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PHYSICS
HIGHER LEVEL
PAPER 3

Candidate session number

Thursday 8 May 2014 (afternoon)

1 hour 15 minutes

Examination code

2	2	1	4	–	6	5	1	5

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 – 5
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Option H — Relativity	15 – 17
Option I — Medical physics	18 – 21
Option J — Particle physics	22 – 25

Option E — Astrophysics

1. This question is about objects in the universe.

(a) State **one** difference between

(i) a main sequence star and a planet. *[1]*

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(ii) a stellar cluster and a constellation. *[1]*

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(Option E continues on the following page)

(Option E, question 1 continued)

(b) State how

(i) it is known that main sequence stars are made predominantly of hydrogen. *[1]*

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(ii) a main sequence star remains in equilibrium despite it having a great mass. *[1]*

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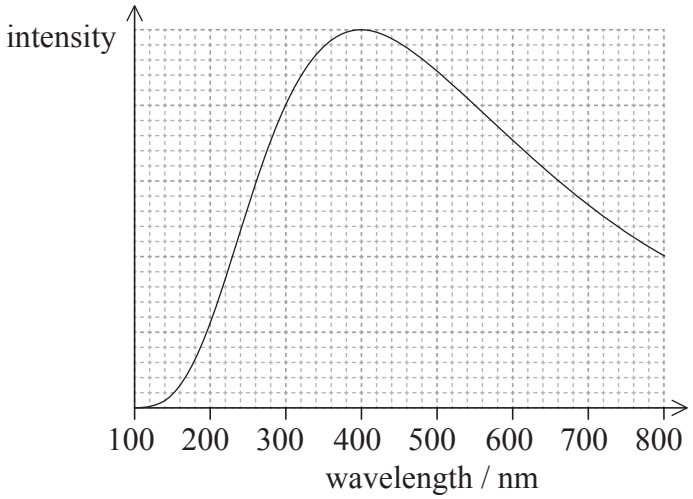
(c) The graph shows the variation with wavelength of the intensity of a main sequence star.



Calculate the surface temperature of this star. *[2]*

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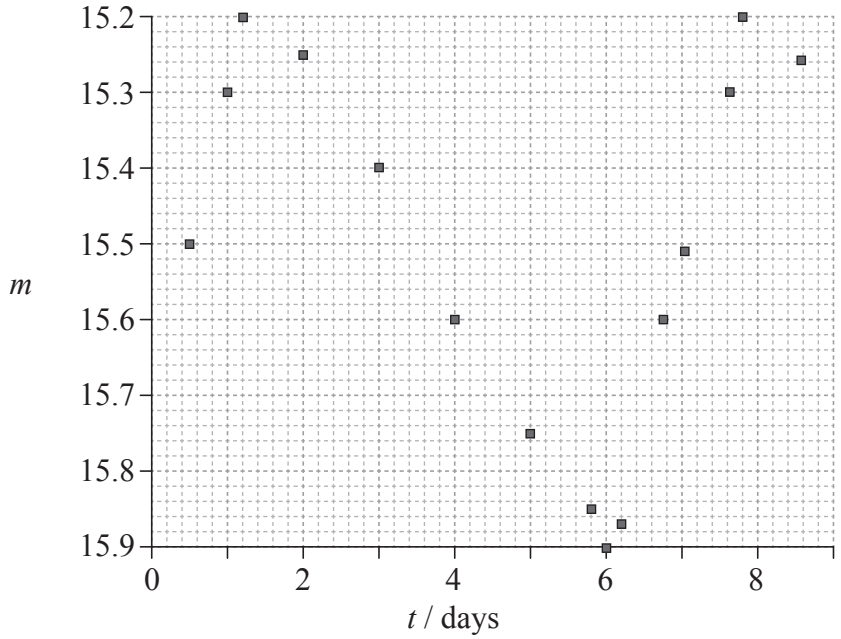
(Option E continues on the following page)

(Option E continued)

2. This question is about a Cepheid star.

(a) The graph shows the variation with time t of the apparent magnitude m of a particular Cepheid star.



State

(i) what apparent magnitude is a measure of. *[1]*

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(ii) the reason for the variation of the star's apparent magnitude. *[1]*

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(Option E continues on the following page)

(Option E, question 2 continued)

(b) The period T, in days, of variation of the apparent magnitude is related to the average absolute magnitude M of the star in (a) through the equation below.

$$M = -(2.81 \times \lg T) - 1.43$$

Determine the distance to the star. *[5]*

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(c) The apparent brightness of the Cepheid star is $b = 1.5 \times 10^{-14}\ \text{W m}^{-2}$. Determine the luminosity of the star. *[3]*

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(Option E continues on the following page)

(Option E continued)

3. This question is about the cosmic microwave background (CMB) radiation.

(a) State **two** characteristics of the cosmic microwave background (CMB) radiation. *[2]*

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(b) Explain how CMB radiation is evidence for the Big Bang model of an expanding universe. *[2]*

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4. This question is about stellar evolution.

