88126503

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Baccalauréat International
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PHYSICS
HIGHER LEVEL
PAPER 3

Candidate session number

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Wednesday 14 November 2012 (morning)

1 hour 15 minutes

Examination code

8	8	1	2	–	6	5	0	3

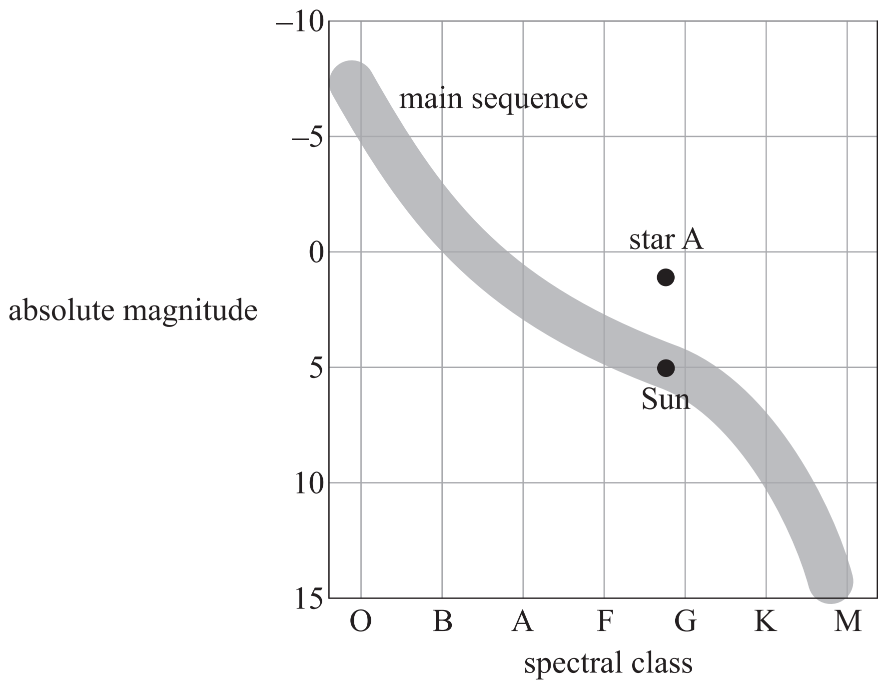
INSTRUCTIONS TO CANDIDATES

- 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 E — Astrophysics

E1. This question is about stars.

The Hertzsprung–Russell (HR) diagram shows the Sun, a star labelled A and the main sequence.



(a) (i) Define *absolute magnitude*. *[1]*

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(ii) State **one** physical property of a star that is determined by its spectral class. *[1]*

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(This question continues on the following page)

(Question E1 continued)

(iii) Suggest why star A has a greater radius than the Sun. *[1]*

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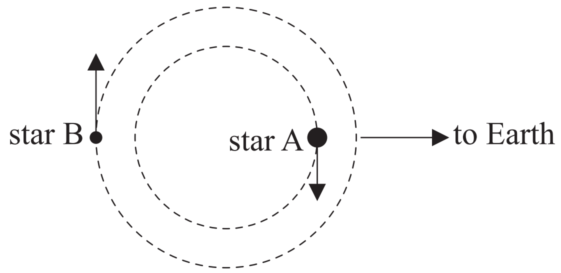
(b) Star A is part of a binary star system. The diagram shows the orbit of star A and the orbit of its companion, star B.



The temperature of star A is T_A, the temperature of star B is T_B and $\frac{T_A}{T_B} = 0.60$. The radius of star A is R_A, the radius of star B is R_B and $\frac{R_A}{R_B} = 270$.

(i) Show that the luminosity of star A is 9.4×10^3 times greater than the luminosity of star B. *[2]*

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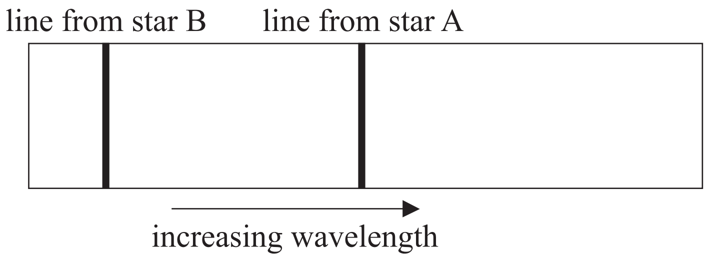
(ii) Draw the approximate position of star B onto the HR diagram on page 2. *[1]*

(This question continues on the following page)

(Question E1 continued)

(c) The diagram below shows the spectrum of the stars as observed from Earth. The spectrum shows one line from star A and one line from star B, when the stars are in the position shown in the diagram (b).



On the spectrum draw lines to show the approximate positions of these spectral lines after the stars have completed one quarter of a revolution. *[2]*

E2. This question is about Cepheid stars.

