Diploma Programme
Programme du diplôme
Programa del Diploma

Physics
Higher level
Paper 3

Monday 11 May 2015 (afternoon)

1 hour 15 minutes

Candidate session number

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	10–13
Option H — Relativity	14–17
Option I — Medical physics	18–21
Option J — Particle physics	22–26

2215–6509

Option E — Astrophysics

1. 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 increasing mass. [1]

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

2. 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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(Option E continues on the following page)

(Option E, question 2 continued)

(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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(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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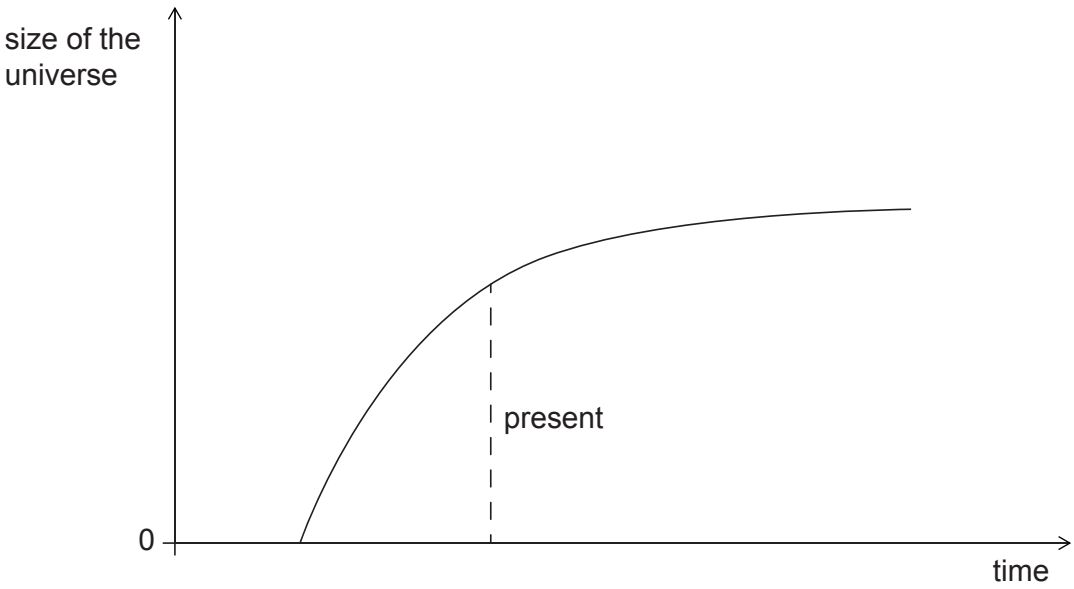
(Option E continues on the following page)

(Option E continued)

3. 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.



(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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(Option E continues on the following page)

(Option E continued)

4. This question is about the mass–luminosity relation.

Star X is 1.5×10^5 more luminous than the Sun and has a mass 30 times that of the Sun.

(a) Identify whether star X is on the main sequence. Assume that $n = 3.5$ in the mass–luminosity relation. [2]

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(b) (i) State the evolution of star X. [1]

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(ii) Explain the eventual fate of star X. [2]

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(Option E continues on the following page)

(Option E continued)

5. This question is about Hubble's law.

(a) The light from distant galaxies is red-shifted. Explain how this red-shift arises. [3]