(a) Achernar is a main sequence star with a mass that is eight times the mass of the Sun. Deduce that Achernar has a greater temperature than the Sun. *[2]*

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(Option E continues on the following page)

(Option E, question 4 continued)

(b) Outline why Achernar will spend less time on the main sequence than the Sun. *[2]*

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(c) Achernar may evolve to become a neutron star.

(i) State the condition relating to mass that must be satisfied for Achernar to become a neutron star. *[2]*

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(ii) Some neutron stars rotate about their axes and have strong magnetic fields. State how these stars may be detected. *[1]*

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(Option E continues on the following page)

(Option E continued)

5. This question is about Hubble's law.

The spectrum of hydrogen from a source in the laboratory has a spectral line at wavelength 656 nm. The same line, viewed from Earth, in the spectrum of a distant galaxy has wavelength 682 nm.

(a) Suggest why the two wavelengths are different. *[1]*

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(b) Determine the distance to this galaxy from Earth using a Hubble constant of $74\,\text{km}\,\text{s}^{-1}\,\text{Mpc}^{-1}$. *[2]*

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End of Option E

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

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will not be marked.

Option F — Communications

6. This question is about modulation.

(a) (i) Explain what is meant by frequency modulation (FM). *[2]*

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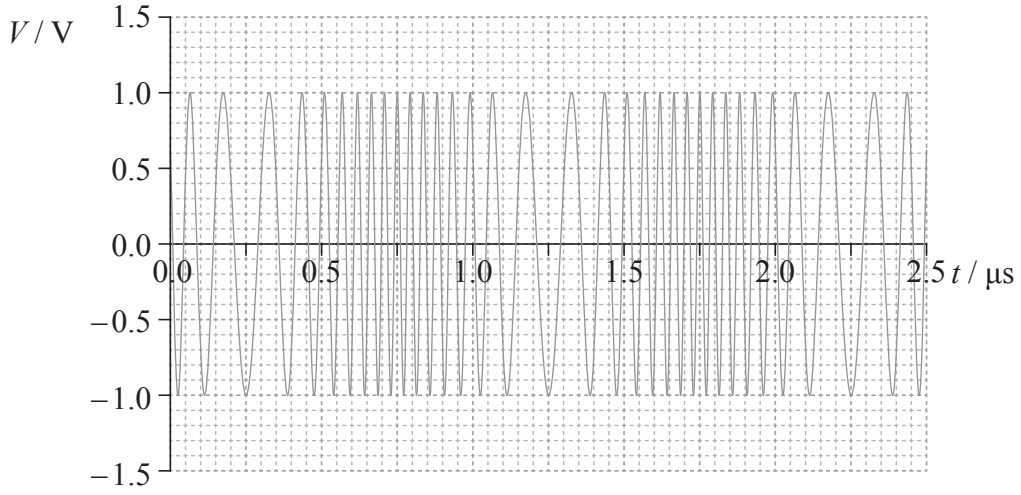
(ii) The graph shows the variation with time t of the voltage V of a frequency modulated carrier wave. The amplitude of the signal wave is 1.0 V.



On the axes, draw a sketch graph to show the variation with time t of the voltage of the signal wave. *[2]*

(Option F continues on the following page)

(Option F, question 6 continued)

(b) Using the graph in (a)(ii), determine the frequency of the

(i) carrier wave. *[1]*

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(ii) signal wave. *[2]*

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(c) State **one** advantage and **one** disadvantage of FM modulation compared to amplitude modulation (AM). *[2]*

Advantage:

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Disadvantage:

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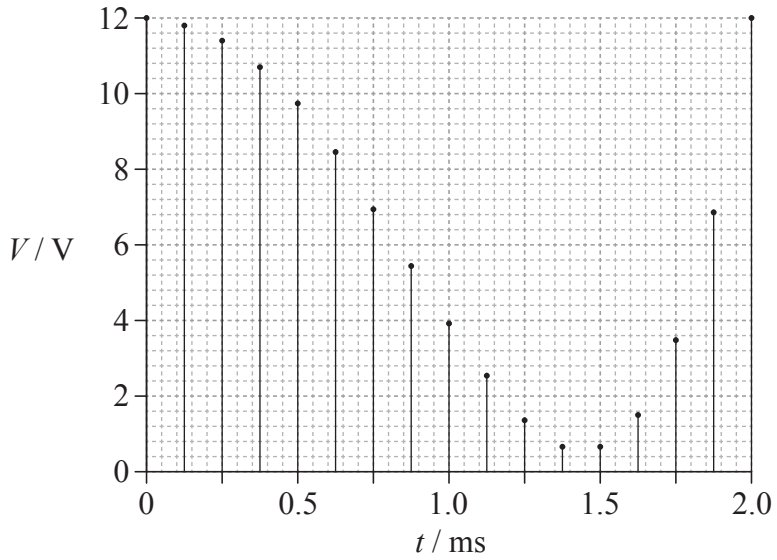
(Option F continues on the following page)

(Option F continued)

7. This question is about sampling.

An analogue signal is sampled. The graph shows the variation with time t of the voltage V of each sample.



