M11/4/PHYSI/HP3/ENG/TZ1/XX

22116509

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PHYSICS
HIGHER LEVEL
PAPER 3

Thursday 12 May 2011 (morning)

1 hour 15 minutes

Candidate session number

0	0							

Examination code

2	2	1	1	–	6	5	0	9

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.

0148

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

Answers written on this page
will not be marked.

Option E — Astrophysics

E1. This question is about some of the planets in the solar system.

Four of the planets in the solar system are Mars, Venus, Jupiter and Neptune.

(a) List these planets in order of increasing distance from the Sun. *[2]*

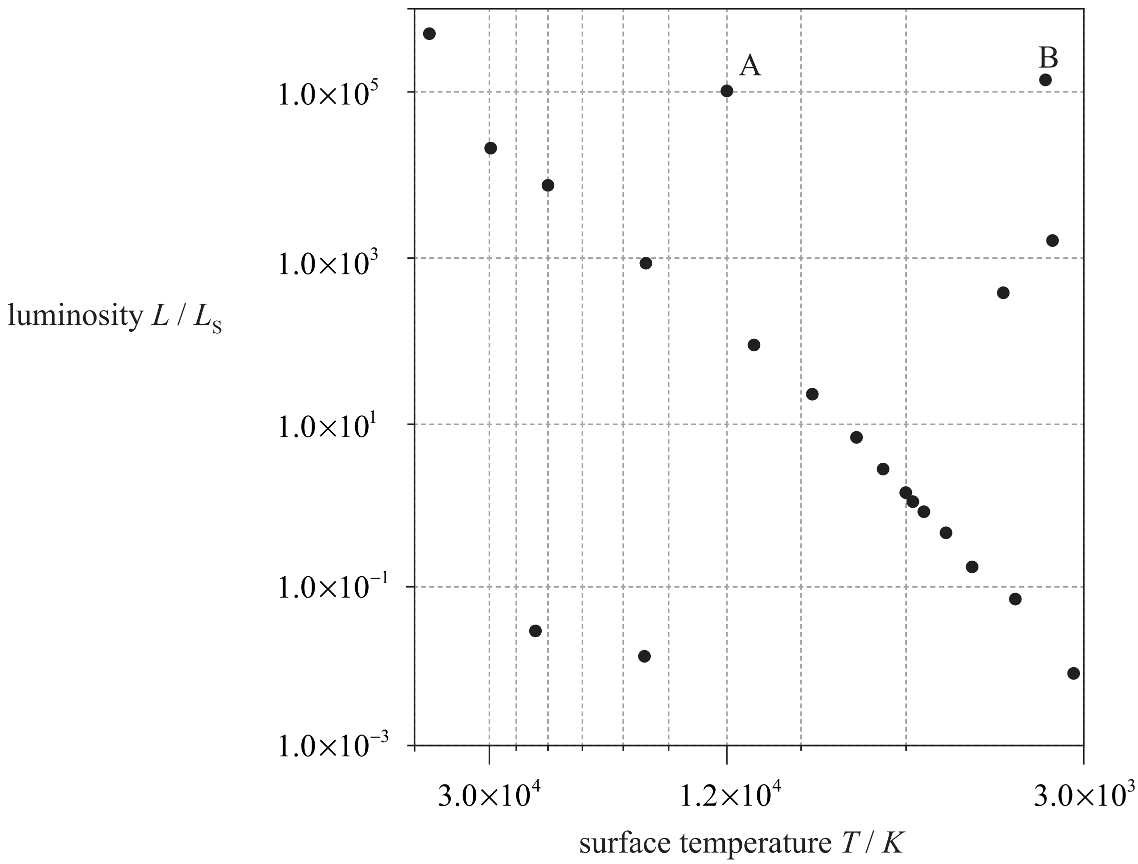
Nearest the Sun	
↓	
Furthest from the Sun	

(b) List these planets in order of decreasing diameter. *[2]*

Largest diameter	
↓	
Smallest diameter	

E2. This question is about the Hertzsprung–Russell (HR) diagram and using it to determine some properties of stars.

The diagram below shows the grid of a HR diagram, on which the positions of selected stars are shown. (L_S = luminosity of the Sun.)



(a) (i) Draw a circle around the stars that are red giants. Label this circle R. *[1]*

(ii) Draw a circle around the stars that are white dwarfs. Label this circle W. *[1]*

(iii) Draw a line through the stars that are main sequence stars. *[1]*

(This question continues on the following page)

(Question E2 continued)

(b) Explain, without doing any calculation, how astronomers can deduce that star B has a larger diameter than star A. *[3]*

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(c) Using the following data and information from the HR diagram, show that star A is at a distance of about 800 pc from Earth. *[4]*

Apparent brightness of the Sun $= 1.4 \times 10^{3}\ \text{W m}^{-2}$
Apparent brightness of star A $= 4.9 \times 10^{-9}\ \text{W m}^{-2}$
Mean distance of Sun from Earth $= 1.0\ \text{AU}$
$1\ \text{pc} = 2.1 \times 10^{5}\ \text{AU}$

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(d) Explain why the distance of star A from Earth cannot be determined by the method of stellar parallax. *[1]*

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E3. This question is about cosmology.

(a) State how the observed red-shift of many galaxies is explained. *[1]*

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(b) Explain how the cosmic microwave background (CMB) radiation is consistent with the Big Bang model. *[2]*

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(c) Calculate the temperature of the universe when the peak wavelength of the CMB was equal to the wavelength of red light (7.0×10^{-7} m). *[2]*

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E4. This question is about the main sequence star Khad (Phi Orionis).

The luminosity of Khad is $2.0\times10^4\,L_S$, where L_S is the luminosity of the Sun.

