PHYSICS
STANDARD LEVEL
PAPER 3

Candidate number

Wednesday 12 November 2003 (morning)

1 hour

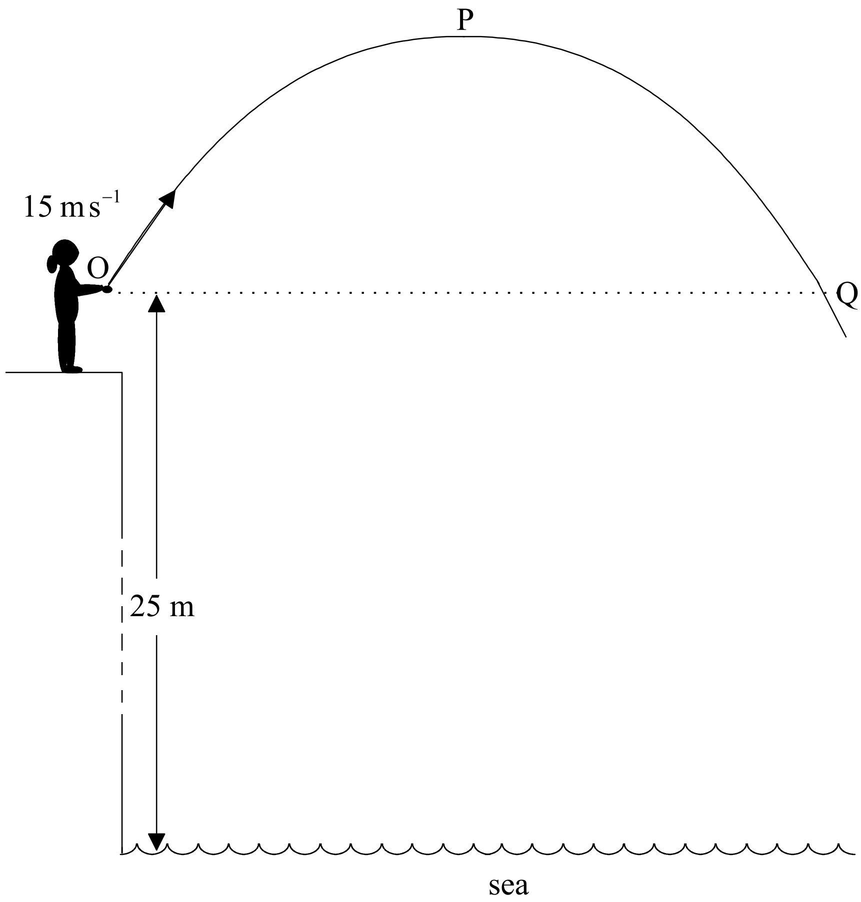
INSTRUCTIONS TO CANDIDATES

- 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. You may continue your answers on answer sheets. Write your candidate number on each answer sheet, and attach them to this examination paper and your cover sheet using the tag provided.
- At the end of the examination, indicate the letters of the Options answered in the candidate box on your cover sheet and indicate the number of answer sheets used in the appropriate box on your cover sheet.

OPTION A — MECHANICS EXTENSION

A1. This question is about projectile motion and the use of an energy argument to find the speed with which a thrown stone lands in the sea.

Christina stands close to the edge of a vertical cliff and throws a stone. The diagram below *(not drawn to scale)* shows part of the trajectory of the stone. Air resistance is negligible.



Point P on the diagram is the highest point reached by the stone and point Q is at the same height above sea level as point O.

(a) At point P on the diagram above draw arrows to represent

(i) the acceleration of the stone (label this A). *[1]*

(ii) the velocity of the stone (label this V). *[1]*

(This question continues on the following page)

(Question A1 continued)

The stone leaves Christina's hand (point O) at a speed of $15\,\mathrm{m\,s^{-1}}$ in the direction shown. Her hand is at a height of 25 m above sea level. The mass of the stone is 160 g. The acceleration due to gravity $g = 10\,\mathrm{m\,s^{-2}}$.

(b) (i) Calculate the kinetic energy of the stone immediately after it leaves Christina's hand. *[1]*

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(ii) State the value of the kinetic energy at point Q. *[1]*

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(iii) Calculate the loss in potential energy of the stone in falling from point Q to hitting the sea. *[1]*

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(iv) Determine the speed with which the stone hits the sea. *[2]*

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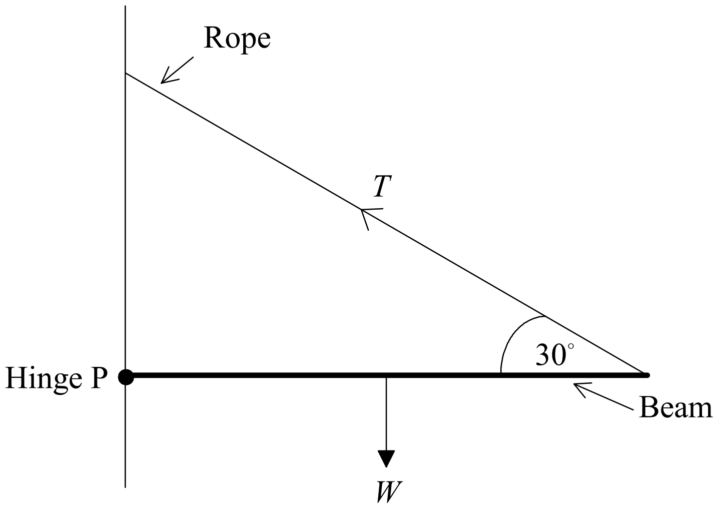
A2. This question is about static equilibrium.

