IB DIPLOMA PROGRAMME
PROGRAMME DU DIPLÔME DU BI
PROGRAMA DEL DIPLOMA DEL BI

M04/432/S(3)+

PHYSICS
STANDARD LEVEL
PAPER 3

Candidate number

Wednesday 5 May 2004 (morning)

1 hour

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.

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Option A — Mechanics Extension

A1. This question is about equilibrium.

Explain whether each of the following is in equilibrium.

(a) A satellite in orbit at constant speed round the Earth. *[2]*

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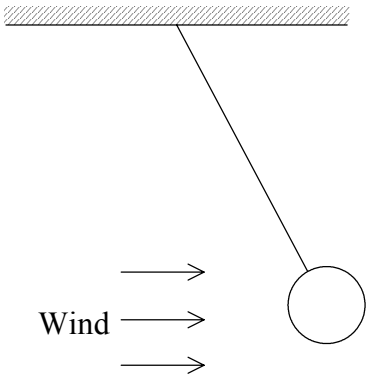
(b) A small weight suspended on a string and blown to one side by a wind so that the string makes a constant angle with the vertical, as shown below. *[2]*



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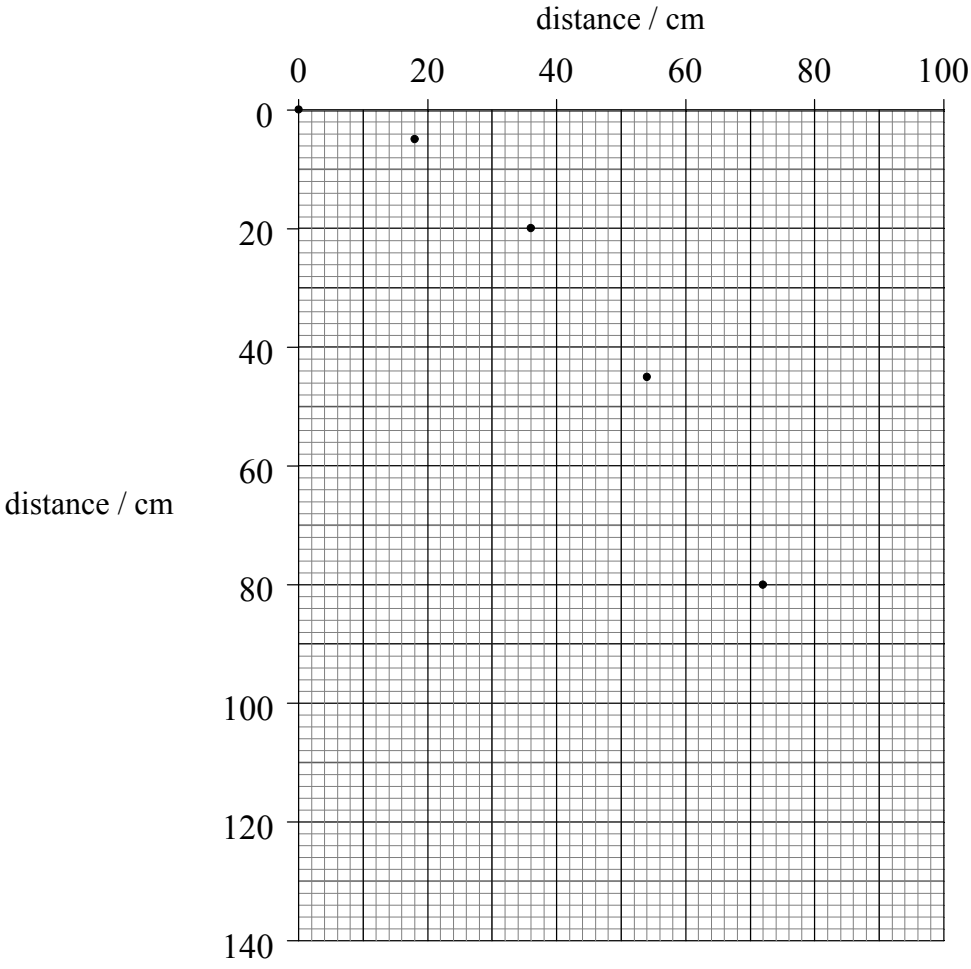
A2. This question is about projectile motion.

