charge to build on a pixel. [2]

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**(Option C continues on the following page)**

**(Option C, question 9 continued)**

(c) This CCD is replaced with another that has a greater quantum efficiency. Suggest **two** implications that this change in quantum efficiency has for the observation of distant objects. [2]

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**(Option C continues on the following page)**

**(Option C continued)**

**10.** 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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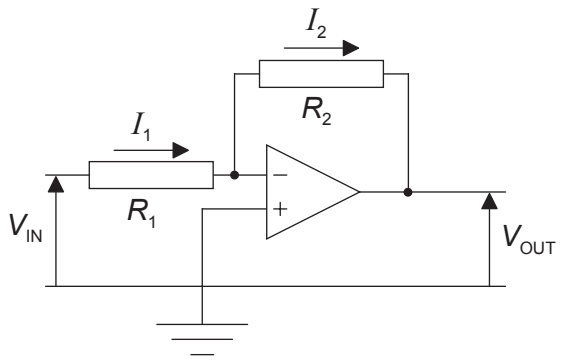
(b) The diagram shows an op-amp connected as an inverting amplifier. The input voltage is $V_{IN}$ and the output voltage is $V_{OUT}$.




Show that the gain of the amplifier is $\frac{V_{OUT}}{V_{IN}} = -\frac{R_2}{R_1}$. [3]

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**(Option C continues on the following page)**

**(Option C, question 10 continued)**

(c) The op-amp in (b) is powered by a supply of ±15 V. The resistance $R_1$ is 50 kΩ and the resistance $R_2$ is 600 kΩ. State and explain, the value of the output voltage $V_{OUT}$ when the input voltage $V_{IN}$ is 1.7 V. [2]

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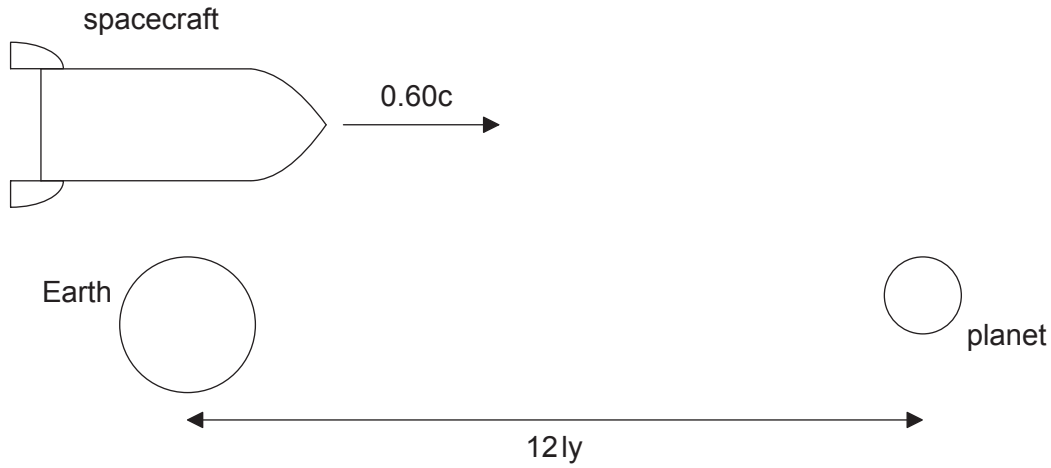
## End of Option C

**Option D — Relativity and particle physics**

**11.** 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]

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(ii) observer in the spacecraft. [2]

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**(Option D continues on the following page)**

**(Option D, question 11 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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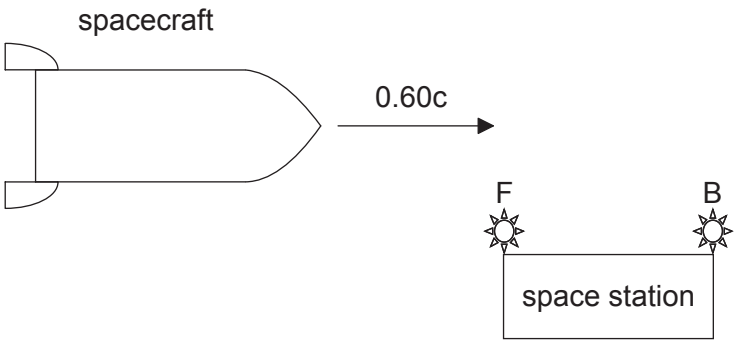
**(Option D continues on the following page)**