(a) The star η Aquilae is a Cepheid star. Its apparent magnitude varies from 3.6 to 4.4 with a period of 7.2 days.

(i) State the reason for the variation of the Cepheid's brightness. *[1]*

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(ii) The average absolute magnitude M of a Cepheid star and the period T in days of the variation of its brightness are related by the equation below.

$$M = -2.83\log_{10} T - 1.81$$

Determine the distance to η Aquilae. *[3]*

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(b) A Cepheid star and non-Cepheid star both belong to the same distant galaxy. Explain, stating the quantities that need to be measured, how the luminosity of the non-Cepheid star may be determined. *[2]*

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E3. This question is about cosmology.

(a) Theoretical studies indicate that the universe may be open, closed or flat.

(i) State, by reference to critical density, the condition that must be satisfied for the universe to be flat. *[1]*

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(ii) In a flat universe, the rate of expansion would be slowing down. Suggest a reason for this. *[1]*

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(iii) Outline why it has been difficult to determine whether the universe is open, closed or flat. *[2]*

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(Question E3 continued)

(b) Outline **one** piece of experimental evidence that supports the fact that the universe is expanding. *[2]*

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E4. This question is about stellar evolution.

(a) A main sequence star has a mass of $2.2\,M_{\odot}$ where $M_{\odot}=1$ solar mass. The lifetime of a star on the main sequence is proportional to $\dfrac{M}{L}$ where M is the mass and L is the luminosity of the star.

Using the mass–luminosity relation $L \propto M^{3.5}$ show that the

(i) luminosity of the star is $16\,L_{\odot}$ where $L_{\odot}=1$ solar luminosity. *[1]*

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(ii) lifetime of this star on the main sequence will be approximately $\dfrac{1}{7}$ of the lifetime of the Sun. *[2]*

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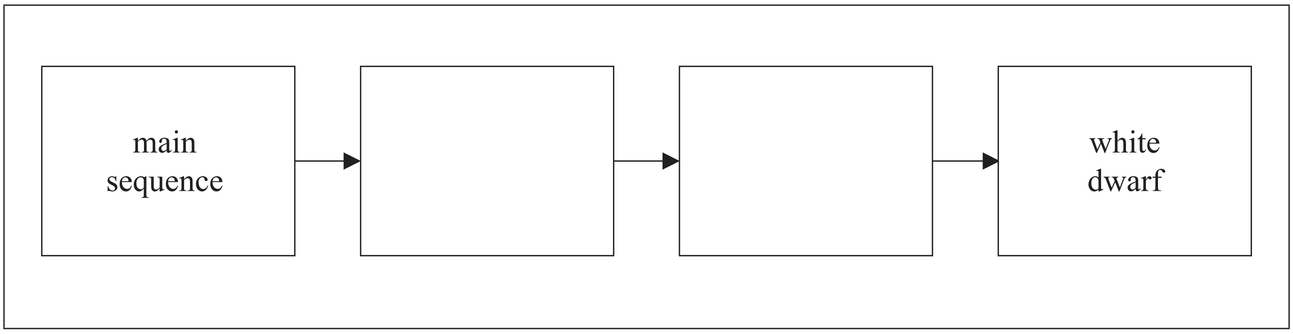
(Question E4 continued)

(b) The star in (a) will evolve to become a white dwarf. The diagram represents the stages in the evolution of the star.



(i) On the diagram, label the **two** intermediate stages. *[2]*

(ii) State what may be deduced about the mass of this star when it is in the white dwarf stage. *[1]*

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E5. This question is about Hubble's law.

(a) The fractional change in the wavelength λ of light from the galaxy Hydra is $\frac{\Delta\lambda}{\lambda} = 0.204$. The distance to Hydra is 820 Mpc.

Estimate in $\text{km s}^{-1}\,\text{Mpc}^{-1}$ a value for the Hubble constant. *[2]*

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(b) An estimate of the age of the universe is $\frac{1}{H}$ where H is the Hubble constant. Suggest why $\frac{1}{H}$ overestimates the age of the universe. *[2]*

