Diploma Programme
Programme du diplôme
Programa del Diploma

Physics
Standard level
Paper 3

Monday 11 May 2015 (afternoon)

Candidate session number

1 hour

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]**.

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2215–6512

33 pages

Option A — Sight and wave phenomena

1. This question is about the eye and its resolution.

A house on a hillside is viewed at night by a human eye.

(a) Distinguish, with reference to cells in the retina and their properties, between the image viewed at night time and that seen during the day. [3]

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(b) The eye viewing the house has a pupil of diameter 2.5 mm. Two lamps on the wall of the house are separated by a horizontal distance of 1.5 m and produce light of average wavelength 450 nm. The eye can just resolve the images of the two lamps. Determine the distance between the house and the eye. [3]

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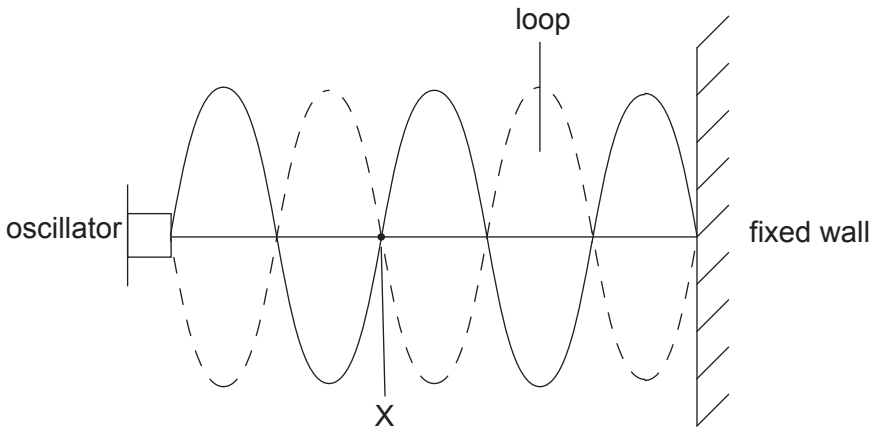
(Option A continues on the following page)

(Option A continued)

2. This question is about standing (stationary) waves.

The diagram shows an arrangement used to produce a standing (stationary) wave on a stretched string of length 2.4 m. A standing wave with five loops appears when the frequency of the oscillator is set to 150 Hz, as shown below.



(a) State the name given to point X on the string. [1]

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(b) (i) Calculate the speed of the wave along the string. [2]

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(ii) Calculate the frequency of the oscillator that would produce a standing wave with two loops on this string. [1]

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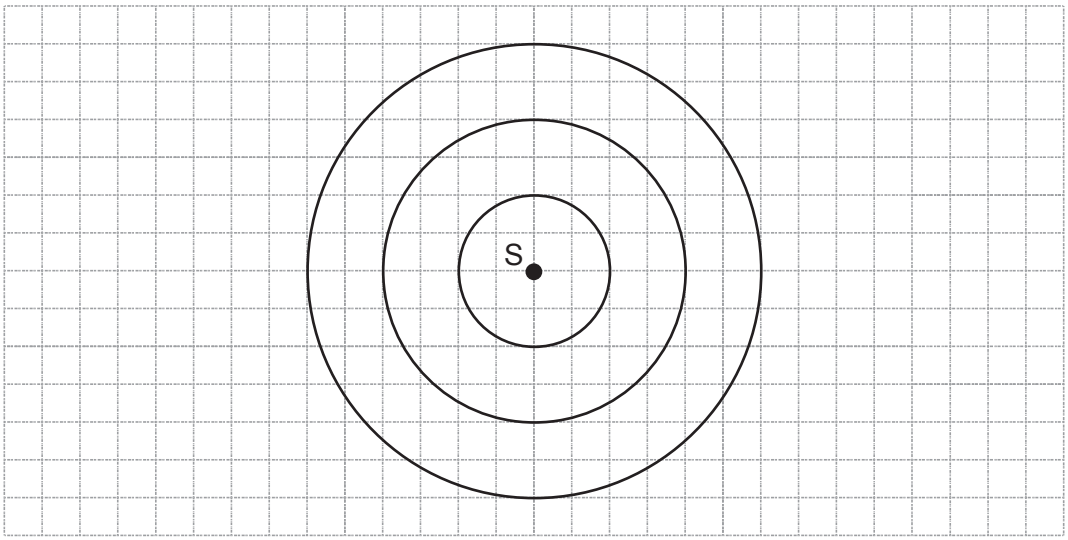
(Option A continues on the following page)

