PHYSICS
HIGHER LEVEL
PAPER 3

Candidate number

Wednesday 5 May 2004 (morning)

1 hour 15 minutes

INSTRUCTIONS TO CANDIDATES

- Write your candidate number in the box above.
- Do not open this examination paper until instructed to do so.
- Answer all of the questions from two of the Options in the spaces provided.
- At the end of the examination, indicate the letters of the Options answered in the candidate box on your cover sheet.

Option D — Biomedical Physics

D1. This question is about scaling.

Fernando has a mass of 70 kg and is 175 cm tall. Jorge has the same build and a mass of 85 kg.

(a) Estimate

(i) the height of Jorge. *[2]*

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(ii) the ratio $\dfrac{\text{surface area of Jorge}}{\text{surface area of Fernando}}$. *[2]*

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(b) Fernando and Jorge have the same rate of production of thermal energy per unit body mass. Explain quantitatively the consequence of the difference in body mass on the rate of loss of heat per unit area if both are to maintain the same body temperature. *[4]*

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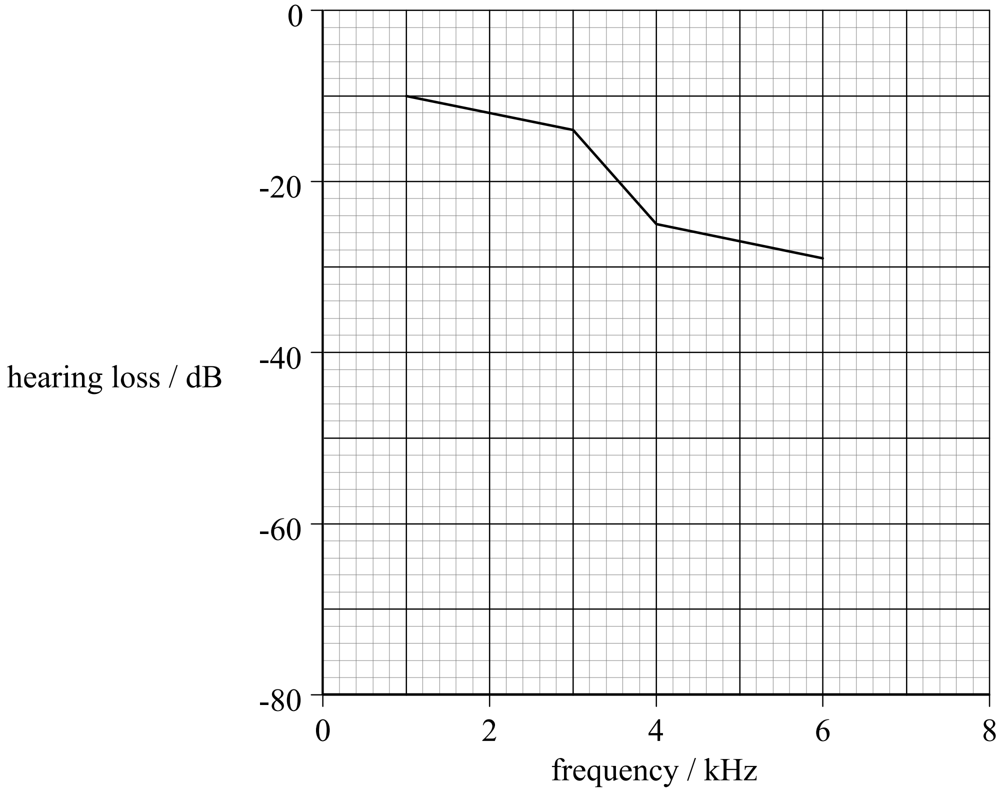
D2. This question is about defects of hearing.

The graph below shows an audiogram for a person who has **not** been exposed to high noise levels.



(a) Suggest the hearing defect from which the person is suffering. *[1]*

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A person with normal hearing can detect a sound of intensity 1.0×10^{-12} W m^{-2} at a frequency of 3.0 kHz.

(b) Use data from the graph to determine the minimum **intensity** at 3.0 kHz that can be detected by the person with the hearing defect. *[2]*

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(c) On the graph, draw a second line to illustrate the hearing loss caused by many years of exposure to high noise levels in the workplace. *[2]*

D3. This question is about medical diagnosis.

State and explain the use of

(a) a barium meal in X-ray diagnosis. *[2]*

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(b) a gel on the skin during ultrasound imaging. *[2]*

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(c) a non-uniform magnetic field superimposed on a much larger constant field in diagnosis using nuclear magnetic resonance. *[3]*

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D4. This question is about the use of radiation in medicine.

When referring to radiation dosage, α-radiation and γ-radiation have different quality factors.