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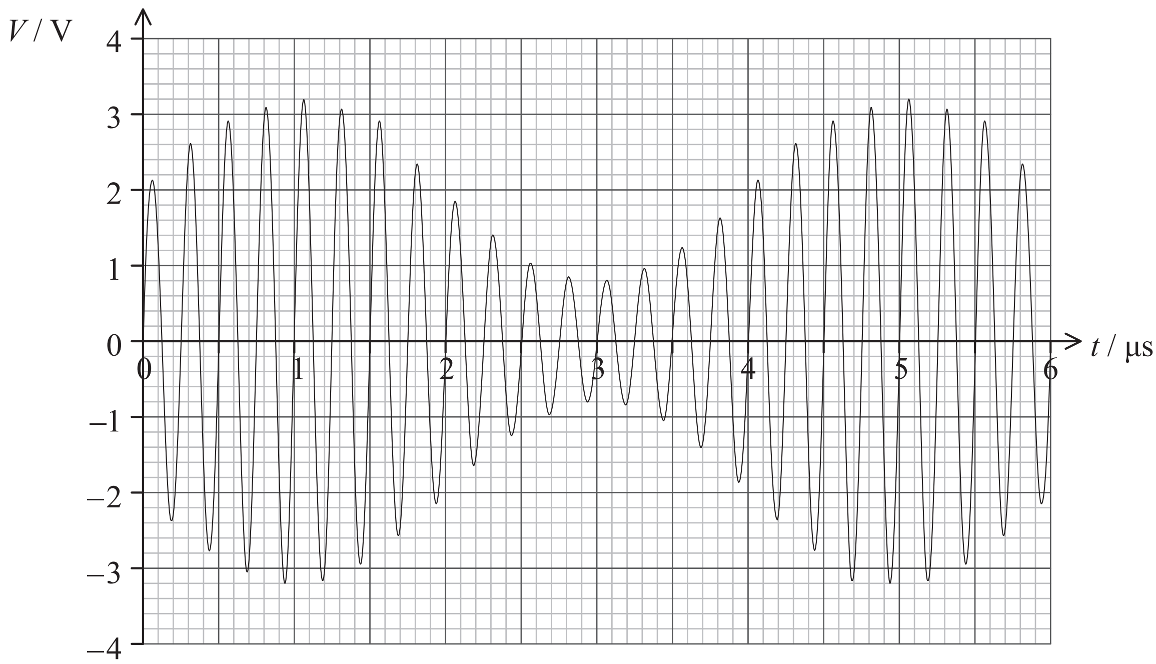
Please **do not** write on this page.

Answers written on this page
will not be marked.

Option F — Communications

F1. This question is about modulation.

The diagram shows the variation with time t of the voltage signal V of an amplitude modulated carrier wave.



(a) Determine the

(i) frequency of the carrier wave. *[1]*

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(ii) frequency of the signal (information) wave. *[1]*

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(Question F1 continued)

(iii) amplitude of the signal wave. *[1]*

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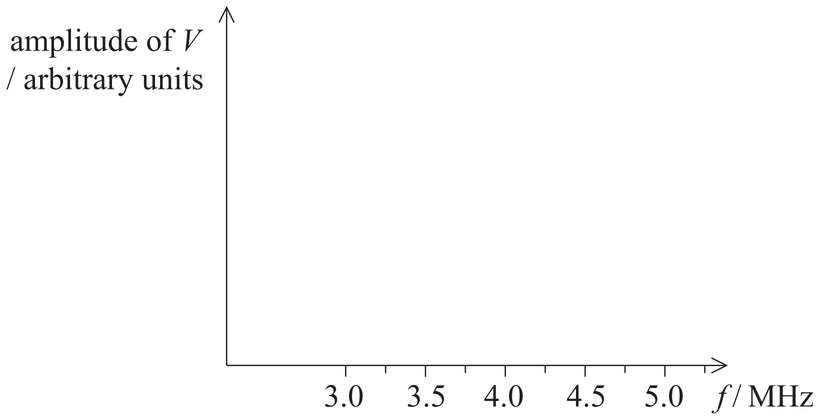
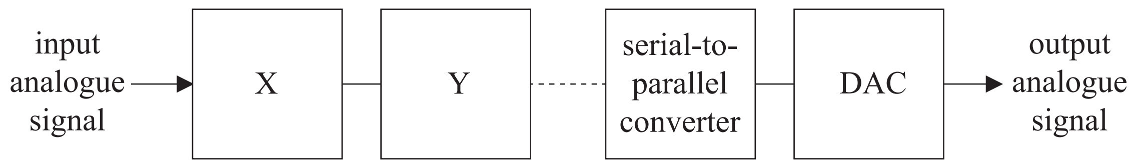
(b) On the axes below, draw the spectrum of the modulated wave, *i.e.* the variation with frequency f of the amplitude of the voltage V. *[2]*



F2. This question is about digital transmission.

(a) The diagram below is a block diagram for the digital transmission of an analogue signal.



(i) State the names of blocks X and Y. *[2]*

X: ....

Y: ....