A small steel ball is projected horizontally from the edge of a bench. Flash photographs of the ball are taken at 0.10 s intervals. The resulting images are shown against a scale as in the diagram below.



(a) Use the diagram to determine

(i) the constant horizontal speed of the ball. *[2]*

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(ii) the acceleration of free fall. *[2]*

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(This question continues on the following page)

(Question A2 continued)

(b) Mark on the diagram the position of the ball 0.50 s after projection. *[3]*

In the space below, you should carry out any calculations so that you can accurately position the ball.

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(c) A second ball is projected from the table at the same speed as the original ball. The ball has small mass so that air resistance cannot be neglected. Draw on the diagram the approximate shape of the path you would expect the ball to take. *[3]*

A3. This question is about escape speed and Kepler's third law.

Jupiter and Earth are two planets that orbit the Sun.

The Earth has mass M_e and diameter D_e. The escape speed from Earth is $11.2\ \text{km s}^{-1}$.

Data for Jupiter are given below.

Mass:	1.90×10^{27} kg	$(318\ M_e)$
Mean diameter:	1.38×10^{5} km	$(10.8\ D_e)$

(a) (i) State what is meant by *escape speed.* *[1]*

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(ii) Escape speed v is given by the expression

$$v = \sqrt{\left(\frac{2GM}{R}\right)}.$$

Determine the escape speed from Jupiter. *[2]*

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(b) (i) State Kepler's third law. *[1]*

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(ii) In 1610, the moon Ganymede was discovered orbiting Jupiter. Its orbit was found to have a radius of 15.0 R and period 7.15 days, where R is the radius of Jupiter. Another moon of Jupiter, Lysithea, was discovered in 1938 and its orbit was found to have a radius of 164 R and a period of 260 days. Show that these data are consistent with Kepler's third law. *[2]*

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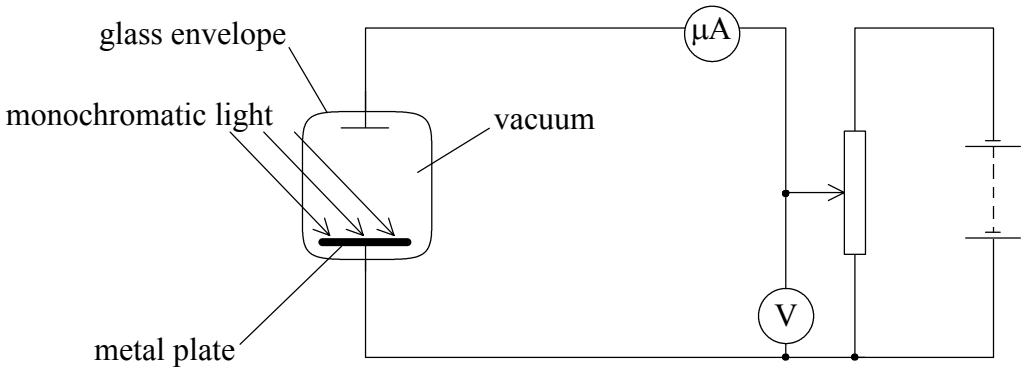
Option B — Quantum Physics and Nuclear Physics

B1. This question is about the photoelectric effect.

In order to demonstrate the photoelectric effect, the apparatus shown below is used.



Monochromatic light is incident on the metal plate. The potentiometer is adjusted to give the minimum voltage at which there is zero reading on the microammeter.

(a) State and explain what change, if any, will occur in the reading of the microammeter when

(i) the intensity of the incident light is increased but the frequency remains unchanged. *[2]*

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(ii) the frequency of the light is increased at constant intensity. *[2]*

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(b) For light of wavelength 540 nm, the minimum reading on the voltmeter for zero current is 1.9 V.

(i) State the connection between photon energy and the energy of the emitted electron. *[1]*

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(ii) Hence calculate the work function of the surface of the metal plate. *[3]*

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B2. This question is about a model of the atom.

The Schrödinger model of the atom pictures electrons as clouds of negative charge surrounding the nucleus. The distribution of charge and mass can be represented by a three-dimensional standing wave.

(a) Identify the feature of the standing wave that gives the probability of finding the electron at a particular position. *[2]*

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An electron of mass m in an atom has total energy E, potential energy E_P and kinetic energy E_K.