(a) Assuming that the exponent n in the mass–luminosity relation is 3.5, show that the mass of Khad is about 17 solar masses. *[2]*

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(b) Outline the likely evolution of the star Khad after it leaves the main sequence. *[3]*

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E5. This question is about Hubble's law and the age of the universe.

(a) (i) State Hubble's law. *[1]*

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(ii) State why Hubble's law cannot be used to determine the distance from Earth to nearby galaxies, such as Andromeda. *[1]*

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(b) (i) Show that $\frac{1}{H_0}$ is an estimate of the age of the universe, where H_0 is the Hubble constant. *[2]*

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(ii) Assuming $H_0 = 80\,\text{km}\,\text{s}^{-1}\text{M}\,\text{pc}^{-1}$, estimate the age of the universe in seconds. *[1]*

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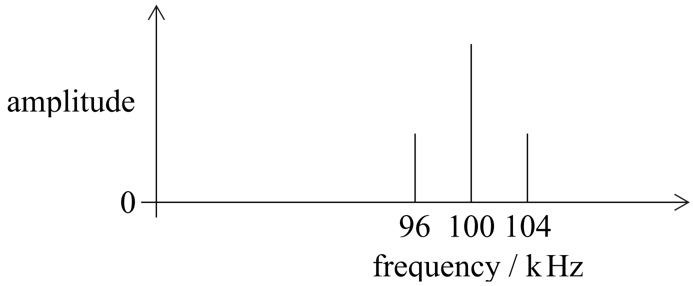
Option F — Communications

F1. This question is about modulation.

In order to test a temporary radio communication link, an audio signal is broadcast using amplitude modulation (AM). The power spectrum of the resulting carrier wave is shown below.



(a) Use the information in the power spectrum to determine the

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

. . . .

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

. . . .

(iii) bandwidth of this signal. *[1]*

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(This question continues on the following page)

(Question F1 continued)

(b) (i) Distinguish between AM and frequency modulation (FM). *[2]*

AM: . . . .

. . . .

FM: . . . .

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(ii) Outline **one** advantage and **one** disadvantage of using FM as opposed to AM for the transmission. *[2]*

Advantage: . . . .

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Disadvantage: . . . .

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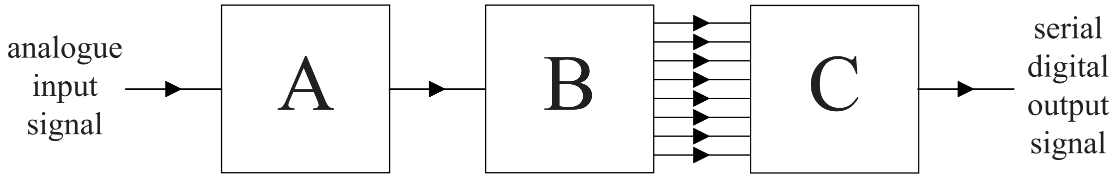
F2. This question is about data transmission systems.

The block diagram below represents an electronic system, S_1, which converts an analogue input signal into a serial digital output signal ready for transmission. It involves three separate system blocks labelled A, B and C.

System S_1



(a) State whether the signal between block A and block B is analogue, digital or multiplexed. *[1]*

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(b) State the function of system block A. *[1]*

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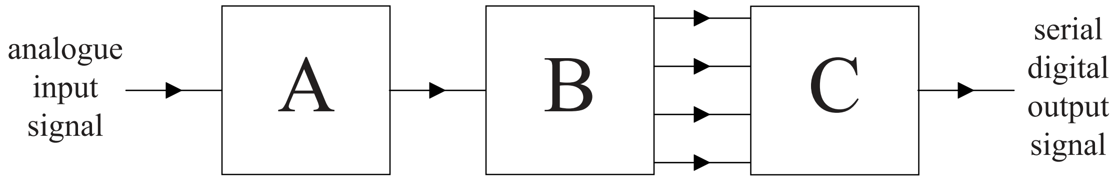
(This question continues on the following page)

(Question F2 continued)

(c) A similar system, S_2, is based on the same system blocks as S_1, but has fewer signal lines between block B and block C, as shown below.

System S_2



Explain what differences, if any, there are between S_1 and S_2 with respect to the maximum quality of the reproduction of the analogue signal after transmission. *[2]*

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(d) The serial digital output signal is transmitted using an optical fibre link. The attenuation per unit length of the optical fibre is $-4\,\text{dB}\,\text{km}^{-1}$.

(i) Define *attenuation*. *[1]*

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(ii) The input power to the fibre optic cable is 100 mW and the output power at the end of the cable is 1 mW. Determine the length of the cable. *[2]*

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(This question continues on the following page)

(Question F2 continued)

(iii) State **two** processes that must take place in order for this digital signal to be transmitted over a very long distance. *[2]*

1. . . . .

2. . . . .

F3. This question is about satellites.

A geostationary satellite is used by one country to broadcast information to a different country.