A uniform, rigid rod of weight W is hinged at point P on a vertical wall. The rod is kept horizontal by means of a rope as shown in the diagram below.



The pull of the string T on the rod and the weight W of the rod are shown on the diagram.

(a) Draw an arrow on the diagram to show the direction of the reaction force N at the hinge. *[2]*

(b) Given that $T = W = 20.0$ N, determine the horizontal force that the hinge exerts on the rod. *[2]*

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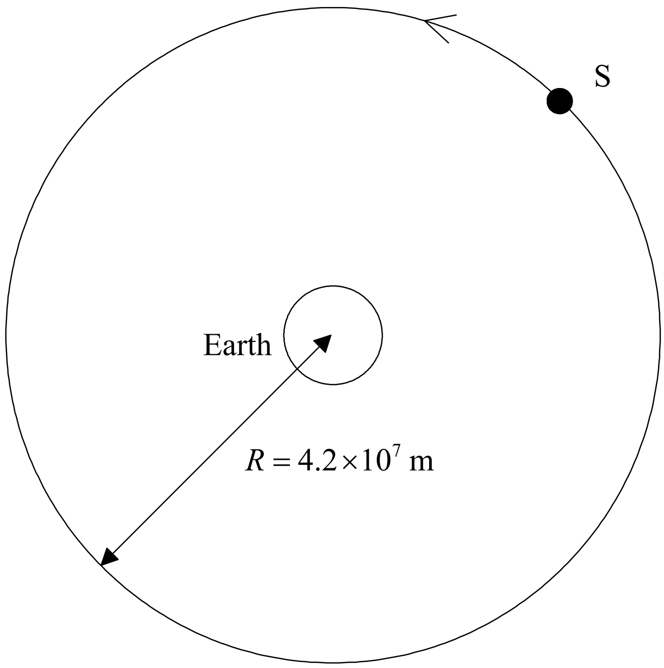
A3. This question is about a satellite orbiting the Earth.

A Satellite S is in orbit round the Earth, a distance $R = 4.2 \times 10^7$ m from the centre of the Earth.



(a) On the diagram above, for the satellite in the position shown, draw arrow(s) to represent the force(s) acting on the satellite. *[1]*

(b) Deduce that the velocity v of the satellite is given by the expression

$$v^2 = \frac{GM}{R}$$

where M is the mass of the Earth. *[1]*

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(c) Hence deduce that the period of orbit T of the satellite is given by the following expression.

$$T^2 = \frac{4\pi^2 R^3}{GM}$$ *[3]*

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(This question continues on the following page)

(Question A3 continued)

(d) Use the following information to determine that the orbital period of the satellite is about 24 hours.

Acceleration due to gravity at the surface of the Earth $g = \frac{GM}{{R_E}^2} = 10\ \text{m s}^{-2}$, where M is the mass of the Earth and R_E is the radius of the Earth $= 6.4 \times 10^6$ m. *[2]*

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(e) The satellite is moved into an orbit that is closer to the Earth. State what happens to its

(i) potential energy. *[1]*

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(ii) kinetic energy. *[1]*

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OPTION B — QUANTUM PHYSICS AND NUCLEAR PHYSICS

B1. This question is about the wave nature of electrons.

(a) Describe the de Broglie hypothesis. *[2]*

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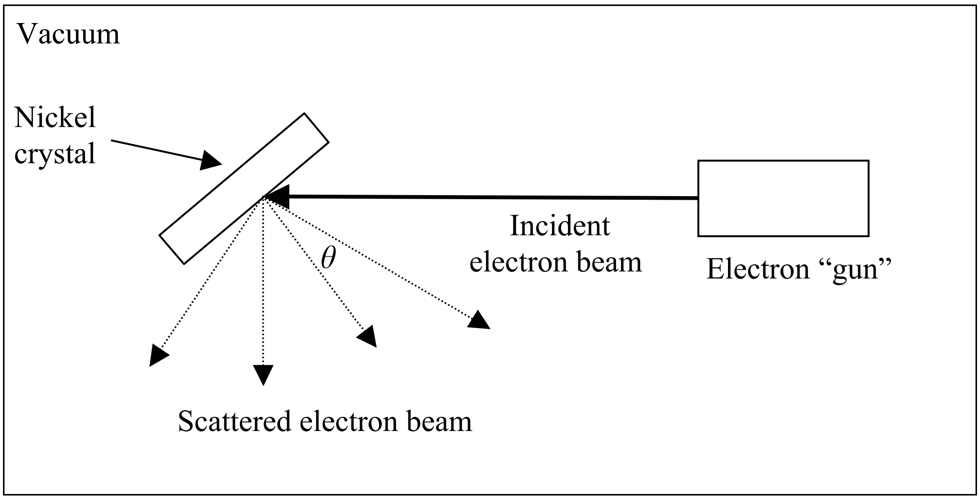
An experiment is carried out in which a beam of electrons is scattered from a single nickel crystal. A schematic diagram of the apparatus is shown below.



The electrons are accelerated in the electron "gun" by a potential difference of 75 V.