(ii) Describe the function of the serial-to-parallel converter. *[2]*

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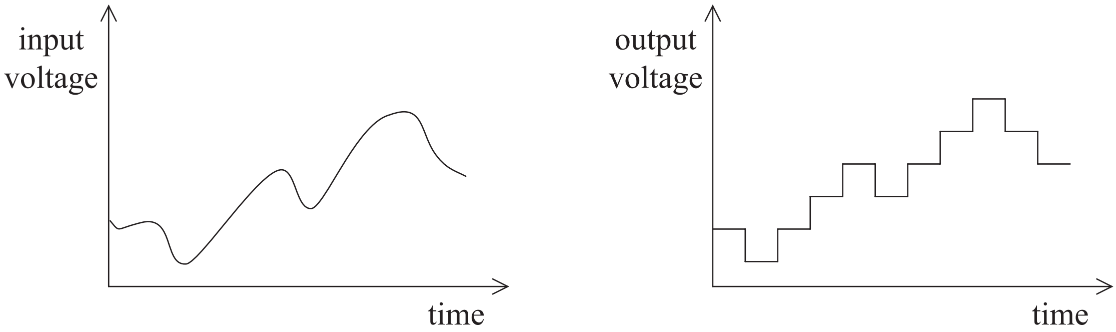
(This question continues on the following page)

(Question F2 continued)

(b) The diagrams show the variation with time of the input and output analogue signal voltages.



State and explain **two** ways in which the output signal could be made to be a more accurate reproduction of the input signal. *[4]*

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F3. This question is about optic fibres.

(a) State **one** advantage of the use of an optic fibre rather than a coaxial cable for the transmission of information. *[1]*

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(b) Suggest why, in transmitting information in an optic fibre, infrared electromagnetic radiation rather than visible light is used. *[2]*

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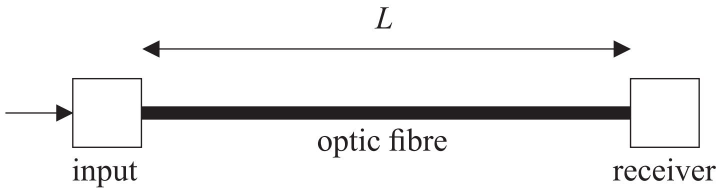
(c) A signal is fed into an optic fibre of length *L*.



The noise power at the receiver is $P_{\text{noise}} = 4.2\,\mu\text{W}$. The signal to noise ratio $\left(i.e.\ 10\log\dfrac{P_{\text{signal}}}{P_{\text{noise}}}\right)$ at the receiver must exceed 25 dB.

(i) Show that the minimum signal power at the receiver is 1.3 mW. *[1]*

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(This question continues on the following page)

(Question F3 continued)

(ii) A signal of power 25 mW is input to the optic fibre. The attenuation per unit length of the optic fibre is 0.30 dB km^{-1}. Determine the maximum length L of the optic fibre. *[3]*

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F4. This question is about the operational amplifier (op-amp).

(a) State **two** properties of an ideal operational amplifier (op-amp). *[2]*

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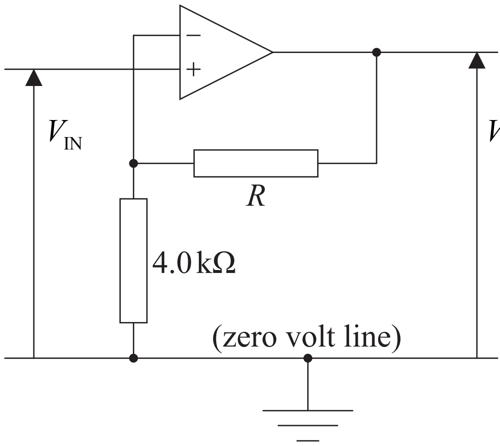
(Question F4 continued)

(b) The diagram shows a circuit that includes an op-amp.



The overall gain of this circuit is $\frac{V_{OUT}}{V_{IN}} = 26$. Calculate the resistance of resistor *R*. *[2]*

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(c) The op-amp operates with a ±9.0 V supply. Determine the value of the output voltage V_{OUT} for input voltages V_{IN} of

(i) – 0.30 V. *[1]*

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(ii) +3.0 V. *[1]*

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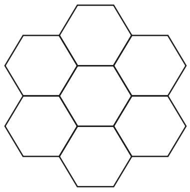
F5. This question is about the mobile phone system.

The diagram shows a few of the cells in a mobile phone system. Each cell has its own base station. The base stations are connected to a cellular exchange.



(a) Suggest why the size of each cell is usually limited to no more than a few kilometres. *[2]*

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(b) Describe how, at any one instant, many mobile phones may be communicating with the same base station. *[2]*

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Option G — Electromagnetic waves

G1. This question is about interference of light at two parallel slits.