(a) (i) State which type of radiation has the larger quality factor. *[1]*

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(ii) Explain why, for the same absorbed dose, the radiations have different effects. *[3]*

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(b) The risk factor attached to any particular dose equivalent depends not only on the total dose but also on the dose rate. Explain why the risk factor depends on dose rate. *[3]*

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Iodine-131 is used to label human serum albumin. This isotope has a physical half-life of 8.0 days and a biological half-life of 21 days.

(c) Determine the time taken for the activity within the body of a particular dose of this isotope to be reduced to $\frac{1}{4}$ of its initial activity. *[3]*

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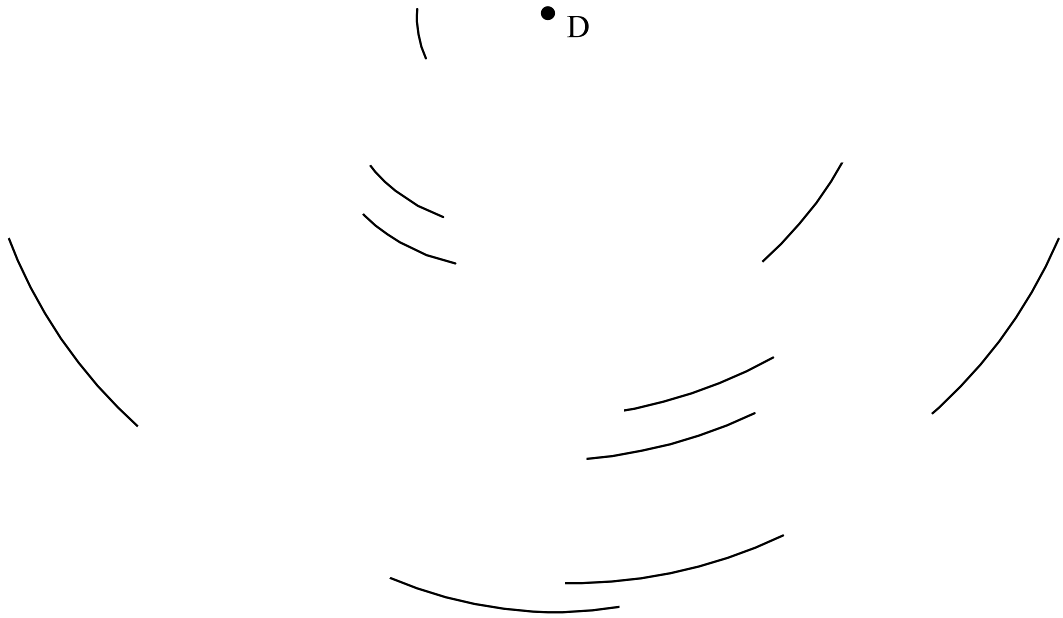
Option E — The History and Development of Physics

E1. A student photographed the night sky by placing a camera on a tripod and then leaving open the shutter of the camera for 90 minutes. The diagram below illustrates the photograph obtained. Only some of the brighter lines are shown.



(a) Identify the bright point labelled D. *[1]*

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(b) Describe qualitatively how it may be deduced from the photograph that the Earth is rotating. *[2]*

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(c) By taking measurements from the diagram, deduce a value for the period of rotation of the Earth. *[3]*

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E2. This question is about the caloric theory.

The theory of heat that was accepted by most scientists until well into the nineteenth century is the "caloric theory".

(a) State how the following phenomena are explained on the basis of the caloric theory.

(i) The cooling of a body *[1]*

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(ii) Conduction of heat *[2]*

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(iii) Differences in specific heat capacity *[1]*

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(b) Suggest how Count Rumford's observations in 1798 led to doubt being cast on the validity of the caloric theory. *[3]*

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E3. This question is about early models of the atom.

(a) Suggest how Rutherford's model of the atom may be used to explain that the atoms in an ideal gas behave as solid spheres. *[3]*

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The existence in the nucleus of a neutral particle having a mass about equal to that of the proton was suggested in 1920. However, the neutron was not discovered until 1932.

(b) (i) Suggest why the presence of the neutron was difficult to detect. *[1]*

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(ii) Outline how the radiation resulting from the bombardment of boron or beryllium with α-particles led to the discovery of the neutron. *[3]*

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E4. This question is about models of the atom.

(a) State **three** ways in which the Bohr and Schrödinger models of the hydrogen atom differ. *[3]*

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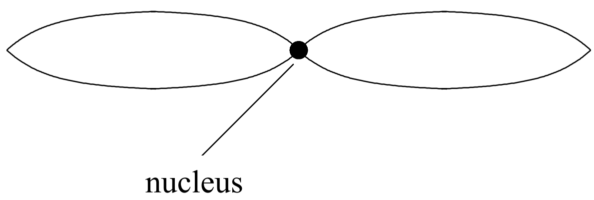
The diagram below shows a simplified stationary wave for an electron in a hydrogen atom.