(b) Determine the wavelength associated with the electrons as predicted by the de Broglie hypothesis. *[4]*

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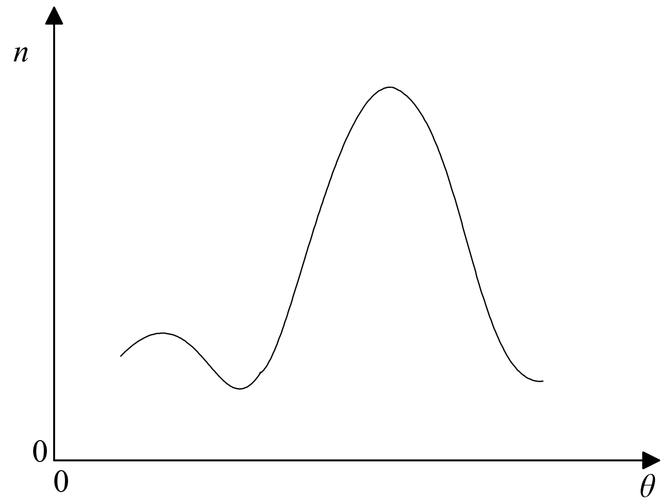
(Question B1 continued)

The number n of electrons scattered per second through an angle θ is measured. The graph below shows the variation with angle θ of n.



(c) Suggest how the shape of this graph supports the de Broglie hypothesis. *[3]*

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B2. This question is about atomic spectra and energy levels.

Diagram 1 below shows part of the emission line spectrum of atomic hydrogen. The wavelengths of the principal lines in the visible region of the spectrum are shown.

Diagram 2 shows some of the principal energy levels of atomic hydrogen.

Diagram 1

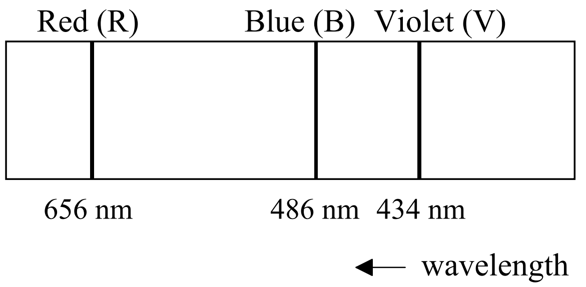
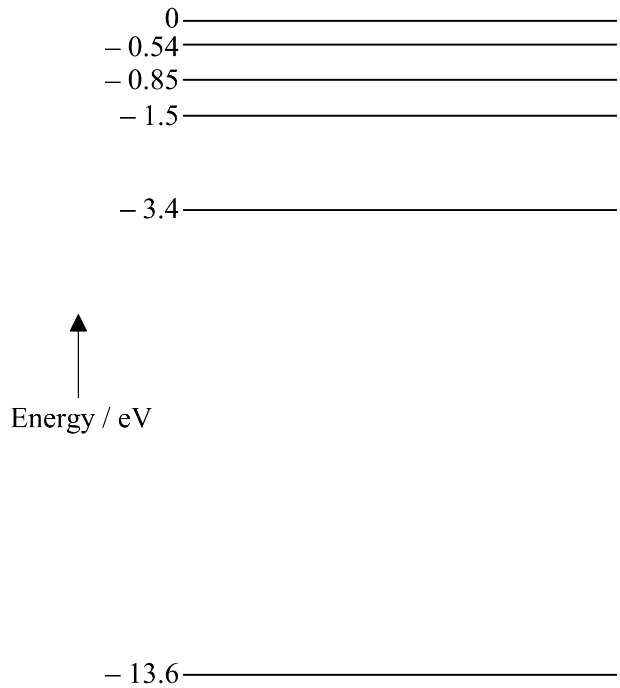


Diagram 2



(a) Show, by calculation, that the energy of a photon of red light of wavelength 656 nm is 1.9 eV. *[3]*

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(b) On diagram 2, draw arrows to represent

(i) the electron transition that gives rise to the red line (label this arrow R). *[1]*

(ii) a possible electron transition that gives rise to the blue line (label this arrow B). *[1]*

B3. This question is about the radioactive decay of potassium-40.

A nucleus of the nuclide ${}^{40}_{19}\mathrm{K}$ (potassium-40) decays to a stable nucleus of the nuclide ${}^{40}_{18}\mathrm{Ar}$ (argon-40).

(a) State the names of the **two** particles emitted in this decay. *[2]*

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(b) A sample of the isotope potassium-40 initially contains 1.5×10^{16} atoms. On average, 16 nuclei in this sample of the isotope undergo radioactive decay every minute.

Deduce that the decay constant for potassium-40 is $1.8\times10^{-17}\ \mathrm{s}^{-1}$. *[3]*

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(c) Determine the half-life of potassium-40. *[1]*

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OPTION C — ENERGY EXTENSION

C1. This question is about estimating the area of solar panels and the diameter of a wind turbine.

It is suggested that a combination of solar power and wind power be used to provide the hot water system in a house.

An active solar heater is to provide the energy to heat the water. A wind turbine is to provide the energy to pump the water.