(a) State which part of the electromagnetic spectrum is used for this type of communication. *[1]*

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(b) Explain **two** disadvantages of using a polar satellite for this type of communication, when compared with using a geostationary satellite. *[2]*

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(c) Outline **one** possible ethical issue associated with this broadcast. *[1]*

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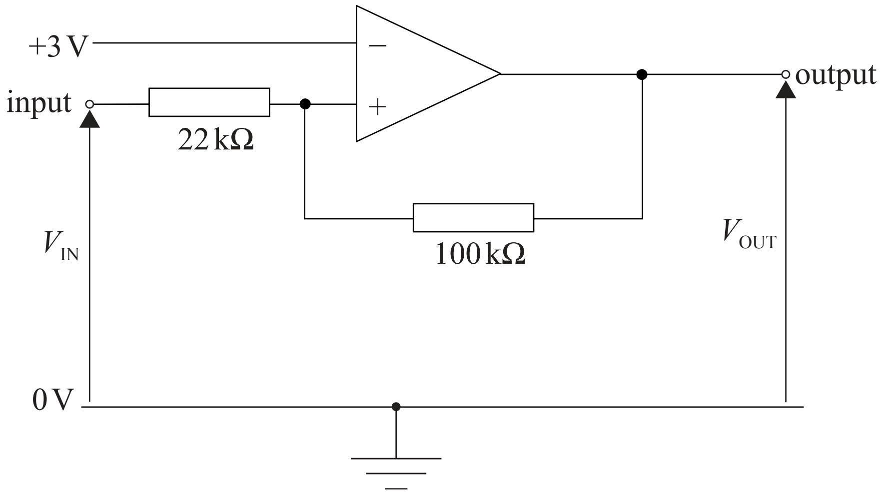
F4. This question is about a Schmitt trigger.

The diagram below shows a Schmitt trigger circuit based on an operational amplifier (op-amp).



The output of this Schmitt trigger is positive saturation (+13 V) or negative saturation (–13 V).

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

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(b) Determine the input value that will cause the output to switch from –13 V to +13 V. *[3]*

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(This question continues on the following page)

(Question F4 continued)

(c) Explain how a Schmitt trigger can be used to reshape a digital pulse. *[3]*

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F5. This question is about a mobile phone network.

Erin is a passenger on a train making a call to a standard fixed telephone line ("landline") from her mobile phone. The train moves Erin between adjacent communication cells. Outline the changes, if any, that take place in the

(a) cellular exchange. *[1]*

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(b) public switched telephone network (PSTN). *[1]*

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Option G — Electromagnetic waves

G1. This question is about dispersion.

(a) State an approximate value for the wavelength of visible light. *[1]*

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(b) Describe what is meant by dispersion. *[2]*

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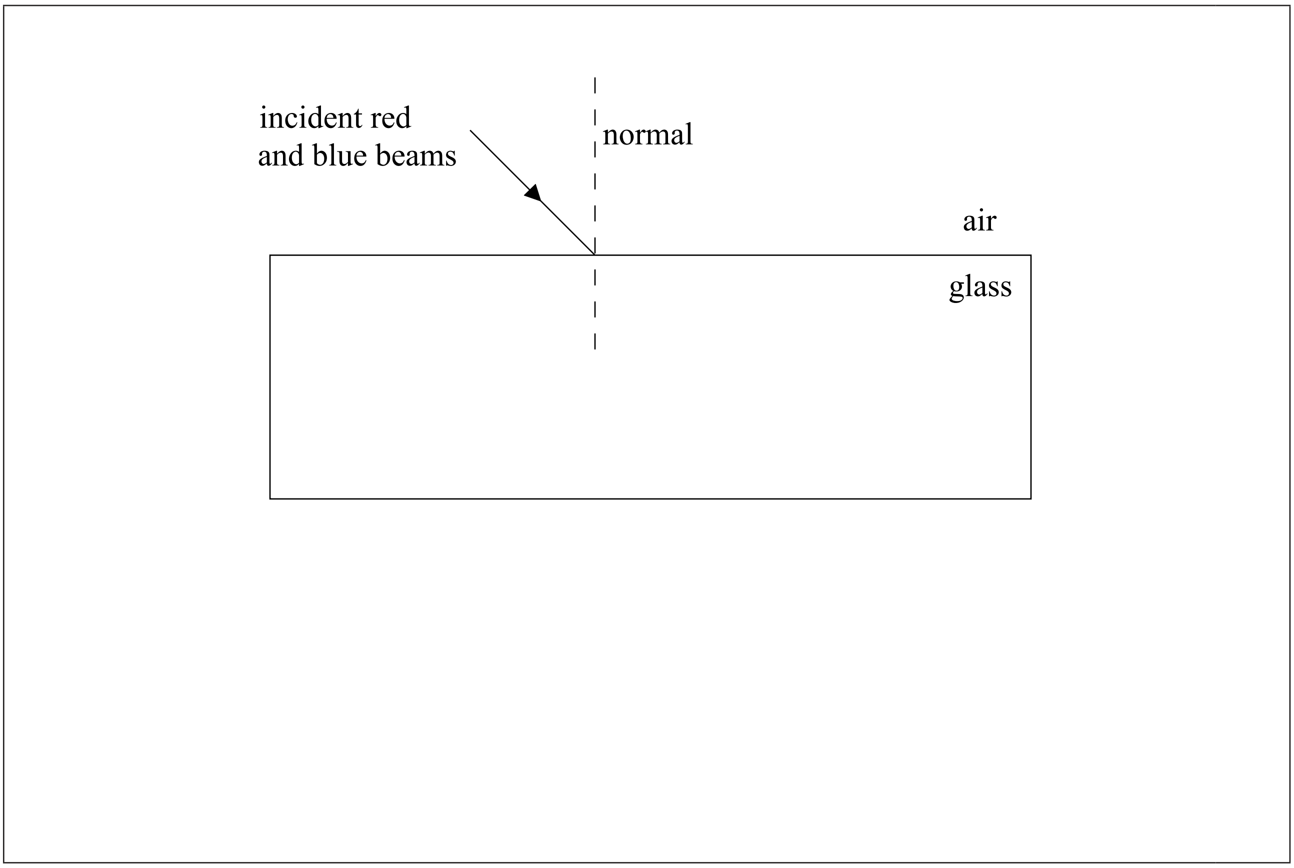
(This question continues on the following page)

(Question G1 continued)