(b) Write down expressions for

(i) the relation between E, E_P and E_K. *[1]*

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(ii) the momentum p of the electron in terms of E_K. *[1]*

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(iii) the associated wavelength λ of the electron in terms of its total energy E. *[2]*

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B3. This question is about radioactive decay.

Cerium-145 is a radioactive isotope with a half-life of 3.0 minutes. It emits β^- particles and also anti-neutrinos.

(a) Give **one** reason why the existence of the neutrino was postulated in order to explain β-decay. *[1]*

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(b) State the class of particle to which the neutrino belongs. *[1]*

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(c) Determine the probability for the decay of a Cerium-145 nucleus in a time of 1.0 minute. *[2]*

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(d) Determine the time taken for the activity of a particular sample of Cerium-145 to be reduced to a fraction $\frac{1}{10}$ of its initial activity. *[2]*

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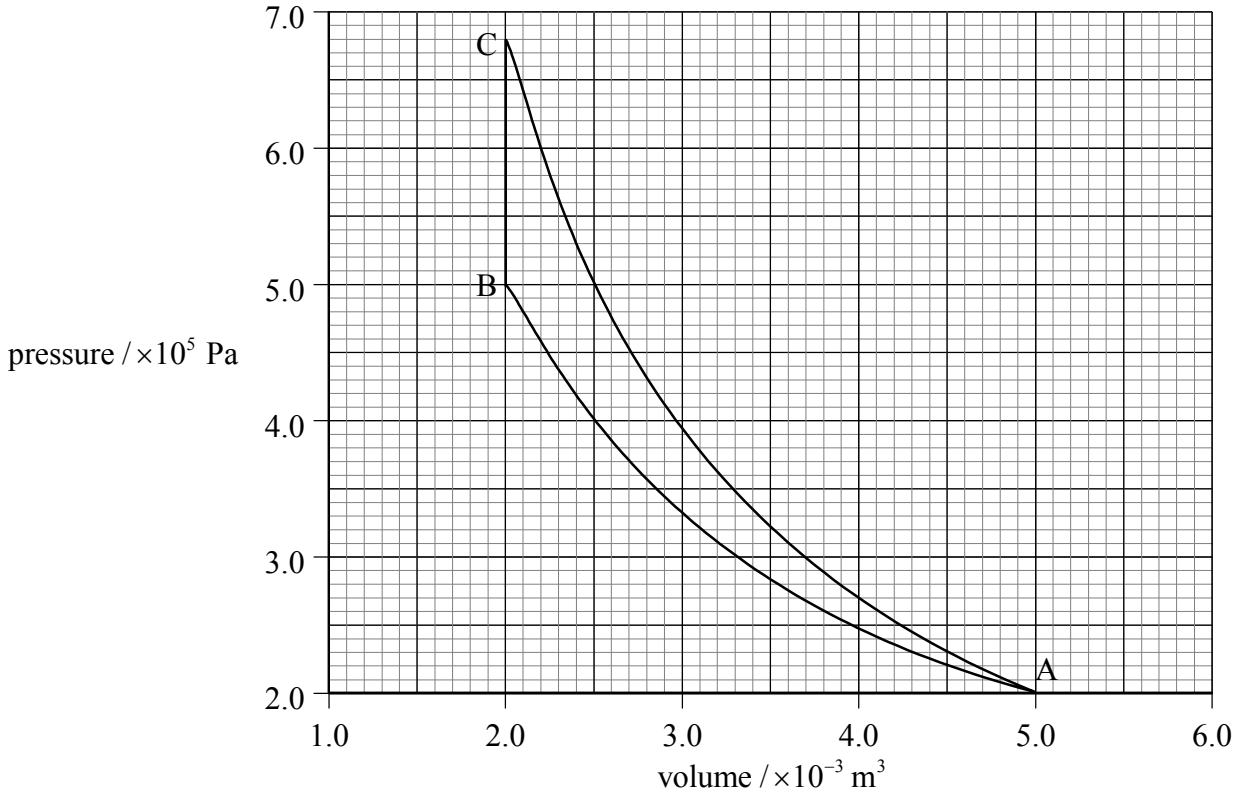
Option C — Energy Extension

C1. This question is about *p*–*V* diagrams.

The graph below shows the variation with volume of the pressure of a fixed mass of gas when it is compressed adiabatically and also when the same sample of gas is compressed isothermally.