Solar heater

The following data are available:

volume of hot water tank	$= 1.2\ \text{m}^3$
density of water	$= 1.0 \times 10^3\ \text{kg m}^{-3}$
initial temperature of the water	$= 10\ ^\circ\text{C}$
final temperature of the water	$= 40\ ^\circ\text{C}$
specific heat capacity of water	$= 4.2 \times 10^3\ \text{J kg}^{-1}\ \text{K}^{-1}$
average power per unit area from the Sun	$= 0.80\ \text{kW m}^{-2}$
time required to heat the water	$= 2.0$ hours

(a) Using the above data,

(i) deduce that 1.5×10^8 J of energy is required to heat the volume of water in the tank from $10\ ^\circ\text{C}$ to $40\ ^\circ\text{C}$. *[2]*

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(ii) estimate the minimum area of the solar panel needed to provide 1.5×10^8 J of energy in 2.0 hours. *[2]*

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(iii) discuss whether, in this situation, using a solar panel to heat the water is a sensible method. *[2]*

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(Question C1 continued)

Wind turbine

The following data are available:

power of solar heater pump = 0.4 kW
average local wind speed = $6.0\ \text{m}\,\text{s}^{-1}$
average density of air = $1.0\ \text{kg}\,\text{m}^{-3}$

(b) (i) Using the above data, estimate the minimum radius of the wind turbine needed to provide the power required to drive the solar heater pump. *[3]*

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(ii) Discuss, whether in this situation, using a wind turbine to pump the water is a sensible method. *[1]*

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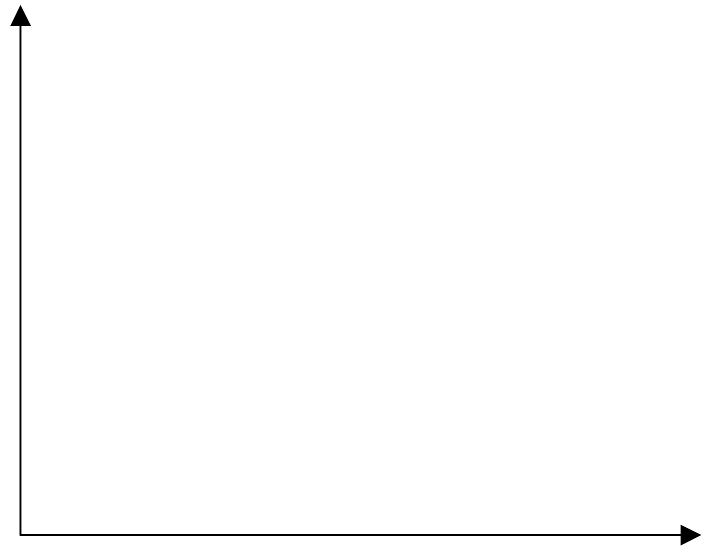
C2. This question is about the Carnot cycle.

A heat engine operates in a Carnot cycle between two reservoirs, one at temperature T_1 the other at a lower temperature T_2. The heat engine uses an ideal gas as the working substance.

(a) Using the axes below, draw a sketch-graph to show the changes in the pressure and the volume of the ideal gas during one cycle of the engine. *[3]*



(b) On your sketch-graph

(i) label, with the letter I, the change(s) that are isothermal. *[1]*

(ii) label, with the letter A, the change(s) that are adiabatic. *[1]*

(iii) indicate which change(s) takes place at the higher temperature T_1. *[1]*

(iv) indicate which change takes place at the lower temperature T_2. *[1]*

(This question continues on the following page)

(Question C2 continued)

(c) Given that $T_1 = 1000\ \text{K}$ and $T_2 = 300\ \text{K}$ and that the engine has a power output of 75 kW, determine

(i) the efficiency of the engine. *[1]*

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(ii) the thermal power input to the engine. *[2]*

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OPTION D — BIOMEDICAL PHYSICS

D1. This question is about scaling.

(a) There is a very large variation in the size of different land mammals. They vary from about 2 cm to 4 m in length.

(i) Estimate the ratio

$$\frac{\text{rate of energy loss per unit mass from the smallest land mammal}}{\text{rate of energy loss per unit mass from the largest land mammal}}.$$ *[4]*

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(ii) State **one** assumption that you have made in your estimation. *[1]*

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(b) State, and explain, **one** reason why no land mammals are found in nature that are

(i) smaller than about 2 cm in length. *[2]*

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(ii) larger than about 4 m in length. *[2]*

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D2. This question is about the hearing abilities of two different people, where one is much older than the other.

Carmen is just able to hear a sound of frequency 1000 Hz when its intensity is 10^{-12} W m^{-2}. Her grandfather, Jorge, cannot hear this sound frequency until its intensity is increased to 10^{-6} W m^{-2}.

(a) Determine the ratio

$$\frac{\textbf{amplitude} \text{ of the sound wave just heard by Carmen}}{\textbf{amplitude} \text{ of the sound wave just heard by Jorge}}.$$ *[2]*

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(b) Determine Jorge's hearing loss in dB at this frequency compared with Carmen. *[2]*

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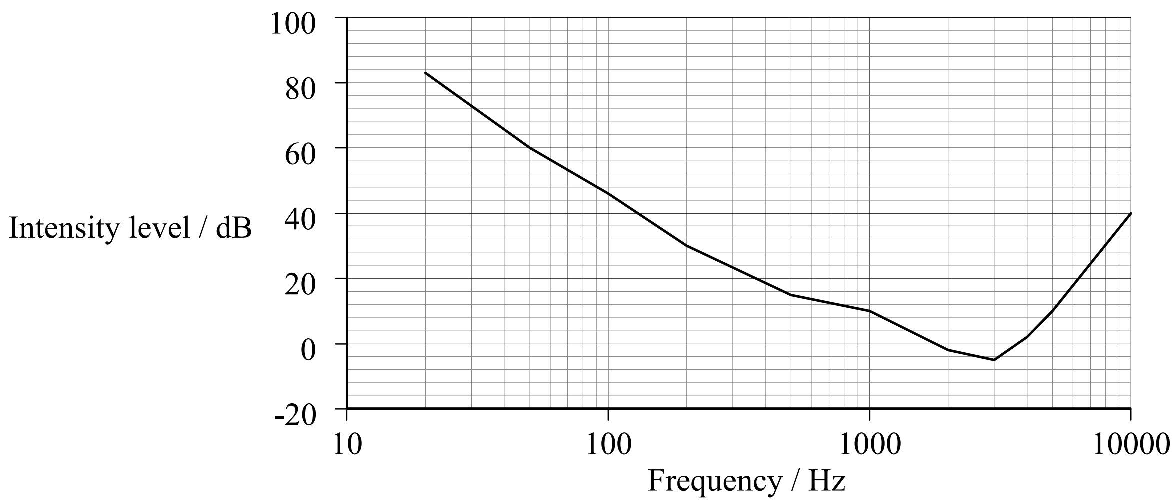
The graph below shows the threshold of hearing for Carmen as a function of frequency.