(b) (i) On the diagram, mark with the letter L a position where the electron is most likely to be found. *[1]*

(ii) The radius of the hydrogen atom is 1.0×10^{-10} m. State the de Broglie wavelength of the electron. *[1]*

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(iii) Determine the kinetic energy of the electron. *[3]*

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(This question continues on the following page)

(Question E4 continued)

(c) Knowledge of the de Broglie wavelength of the electron enables the momentum of the electron to be determined. By reference to the Heisenberg uncertainty principle, state and explain why a precise determination of the momentum of the electron cannot be made. *[2]*

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Option F — Astrophysics

F1. This question is about various bodies in the universe.

(a) Briefly describe the nature of a star. *[2]*

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(b) Distinguish between a constellation and a galaxy. *[4]*

Constellation: . . . .

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Galaxy: . . . .

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F2. This question is about the mean density of matter in the universe.

(a) Explain the significance of the *critical density* of matter in the universe with respect to the possible fate of the universe. *[3]*

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The critical density ρ_0 of matter in the universe is given by the expression

$$\rho_0 = \frac{3{H_0}^2}{8\pi G},$$

where H_0 is the Hubble constant and G is the gravitational constant.

An estimate of H_0 is $2.7 \times 10^{-18}\ \text{s}^{-1}$.

(b) (i) Calculate a value for ρ_0. *[1]*

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(ii) Hence determine the equivalent number of nucleons per unit volume at this critical density. *[1]*

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F3. This question is about Cepheid variables.

The characteristics of a Cepheid variable were first observed in 1784.

(a) (i) Describe the characteristic by which a Cepheid variable may be identified from Earth. *[2]*

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(ii) Outline the cause of this characteristic. *[2]*

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A particular Cepheid variable is found to have an average value of apparent magnitude of 5.2 and a time period of pulsation of 50 days. Apparent magnitude m is related to absolute magnitude M and distance d (measured in parsec) by the expression

$$m - M = 5\lg d - 5.$$

(b) (i) Distinguish between *apparent magnitude* and *absolute magnitude*. *[2]*

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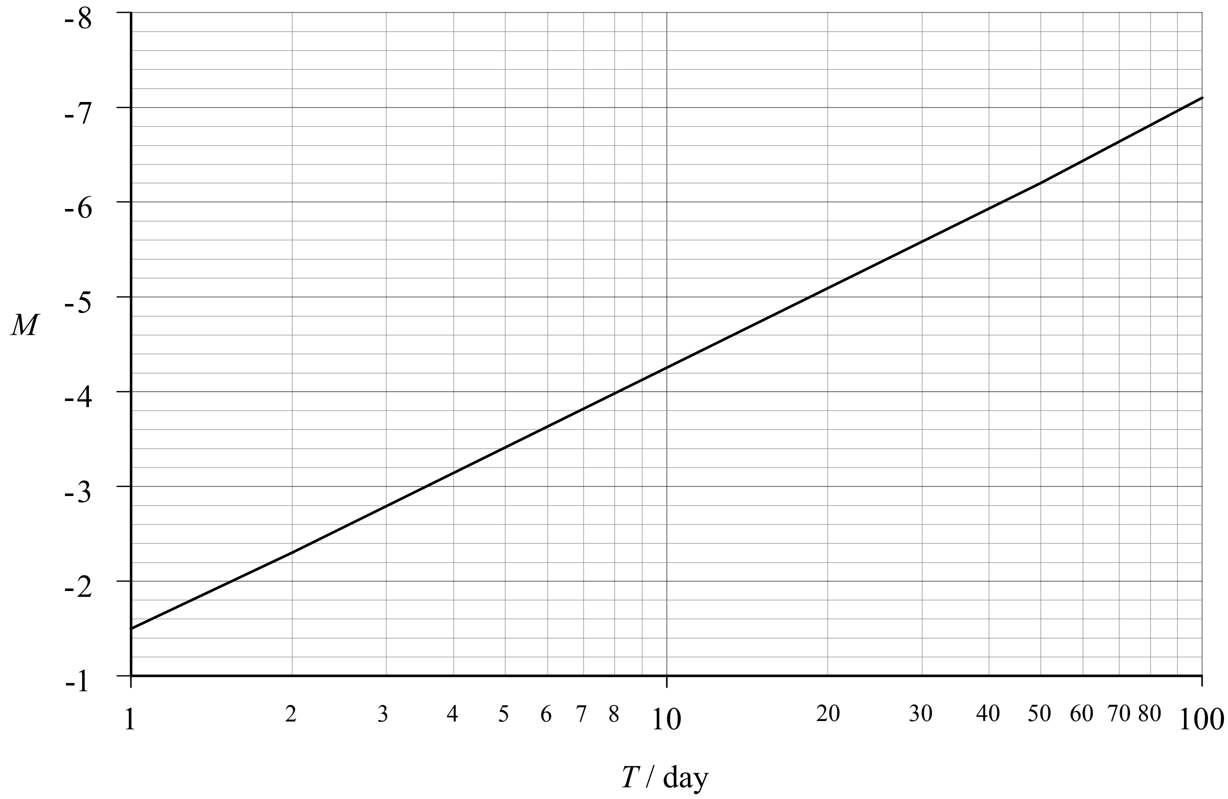
(Question F3 continued)