The voltage in each sample is rounded to the nearest integer.

(a) Determine the sampling frequency. *[2]*

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(b) The highest voltage in a sample is 12 V. Determine the minimum number of bits that are required in order to represent each sample. *[2]*

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(Option F continues on the following page)

(Option F, question 7 continued)

(c) Calculate the binary equivalent of the seventh sample. *[1]*

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(Option F continues on the following page)

(Option F continued)

8. This question is about digital transmission and optical fibres.

(a) State what is meant by attenuation. *[1]*

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(b) A digital signal is to be transmitted along an optic fibre. The signal to noise ratio $\left(\text{that is } 10\lg\frac{P_{\text{signal}}}{P_{\text{noise}}}\right)$ in the fibre must not fall below 35 dB.

The following data are available.

Attenuation per unit length of the optic fibre $= 2.6\,\text{dB}\,\text{km}^{-1}$
Power of the input signal is $P_{\text{signal}} = 88\,\text{mW}$
Noise power in the fibre is constant at $P_{\text{noise}} = 52\,\text{pW}$

(i) Determine, using the data, the greatest distance the signal can travel before it must be amplified. *[3]*

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(Option F continues on the following page)

(Option F, question 8 continued)

(ii) The optic fibre has a total length of 5600 km. The total transmission time along the length of the fibre is 28 ms. Estimate the refractive index of the core of the fibre. *[2]*

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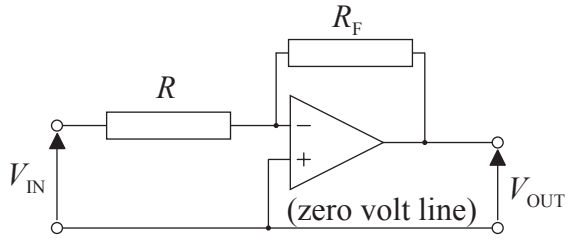
(Option F continues on the following page)

(Option F continued)

9. This question is about operational amplifiers (op-amps).

(a) The diagram shows an inverting amplifier.



The op-amp operates with a power supply of ±6.0 V. The resistance of R_F is 75 kΩ and the resistance of R is 15 kΩ.

(i) State **one** property of an ideal op-amp. *[1]*

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(ii) Determine the closed loop gain of the inverting amplifier. *[1]*

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(iii) Calculate the input voltage at which positive saturation is achieved. *[1]*

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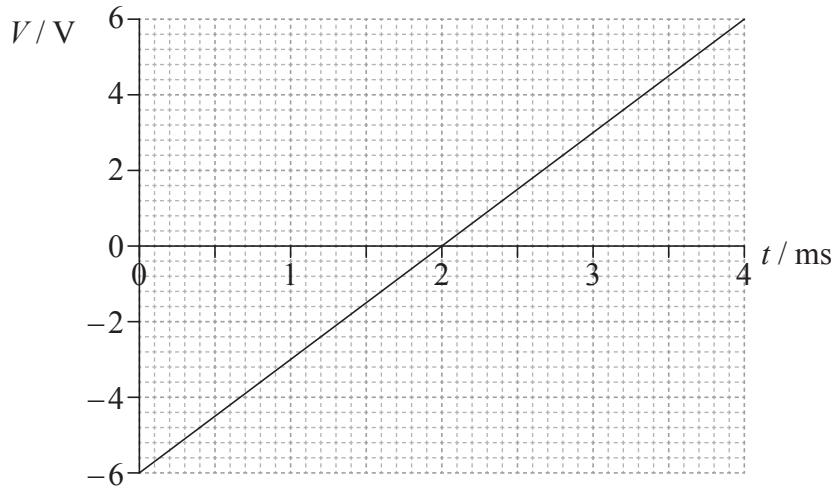
(Option F continues on the following page)

(Option F, question 9 continued)

(b) The input voltage V to the inverting amplifier in (a) varies with time t according to the graph.



On the axes, sketch a graph to show how the output voltage varies with time. *[3]*

10. This question is about the mobile phone system.

A train passenger in France has a 10 minute conversation on her mobile phone with a friend in Canada. Outline the role of base stations, the cellular exchange and the public switched telephone network (PSTN) in this phone call. *[4]*