(a) State the condition necessary to observe interference between two light sources. *[1]*

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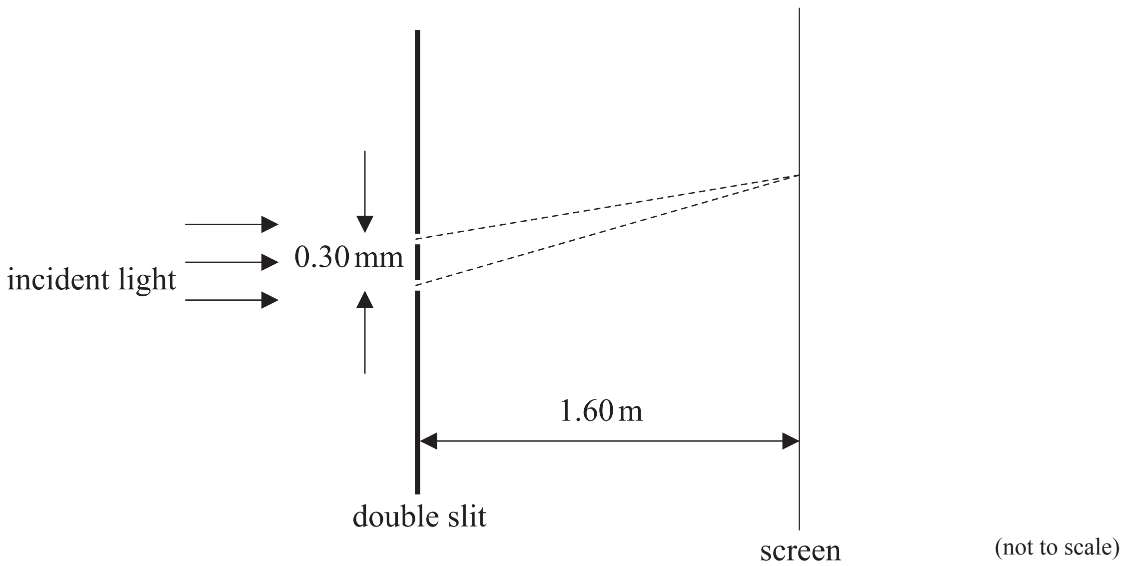
(b) The diagram below shows an arrangement for observing a double slit interference pattern. A parallel beam of coherent light of wavelength 410 nm is incident on two parallel narrow slits separated by 0.30 mm. A screen is placed 1.60 m beyond the slits.



Calculate the fringe spacing on the screen. *[2]*

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(This question continues on the following page)

(Question G1 continued)

(c) The slits in (b) are replaced by a large number of slits of the same width and separation as the double slit. Describe the effects that this change will have on the appearance of the fringes on the screen. *[3]*

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G2. This question is about the simple magnifying glass and the compound microscope.

(a) Define, for the unaided eye, the term *near point*. *[1]*

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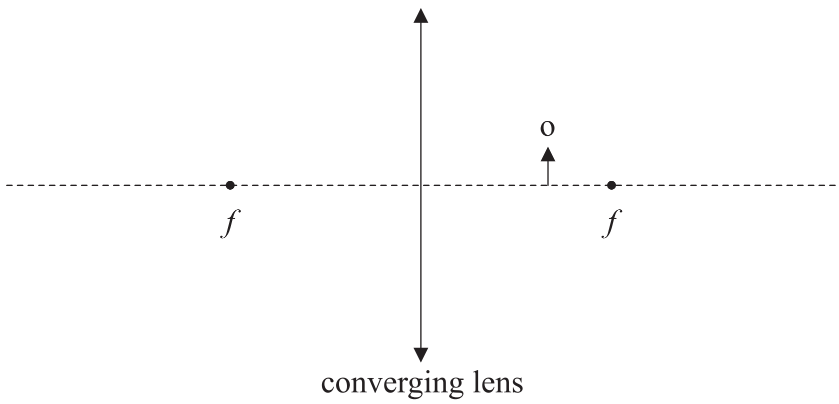
(b) A converging lens is used as a magnifying glass. On the diagram draw rays to construct the image of the object, o. *[3]*



(This question continues on the following page)

(Question G2 continued)

(c) The lens has a focal length f. When the image is formed at the near point, the distance u of the object from the lens is given by

$$u = \frac{fD}{D + f}$$

where D is the near point distance.

Deduce that the angular magnification M is given by

$$M = 1 + \frac{D}{f}.$$

[2]

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(This question continues on the following page)

(Question G2 continued)

(d) A compound microscope consists of an eyepiece lens of focal length 6.0 cm and an objective lens of focal length 2.8 cm. An object is placed 3.4 cm from the objective lens and the final image of the object is formed by the microscope at the near point.

Determine the

(i) angular magnification of the eyepiece. Take the near point distance to be 25 cm. *[1]*

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(ii) distance from the objective lens of the intermediate image formed by this lens. *[2]*

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(iii) overall magnification of the compound microscope. *[2]*

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G3. This question is about the scattering of light.

Explain, with reference to the scattering of light, why the sky appears red at sunset. *[3]*

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G4. This question is about X-rays.

(a) X-rays are produced in an X-ray tube.