(Option A continued)

3. This question is about the Doppler effect.

The diagram shows wavefronts in air produced by a stationary source S of sound.
The distance between successive wavefronts is equal to the wavelength of the sound.
The speed of sound is *c*.

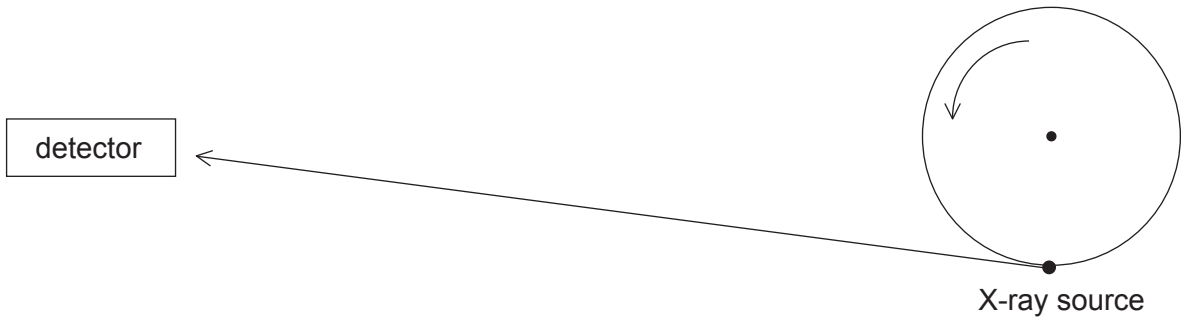


(a) On the diagram, sketch three successive wavefronts produced when S is moving to the left at a speed of 0.5*c*. [2]

(Option A continues on the following page)

(Option A, question 3 continued)

(b) A source of X-rays rotates on a turntable. Radiation of wavelength 7.5 nm is emitted by the source and undergoes a maximum shift of 0.50 fm. The distance between the source and the detector is large in comparison to the diameter of the turntable.



(i) Determine the speed of a point on the edge of the turntable. [2]

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(ii) State the assumption you made in your answer to (b)(i). [1]

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(Option A continues on the following page)

(Option A continued)

4. This question is about polarized light.

An analyser is used with polarized light.

(a) Outline the function of an analyser in this context. [2]

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(b) Polarized light of intensity I_0 is incident on the analyser.

(i) The transmission axis of the analyser is at an angle of 25° to the electric field of the polarized light. Calculate, in terms of I_0, the intensity of the light that leaves the analyser. [1]