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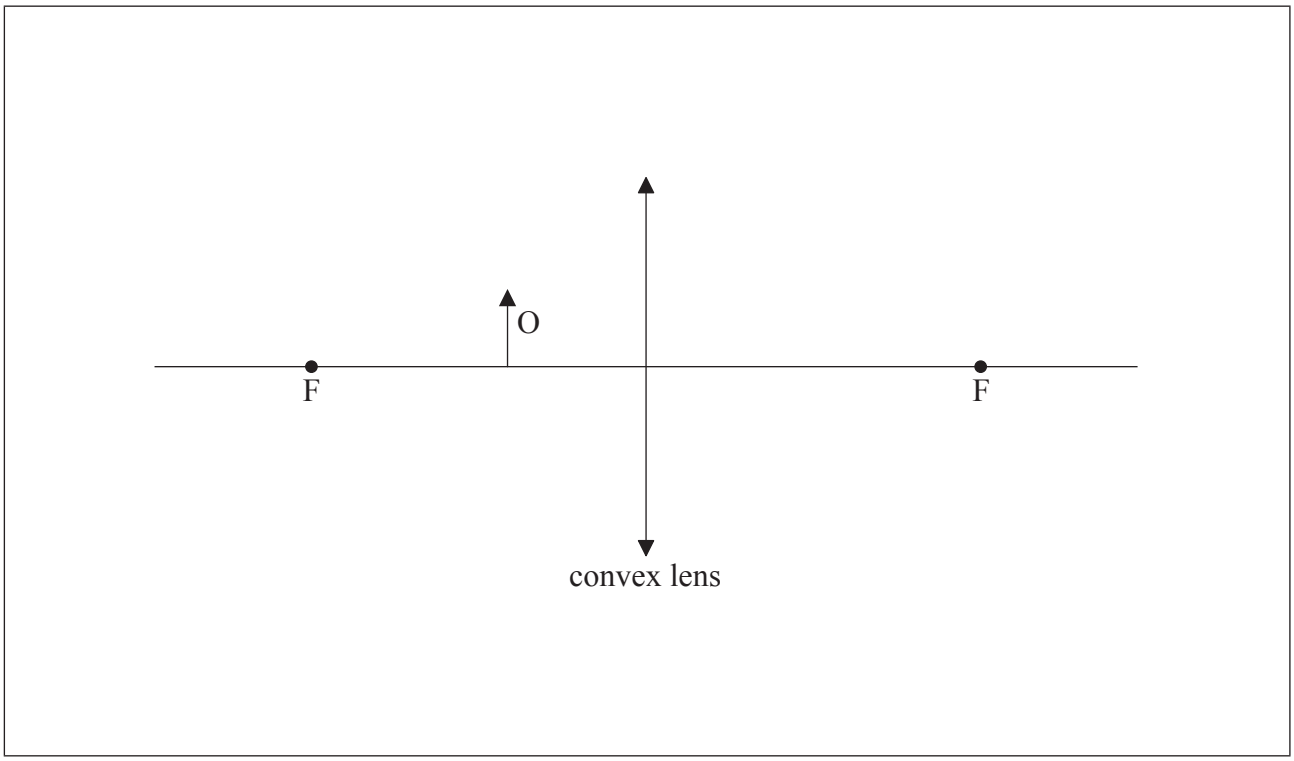
End of Option F

Option G — Electromagnetic waves

11. This question is about a magnifying glass and a telescope.

(a) A thin converging (convex) lens is used as a magnifying glass. Object O is placed between a focal point of the lens and the centre of the lens. The focal points of the lens are shown, labelled F.



(i) Define the term *focal point*. *[2]*

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(ii) On the diagram, construct rays to locate the position of the image of the object. Label the image I. *[3]*

(Option G continues on the following page)

(Option G, question 11 continued)

(b) The position of the lens in (a) is changed so that a virtual image of the object is formed at the near point of the eye. The eye is very close to the lens.

(i) Define the term *near point*. *[1]*

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(ii) Outline the advantage of having the image positioned at the near point of the eye. *[1]*

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(c) The lens in (a) has a focal length of 6.0 cm and is now used as the eyepiece of an astronomical telescope. The objective lens of the telescope has a focal length of 90 cm. The telescope is used in normal adjustment.

(i) State the separation of the objective lens and the eyepiece lens. *[1]*

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(ii) Determine the angular magnification of the telescope. *[2]*

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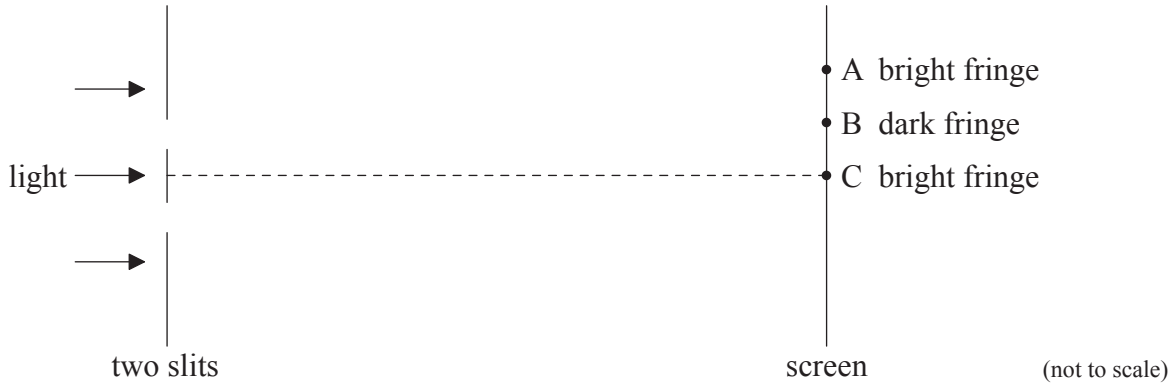
(Option G continues on the following page)

(Option G continued)

12. This question is about interference.

Light from a laser is incident on two identical parallel slits. The light from the two slits produces a fringe pattern on a screen.