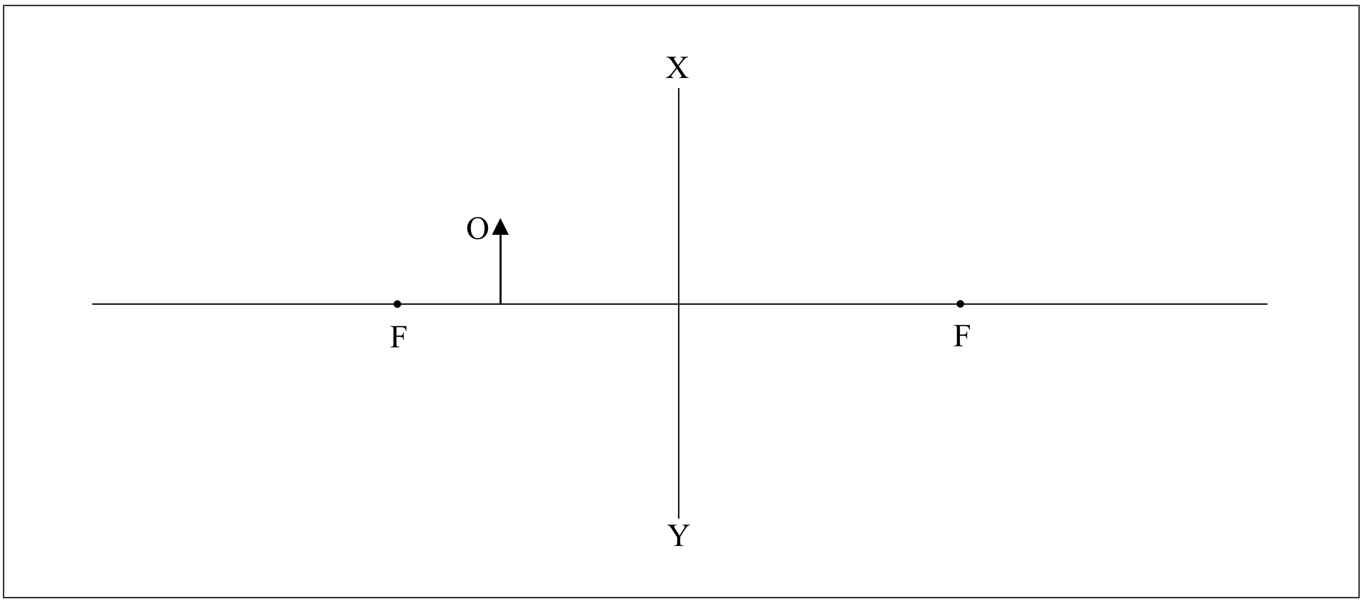
(c) A narrow beam, consisting of a mixture of red and blue light, is incident upon a rectangular glass block. The normal to the incident surface is shown.



On the diagram above, draw labelled lines to show the paths of the red and blue beams, as they pass through the glass block and out to the air on the other side. *[2]*

G2. This question is about a convex lens.

The diagram below, drawn to scale, shows a small object O placed in front of a thin convex (converging) lens. The focal points of the lens are shown, labelled F. The lens is represented by the straight line XY.



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

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(ii) On the diagram above, construct the paths of two rays in order to locate the position of the image formed by the lens. Label the image I. *[3]*

(iii) Explain whether the image is real **or** virtual. *[1]*

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(This question continues on the following page)

(Question G2 continued)

(b) A converging lens, of focal length 5.0 cm, is used as a simple magnifying glass to view an object of length 0.80 cm. The observer's eye is very close to the lens. The image is formed at the near point (25 cm).

(i) Determine the distance of the object from the lens. *[2]*

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(ii) Determine the length of the image. *[2]*

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G3. This question is about using a diffraction grating to view the emission spectrum of sodium.

Light from a sodium discharge tube is incident normally upon a diffraction grating having 8.00×10^5 lines per metre. The spectrum contains a double yellow line of wavelengths 589 nm and 590 nm.

(a) Determine the angular separation of the two lines when viewed in the second order spectrum. *[4]*

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(b) State why it is more difficult to observe the double yellow line when viewed in the first order spectrum. *[1]*

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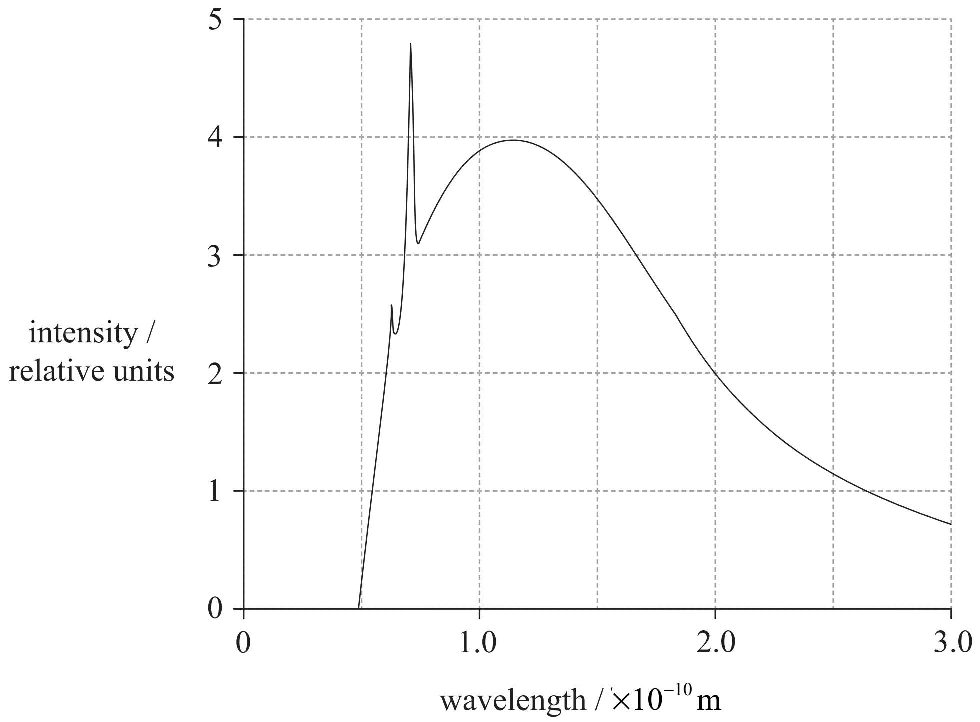
G4. This question is about X-rays.