(c) Using the data from the graph, state and explain the frequency to which Carmen's ear is most sensitive. *[2]*

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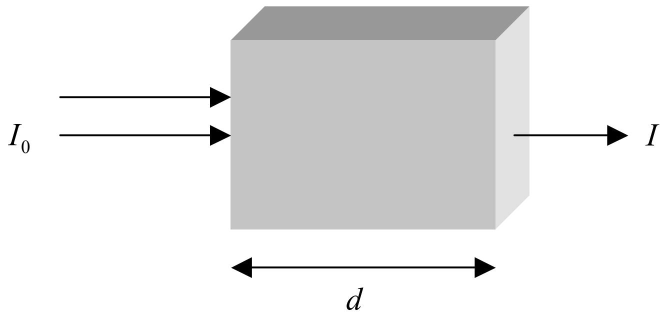
(d) Using your answer to (b), mark on the graph Jorge's threshold of hearing at a frequency of 1000 Hz. *[1]*

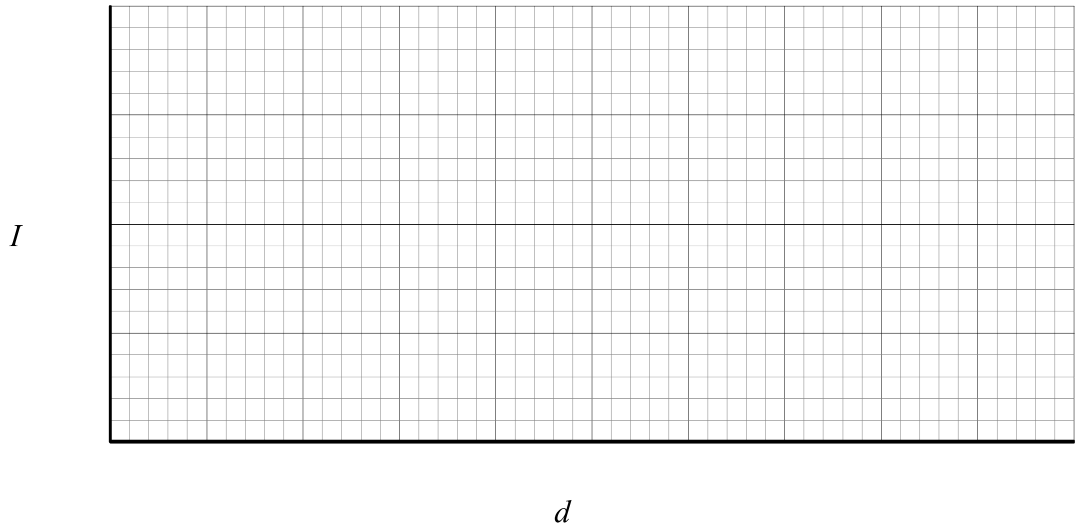
D3. This question is about X-rays.

When an X-ray beam passes through matter, the beam is attenuated.

The diagram below shows a parallel beam of X-rays of intensity I_0 entering a sample of material of thickness *d*. The intensity of the emergent beam is *I*.



(a) Using the grid below, sketch a graph to show the variation with thickness *d* of the intensity *I*. *[2]*



The attenuation of X-rays depends not only on the nature of the material through which they travel but also on the photon energy. For photons with energy of about 30 keV, the *half-value thickness* of muscle is about 50 mm and for photons of energy 5 keV, it is about 10 mm.

(b) Explain which photon energy would be most suitable for obtaining a sharp picture of a broken leg. *[2]*

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OPTION E — THE HISTORY AND DEVELOPMENT OF PHYSICS

E1. This question is about Newton's contribution to understanding the motion of heavenly bodies.

Newton believed that the nature of the force that causes the acceleration of objects close to the surface of the Earth was the same as that of the force that keeps the Moon in orbit about the Earth. To support his argument, he assumed that the force F exerted by the Earth on an object distance R from the centre of the Earth may be expressed as

$$F = \frac{K}{R^2}$$

where K is a constant.

(a) The distance from the centre of the Moon to the centre of the Earth is about $60R_E$ where R_E is the radius of the Earth.