The graph below shows how the absolute magnitude M of some Cepheid variables varies with time period T of pulsation.



(ii) Use the graph to obtain a value for the absolute magnitude of this Cepheid variable and hence determine its distance from Earth. *[3]*

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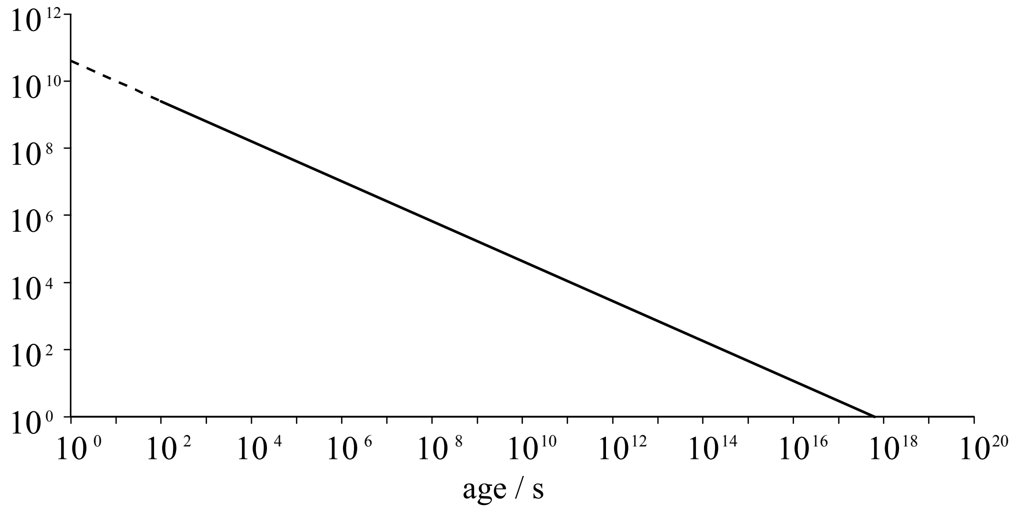
F4. This question is about the Big Bang model of the universe.

The graph below shows the variation with age of the universe of its temperature, based on the Big Bang model of the universe.



(a) On the graph,

(i) mark the point (labelled N) at which light nuclei formed. *[1]*

(ii) mark the point (labelled G) at which stars and galaxies began forming. *[1]*

(b) Measurements of the present temperature of the universe indicate a temperature of approximately 3 K. When taking measurements on the carbon clouds in a very distant galaxy, the temperature indicated is 7 K. Suggest how this observation provides evidence for the cooling of the universe. *[2]*

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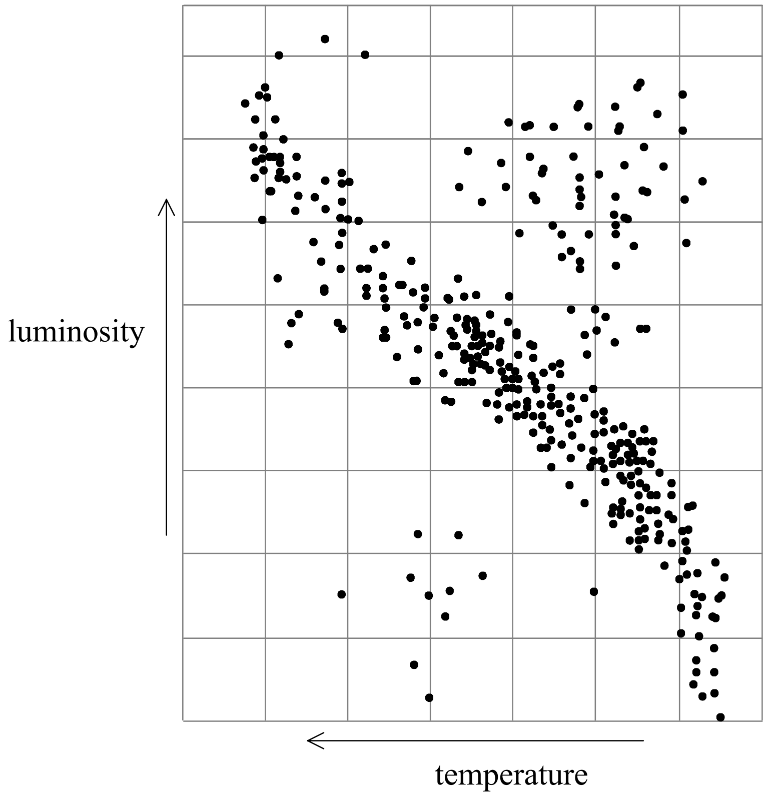
F5. A partially completed Hertzsprung-Russell (H-R) diagram for some stars in the Milky Way galaxy is shown below.