**(Option D, question 11 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 D continues on the following page)**

**(Option D continued)**

**12.** 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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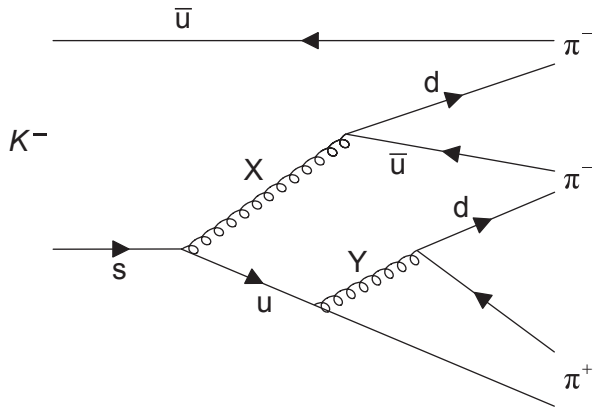
**(Option D continues on the following page)**

**(Option D, question 12 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 D continues on the following page)**

**(Option D, question 12 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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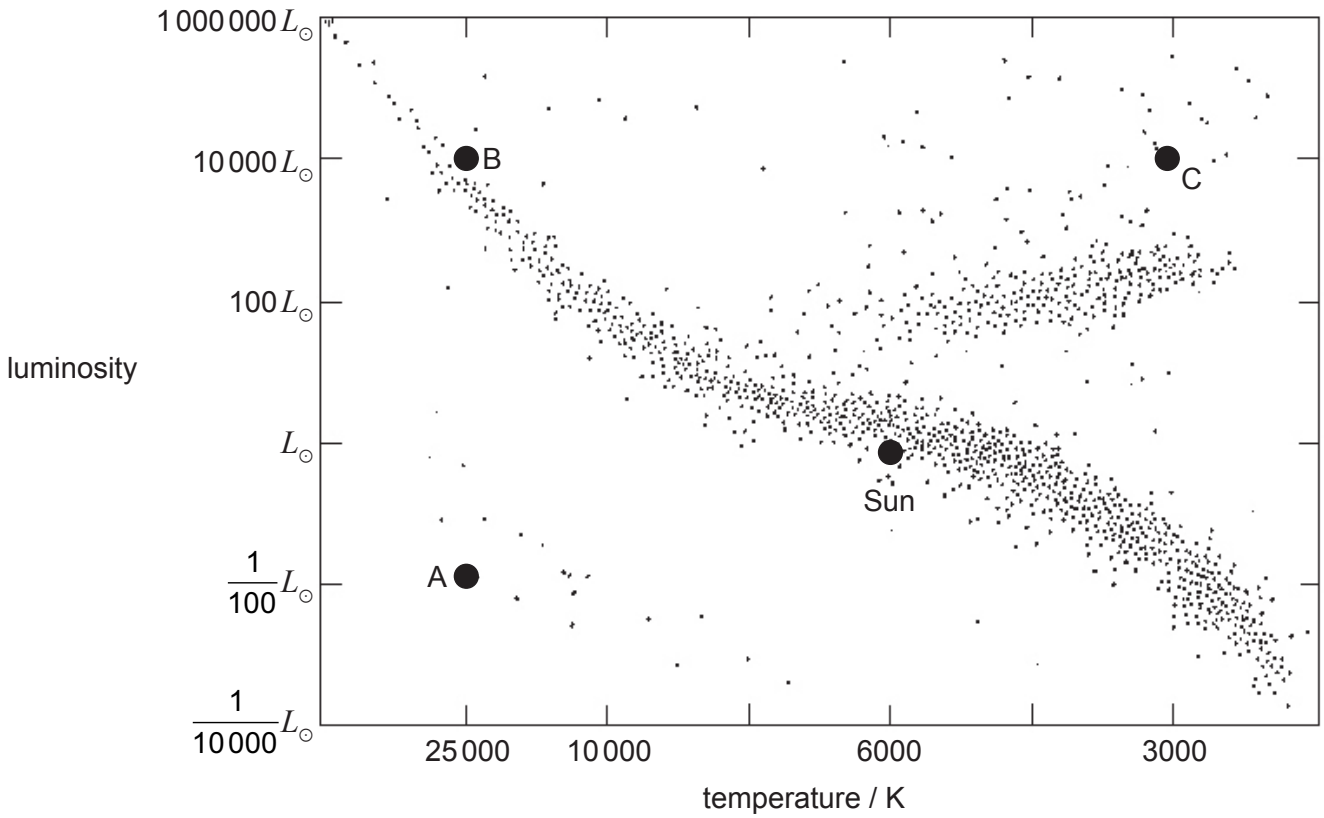
## End of Option D