A central bright fringe is produced at C. The next bright fringe is produced at A. There is a dark fringe at B.

(a) The light from the laser is coherent and monochromatic. Outline what is meant by the term

(i) coherent. *[1]*

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(ii) monochromatic. *[1]*

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(Option G continues on the following page)

(Option G, question 12 continued)

(b) State the phase difference between the light waves from the two slits that meet at B. *[1]*

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(c) The distance from the two slits to the screen is 1.5 m. The distance BC is 1.8 mm and the distance between the slits is 0.30 mm.

(i) Show that the laser produces light of wavelength equal to 720 nm. *[3]*

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(ii) State the path difference, in metres, between the waves that meet at B. *[1]*

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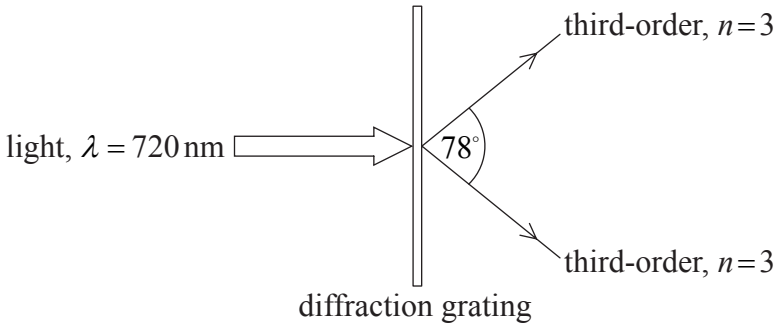
(Option G continues on the following page)

(Option G, question 12 continued)

(d) The light from the laser is now incident normally on a diffraction grating. The angle between the third-order intensity maxima is 78°.



Determine the number of lines per metre of the diffraction grating. *[3]*

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(Option G continues on the following page)

(Option G continued)

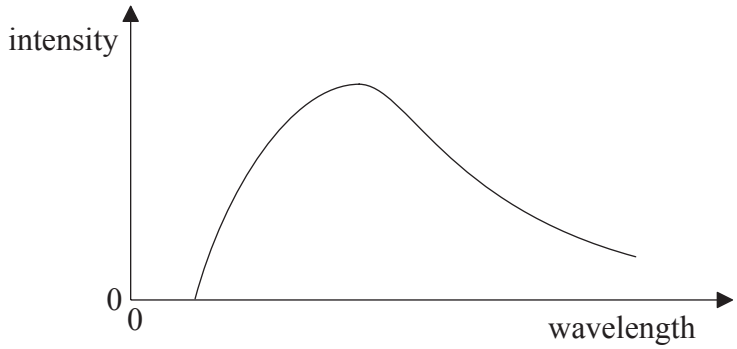
13. This question is about X-rays.

(a) Draw a labelled diagram of the apparatus that is used for the production of X-rays. *[3]*

(Option G continues on the following page)

(Option G, question 13 continued)

(b) The diagram shows the variation with wavelength of the intensity of a particular X-ray source.



Outline the reason why a characteristic X-ray spectrum is not produced. *[2]*

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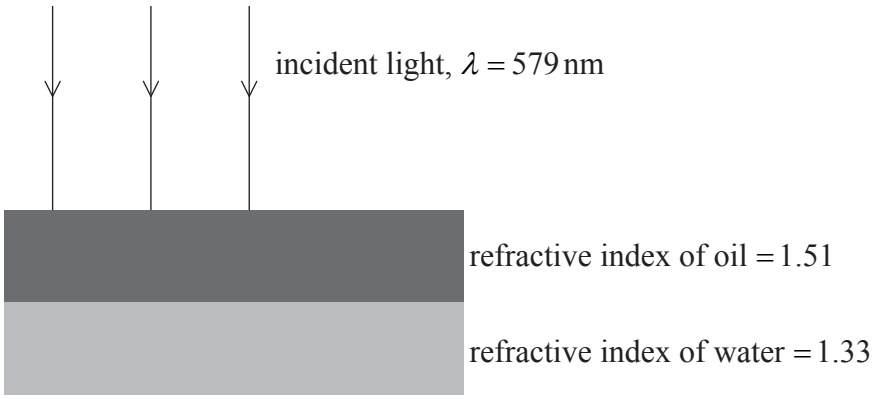
(Option G continues on the following page)

(Option G continued)

14. This question is about thin-film interference.

A thin layer of oil of refractive index 1.51 floats on water of refractive index 1.33. Light of wavelength 579 nm is incident normally to the surface.