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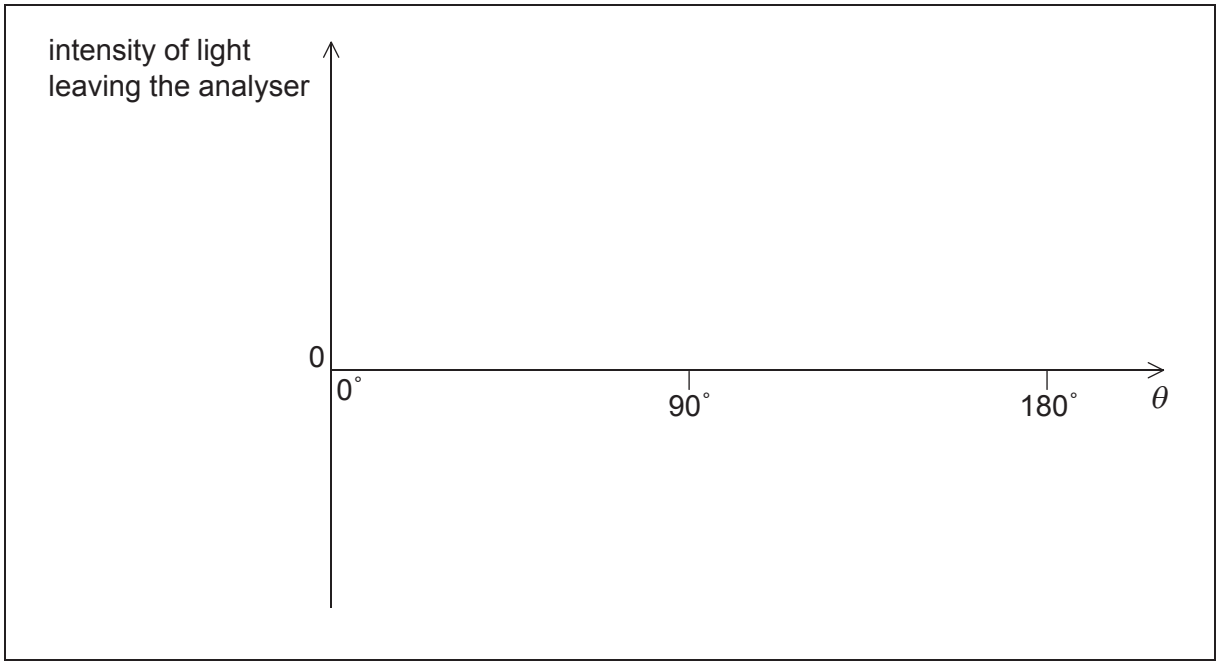
(Option A continues on the following page)

(Option A, question 4 continued)

(ii) The angle θ between the transmission axis of the analyser and the electric field of the polarized light is varied. On the axes, sketch a graph to show the variation with θ of the intensity of the light leaving the analyser. [2]



End of Option A

Option B — Quantum physics and nuclear physics

5. This question is about the photoelectric effect and the de Broglie hypothesis.

When photons are incident on a lithium surface photoelectrons are emitted. The work function ϕ of lithium is 2.9 eV.

(a) Define *work function*. [1]

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(b) Determine the maximum wavelength of the photons that can cause photoemission. [2]

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(c) Calculate the momentum of an electron that has the same de Broglie wavelength as the wavelength of the photons in (b). [2]

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(Option B continues on the following page)

(Option B continued)

6. This question is about quantum aspects of electrons.

The electron in a hydrogen atom can be modeled as being confined to a one-dimensional box of length L.

(a) Explain how this model accounts for atomic energy levels. [3]

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(Option B continues on the following page)

(Option B, question 6 continued)

(b) The lowest energy level E_1 for the electron in the box is 11.7 eV.

(i) Show that the length L of the box is about 2×10^{-10} m. [2]

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(ii) The maximum uncertainty in the position of the electron is L. Determine the minimum uncertainty in the momentum of the electron. [2]

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(iii) Outline why the third energy level E_3 of the electron must be 105 eV. [1]

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(iv) Calculate the frequency of the photon emitted when an electron moves between the energy levels E_3 to E_1. [2]

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(Option B continues on the following page)

(Option B continued)

7. This question is about radioactive decay.

A nucleus of magnesium-23 decays forming a nucleus of sodium-23 with the emission of an electron neutrino and a β^+ particle.

(a) Outline why the existence of neutrinos was hypothesized to account for the energy spectrum of beta decay. [3]

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(b) The decay constant for magnesium-23 is $0.061\,s^{-1}$. Calculate the time taken for the number of magnesium-23 nuclei to fall to 12.5 % of its initial value. [2]

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End of Option B

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Option C — Digital technology

8. This question is about data capture and data storage.

(a) Describe the mechanism that occurs within a pixel when light is incident on a charge-coupled device (CCD). [4]

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(b) A picture of two stars is taken with a 12 megapixel digital camera. The camera has a CCD with dimensions 36 mm × 24 mm. The distance between the two stars is 7.1×10^{15} m and the magnification of the CCD is 10^{-20}.