**Option E — Astrophysics**

**13.** 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 13 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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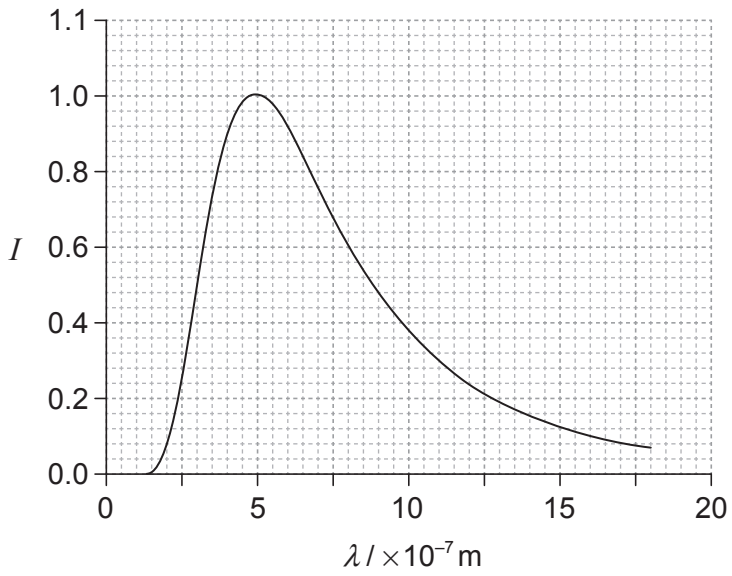
**(Option E continues on the following page)**

**(Option E, question 13 continued)**

(d) The graph shows the variation with wavelength $\lambda$ 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.



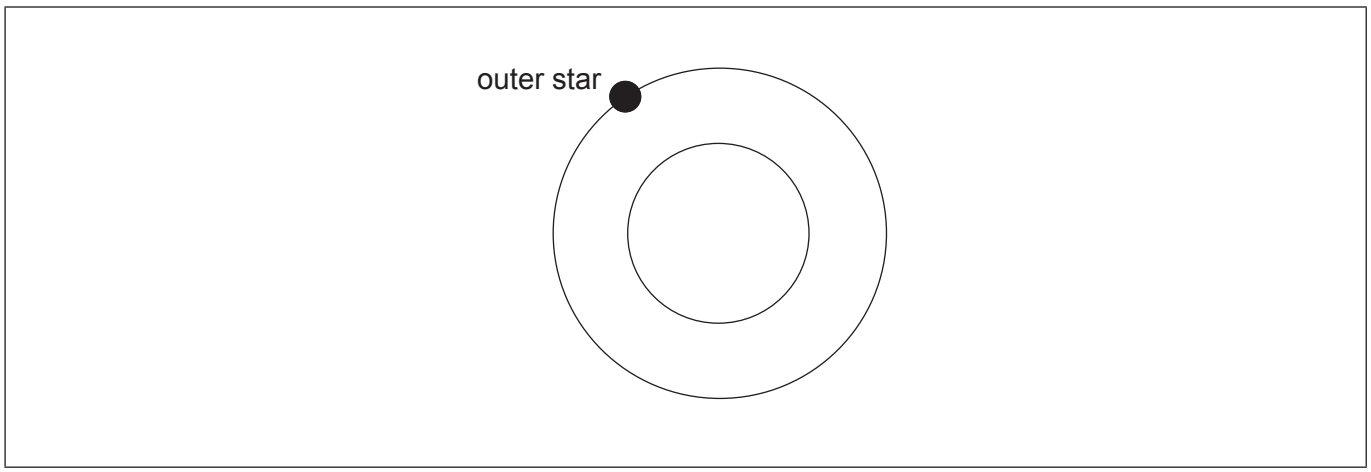

On the grid, draw a corresponding graph for star C. Your curve should have a maximum intensity of 1. [2]

**(Option E continues on the following page)**

**(Option E continued)**

**14.** 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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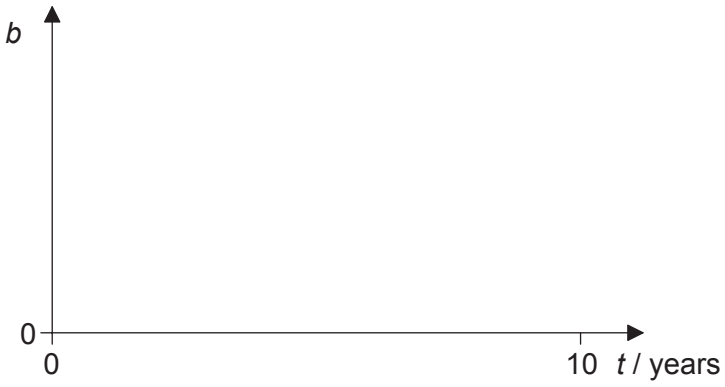
(c) The two stars have the same radius but different apparent brightness. The period of revolution of the two stars is 10 years. On the axes, sketch a graph to show the variation with time *t* of the combined apparent brightness *b* of the two stars. [2]