(i) State and explain how the continuous and characteristic X-ray spectra are produced. *[4]*

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(ii) Outline how the intensity of the X-rays produced is controlled. *[2]*

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(This question continues on the following page)

(Question G4 continued)

(b) (i) Some X-rays are produced by an accelerating potential of 25 kV. Show that the minimum wavelength of these X-rays is 5.0×10^{-11} m. *[2]*

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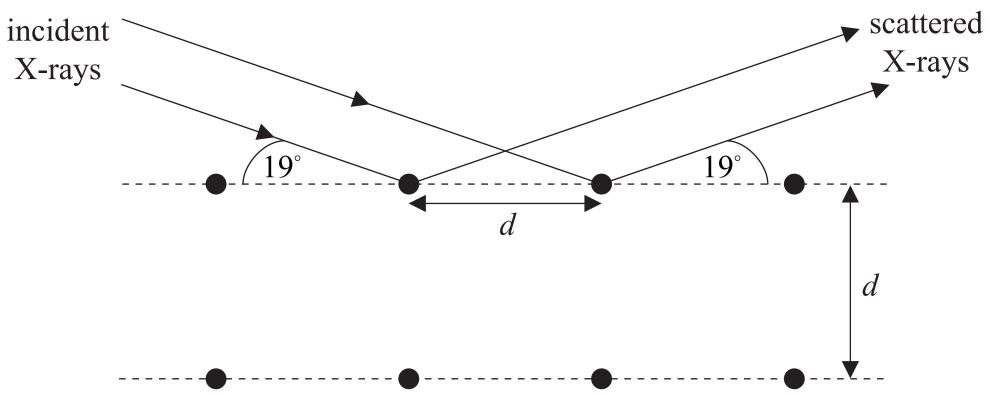
(ii) X-rays of wavelength 5.0×10^{-11} m are incident on a crystal. An intense scattered beam is observed at an angle of 19° to a set of lattice planes in the crystal.



Calculate the lattice spacing d of these planes. *[2]*

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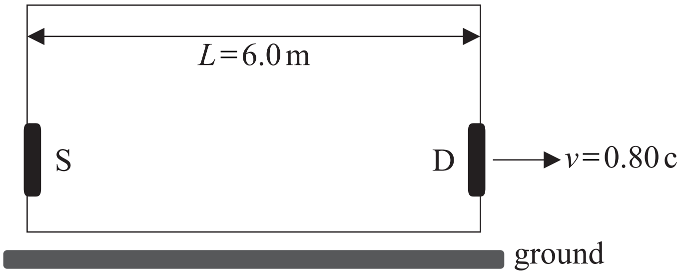
Option H — Relativity

H1. This question is about relativistic kinematics.

A source of light S and a detector of light D are placed on opposite walls of a box as shown in the diagram.



According to an observer in the box the distance L between S and D is 6.0 m. The box moves with speed $v = 0.80\,c$ relative to the ground.

Consider the following events.

Event 1: a photon is emitted by S towards D
Event 2: the photon arrives at D

(a) In the context of the theory of relativity, state what is meant by an event. *[1]*

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(This question continues on the following page)

(Question H1 continued)

(b) (i) Calculate the time interval t between event 1 and event 2 according to an observer in the box. *[1]*

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(ii) According to an observer on the ground the time interval between event 1 and event 2 is T. One student claims that $T = \frac{t}{\sqrt{1-\frac{v^2}{c^2}}}$ and another that $T = t\sqrt{1-\frac{v^2}{c^2}}$.

Explain why both students are wrong. *[2]*

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(This question continues on the following page)

(Question H1 continued)

(c) Relative to an observer on the **ground**,

(i) calculate the distance between S and D. *[2]*

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(ii) state the speed of the photon leaving S. *[1]*

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(iii) state an expression for the distance travelled by detector D in the time interval T (T is the interval in (b)(ii)). *[1]*

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(iv) determine T, using your answers to (c)(i), (ii) and (iii). *[2]*

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(This question continues on the following page)

(Question H1 continued)

(d) Describe how the Hafele–Keating experiment provides evidence in support of the special theory of relativity. *[3]*

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H2. This question is about rest mass and relativistic energy.

(a) (i) Define the *rest mass* of a particle. *[1]*

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(ii) The rest mass of a particle is said to be an invariant quantity. State, with reference to special relativity, what is meant by the term invariant. *[1]*

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(b) In a thought experiment, two particles X and Y, each of rest mass $380\,\text{MeV}\,\text{c}^{-2}$, are approaching each other head on.

The speed of X and of Y is 0.60 c relative to a laboratory.

(i) Calculate the momentum of X in the frame of reference in which Y is at rest. *[3]*

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(This question continues on the following page)

(Question H2 continued)

(ii) As a result of the collision a single particle Z is formed. Determine the rest mass of Z. The gamma factor for a speed of 0.60 c is 1.25. *[2]*

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H3. This question about general relativity.