(a) State and explain which line AB or AC represents the isothermal compression. *[2]*

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(b) On the graph, shade the area that represents the difference in work done in the adiabatic change and in the isothermal change. *[1]*

(c) Determine the difference in work done, as identified in (b). *[3]*

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(This question continues on the following page)

(Question C1 continued)

(d) Use the first law of thermodynamics to explain the change in temperature during the adiabatic compression. *[3]*

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C2. This question is about energy sources.

(a) Fossil fuels are being produced continuously on Earth and yet they are classed as being non-renewable. Outline why fossil fuels are classed as non-renewable. *[2]*

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(b) Some energy consultants suggest that the solution to the problem of carbon dioxide pollution is to use nuclear energy for the generation of electrical energy. Identify **two** disadvantages of the use of nuclear fission when compared to the burning of fossil fuels for the generation of electrical energy. *[2]*

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C3. This question is about solar energy.

(a) By reference to energy transformations, distinguish between a solar panel and a solar cell. *[2]*

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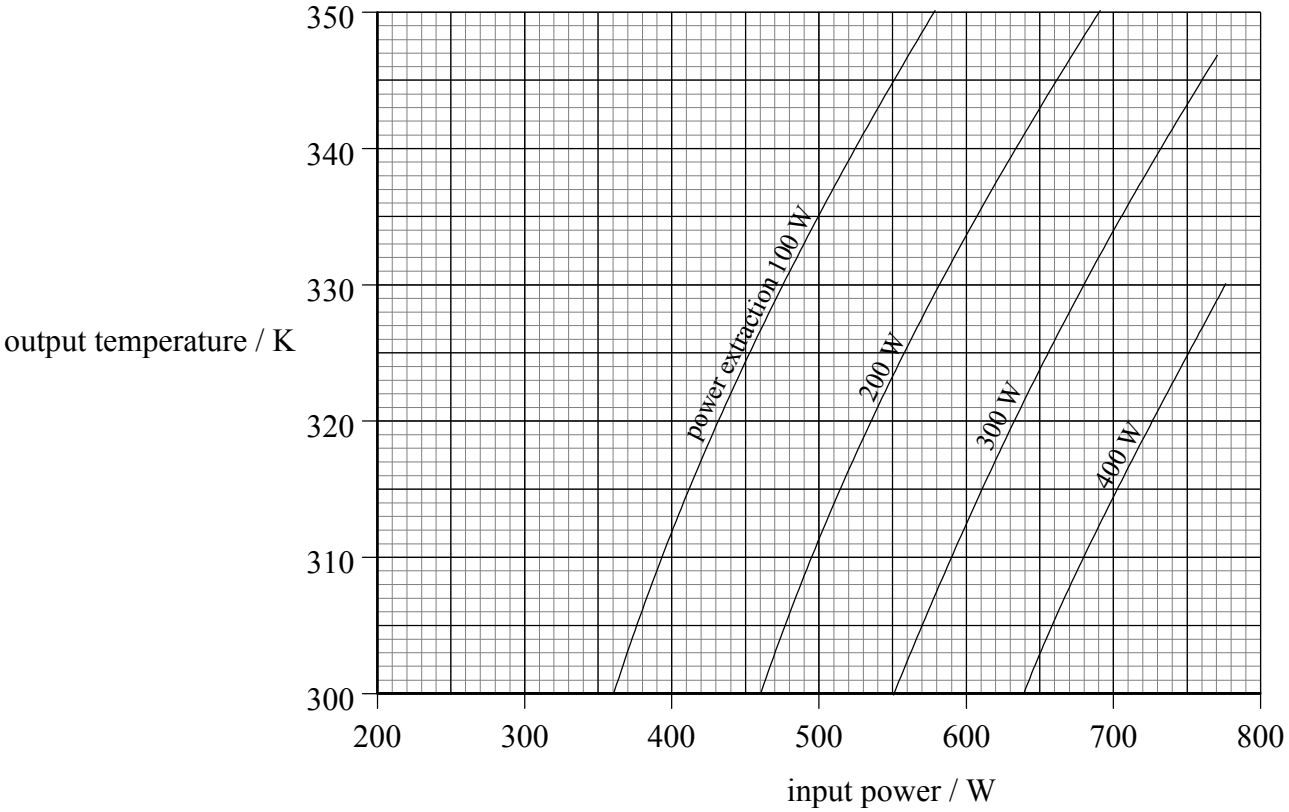
Some students carry out an investigation on a solar panel. They measure the output temperature of the water for different solar input powers and for different rates of extraction of thermal energy. The results are shown below.