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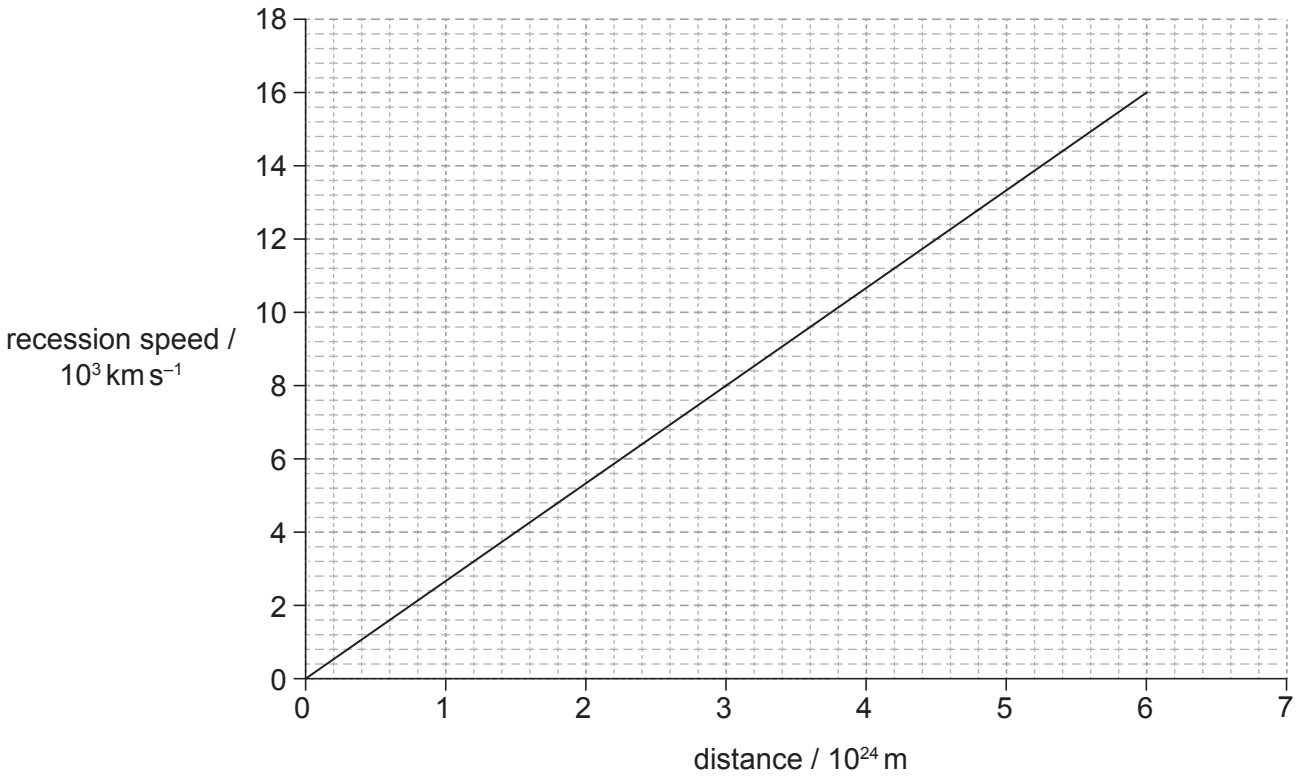
(b) The graph shows the variation of recession speed with distance from Earth for some galactic clusters.



(Option E continues on the following page)

(Option E, question 5 continued)

(i) Calculate, in s^{-1}, the Hubble constant. [2]

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(ii) Estimate, in s, the age of the universe. [1]

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(iii) State the assumption that you made in your estimate in (b)(ii). [1]

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End of Option E

Option F — Communications

6. This question is about radio communication.

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

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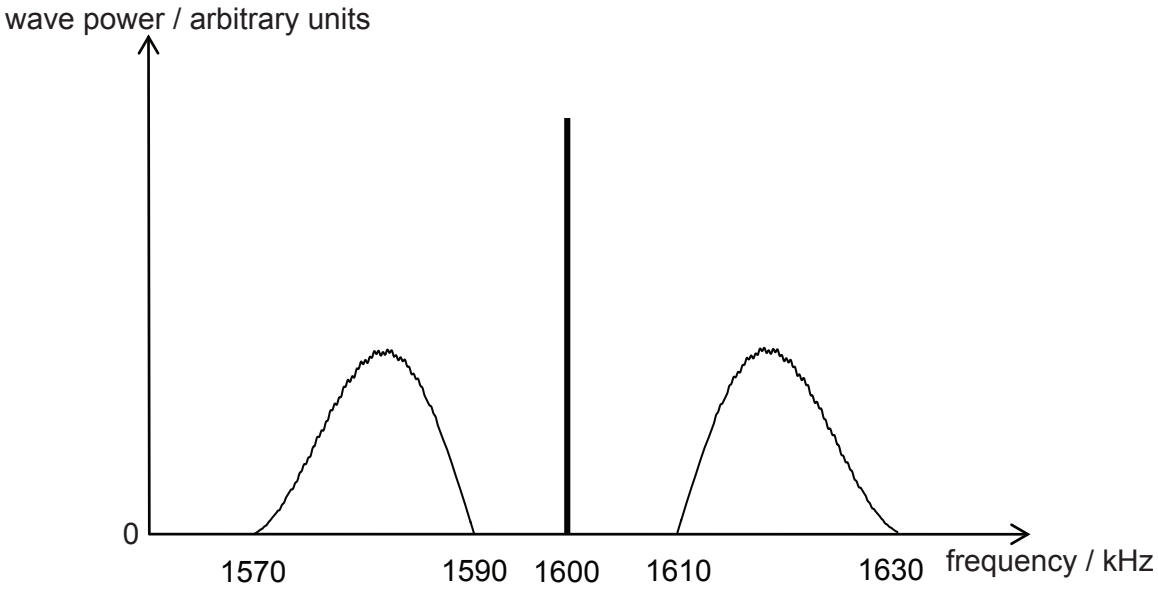
(b) The frequency spectrum of an amplitude-modulated wave transmitted by a radio station is shown.