(i) Define *magnification* of a CCD. [1]

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(ii) Deduce that the images of the two stars on the CCD are resolved. [4]

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(Option C continues on the following page)

(Option C, question 8 continued)

(iii) Each pixel produces 16 bits of data. Calculate how many pictures can be stored in a four gigabyte memory card (1 byte = 8 bits). [2]

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9. An electric signal containing noise is sent to a Schmitt trigger.

(a) Outline the purpose of using a Schmitt trigger with a signal containing noise. [1]

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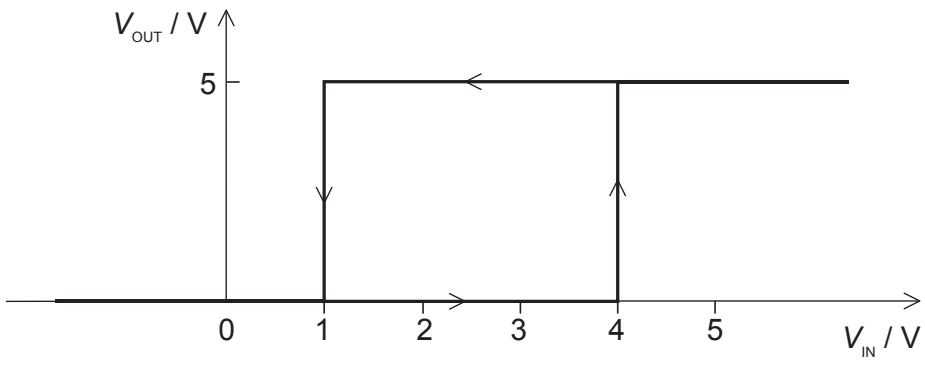
(b) The Schmitt trigger operates between two switch-over voltages, V_1 and V_2. $V_1 = 1\,V$ and $V_2 = 4\,V$.

Graph 1 shows how the output voltage V_{OUT} of the Schmitt trigger varies with the input voltage V_{IN}. The saturation voltages are $V_{low} = 0\,V$ and $V_{high} = 5\,V$.