(i) Use the above expression to estimate the acceleration of the Moon in orbit about the Earth (the acceleration due to gravity at the surface of the Earth $g = 10\ \text{m s}^{-2}$). *[4]*

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(Question E1 continued)

The acceleration of the Moon in orbit may also be determined from the following data.

orbital period of the Moon $= 2.4 \times 10^6$ s
radius of the Earth $= 6.4 \times 10^6$ m

(ii) Use the above data to calculate the acceleration of the Moon. *[4]*

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(iii) In view of your answers to (i) and (ii), explain whether Newton was correct in his assumption about the nature of the force that causes the acceleration of objects close to the surface of the Earth being the same as that of the force that keeps the Moon in orbit about the Earth. *[1]*

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(b) Newton proposed that the force law $F = \frac{K}{R^2}$ is a universal force law. Explain what is meant by *universal* in this context. *[2]*

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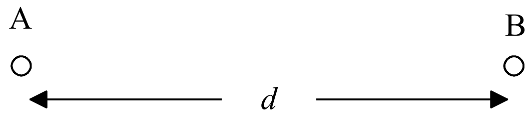
E2. This question is about the experimental verification of Coulomb's law.

A small metal sphere A is given a charge $+Q$. It is then brought into contact with an identical, uncharged metal sphere B. The two spheres are then held at a distance d apart as shown below.



The distance d is much greater than the radius of the spheres.

(a) Assuming that the spheres are isolated from any other charges, write down an expression for the electrostatic force F on either sphere. *[1]*

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Sphere B is now discharged and once more brought into contact with sphere A after which the spheres are again held at a distance d apart.

(b) Write down an expression, in terms of F, for the new electrostatic force on either sphere. *[1]*

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(c) State why the answers you have given in (a) and (b) depend on the fact that d is much greater than the radius of the spheres. *[1]*

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(d) Outline how the above procedure enabled Coulomb to establish that the force between two point charges is proportional to the product of their magnitudes. *[2]*

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(This question continues on the following page)

(Question E2 continued)

(e) Describe briefly, with the aid of a diagram, how Coulomb was able to measure the electrostatic force between two small, charged metal spheres. *[4]*

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OPTION F — ASTROPHYSICS

F1. This question is about some facts regarding some of the planets in the Solar system.

Four of the planets in the Solar system are Jupiter, Earth, Mars and Pluto.

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

☐ → ☐ → ☐ → ☐

nearest ⟶ furthest

increasing distance from Sun

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

☐ → ☐ → ☐ → ☐

smallest ⟶ largest

increasing diameter

F2. This question is about some of the properties of Barnard's star.

Barnard's star, in the constellation Ophiuchus, has a *parallax angle* of 0.549 arc-second as measured from Earth.

(a) With the aid of a suitable diagram, explain what is meant by *parallax angle* and outline how it is measured. *[6]*

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(b) Deduce that the distance of Barnard's star from the Sun is 5.94 ly. *[2]*

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(Question F2 continued)

(c) The ratio $\frac{\text{apparent brightness of Barnard's star}}{\text{apparent brightness of the Sun}}$ is 2.6×10^{-14}.

(i) Define the term *apparent brightness*. *[2]*

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(ii) Determine the value of the ratio $\frac{\text{luminosity of Barnard's star}}{\text{luminosity of the Sun}}$ *[4]*

$(1 \text{ ly} = 6.3 \times 10^4 \text{ AU})$.

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(d) The surface temperature of Barnard's star is about 3 500 K. Using this information and information about its luminosity, explain why Barnard's star cannot be

(i) a white dwarf. *[1]*

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(ii) a red giant. *[1]*

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OPTION G — RELATIVITY

Note that there is only one question in this Option.

G1. This question is about evidence to support the Special Theory of Relativity and relativistic mass increase.

The following is an extract from an article on Relativity.

> *"…The* ***proper length*** *of an object and the* ***proper time*** *interval between events can never be measured directly by the same* ***inertial observer****."*

(a) Define the following terms.

(i) *Proper length* *[1]*

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(ii) *Proper time* *[1]*

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(iii) *Inertial observer* *[1]*

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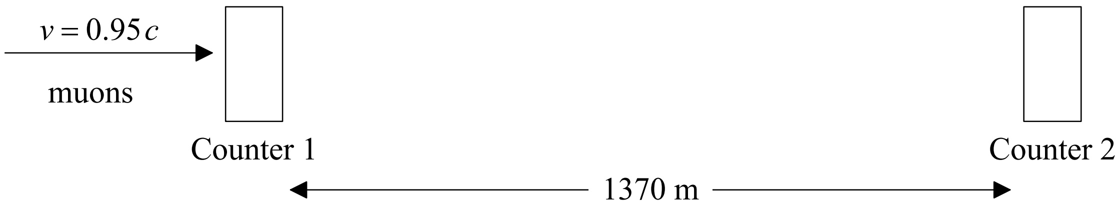
(Question G1 continued)

An experiment is set-up in which muons are accelerated to a speed of 0.95 c, as measured by a laboratory observer. They are counted by the particle counter 1 and the muons that do not decay are counted by counter 2, a distance 1370 m from counter 1 as shown below.



N muons pass through counter 1 in a given time and $\frac{N}{2}$ pass through counter 2 in the same given time.