(a) Determine the minimum thickness of the oil layer that gives rise to the least amount of light being reflected. *[3]*

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(b) Describe the change in the intensity of the reflected light as the thickness of the oil layer in (a) is gradually increased. *[2]*

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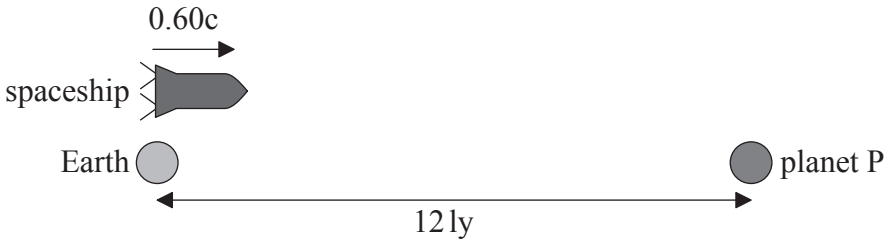
End of Option G

Option H — Relativity

15. This question is about relativistic kinematics.

The diagram shows a spaceship as it moves past Earth on its way to a planet P. The planet is at rest relative to Earth.



The distance between the Earth and planet P is 12 ly as measured by observers on Earth. The spaceship moves with speed 0.60c relative to Earth.

Consider two events:

Event 1: when the spaceship is above Earth
Event 2: when the spaceship is above planet P

Judy is in the spaceship and Peter is at rest on Earth.

(a) State the reason why the time interval between event 1 and event 2 is a proper time interval as measured by Judy. *[1]*

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(b) (i) Calculate the time interval between event 1 and event 2 according to Peter. *[1]*

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(Option H continues on the following page)

(Option H, question 15 continued)

(ii) Calculate the time interval between event 1 and event 2 according to Judy. *[2]*

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(c) Judy considers herself to be at rest. According to Judy, the Earth and planet P are moving to the left.

(i) Calculate, according to Judy, the distance separating the Earth and planet P. *[1]*

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(ii) Using your answers to (b)(ii) and (c)(i), determine the speed of planet P relative to the spaceship. *[1]*

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(iii) Comment on your answer to (c)(ii). *[1]*

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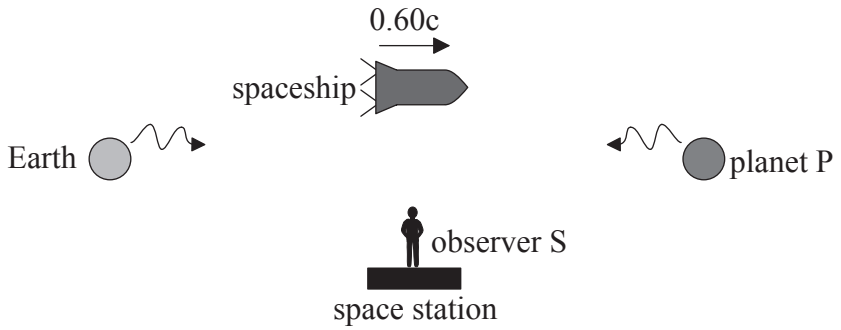
(Option H continues on the following page)

(Option H, question 15 continued)

(d) At a point half-way between the Earth and planet P, the spaceship passes a space station that is at rest relative to the Earth and planet P. At that instant, radio signals are sent towards the spaceship from the Earth and planet P. The signals are emitted simultaneously according to an observer S at rest on the space station.



Determine, according to Judy in the spaceship, which signal is emitted first. *[3]*

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(Option H continues on the following page)

(Option H, question 15 continued)

(e) On reaching planet P, the spaceship circles the planet and begins the return trip back to Earth. This situation leads to the twin paradox.

(i) Describe what is meant by the term twin paradox. *[2]*

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(ii) Suggest how this paradox is resolved. *[2]*

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(Option H continues on the following page)

(Option H continued)

16. This question is about relativistic mechanics.

A rho meson (ρ) decays at rest in a laboratory into a pion (π^+) and an anti-pion (π^-) according to

$$\rho \rightarrow \pi^+ + \pi^-.$$

The rest masses of the particles involved are:

$$m_{\pi^+} = m_{\pi^-} = 140\,\text{MeV}\,\text{c}^{-2}$$
$$m_{\rho} = 770\,\text{MeV}\,\text{c}^{-2}$$

(a) (i) Show that the initial momentum of the pion is $360\,\text{MeV}\,\text{c}^{-1}$. *[3]*

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(ii) Show that the speed of the pion relative to the laboratory is 0.932c. *[2]*