(b) Use the data from the graph to answer the following.

(i) The solar panel is to provide water at 340 K whilst extracting energy at a rate of 300 W when the intensity of the sunlight incident normally on the panel is 800 $W\,m^{-2}$. Calculate the effective surface area of the panel that is required. *[2]*

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(This question continues on the following page)

(Question C3 continued)

(ii) Deduce the overall efficiency of the panel for an input power of 500 W at an output temperature of 320 K. *[3]*

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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 $\frac{\text{surface area of Jorge}}{\text{surface area of Fernando}}$. *[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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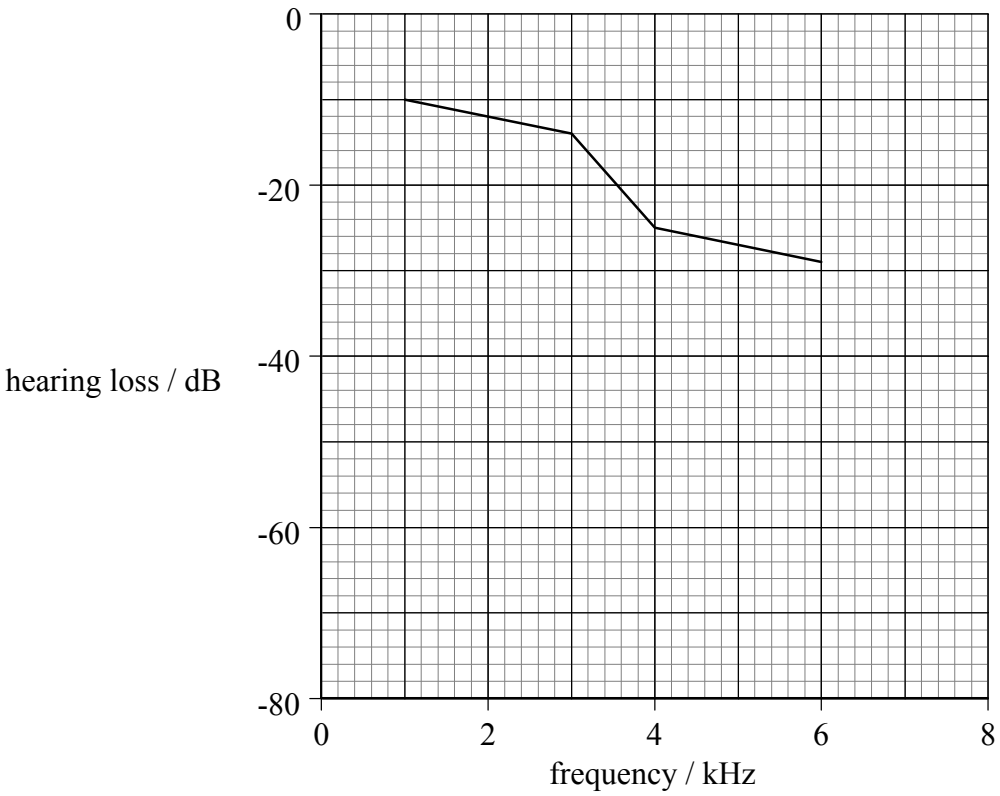
D2. This question is about defects of hearing.