(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 6 continued)

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

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(c) State **one** disadvantage of using amplitude modulation (AM) rather than frequency modulation (FM) in radio communications. [1]

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7. This question is about optic fibre transmission and the Schmitt trigger.

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

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

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

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(Option F continues on the following page)

(Option F, question 7 continued)

(b) After travelling along the optic fibre, the signal in (a) is converted to an electric signal. Both signals contain noise.

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

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(ii) The electric signal is then sent to a Schmitt trigger. Outline the reasons for using Schmitt triggers with a signal containing noise. [2]

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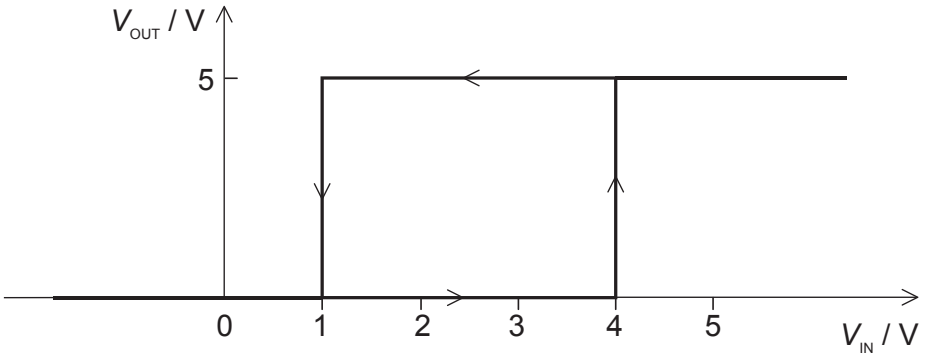
(Option F continues on the following page)

(Option F, question 7 continued)

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

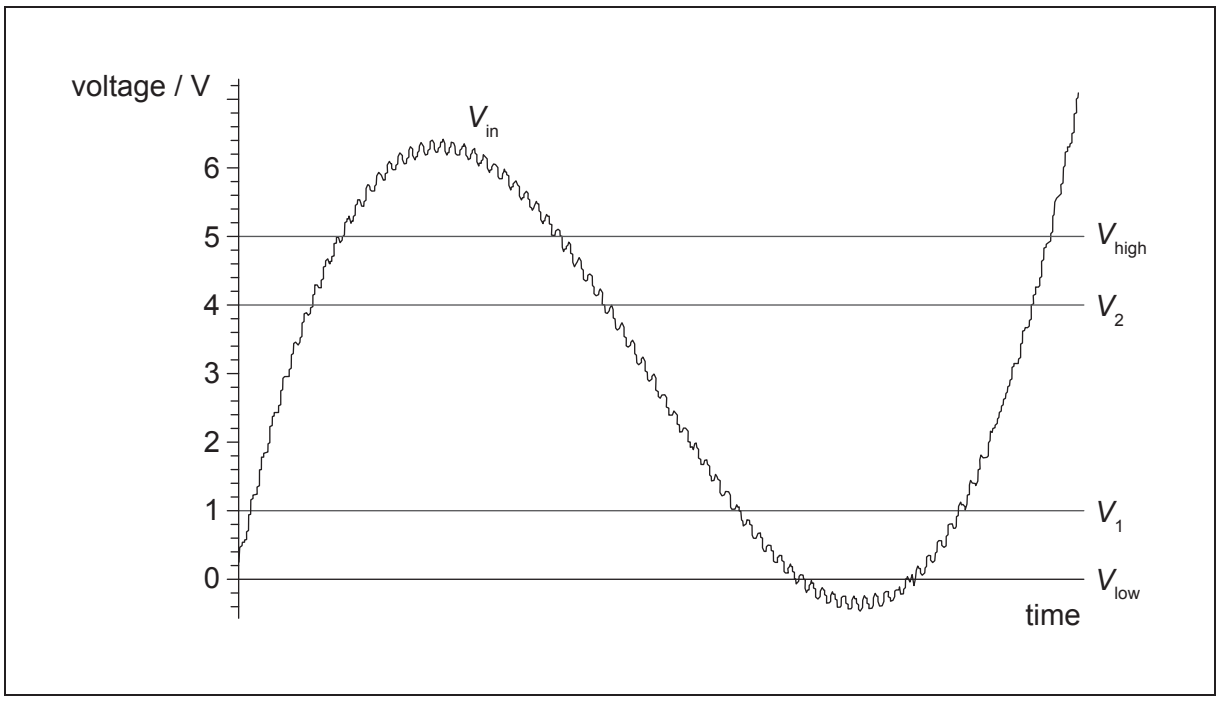
Graph 1 shows how the output voltage V_{OUT} of the Schmitt trigger varies with the input voltage V_{IN}. The saturation voltages are $V_{low} = 0\,V$ and $V_{high} = 5\,V$.