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

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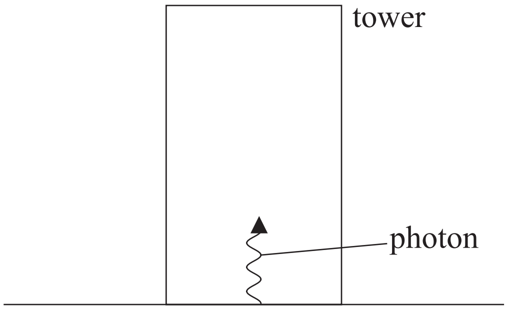
(Question H3 continued)

(b) A gamma-ray photon is emitted from the base of a tower towards the top of the tower.



(i) Explain, using the principle of equivalence, why the frequency of the photon as measured at the top of the tower is less than that measured at the base of the tower. *[3]*

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(ii) The frequency of the photon at the base is 3.5×10^{18} Hz and the tower is 23 m high. Determine the shift Δf in the frequency of the photon at the top of the tower. *[1]*

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(iii) Suggest, using your answer to (b)(ii), why the photon frequency must be measured very precisely for this experiment to be successful. *[1]*

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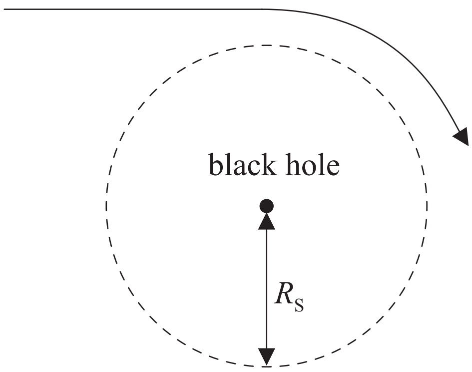
H4. This question is about black holes.

The diagram shows the path of a light ray in the space around a black hole.



(not to scale)

The radius of the dotted circle is the Schwarzschild radius of the black hole.

(a) Define the *Schwarzschild radius* of a black hole. *[1]*

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(b) Explain, using the concept of spacetime, why the path of the light ray is straight at distances far from the black hole and curved when near the black hole. *[3]*

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Option I — Medical physics

I1. This question is about the ear and hearing.

The diagram shows the principal features of the human ear.

(a) On the diagram, identify

(i) the cochlea using the letter C. *[1]*

(ii) the ossicles using the letter O. *[1]*

(iii) the auditory nerves using the letter A. *[1]*

(b) For a person with normal hearing

(i) state the range of frequencies that can be heard. *[1]*

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(This question continues on the following page)

(Question I1 continued)

(ii) describe the effect of increasing age on your answer to (b)(i). *[2]*

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(c) Explain what is meant by the fact that the ear has a logarithmic response to changes in sound intensity. *[2]*

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(d) The intensity of sound at the ear of a person is $10^{-6}\,\text{W m}^{-2}$. Determine by how much the intensity of the sound must be increased for the sound intensity level at the ear to be doubled. *[3]*

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I2. This question is about X-rays.

(a) Define the *attenuation coefficient* as applied to a beam of X-rays travelling through a medium. *[2]*

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(b) Derive the relationship between the attenuation coefficient μ and the half-value thickness $x_{\frac{1}{2}}$. *[2]*

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(This question continues on the following page)

(Question I2 continued)

(c) Aluminium is often used to filter out the low energy X-rays in a beam of X-rays. The following data are available for a particular X-ray beam.

X-ray energy / keV	**half-value thickness of aluminium / mm**
15	0.70
30	3.5

Assuming equal initial intensities, determine, after the X-ray beam has passed through an aluminium sheet 6.0 mm thick, the following ratio. *[3]*

$$\frac{\text{intensity of 15 keV X-rays}}{\text{intensity of 30 keV X-rays}}$$

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(d) Outline why X-rays are not suitable to image an organ such as the liver. *[2]*

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I3. This question is about the use of radioactive isotopes in medicine.

(a) Distinguish between the biological half-life and effective half-life of a radioactive isotope. *[2]*

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(b) The radioactive isotope iodine-131 undergoes beta decay to the stable isotope xenon-131 with a physical half-life of 8.0 days. Gamma radiation is also emitted in this decay. Iodine-131 is readily absorbed by the thyroid gland. The biological half-life is 21 days.

(i) Calculate the effective half-life of iodine-131. *[2]*

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(ii) Suggest why iodine-131 is often chosen to treat cancer of the thyroid gland. *[3]*

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(This question continues on the following page)

(Question I3 continued)

(c) Iodine-131 can be used to estimate the total blood volume of a patient.

A small amount of the isotope is dissolved in $8.0\,cm^3$ of a solution. $4.0\,cm^3$ of this solution is injected into the patient. After a few minutes a $5.0\,cm^3$ blood sample is taken. The activity of this sample is measured to be 96 Bq.

The remaining $4.0\,cm^3$ of the solution is mixed with $1000\,cm^3$ of water. The activity of $5.0\,cm^3$ of this solution is measured to be 510 Bq.