(b) Determine

(i) the half-life of the muons as measured by a laboratory observer. *[2]*

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(ii) the half-life of the muons as measured in the reference frame in which the muons are at rest. *[2]*

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(iii) the separation of the counters as determined in the reference frame in which the muons are at rest. *[1]*

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(c) Use your answers in (b) to explain what is meant by the terms *time dilation* and *length contraction*. *[4]*

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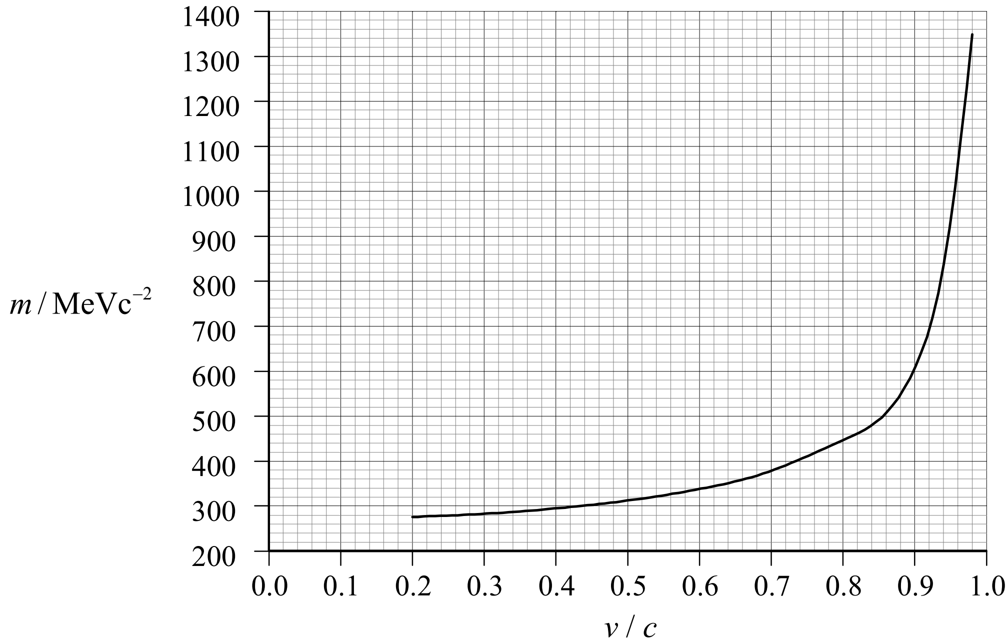
(Question G1 continued)

A muon has a mass m when its speed is v as measured in the laboratory reference frame. The graph below shows the variation with ratio $\frac{v}{c}$ of the mass m. The rest mass of the muon is m_0.



(d) (i) Write down an equation for the above curve. *[1]*

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(ii) Use this equation to explain why a muon can never attain the speed of light. *[2]*

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(e) Use the graph above to determine

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

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(ii) the mass of a muon when it is moving with speed of 0.95 c. *[1]*

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(This question continues on the following page)

(Question G1 continued)

(f) State the total energy in MeV of a muon when it has a speed of $0.95c$. *[1]*

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(g) The charge on a muon is -1.6×10^{-19} C. Calculate the potential difference through which the muon must be accelerated in order to attain a speed of $0.95c$. *[2]*

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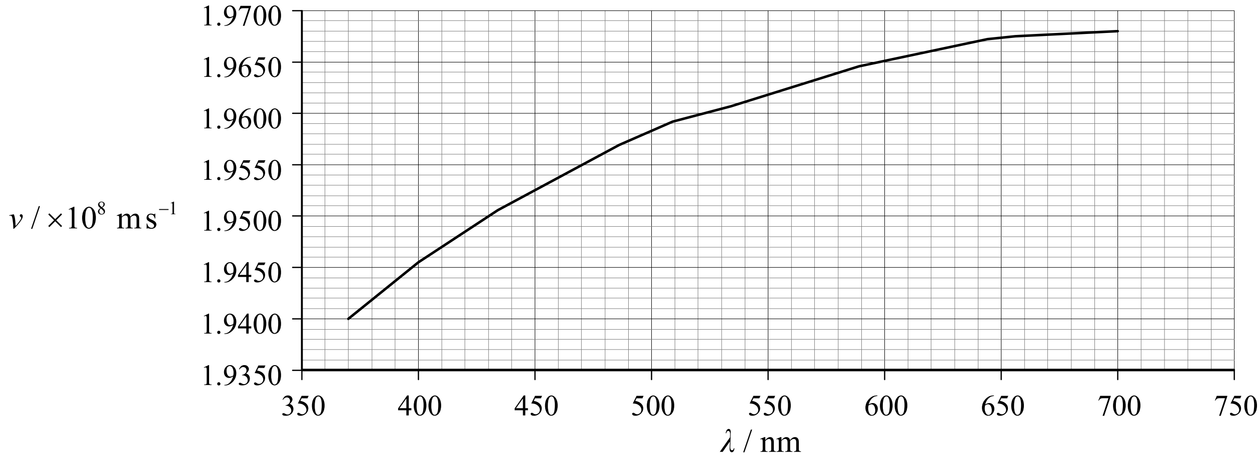
OPTION H — OPTICS

H1. This question is about optical dispersion.

The graph below shows the variation with wavelength λ of the speed v of light in one type of glass.