Graph 1



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 F continues on the following page)

(Option F continued)

8. 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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9. 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 9 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 9.0 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

10. 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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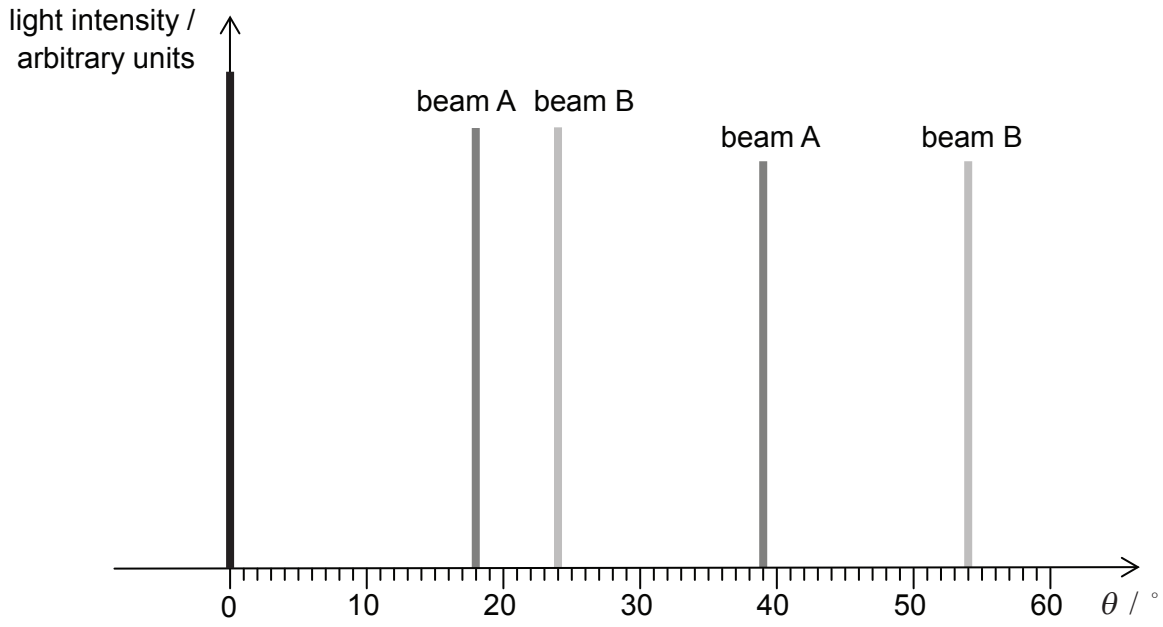
(b) Two laser beams A and B are incident normally at the same position on a diffraction grating. The graph shows how the intensity of the light emerging from the grating varies with the diffraction angle θ. Beam A has wavelength 530 nm.