**(Option E continues on the following page)**

**(Option E continued)**

**15.** 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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## End of Option E

**Option F — Communications**

**16.** 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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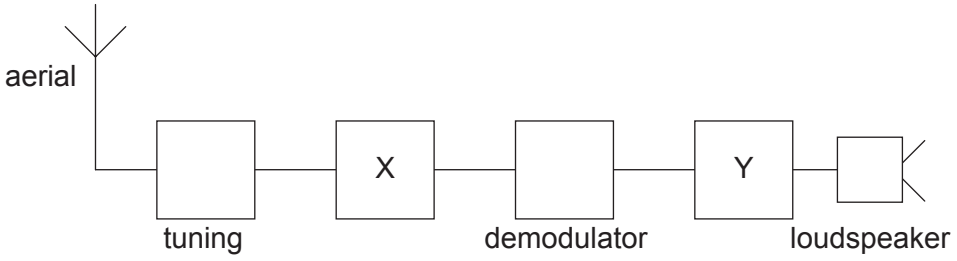
(ii) On the axes, sketch the power spectrum of the modulated carrier wave. [2]


**(Option F continues on the following page)**

**(Option F, question 16 continued)**

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




Identify the blocks labelled X and Y. [2]

X: . . . . . .

Y: . . . . . .

**17.** 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)**

**(Option F, question 17 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)**

**18.** 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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## End of Option F

**Option G — Electromagnetic waves**

**19.** 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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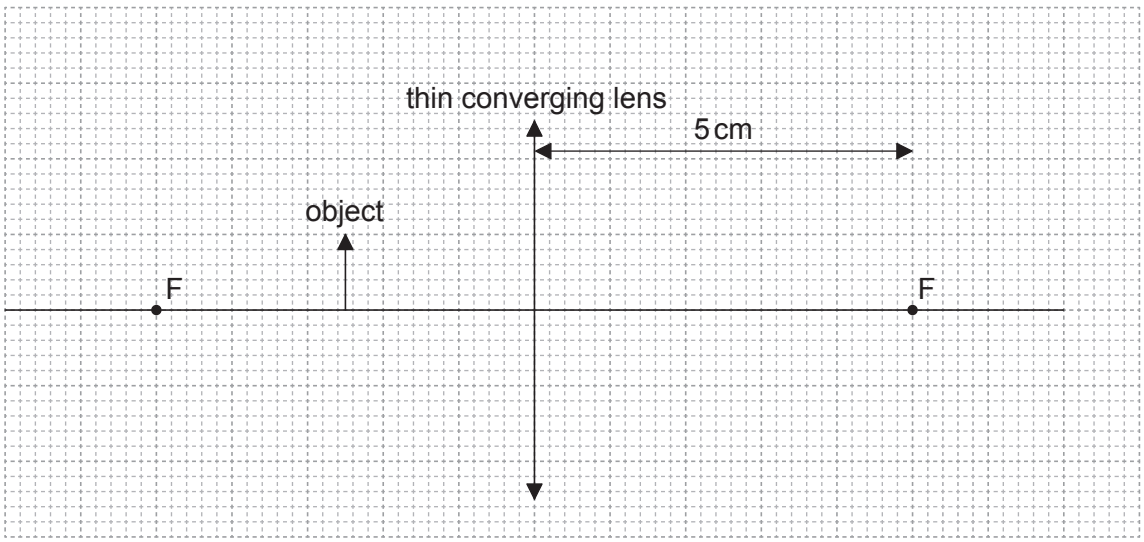
**(Option G continues on the following page)**

**(Option G continued)**

**20.** 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 20 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 82 m 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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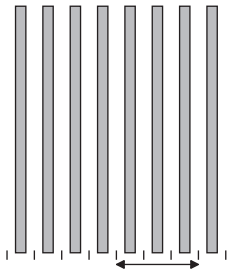
**(Option G continues on the following page)**

**(Option G continued)**

**21.** 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.




(not to scale)

(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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## End of Option G