Electrons are accelerated through a potential difference of 25 kV and strike a molybdenum target. The resulting X-ray spectrum is shown below.



The accelerating potential difference is changed to 15 kV.

(a) Calculate the minimum wavelength of the X-rays produced. *[2]*

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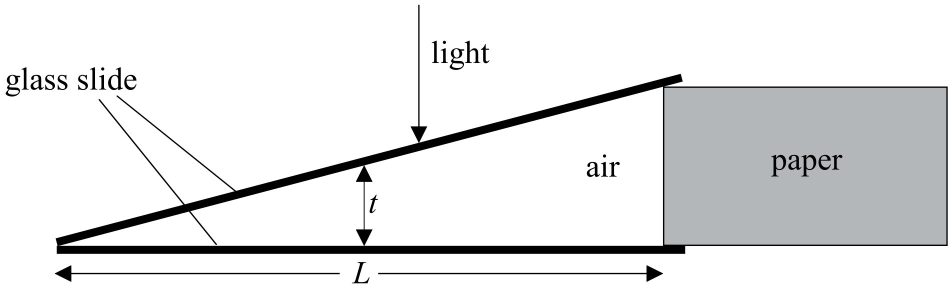
(b) On the graph above, sketch the X-ray spectrum that would be produced. *[3]*

G5. This question is about wedge film interference.

One flat, glass slide is placed at an angle on top of a second identical slide. The slides are in contact along one short edge and are separated at the other edge by a thin piece of paper, as shown below.



(diagram not to scale)

A thin wedge of air of variable thickness, t, is trapped between the two slides. The arrangement is viewed normally from above, using light of wavelength 590 nm. The glass plates are coated, so that reflection only takes place at the bottom surface of the top plate and the top surface of the bottom plate.

A series of straight bright and dark fringes, equally separated and parallel to the short edge of the slides, is seen.

(a) Deduce that the thickness of the air wedge t that gives rise to a bright fringe, is given by $2t = (m + \frac{1}{2})\lambda$. *[2]*

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(This question continues on the following page)

(Question G5 continued)

(b) The length of the air wedge, L, is 8.2 cm. The bright fringes are each separated by a distance of 1.2 mm. Calculate the thickness of the paper. *[3]*

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Option H — Relativity

H1. This question is about length contraction and simultaneity.

(a) Define *proper length.* *[1]*

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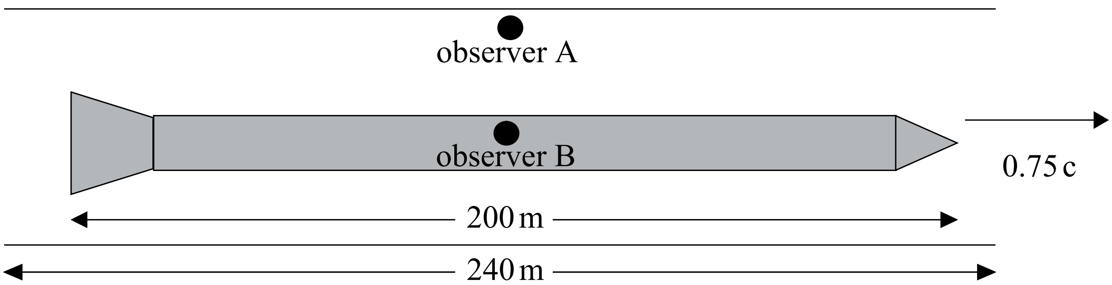
(b) A spaceship is travelling to the right at speed 0.75 c, through a tunnel which is open at both ends. Observer A is standing at the centre of one side of the tunnel. Observer A, for whom the tunnel is at rest, measures the length of the tunnel to be 240 m and the length of the spaceship to be 200 m. The diagram below shows this situation from the perspective of observer A.



Observer B, for whom the spaceship is stationary, is standing at the centre of the spaceship.

(i) Calculate the Lorentz factor, γ, for this situation. *[1]*

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(ii) Calculate the length of the tunnel according to observer B. *[1]*

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(This question continues on the following page)

(Question H1 continued)

(iii) Calculate the length of the spaceship according to observer B. *[1]*

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(iv) According to observer A, the spaceship is completely inside the tunnel for a short time. State and explain whether or not, according to observer B, the spaceship is ever completely inside the tunnel. *[2]*