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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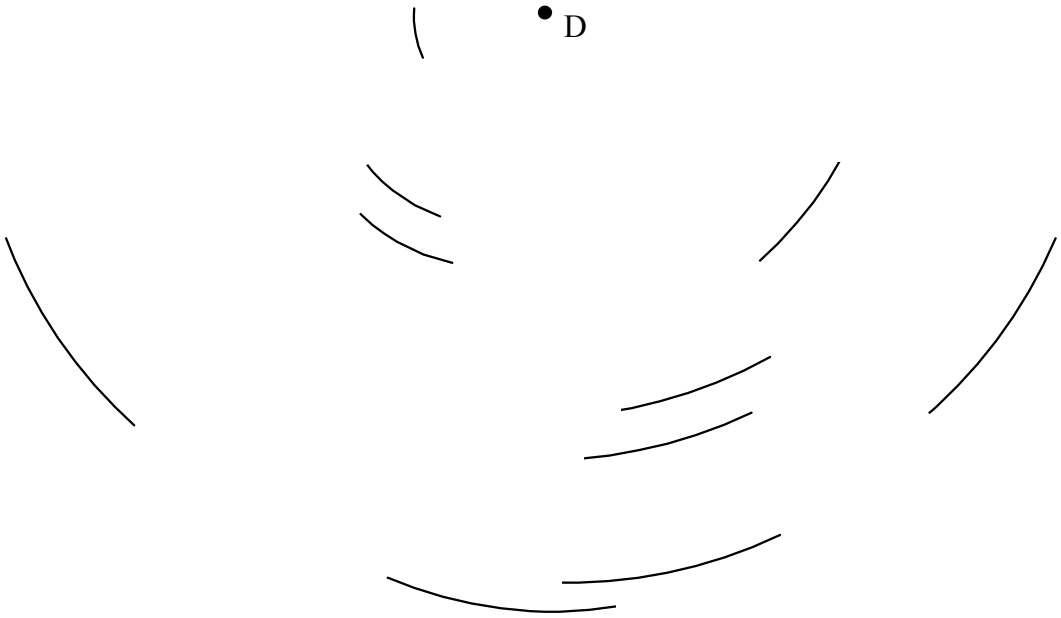
Option E — The History and Development of Physics

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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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

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

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

An estimate of H_0 is $2.7\times10^{-18}\ \mathrm{s}^{-1}$.

(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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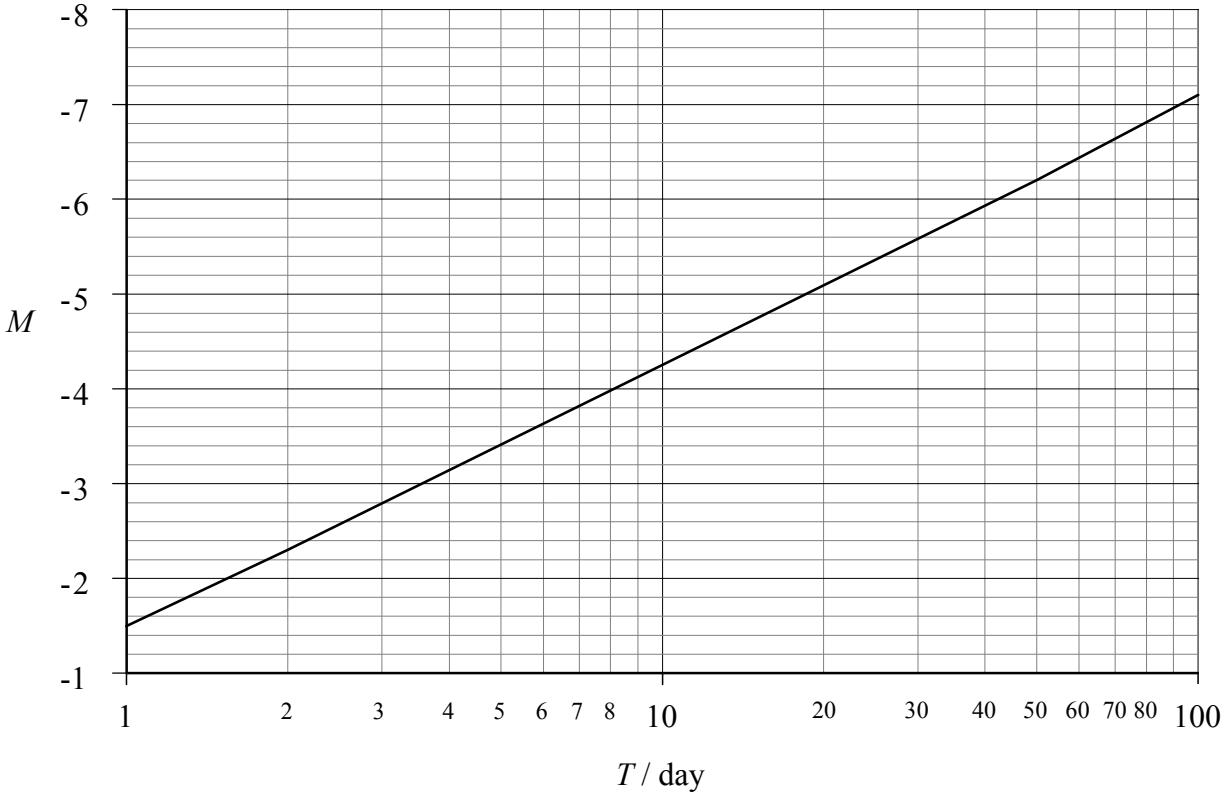
(This question continues on the following page)