(Option G continues on the following page)

(Option G, question 10 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)

11. 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 11 continued)

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

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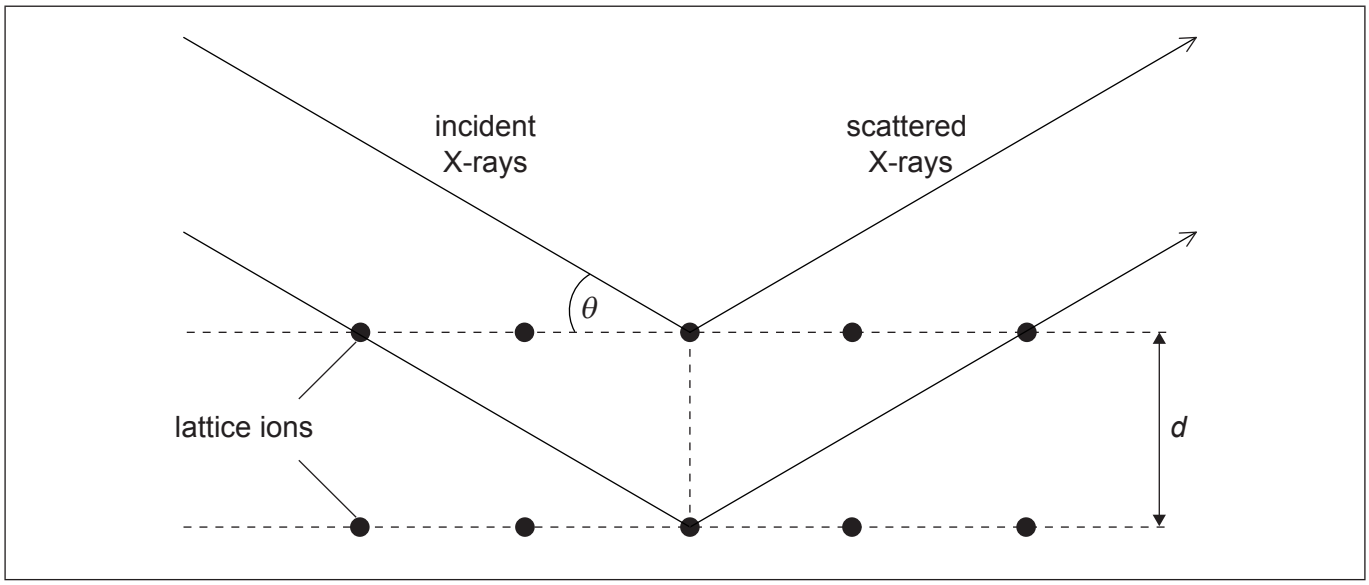
(Option G continues on the following page)

(Option G continued)

12. This question is about X-ray diffraction.

In an experiment, X-rays of wavelength λ are used to determine the distance d between atomic layers in a crystal. The diagram shows part of a crystal with incident and scattered X-rays.



(a) (i) On the diagram, construct **two** lines that enable the path difference between the rays scattered from different crystal planes to be shown. [1]

(ii) Derive an equation, in terms of d and λ, for the minimum non-zero angle θ at which the X-rays interfere constructively. [2]

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(Option G continues on the following page)

(Option G, question 12 continued)

(b) The X-rays are produced when electrons in an X-ray tube are accelerated from rest through a potential difference of 15 kV. Calculate the minimum wavelength of the X-rays produced. [2]

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13. This question is about thin-film interference.

A thin film of oil lies on a puddle of water. White light from above shines on the film at normal incidence.

(a) Outline the process by which coloured fringes are formed. [3]

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(b) The following data are available:

Refractive index of oil = 1.4
Refractive index of water = 1.3
Thickness of the oil film = 250 nm

Calculate the maximum wavelength of the incident light for which **destructive** interference occurs. [2]

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End of Option G

Option H — Relativity

14. 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*.

(i) Outline whether this observation contravenes the theory of special relativity. [2]

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(ii) Determine, according to an observer in one of the spaceships, the speed of the other spaceship. [3]

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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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(Option H continues on the following page)

(Option H, question 14 continued)

(ii) Outline whether the time interval measured by the observer on Earth is a proper time interval. [1]

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

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(iv) The observers in the spaceship send a message to Earth halfway through their journey. Determine how long it takes the message to arrive at Earth according to the observers on the spaceship. [3]

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(Option H continues on the following page)

(Option H continued)

15. This question is about relativistic energies.

(a) Calculate the speed of an electron when its total energy is equal to five times its rest mass energy. [3]