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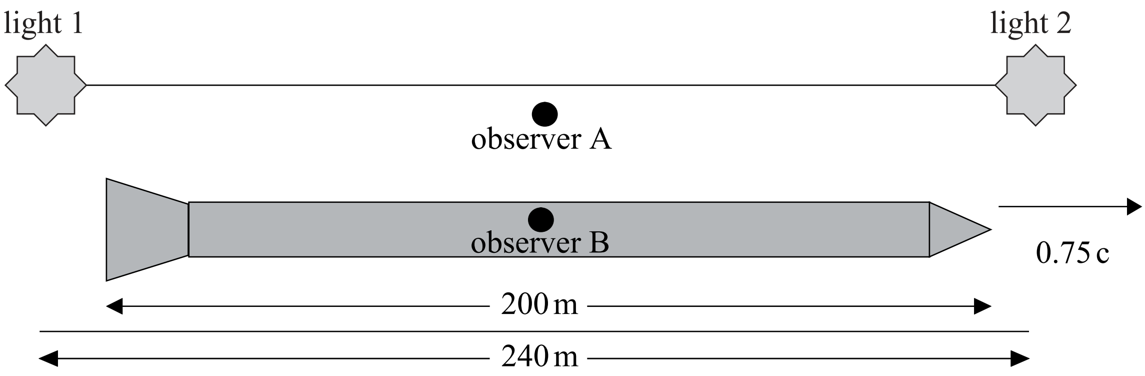
(This question continues on the following page)

(Question H1 continued)

(c) Two sources of light are located at each end of the tunnel. The diagram below shows this situation from the perspective of observer A.



According to observer A, at the instant when observer B passes observer A, the two sources of light emit a flash. Observer A sees the two flashes simultaneously. Discuss whether or not observer B sees the two flashes simultaneously. *[4]*

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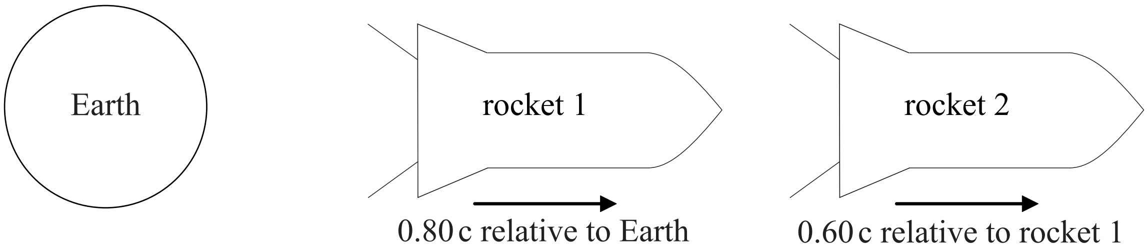
H2. This question is about relative velocities and energy at relativistic speeds.

Two identical rockets are moving along the same straight line as viewed from Earth. Rocket 1 is moving away from the Earth at speed 0.80 c **relative to the Earth** and rocket 2 is moving away from rocket 1 at speed 0.60 c **relative to rocket 1**.



(a) Calculate the velocity of rocket 2 relative to the Earth, using the

(i) Galilean transformation equation. *[1]*

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(ii) relativistic transformation equation. *[2]*

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(This question continues on the following page)

(Question H2 continued)

(b) Comment on your answers in (a). *[2]*

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(c) The rest mass of rocket 1 is 1.0×10^{3} kg. Determine the **relativistic** kinetic energy of rocket 1, as measured by an observer on Earth. *[3]*

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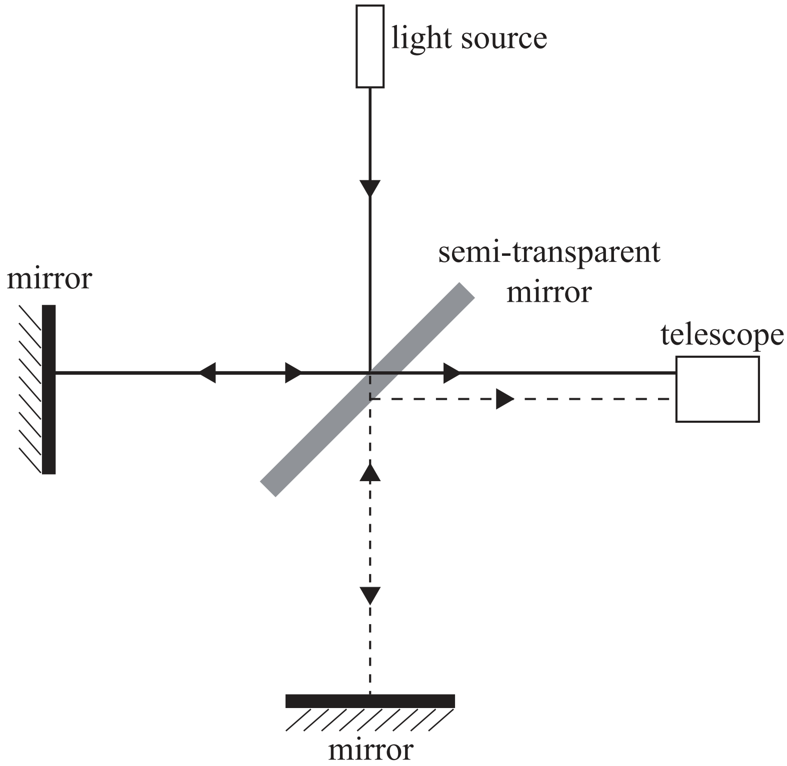
H3. This question is about the Michelson–Morley experiment.

The diagram below shows the essential features of the apparatus used in the Michelson–Morley experiment.



(a) State and explain how this apparatus was used to try and measure the speed of the Earth relative to the aether. *[4]*

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(This question continues on the following page)

(Question H3 continued)

(b) State the result of this experiment and explain how this result supports the special theory of relativity. *[2]*

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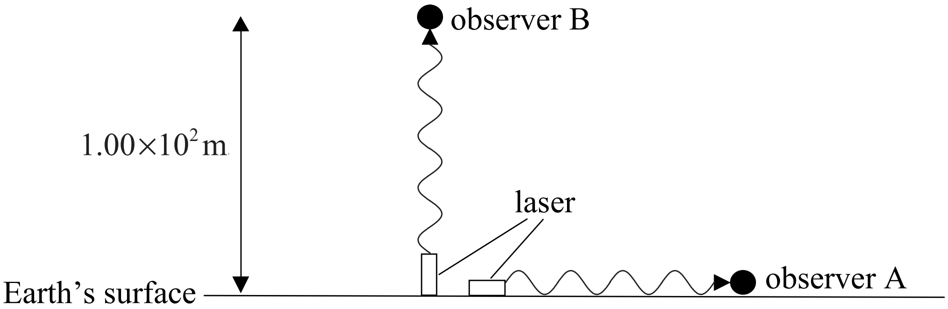
H4. This question is about gravitational red-shift.