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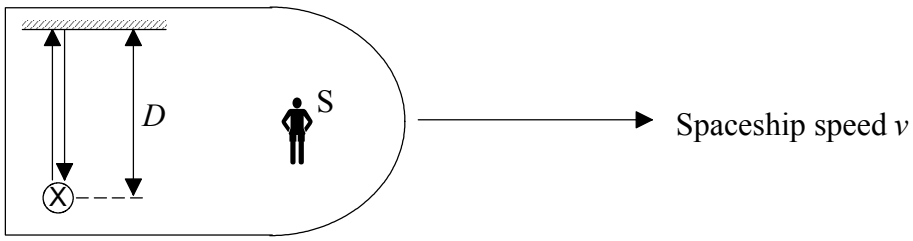
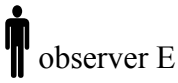
An observer S in a spacecraft sees a flash of light. The light is reflected from a mirror, distance D from the flash, and returns to the source of the flash as illustrated below. The speed of light is c.





(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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(This question continues on the following page)

(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 2.8×10^{8} 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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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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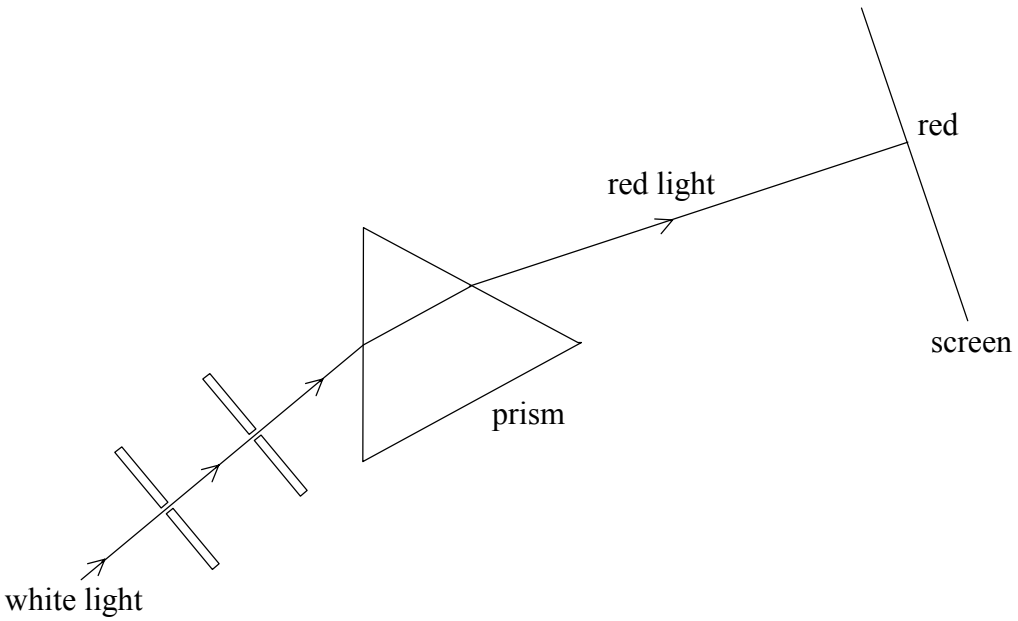
A student used the apparatus illustrated below in order to show the spectrum of white light.