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(iii) Calculate, in $\text{MeV}\,\text{c}^{-2}$, the mass that has been converted into energy in this decay. *[1]*

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(Option H continues on the following page)

(Option H, question 16 continued)

(b) The pion (π^+) emits a muon in the same direction as the velocity of the pion. The speed of the muon is 0.271c relative to the pion. Calculate the speed of the muon relative to the laboratory. *[2]*

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(Option H continues on the following page)

(Option H continued)

17. This question is about general relativity.

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

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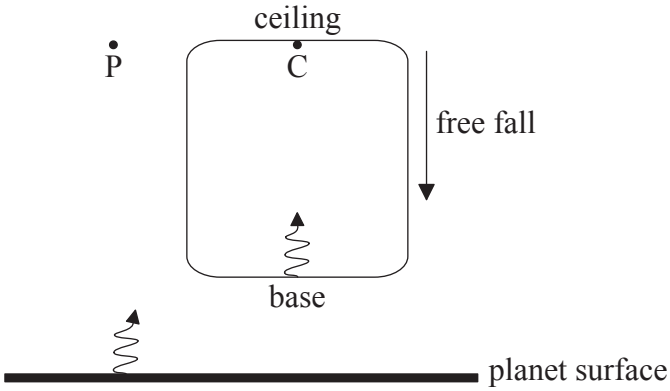
(b) The diagram shows monochromatic light of frequency f_0 being emitted from the base of a box towards an observer C at the ceiling of the box. The box is in free fall above the surface of the planet. Light of the same frequency is also emitted from the surface of the planet towards an observer P at rest above the surface of the planet.



The frequency of the light as measured by C is f_C and the frequency of the light as measured by P is f_P.

State and explain whether the frequencies f_C and f_P are less than, equal to or greater than f_0.

(i) f_C *[2]*

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(Option H continues on the following page)

(Option H, question 17 continued)

(ii) f_P *[3]*

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(c) Newton explained the motion of a planet around the Sun in terms of a force of gravitation between the Sun and the planet. Describe how Einstein's theory of general relativity explains the motion of the planet around the Sun. *[2]*

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End of Option H

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will not be marked.

Option I — Medical physics

18. This question is about sound intensity.

(a) Define *intensity* of a sound wave. *[1]*

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(b) A factory siren produces sound of power 25 W that is emitted uniformly in all directions. A person stands at a distance of 4.5 m from the siren.

(i) Show that, at the position of the person, the sound intensity level is 110 dB. *[3]*

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(ii) Outline **two** possible effects on the person from long-term exposure to sound at this intensity level. *[2]*

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(Option I continues on the following page)

(Option I continued)

19. This question is about medical imaging.

(a) Outline how an image is produced using computed tomography (CT). *[5]*

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(b) State **one** disadvantage of producing a CT image of a person rather than a standard X-ray image. *[1]*

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(Option I continues on the following page)

(Option I, question 19 continued)

(c) The intensity of a parallel X-ray beam is reduced to 50 % of its initial intensity when it passes through bone of thickness 1.2 cm. Determine the thickness of bone needed to reduce the intensity of the same X-ray beam to 15 % of its initial value. *[3]*

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(Option I continues on the following page)

(Option I continued)

20. This question is about ultrasound.

(a) Define *acoustic impedance*. *[1]*

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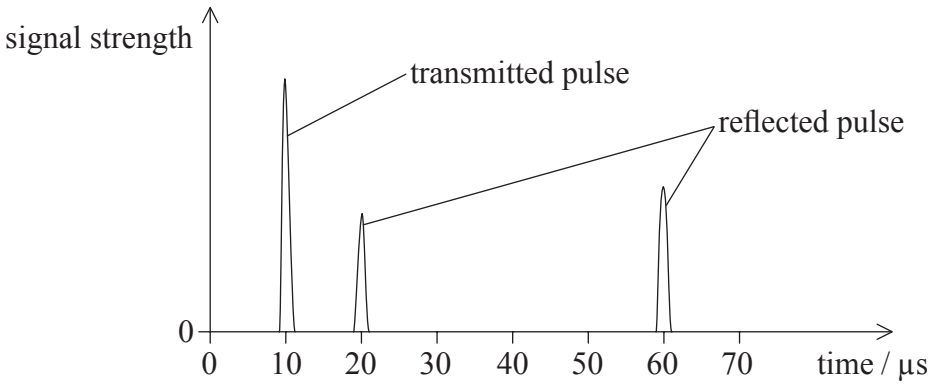
(b) An ultrasound pulse is transmitted into the body of a patient. The pulse is partially reflected at a fat–muscle boundary and then, deeper in the body, at a muscle–bone boundary. The graph shows the variation with time of the signal strength at the transducer.



Muscle has density $1.08 \times 10^3\,\text{kg m}^{-3}$ and acoustic impedance $1.70 \times 10^6\,\text{kg m}^{-2}\,\text{s}^{-1}$.