Graph 1

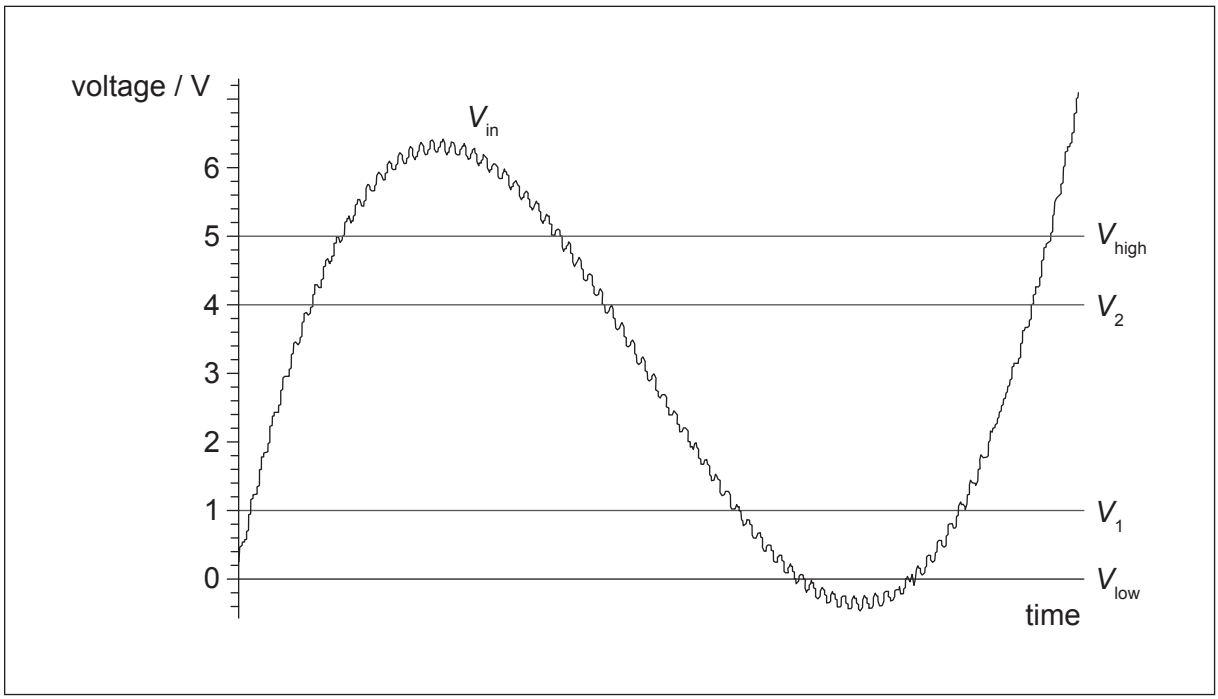


(Option C continues on the following page)

(Option C, question 9 continued)

Graph 2 shows the variation with time of the amplitude V_{IN} of the electrical signal sent to the Schmitt trigger.

Graph 2



Sketch, on Graph 2 above, the output of the Schmitt trigger. [4]

(Option C continues on the following page)

(Option C continued)

10. This question is about mobile phone systems.

(a) A geographical area is covered by one or more cells for the purpose of mobile phone systems. Outline the properties that a cell must have. [2]

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(b) Suggest **two** environmental issues that arise from the use of mobile phones. [2]

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End of Option C

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Answers written on this page will not be marked.

Option D — Relativity and particle physics

11. This question is about relativistic kinematics.

(a) An observer at rest relative to Earth observes two spaceships. Each spaceship is moving with a speed of 0.85*c* but in opposite directions. The observer measures the rate of increase of distance between the spaceships to be 1.7*c*. Outline whether this observation contravenes the theory of special relativity. [2]

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(b) The observer on Earth in (a) watches one spaceship as it travels to a distant star at a speed of 0.85*c*. According to observers on the spaceship, this journey takes 8.0 years.

(i) Calculate, according to the observer on Earth, the time taken for the journey to the star. [3]

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(ii) Calculate, according to the observer on Earth, the distance from Earth to the star. [2]

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(Option D continues on the following page)

(Option D, question 11 continued)

(iii) At the instant when the spaceship passes the star, the observer on the spaceship sends a radio message to Earth. The spaceship continues to move at a speed of 0.85*c*. Determine, according to the spaceship observer, the time taken for the message to arrive on Earth. [3]

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(Option D continues on the following page)

(Option D continued)

12. This question is about particles and interactions.

Exchange particles and photons have been observed to be produced when a Higgs particle (boson) decays.

(a) The suggested mass of the Higgs boson is 125 GeV c^{-2}. Determine the likely range of the interaction mediated by the Higgs boson. [3]

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(b) The energy of the Higgs bosons produced in an experiment has been measured with an uncertainty of about 17 MeV. Determine the maximum time that Higgs bosons can spend in this state before decaying into other particles. [3]

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(Option D continues on the following page)

(Option D continued)

13. This question is about quarks.

An interaction between an electron and a positron can lead to the production of hadrons via the reaction

$$e^- + e^+ \rightarrow u + \overline{u}$$

where *u* is an up quark. This process involves the electromagnetic interaction.

(a) Draw a Feynman diagram for this interaction. [2]

(b) Outline, with reference to the strong interaction, why hadrons are produced in the reaction. [2]

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End of Option D

Option E — Astrophysics

14. This question is about planets.

Four of the outer planets of the solar system are Jupiter, Neptune, Saturn and Uranus.