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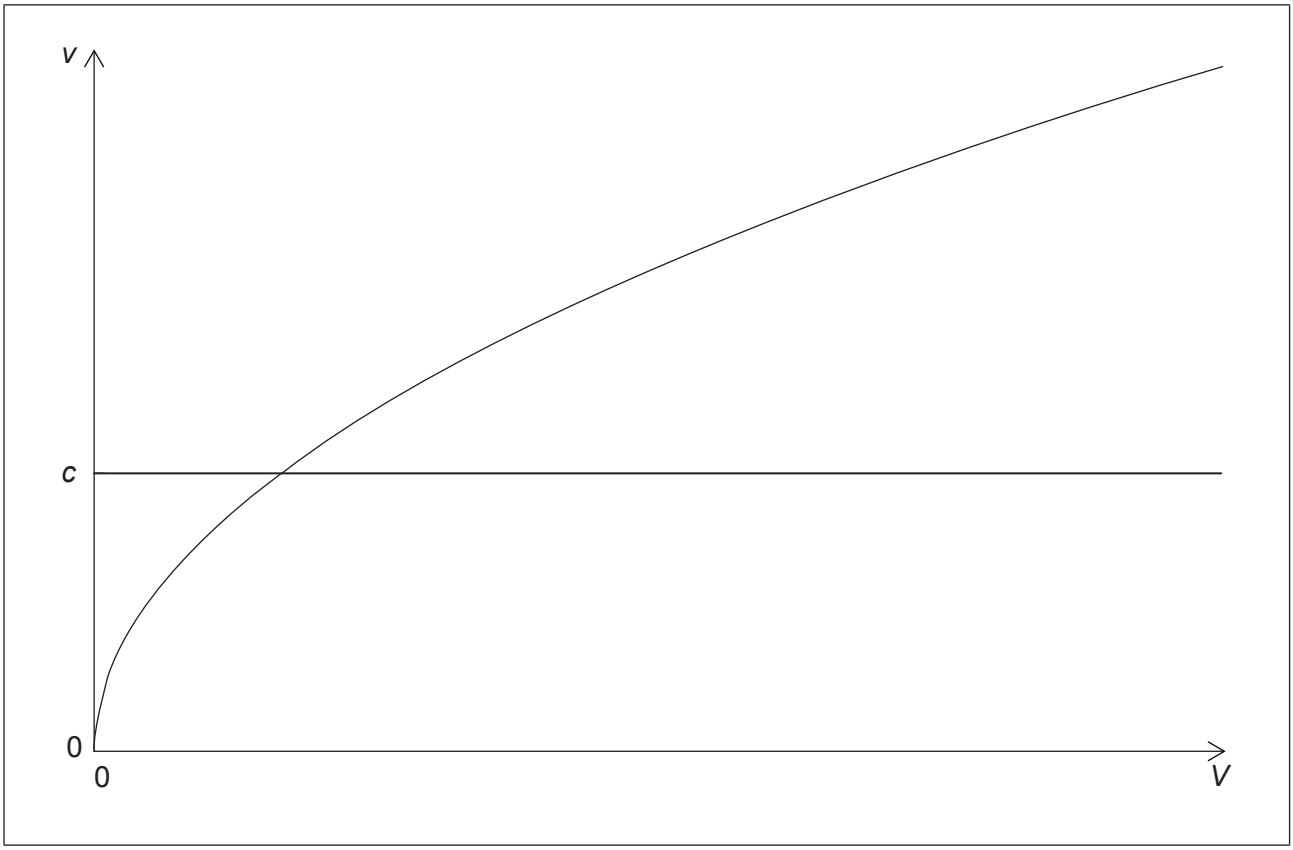
(b) The electron is accelerated from rest through a potential difference V. The graph shows how the speed v of the electron after acceleration varies with V assuming that Newtonian mechanics applies.



On the graph, sketch a line to show the variation with V of v according to relativistic mechanics. [2]

(Option H continues on the following page)

(Option H continued)

16. This question is about general relativity.

(a) Calculate the Schwarzschild radius for an astronomical object of mass 5.0×10^{30} kg. [2]

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(b) A spaceship is travelling towards the object in (a). The spaceship moves in a straight line such that its distance of closest approach would be about 10^7 m. Discuss why the presence of the object in (a) will **not** significantly affect the motion of the spaceship. [2]

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(c) An observer, when viewing a distant galaxy, sees two images of the galaxy separated by a small angle. A massive star is positioned between the observer and the galaxy. Outline how these observations give support to the theory of general relativity. [3]

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(Option H continues on the following page)

(Option H continued)

17. In the Hafele–Keating experiment a clock was flown around the world. Discuss the effects of this journey on the time registered by the clock compared to the time registered by a clock that remains on the Earth's surface. You should refer to both the special and general theories of relativity in your answer. [4]

Effect of special relativity:

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Effect of general relativity:

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End of Option H

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

Answers written on this page will not be marked.