(a) Use data from the graph to determine, to the correct number of significant digits, the refractive index for blue light of wavelength 400 nm in this type of glass (free space speed of light $c = 2.9979 \times 10^8\ \mathrm{m\,s^{-1}}$). *[2]*

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(b) The refractive index of red light of wavelength 650 nm in this type of glass is about 1.52. Use this fact and your answer in (a) to explain optical dispersion. *[2]*

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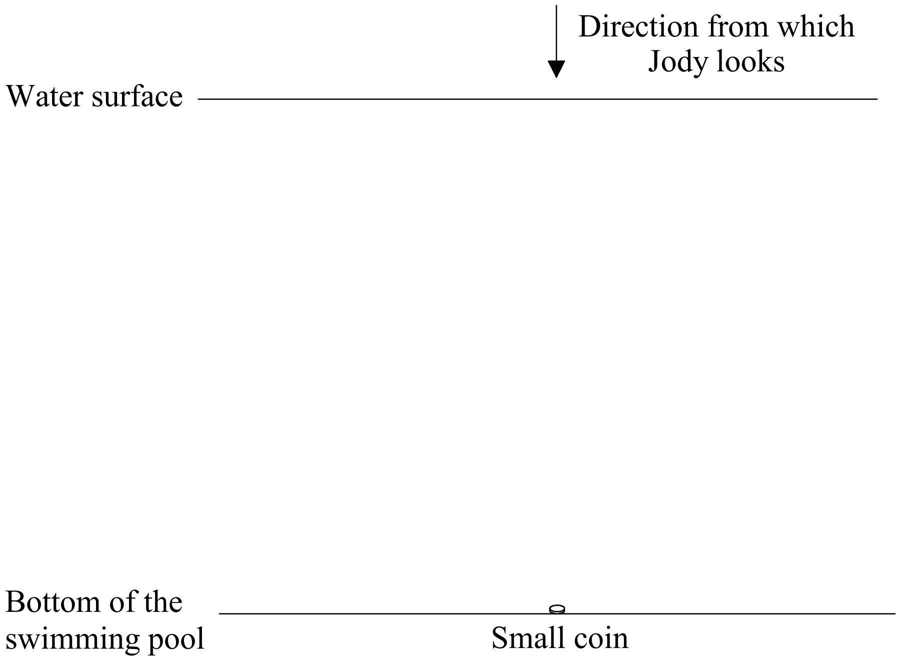
H2. This question is about real and apparent depth.

Jody looks straight down on to the surface of the water in a swimming pool. A small coin is lying on the bottom of the swimming pool. The situation is represented in the diagram below.



(a) On the diagram above, draw appropriate rays to show the position of the image of the coin as seen by Jody. *[2]*

(b) Explain whether the image that Jody observes is real **or** virtual. *[1]*

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The real depth d and the apparent depth a are related by the expression $\frac{d}{a} = n$ where n is the refractive index of the water.

The refractive index of the water in the swimming pool is 1.3 and the coin is at a depth of 3.0 m.

(c) Determine the position of the image, relative to the bottom of the pool, as observed by Jody. *[3]*

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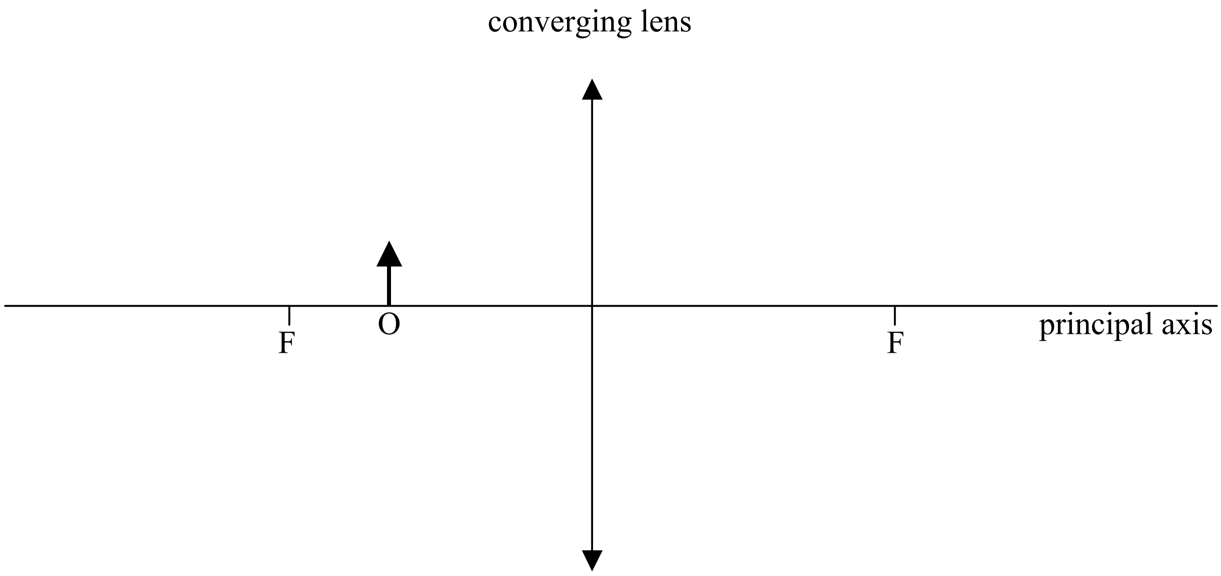
H3. This question is about the simple magnifying glass.

An object O is placed in front of a converging lens in the position shown in the diagram below. The principal foci of the lens are marked F.



(a) On the diagram,

(i) construct rays to locate the position of the image. *[1]*

(ii) draw in the image and label it I. *[1]*

(iii) show on the diagram where the eye must be placed in order to view this image. *[1]*

(This question continues on the following page)

(Question H3 continued)

For a particular lens, the focal length is 10.0 cm and the distance of O from the lens is such that the image is formed at the *near point* of the eye. The distance of the lens from the eye is 3.0 cm.

(b) (i) Explain what is meant by the term *near point*. *[1]*

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(ii) Calculate the distance of the object from the lens if the near point is 25.0 cm from the eye. *[4]*

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(iii) State, and explain, where the object should be placed if the image is to be formed at the *far point*. *[2]*

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