List these planets in order of

(a) increasing distance from the Sun. [1]

	Planet
closest to the Sun ↓	. . . . .
	. . . . .
	. . . . .
furthest from the Sun	. . . . .

(b) increasing mass. [1]

	Planet
smallest mass ↓	. . . . .
	. . . . .
	. . . . .
largest mass	. . . . .

(Option E continues on the following page)

(Option E continued)

15. This question is about a particular star called Barnard's star.

The peak wavelength in the spectrum of Barnard's star is 940 nm. The following data are available.

$$\frac{\text{apparent brightness of Barnard's star}}{\text{apparent brightness of the Sun}} = 2.5 \times 10^{-14}$$

$$\frac{\text{luminosity of Barnard's star}}{\text{luminosity of the Sun}} = 3.8 \times 10^{-3}$$

(a) (i) Show that the surface temperature of Barnard's star is about 3000 K. [2]

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(ii) Suggest why Barnard's star is **not** likely to be either a white dwarf or a red giant. [2]

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(b) (i) Determine, in astronomical units (AU), the distance between Earth and Barnard's star. [3]

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(Option E continues on the following page)

(Option E, question 15 continued)

(ii) Calculate the parallax angle for Barnard's star as observed from Earth. [2]

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(iii) Outline how the parallax angle is measured. [3]

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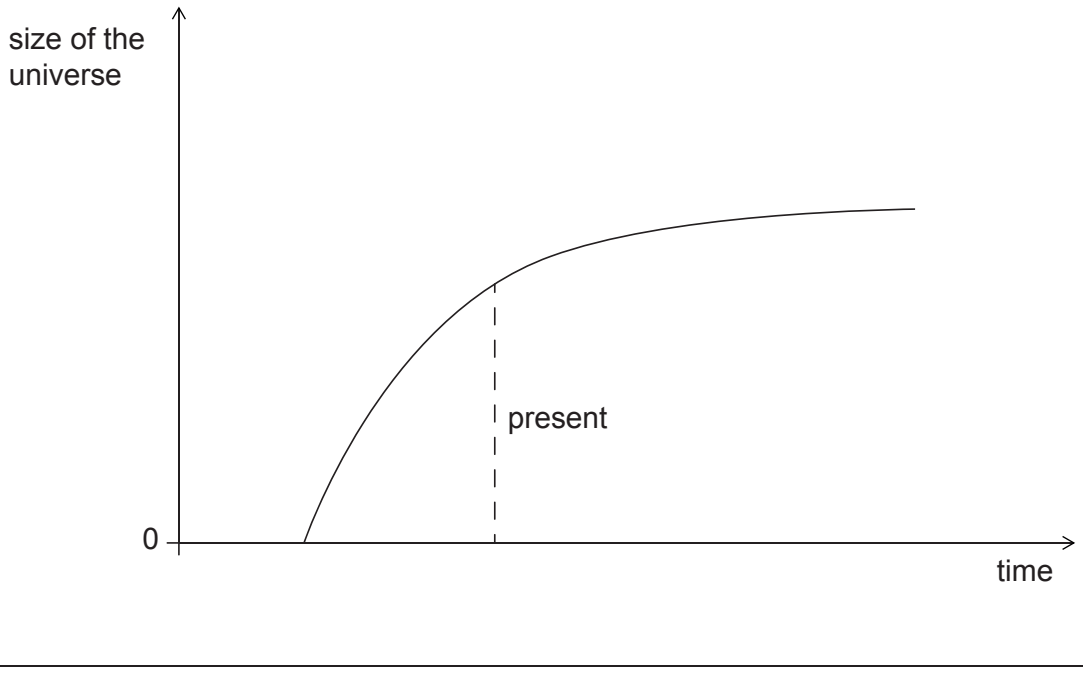
16. This question is about the development of the universe.

The graph shows one possible way in which the universe is thought to change with time. This type of universe is known as a flat universe.