Option I — Medical physics

18. This question is about hearing loss.

(a) Define *sound intensity level (IL)*. [1]

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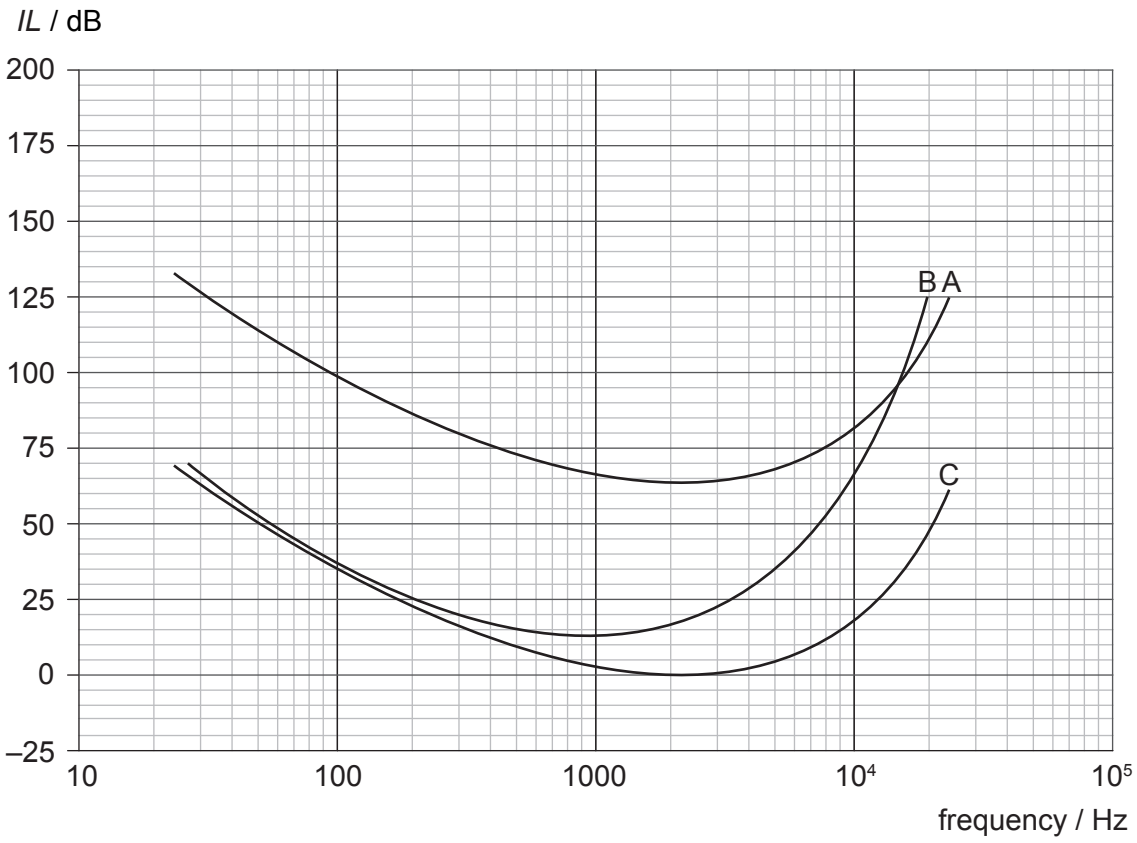
(b) The graph shows the variation with frequency *f* of sound intensity level *IL* for the threshold of hearing for three people A, B, and C. Person C has normal hearing.



(Option I continues on the following page)

(Option I, question 18 continued)

(i) Compare the hearing of persons A and B with that of person C. [2]

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(ii) Determine the intensity of a sound of frequency 100 Hz that can just be heard by person C. [3]

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19. This question is about ultrasound scanning.

(a) Outline how ultrasound is generated for medical diagnostic purposes. [2]

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(Option I continues on the following page)

(Option I, question 19 continued)

(b) When ultrasound of intensity I_0 travels in a medium of acoustic impedance Z_1 and is incident on a medium of acoustic impedance Z_2, the intensity I_R that is reflected at the interface is given by the following equation.

$$I_R = \left(\frac{Z_1 - Z_2}{Z_1 + Z_2} \right)^2 I_0$$

The following data are available.