(a) On the diagram,

(i) identify the regions associated with red giants (label the region R) and white dwarfs (label the region W). *[1]*

(ii) mark with the letter S the approximate present position of the Sun. *[1]*

(iii) draw the evolutionary path of the Sun from its present position to its ultimate position. *[2]*

(b) At the end of its main sequence lifetime, a star of approximately ten times the mass of the Sun will start to produce energy at a much higher rate and its surface will become cooler. Outline how it is possible for the star to be producing more power and yet its surface is cooling. *[2]*

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Option G — Relativity

G1. This question is about time dilation.

(a) State what is meant by an *inertial* frame of reference. *[1]*

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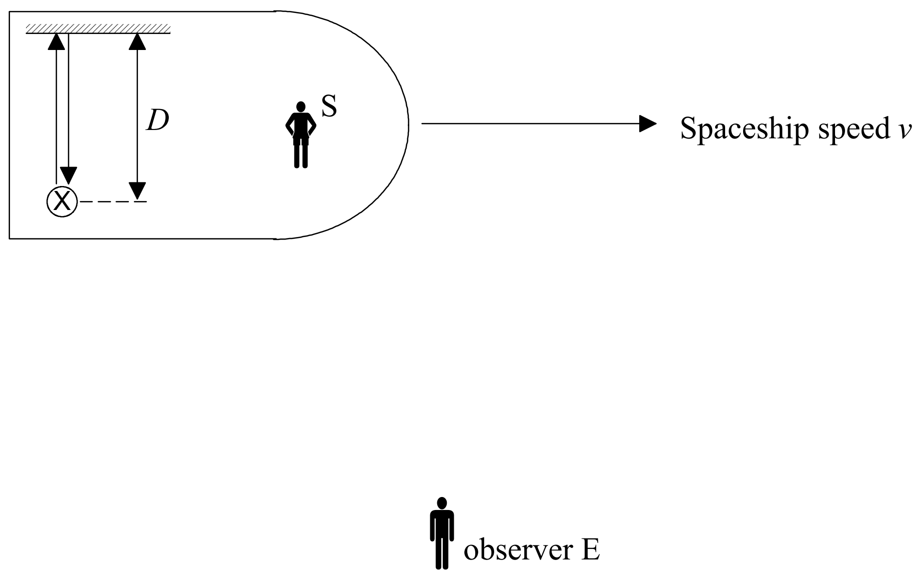
An observer S in a spacecraft sees a flash of light. The light is reflected from a mirror, distance D from the flash, and returns to the source of the flash as illustrated below. The speed of light is c.



(b) Write down an expression, in terms of D and c, for the time T_0 for the flash of light to return to its original position, as measured by the observer S who is at rest relative to the spaceship. *[1]*

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The spaceship is moving at speed v relative to the observer labelled E in the diagram. The speed of light is c.

(c) (i) Draw the path of the light as seen by observer E. Label the position F from where the light starts and the position R where the light returns to the source of the flash. *[1]*

(ii) The time taken for the light to travel from F to R, as measured by observer E, is T. Write down an expression, in terms of the speed v of the spacecraft and T, for the distance FR. *[1]*

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(Question G1 continued)

(iii) Using your answer in (ii), determine, in terms of v, T and D, the length L of the path of light as seen by observer E. *[2]*

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(iv) Hence derive an expression for T in terms of T_0, v and c. *[4]*

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G2. This question is about the half-life of muons.

The half-life of muons is 3.1×10^{-6} s as measured in a frame of reference that is stationary relative to the muons.

A pulse of muons is produced such that the muons have a speed of $2.8\times10^{8}\ \text{m s}^{-1}$ relative to a stationary observer.

Determine the distance travelled by the pulse, as measured by the observer, when half of the muons have decayed. *[3]*

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G3. This question is about mass-energy.