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

(Option E, question 16 continued)

(a) On the graph, draw lines to show the variation with time of the size of the universe for both a closed universe and an open universe. Label your line for the closed universe C and your line for the open universe O. [2]

(b) Explain how the open and closed outcomes for the universe depend on the critical density of matter in the universe. [3]

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(c) State **one** reason why it is difficult to determine the density of the universe. [1]

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End of Option E

Option F — Communications

17. This question is about radio communication.

(a) Distinguish between a carrier wave and a signal wave. [2]

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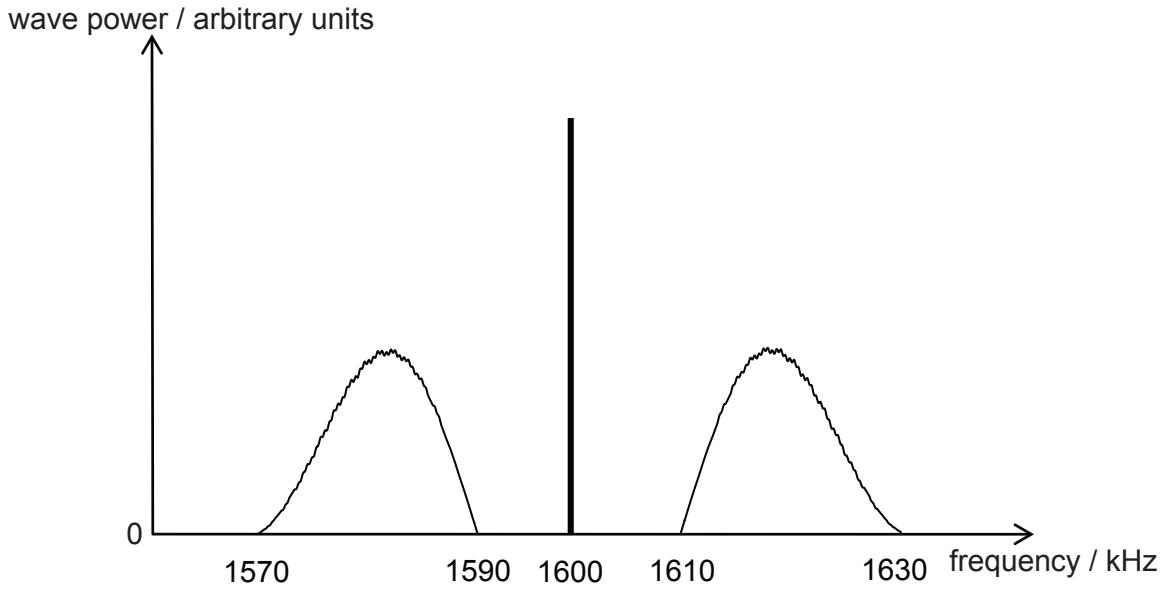
(b) The frequency spectrum of an amplitude-modulated wave transmitted by a radio station is shown.



(i) Define *bandwidth*. [1]

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(ii) State the frequency of the carrier wave. [1]

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(Option F continues on the following page)

(Option F, question 17 continued)

(iii) Determine the bandwidth of the transmitted (modulated) wave. [2]

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(iv) Identify the feature of the frequency spectrum that indicates that the signal is amplitude-modulated. [1]

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18. This question is about optic fibre transmission.

(a) A light pulse travelling along an optic fibre is dispersed.

(i) Outline what is meant by dispersion. [1]

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(Option F continues on the following page)

(Option F, question 18 continued)

(ii) Explain **two** mechanisms that produce dispersion in optic fibres. [3]

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(b) After travelling along the optic fibre, the signal in (a) is converted to an electric signal. Both signals contain noise. State what is meant by noise. [1]

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19. This question is about satellite communications and time-division multiplexing.

(a) Explain the advantages that polar-orbiting satellites have over geostationary satellites for communication. [2]

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(Option F continues on the following page)

(Option F, question 19 continued)

(b) Many digital signals are transmitted from a satellite to a ground station. The signals appear to be sent along a single transmission channel at the same time.