Estimate the total volume of blood in the patient. *[3]*

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Option J — Particle physics

J1. This question is about quarks.

(a) State the name of a particle that is its own antiparticle. *[1]*

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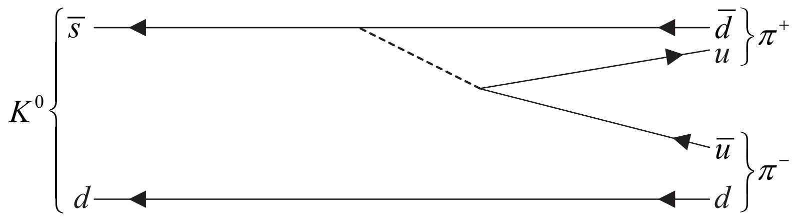
(b) The meson K^0 consists of a d quark and an anti s quark. The K^0 decays into two pions as shown in the Feynman diagram.



(i) State a reason why the kaon K^0 cannot be its own antiparticle. *[1]*

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(ii) Explain how it may be deduced that this decay is a weak interaction process. *[2]*

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(This question continues on the following page)

(Question J1 continued)

(iii) State the name of the particle denoted by the dotted line in the diagram. *[1]*

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(iv) The mass of the particle in (b)(iii) is approximately 1.6×10^{-25} kg. Determine the range of the weak interaction. *[2]*

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(c) (i) Explain why the meson K^0 does not have any colour quantum number. *[2]*

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(ii) The decay $K^0 \rightarrow p^+ + \pi^-$ is not observed. State **one** conservation law that would be violated if this decay were to occur. *[1]*

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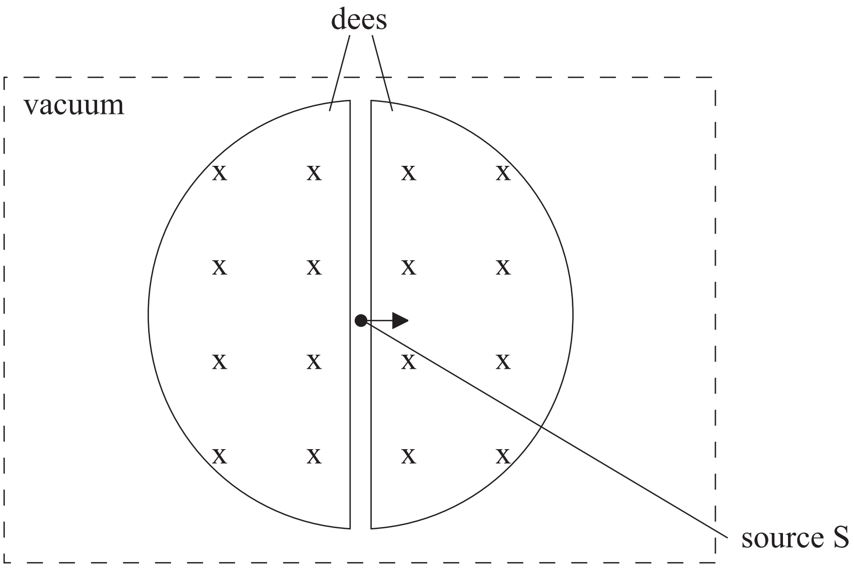
J2. This question is about the cyclotron and the wire chamber.

(a) The diagram shows the "dees" of a cyclotron.



Protons are injected into the cyclotron from a source S. The arrow indicates the direction of a proton after it has left the source. The magnetic field is directed into the plane of the page.

(i) Describe how the protons are accelerated in the cyclotron. *[3]*

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(ii) On the diagram draw the path of a proton after it leaves S. *[1]*

(This question continues on the following page)

(Question J2 continued)

(b) The maximum kinetic energy of the accelerated protons is 8.0 MeV. One of the accelerated protons collides with a stationary proton. Determine the available energy in the collision. *[2]*

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(c) Modern particle detectors use wire chambers.

(i) State the function of a wire chamber. *[1]*

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(ii) Outline the operation of a wire chamber. *[3]*

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J3. This question is about deep inelastic scattering.

(a) A student states that "the strong interaction is the strongest of the four fundamental interactions". Explain why this statement is not correct. *[2]*

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(b) Describe how deep inelastic scattering experiments support your answer to (a). *[2]*

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(c) State **two** other conclusions that may be reached from deep inelastic scattering experiments. *[2]*

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J4. This question is about the early universe.

(a) The Large Hadron Collider (LHC) at CERN is designed to collide protons of total energy 7 TeV with protons of the same total energy moving in the opposite direction. In this way it is hoped to recreate conditions of the very early universe. Predict the temperature of the universe that the LHC will be recreating. *[2]*

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(b) The very early universe contained almost equal quantities of matter and antimatter. Explain why the universe now predominantly contains matter. *[2]*

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

Answers written on this page
will not be marked.