Two identical lasers are situated on the surface of the Earth. One is directed horizontally towards observer A, who measures the frequency to be 4.62×10^{14} Hz. The other is directed vertically upwards towards observer B, who is at a height of 1.00×10^{2} m.



(a) (i) State how the frequency as measured by observer B compares with the frequency as measured by observer A. *[1]*

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(ii) Calculate the difference in frequency between the laser light as measured by observers A and B. *[2]*

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(iii) State **one** assumption that you made in (a)(ii). *[1]*

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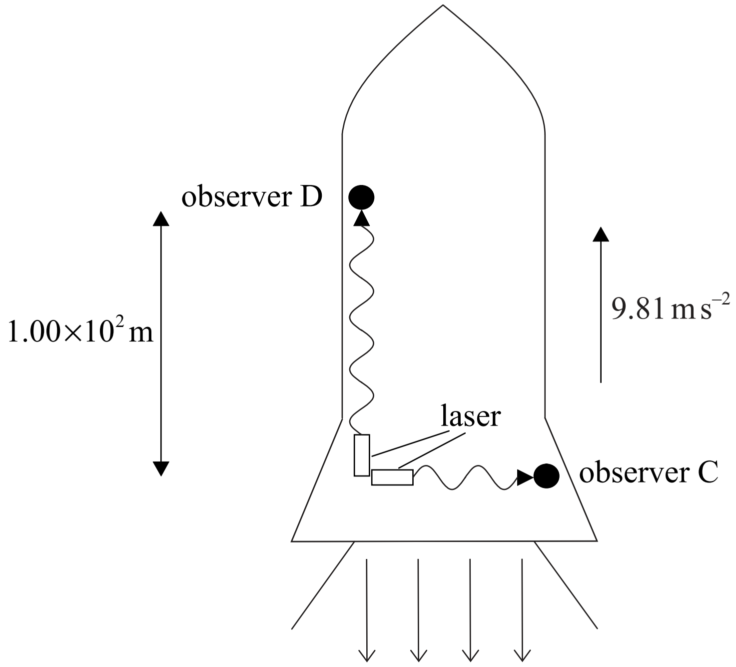
(This question continues on the following page)

(Question H4 continued)

(b) The lasers are now placed on a spaceship, which is accelerating upwards at a constant rate of $9.81\,m\,s^{-2}$, far away from any other masses as shown below. The distance of observer D from the laser is $1.00\times10^{2}\,m$. Observer C is at the bottom of the spaceship.



Explain, with reference to the equivalence principle, the frequencies measured by observers C and D, as compared to observers A and B. *[2]*

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Option I — Medical physics

I1. This question is about sound intensity levels.

As part of a safety inspection of a new factory, a data logger measures the intensity of the sounds generated by the machines. The sound intensity levels need to be within acceptable limits.

(a) Define *intensity* and *intensity level*. *[2]*

Intensity: . . . .

. . . .

Intensity level: . . . .

. . . .

(b) The data logger is moved between five different locations in the factory ($A \rightarrow E$). The readings are shown below.

Location	Reading on data logger / $mW\,m^{-2}$
A	302
B	158
C	891
D	413
E	524

(i) Determine the intensity level at the noisiest location. *[3]*

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(This question continues on the following page)

(Question I1 continued)

(ii) Using your answer to (b)(i), discuss whether or not it is necessary for the machine operators to use ear protectors when working in this factory. *[2]*

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(iii) One possible effect on hearing of long-term exposure to noise is tinnitus. Outline what is meant by tinnitus. *[1]*

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I2. This question is about medical imaging.

A patient is suspected of having a partial blockage in his intestine as it leads away from his stomach. Possible medical imaging techniques include X-ray photography, ultrasound and the use of an endoscope.

(a) When producing the X-ray photograph, the dose is kept to a minimum by a technique called enhancement.

(i) Outline why the dose needs to be kept to a minimum. *[2]*

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(ii) Describe **one** possible enhancement technique. *[2]*

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(iii) Discuss any extra procedures that are needed to get an appropriate image of the intestine in this situation. *[2]*

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(This question continues on the following page)

(Question I2 continued)

(b) A successful ultrasound scan relies on changes of acoustic impedance around the structure being imaged.

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

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(ii) State the SI unit in which it is measured. *[1]*

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(iii) Explain, in terms of acoustic impedance, why gel needs to be applied on the surface of the skin before the ultrasound scan. *[2]*

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(This question continues on the following page)

(Question I2 continued)

(c) The blockage is cut out and removed in a procedure which involves a laser and an endoscope.

(i) Outline how it is possible to use a laser as a scalpel (knife). *[2]*

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(ii) By referring to the role played by optic fibres, discuss how an endoscope is used in this situation. *[2]*

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I3. This question is about radiation in medicine.

A nuclear stress test is used to investigate the blood flow within a patient's heart during exercise. The radioisotope thallium-201 is injected into the patient's blood and a gamma-ray detector is then used to record its distribution within the heart muscle.

The following information about this procedure is available.