(i) Outline how the signals are sent along the transmission channel. [4]

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(ii) Each signal for this transmission channel is sampled at a frequency of 25 kHz. The duration of each sample is 10 μs. Determine the maximum number of signals that this transmission channel can carry. [2]

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End of Option F

Option G — Electromagnetic waves

20. This question is about a laser light on a diffraction grating.

(a) With reference to population inversion, describe how laser light is produced. [4]

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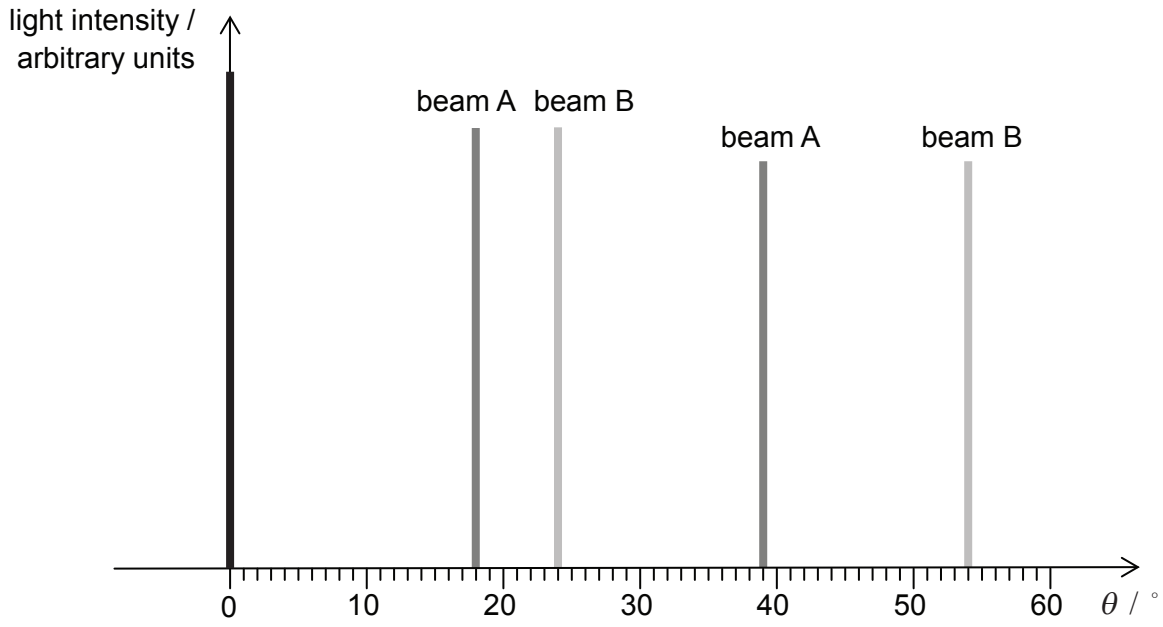
(b) Two laser beams A and B are incident normally at the same position on a diffraction grating. The graph shows how the intensity of the light emerging from the grating varies with the diffraction angle θ. Beam A has wavelength 530 nm.



(Option G continues on the following page)

(Option G, question 20 continued)

(i) Show that the diffraction grating has approximately 600 lines per millimetre. [3]

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(ii) Calculate the wavelength of beam B. [2]

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(iii) Show that a third-order peak cannot be observed for beam B. [2]

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(Option G continues on the following page)

(Option G continued)

21. This question is about a converging (convex) lens.

A small object is placed a distance 2.0 cm from a thin convex lens. The focal length of the lens is 5.0 cm.

(a) State, in dioptres, a value for the power of the lens. [1]

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(b) (i) Deduce the magnification of the lens. [3]

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(ii) State and explain the nature of the image formed by this lens with the object at this position. [2]

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(c) The object is coloured and the image shows chromatic aberration. Explain what is meant by chromatic aberration. [2]

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(Option G continues on the following page)

(Option G, question 21 continued)

(d) Describe how the effects of chromatic aberration may be reduced. [1]

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End of Option G

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