(a) Define *rest mass*. *[2]*

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(b) An electron of rest mass m_0 is accelerated through a potential difference V. Explain why, for large values of V, the formula

$$\tfrac{1}{2} m_0 v^2 = eV$$

is not appropriate for determining the speed v of the accelerated electron. *[3]*

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(c) An electron is accelerated through a potential difference of 5.0×10^6 V. Determine the mass equivalence of the change in kinetic energy of the electron. *[2]*

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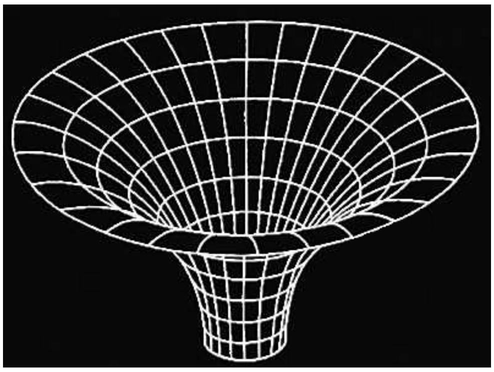
G4. The diagram below illustrates the distortion of space by the gravitational field of a black hole.



(a) (i) Describe what is meant by the *centre* and the *surface* of a black hole. *[3]*

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(ii) With reference to your answer in (i), define the Schwarzchild radius. *[1]*

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(iii) Calculate the Schwarzchild radius for an object having a mass of 2.0×10^{31} kg (ten solar masses). *[2]*

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Science fiction frequently portrays black holes as objects that “swallow” everything in the Universe.

(iv) A spacecraft is travelling towards the object in (iii) such that, if it continues in a straight line, its distance of closest approach would be about 10^7 m. By reference to the diagram and your answer in (iii), suggest whether the fate of the spacecraft is consistent with the fate as portrayed in science fiction. *[2]*

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(Question G4 continued)

In 1979, Wahl, Carswell and Weymann discovered "two" very distant quasars separated by a small angle. Spectroscopic examination of the images showed that they were identical.

(b) Outline how these observations give support to the theory of General Relativity. *[2]*

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Option H — Optics

H1. This question is about a spectrum.

(a) Describe what is meant by the spectrum of white light. *[2]*

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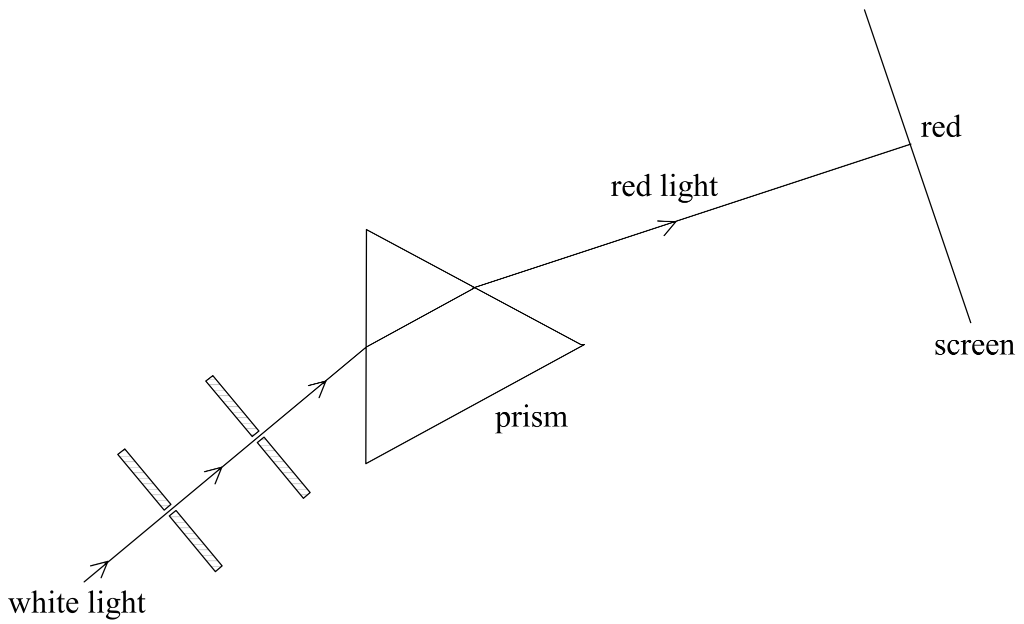
A student used the apparatus illustrated below in order to show the spectrum of white light.