	Speed of sound / m s^{-1}	**Density / kg m^{-3}**
air	330	1.3
skin	1500	1000

Use the data to deduce why a layer of gel must be used between a transducer and the patient's skin in medical ultrasound imaging. [5]

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(c) In medical scanning, practitioners have the option of using A-scans or B-scans. Distinguish, with reference to the techniques used to produce the scans, between an A-scan and a B-scan. [3]

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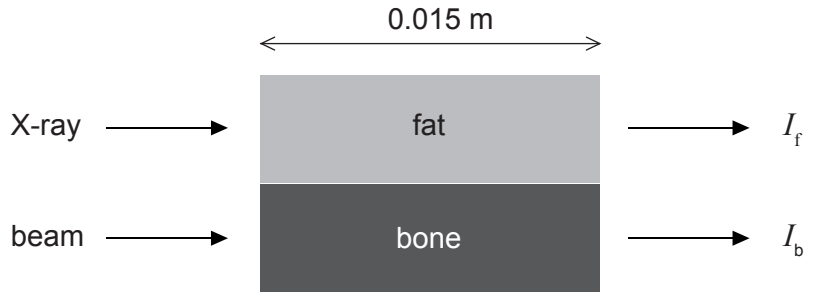
(Option I continues on the following page)

(Option I continued)

20. This question is about X-rays.

(a) Two parallel beams of monochromatic X-rays of the same intensity are incident on equal thicknesses of bone and fat in a patient.



The attenuation coefficient for fat is $180\,m^{-1}$ and the attenuation coefficient for bone is $345\,m^{-1}$. The thickness of both materials is 0.0150 m.

Calculate $\frac{I_b}{I_f}$ where I_b is the intensity of the beam leaving the bone and I_f is the intensity of the beam leaving the fat. [3]

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(b) Explain how fluorescent emitters are used to enhance the image formed on a photographic X-ray plate. [3]

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(Option I continues on the following page)

(Option I continued)

21. This question is about exposure to radiation.

(a) During a medical procedure, a patient of mass 80 kg receives radiation with a dose equivalent of 0.27 mSv. The quality factor (relative biological effectiveness) of the radiation is 5.0. Determine the total energy received by the patient. [2]

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(b) Practitioners using radiation often wear lead aprons to reduce their exposure to the radiation. Identify **two** other ways by which practitioners can minimize their exposure to X-rays. [2]

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(c) High-intensity X-rays are used in radiation therapy.

Outline how knowledge of the response of malignant and normal cells to X-radiation is used to improve the effectiveness of radiation therapy. [4]

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End of Option I

Option J — Particle physics

22. This question is about particles and interactions.

(a) When a free neutron decays to a proton, an electron is one of the decay products.

(i) State the name of the exchange particle and the interaction involved in this decay. [1]

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(ii) The interaction and the exchange particle in (a)(i) may arise when a quark decays. Describe the change in the quark structure of the neutron. [1]

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

(i) 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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(ii) 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 J continues on the following page)

(Option J continued)

23. This question is about particle accelerators.

Charged particles in a cyclotron travel inside two D-shaped conductors (dees).

(a) Outline, with reference to the motion of the particles, why an alternating potential difference is applied between the dees. [4]

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(b) A cyclotron accelerates protons. The radius of the dees in this machine is 0.50 m and the protons leave the machine with a total energy of 1.0 GeV. Determine the alternating frequency of this cyclotron. [4]

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(c) Synchrotrons can accelerate protons to higher energies than cyclotrons. Outline **two** differences in the design features of synchrotrons and cyclotrons that enable these higher energies to be reached. [2]

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(Option J continues on the following page)

(Option J continued)

24. 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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(c) The electron–positron process can also proceed through a neutral current. Outline what is meant by a neutral current. [2]

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(Option J continues on the following page)

(Option J continued)

25. This question is about a K meson decay.

The positive kaon K^+ has a strangeness of +1. It can decay through the interaction

$$K^+ \rightarrow \mu^+ + \nu_\mu.$$

Charge, energy and momentum are conserved in this decay.

(a) State the quark structure of the K^+. [1]

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(b) Deduce one further quantity in this decay that is

(i) conserved. [1]

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. . . . . .

(ii) not conserved. [1]

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(Option J continues on the following page)

(Option J continued)

26. This question is about string theory and the standard model.

(a) State what is meant by an elementary particle. [1]

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(b) Outline how string theory describes particles that the standard model classifies as elementary. [2]

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End of Option J

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

Answers written on this page will not be marked.