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

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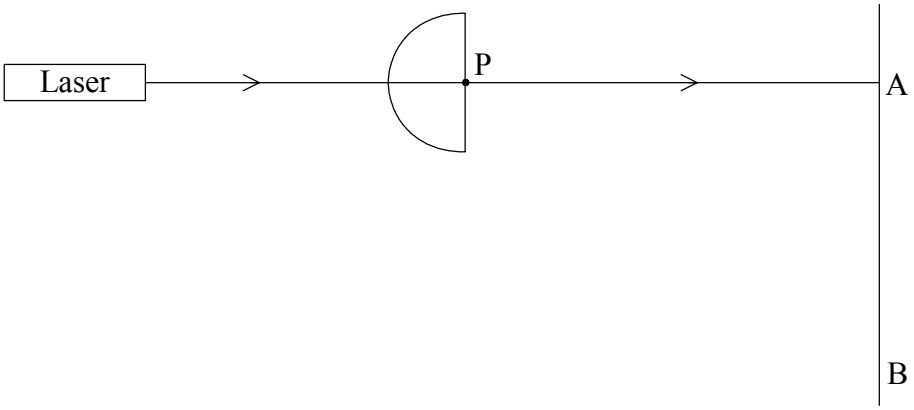
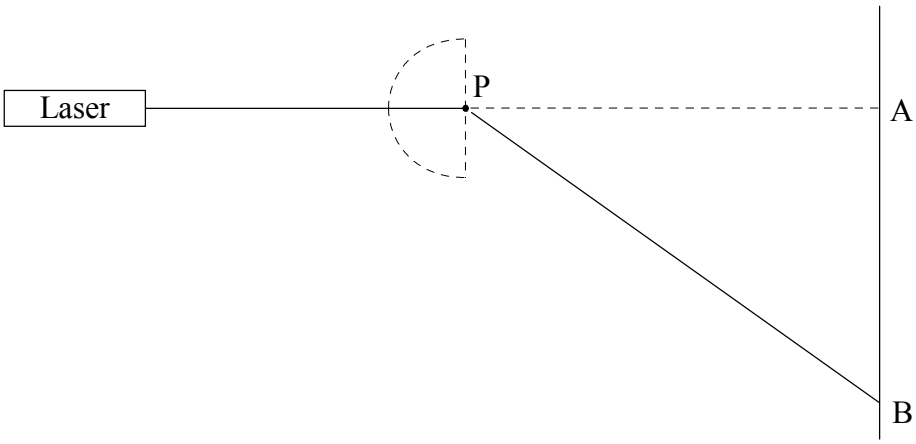
H2. This question is about refractive index.

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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(This question continues on the following page)

(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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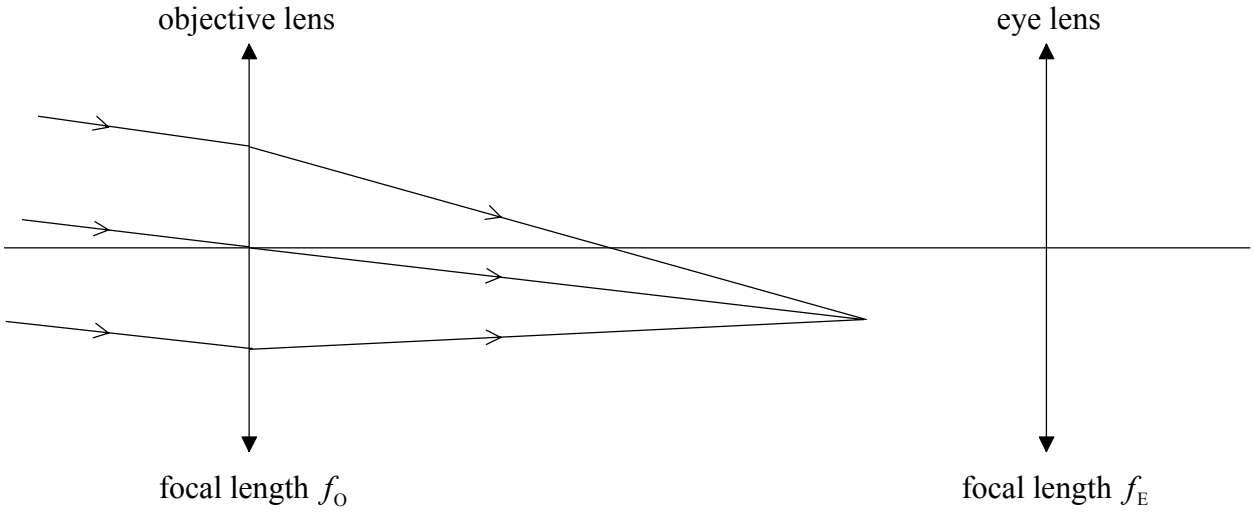
H3. This question is about a telescope.

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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