(b) Complete the diagram to show the path of blue light through the prism and to the screen. *[3]*

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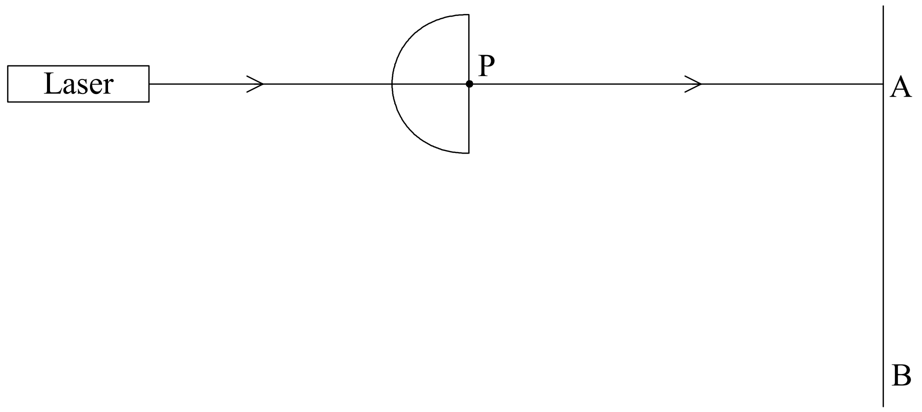
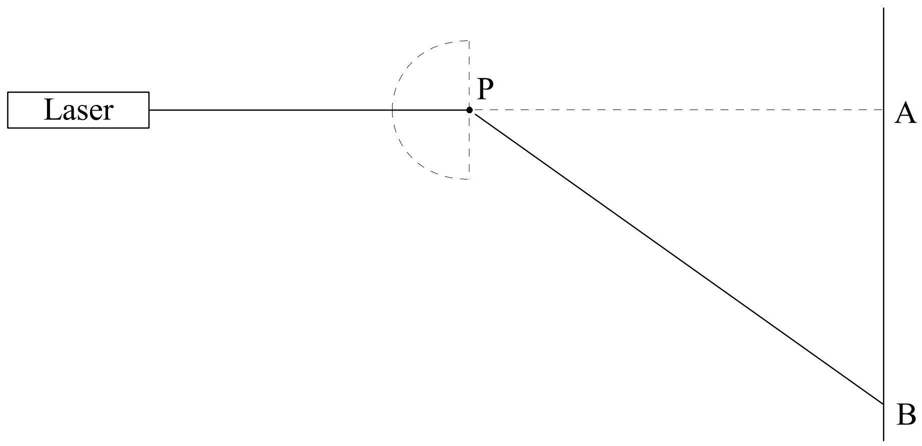
H2. This question is about refractive index.

Light from a laser is directed at a semi-circular glass block. The light passes undeviated through the block and on to a screen, forming a spot at A as shown.



The semi-circular block is rotated about the point P. The spot of light on the screen is seen to move downwards. When the spot reaches point B, it disappears.

(a) Complete the diagram below to show the position of the semi-circular block when the spot is at point B. The original position of the block is shown as a dotted line. *[1]*



In a particular experiment, the distance PA is 120 cm and distance AB is 138 cm.

(b) Calculate the refractive index of the glass of the block. *[3]*

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(Question H2 continued)

The laser is changed for one emitting light of higher frequency. The experiment is then repeated.

(c) State and explain whether the distance AB will be greater or less than 138 cm. *[3]*

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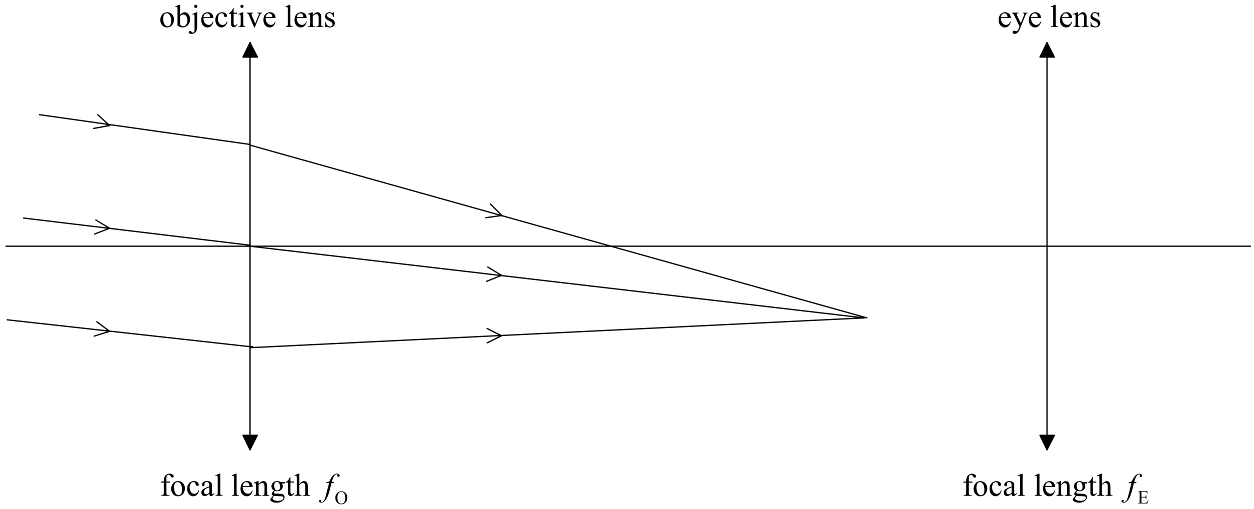
H3. This question is about a telescope.