Mass of patient = 75 kg
Dose equivalent for a nuclear stress test = 25 mSv

(a) The quality factor of the gamma-rays is 1. Determine the energy absorbed by the patient as a result of the thallium injection. *[3]*

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(b) Suggest whether you would expect the energy calculated in (a) to result in a significant increase in the patient's temperature. *[1]*

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(This question continues on the following page)

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(Question I3 continued)

(c) On average, 1 in every 1000 patients who undertake a nuclear stress test go on to develop cancer as a result of the radioactive dose that they received during the test.

(i) By referring to the concept of balanced risk, outline why the test may still be of benefit to the patient. *[2]*

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(ii) The hospital technician who administers the test could also receive an increased dose. Outline how film badges are used to protect technicians from receiving excessive doses of radiation. *[2]*

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Option J — Particle physics

J1. This question is about mesons.

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

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(b) In 1935, the physicist Hideki Yukawa predicted that the strong interaction between nucleons was mediated by particles called mesons. Given that the range of the strong interaction is approximately 1.5×10^{-15} m, calculate a possible value for the rest mass of a meson. *[2]*

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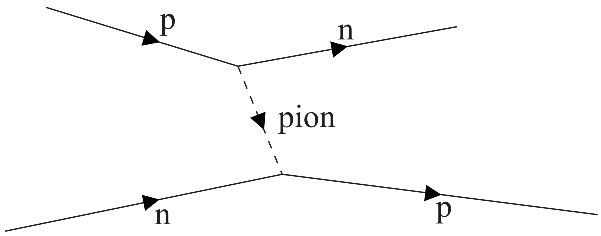
(This question continues on the following page)

(Question J1 continued)

(c) A meson called the pion was detected in cosmic ray reactions in 1947 by Powell and Occhialini. The pion comes in three possible charge states: π^+, π^- and π^0. The Feynman diagram below represents a possible reaction in which a pion participates.



State and explain whether the meson produced is a π^+, π^- **or** a π^0. *[2]*

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(d) State the possible spin numbers of mesons and explain your answer. *[3]*

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(This question continues on the following page)

(Question J1 continued)

(e) Explain why, according to the quark model, it is not possible for a particle to consist of two up quarks only. *[2]*

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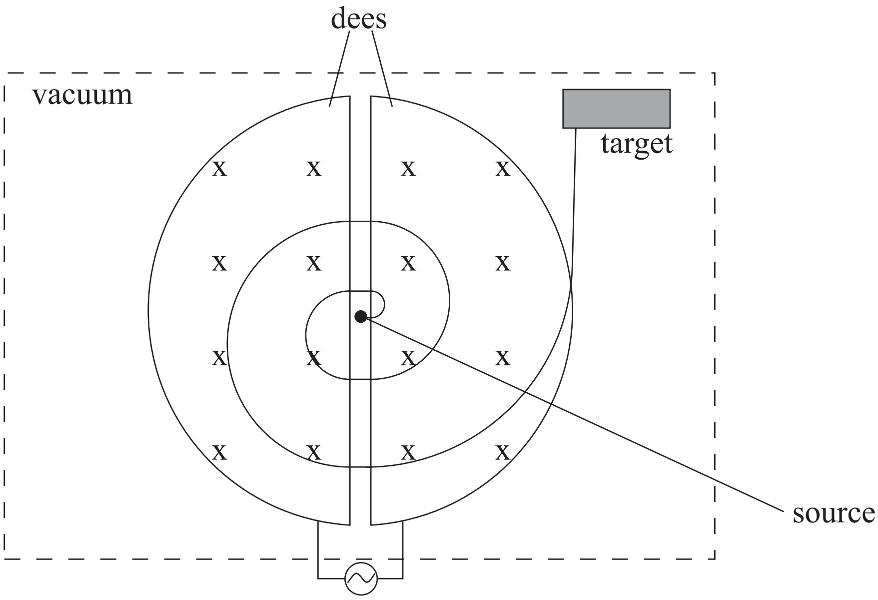
J2. This question is about accelerating particles.

The diagram below shows the basic structure of a cyclotron.



Charged particles are emitted from a source at the centre. They move in a vacuum through two D-shaped cavities or "dees". There is a uniform magnetic field directed into the page, within the region of the dees.

(a) Outline why the voltage applied across the dees must change polarity every half revolution. *[2]*

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(Question J2 continued)

(b) Show that the frequency, *f*, of the applied potential difference is given by the expression

$$f = \frac{qB}{2\pi m}$$

where

q = charge of particle
m = mass of particle
B = magnetic field strength. *[3]*

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(c) State **two** disadvantages of using a cyclotron rather than a synchrotron to accelerate particles. *[2]*

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2. . . . .

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(d) Explain why it is necessary to accelerate particles to high speeds in order to create new particles of large mass. *[2]*

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(Question J2 continued)

(e) High energy particles are used to probe the nucleus. Explain why alpha particles would give better resolution than protons moving at the same speed. *[3]*

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J3. This question is about energy and conservation laws.

Two protons moving at the same speed in opposite directions, collide with each other producing three protons and an anti-proton, as shown below.

$$\mathrm{p} + \mathrm{p} \rightarrow \mathrm{p} + \mathrm{p} + \overline{\mathrm{p}} + \mathrm{p}$$

(a) Calculate the minimum possible kinetic energy of **one** of the colliding protons. *[2]*

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(Question J3 continued)

(b) Explain why the following reaction is not possible, even if the colliding particles have enough energy.

$$p + n \rightarrow p + p + \overline{p}$$ *[2]*

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J4. This question is about cosmology and strings.

(a) The binding energy of a helium nucleus is about 28 MeV. Calculate the temperature of the universe above which helium nuclei could not have existed. *[2]*

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(b) State **two** fundamental differences between the standard model and the theory of strings. *[2]*

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2. . . . .

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

Answers written on this page
will not be marked.