(i) Calculate the speed of ultrasound in muscle. *[1]*

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(Option I continues on the following page)

(Option I, question 20 continued)

(ii) Determine the thickness of the muscle layer in the patient. *[3]*

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(c) State **one** advantage and **one** disadvantage of using ultrasound of frequency 1 MHz, rather than 3 MHz, in medical diagnosis. *[2]*

Advantage:

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Disadvantage:

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(Option I continues on the following page)

(Option I continued)

21. This question is about radiation therapy.

(a) State what is meant by the term absorbed dose. *[1]*

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(b) A patient receives radiation therapy on a tumour of mass 15 g. A radioactive source is implanted into the tumour for a period of 5.0 days so that the tumour receives an absorbed dose of 55 Gy. The source emits beta particles of average energy 6.0×10^5 eV. At the end of the therapy the source is removed.

(i) Determine the average activity of the radioactive source. *[3]*

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(ii) Outline **one** precaution that should be taken by hospital staff who handle the radioactive source. *[1]*

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(Option I continues on the following page)

(Option I, question 21 continued)

(c) Two different sources are considered for the treatment in (b). Both sources emit beta particles of the same average energy as in (b) and both have the same initial activity as the average activity calculated in (b). One source has a half-life of 10 days and the other has a half-life of 75 days.

(i) State and explain which source is more suitable for providing the radiation therapy over the five-day period. *[2]*

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(ii) Suggest **one** advantage of implanting a beta source into the tumour rather than supplying gamma radiation to the tumour from outside the body. *[1]*

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End of Option I

Option J — Particle physics

22. This question is about fundamental interactions.

(a) The kaon is a hadron whose quark structure is $K^+ = u\bar{s}$.

(i) State and explain whether the Pauli exclusion principle applies to kaons. *[2]*

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(ii) Energy is supplied to the kaon in order to break up the particle into its constituent quarks. Predict, by reference to quark colour, what will happen as more and more energy is provided to the K^+. *[3]*

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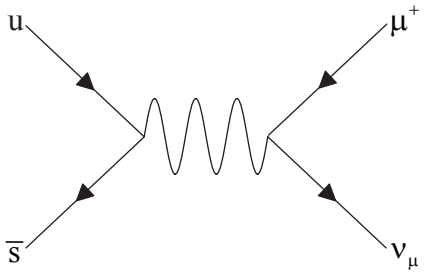
(Option J continues on the following page)

(Option J, question 22 continued)

(b) The kaon ($K^+ = u\bar{s}$) decays into an antimuon and a neutrino as shown by the Feynman diagram.



(i) Explain why the virtual particle in this Feynman diagram must be a weak interaction exchange particle. *[2]*

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(ii) The mass of the virtual particle in (b)(i) is approximately $80\,\text{GeV}\,c^{-2}$. Estimate the range of the weak interaction. *[2]*

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(c) A student claims that the K^+ is produced in neutron decays according to the reaction $n \rightarrow K^+ + e^-$. State **one** reason why this claim is false. *[1]*

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(Option J continues on the following page)

(Option J continued)

23. This question is about particle production and detection.

(a) (i) The mass of a top (t) quark is approximately $173\,\text{GeV}\,\text{c}^{-2}$. Pairs of $\text{t}\overline{\text{t}}$ were first produced in proton–antiproton ($\text{p}\overline{\text{p}}$) collisions in a synchrotron. Calculate the minimum total kinetic energy of the $\text{p}\overline{\text{p}}$ pair needed to produce one $\text{t}\overline{\text{t}}$ pair. *[2]*

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(ii) Pairs of $\text{t}\overline{\text{t}}$ may also be produced when accelerated antiprotons collide with stationary protons. Calculate the required total energy of the accelerated antiproton in order to produce a $\text{t}\overline{\text{t}}$ pair. *[3]*

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(iii) State **one** advantage and **one** disadvantage of $\text{p}\overline{\text{p}}$ collisions in a synchrotron compared with collisions of antiprotons with stationary protons in a linear accelerator. *[2]*

Advantage:

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Disadvantage:

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(Option J continues on the following page)

(Option J, question 23 continued)

(b) Wire chambers are used to detect particle tracks produced in collisions. Outline the operation of a wire chamber. *[3]*

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(Option J continues on the following page)

(Option J continued)

24. This question is about deep inelastic scattering.

(a) State what is meant by deep inelastic scattering experiments. *[1]*

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(b) Suggest how deep inelastic scattering experiments have provided evidence for the existence of

(i) gluons. *[2]*

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(ii) colour. *[2]*

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(Option J continues on the following page)

(Option J continued)

25. This question is about cosmology.

(a) Determine the temperature below which the production of electron–positron pairs out of the vacuum became impossible. *[2]*

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(b) Suggest, with reference to your answer to (a), why the universe today contains predominantly matter whereas the very early universe contained almost equal numbers of particles and antiparticles. *[3]*

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End of Option J

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

Answers written on this page
will not be marked.