The diagram below shows two lenses arranged so as to form an astronomical telescope. The two lenses are represented as straight lines.



The focal lengths of the objective lens and of the eye lens are f_O and f_E respectively. Light from a distant object is shown focused in the focal plane of the objective lens. The final image is to be formed at infinity.

(a) Complete the ray diagram to show the formation of the final image. *[2]*

(b) (i) State what is meant by angular magnification. *[1]*

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(ii) Using the completed ray diagram above, derive an expression in terms of f_O and f_E for the angular magnification of an astronomical telescope. Assume that the final image is at infinity. *[4]*

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(c) When specifying an astronomical telescope, the diameter of the objective lens is frequently quoted. Suggest a reason for quoting the diameter. *[1]*

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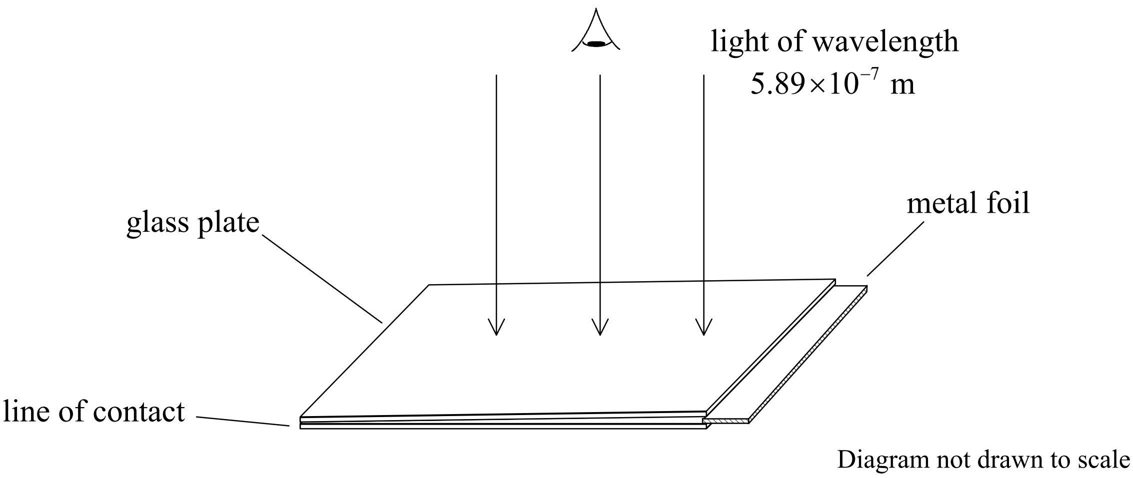
H4. This question is about thin film interference.

Two flat glass plates are in contact along one edge and are separated by a piece of thin metal foil placed parallel to the edge, as shown below.



Air is trapped between the two plates. The gap between the two plates is viewed normally using reflected light of wavelength 5.89×10^{-7} m.

A series of straight fringes, parallel to the line of contact of the plates is seen.

(a) State what can be deduced from the fact that the fringes are straight and parallel. *[1]*

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(b) Explain why a dark fringe is observed along the line of contact of the glass plates. *[3]*

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(c) The distance between the line of contact of the plates and the edge of the metal foil is 9.0 cm. The dark fringes are each separated by a distance of 1.4 mm. Calculate the thickness of the metal foil. *[3]*

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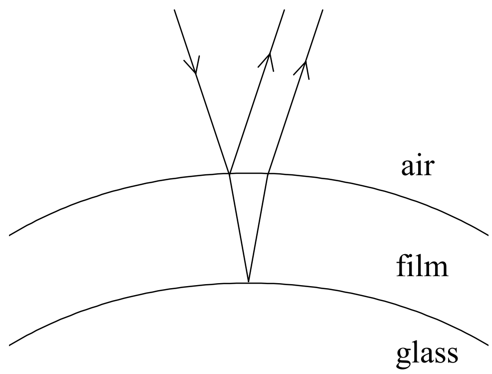
(Question H4 continued)

The lenses used in astronomical telescopes are frequently “bloomed”. This means that a thin film is deposited on the lens in order to reduce the intensity of unwanted light reflected by the lens. Destructive interference occurs between the light reflected from the upper and the lower surfaces of the film. The reflections at both surfaces for one incident ray are shown in the diagram.



(d) (i) State why complete destructive interference of all the reflected light does not occur. *[1]*

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(ii) With reference to your answer in (i), suggest why the film appears to be coloured. *[2]*

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