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

M05/4/PHYSI/HP3/ENG/TZ1/XX+

22056509

PHYSICS
HIGHER LEVEL
PAPER 3

Friday 20 May 2005 (morning)

1 hour 15 minutes

Candidate session number

0	0							

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 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.

0131

Option D — Biomedical Physics

D1. This question is about scaling and thermal energy loss.

An adult of height 1.80 m and a child of height 1.20 m are stranded during a hiking trip and must spend the cold night outdoors.

(a) Estimate the value of the ratio $\frac{Q_{adult}}{Q_{child}}$

where $Q = \frac{\text{total rate of thermal energy loss}}{\text{mass}}$. *[4]*

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(b) Using your answer in (a) explain whether the adult or the child is at greater risk from hypothermia (core body temperature significantly below normal). *[1]*

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D2. This question is about sound and hearing.

(a) State the approximate range of frequencies that are audible to a person with normal hearing. *[1]*

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(b) Outline the mechanism by which different frequencies are distinguished in the cochlea. *[3]*

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(c) A person with normal hearing can just hear a sound of intensity 10^{-12} W m^{-2} at a frequency of 1000 Hz.

(i) A sound wave of frequency 1000 Hz incident on the ear drum has an intensity of 2.7×10^{-5} W m^{-2}. Calculate the sound intensity level at the ear. *[2]*

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(ii) Explain why the response of the ear is measured as a change in sound intensity level rather than a change of intensity of sound. *[3]*

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D3. This question is about various diagnostic techniques.

(a) State and explain **one** situation, in each case, where the following diagnostic techniques would be used.

(i) X-rays *[1]*

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(ii) Ultrasound *[1]*

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(iii) Nuclear magnetic resonance *[1]*

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(b) Apart from health hazards, explain why different means of diagnosis are needed. *[3]*

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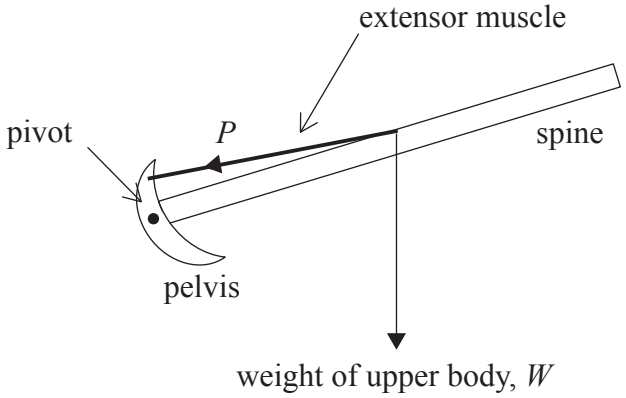
D4. This question is about various forces exerted when a person bends over.

A person bends his/her body at the hips.

A simplified diagram of the spine, pelvis and extensor muscle attached to the spine and pelvis is shown below.



The spine, considered to be a rigid rod, is pivoted at the pelvis.

The magnitude of the force exerted on the spine by the extensor muscle is P.

(a) Explain why the spine is under compression. *[2]*

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(b) On the diagram, draw an arrow to show the direction of the compression force. Label this arrow S. *[1]*

(c) Explain, with reference to the diagram, why the force P and the compression force S on the spine are much greater than the weight W of the upper body of the person. *[2]*

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D5. This question is about radioactive isotopes of iodine.

The isotope iodine-131 is used to treat malignant growths in the thyroid gland. The isotope has a physical half-life of 8 days and a biological half-life of 21 days.

(a) Explain the term *biological half-life*. *[2]*

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(b) Calculate the effective half-life of the isotope. *[2]*

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The isotope iodine-123 has a physical half-life of 13 hours.

(c) Suggest why it is preferable to use this isotope for **imaging** the thyroid rather than iodine-131. *[1]*

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Option E — The History and Development of Physics

E1. This question is about models of the universe.

(a) In the course of one night, the stars appear to move across the sky. Outline how this observed motion is explained in

(i) the Ptolemaic model. *[2]*

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(ii) the Copernican model. *[2]*

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(b) Observations show that the brightnesses of the planets Venus and Mercury vary with time.

Explain why these observations

(i) cannot be explained in the Ptolemaic model of the universe. *[2]*

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(ii) can be explained in the Copernican model. *[2]*

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E2. This question is about force and motion.

(a) Two bodies are moving on a straight horizontal line with constant speed. Body A has double the speed of body B.

State and explain the net force on each body according to Aristotle and Galileo.

(i) Aristotle *[2]*

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(ii) Galileo *[2]*

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(b) A stone and a feather are dropped from rest from the same height. State why on the basis of Aristotle's theory the stone reaches the ground before the feather. *[2]*

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E3. This question is about theories of heat.

(a) State what is meant by *phlogiston*. *[1]*

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(b) State and explain **one** experimental piece of evidence that convinced Lavoisier that the phlogiston did not exist. *[2]*

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(c) State and explain how Rumford reached the conclusion that heat is not a fluid. *[3]*

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E4. This question is about the Bohr model of the hydrogen atom and the extension of the model to include singly ionised helium.

In his theory of the hydrogen atom, Bohr refers to *stable electron orbits*.

(a) State the Bohr postulate that determines which stable orbits are allowed. *[1]*

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(b) Describe how the existence of such orbits accounts for the emission line spectrum of atomic hydrogen. *[3]*

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The Bohr model of the hydrogen atom can be extended to singly ionised helium atoms. The model leads to the following expression for the energy E_n of the electron in an orbit specified by the integer n.

$$E_n = -\frac{k}{n^2}$$

where k is a constant.

In the spectrum of singly ionised helium, the line corresponding to a wavelength of 362 nm rises from electron transitions between the orbit $n = 3$ to the orbit $n = 2$.

(c) Deduce the value of the ionisation energy of singly ionised helium atoms. *[4]*

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(Question E4 continued)

(d) Outline how the Schrödinger model of the **hydrogen atom** leads to the idea of discrete electron energy levels. *[2]*

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Option F — Astrophysics

F1. This question is about eclipsing binary stars.

(a) In a particular binary star system, star A has apparent brightness 8.0×10^{-13} W m^{-2} and star B has apparent brightness 2.0×10^{-14} W m^{-2}.

(i) Explain how it is possible to deduce that star A has a higher luminosity than star B. *[2]*

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(ii) The surface area of star B is 10 000 times smaller than that of star A. Calculate the ratio

$$\frac{\text{surface temperature of star B}}{\text{surface temperature of star A}}.$$ *[4]*

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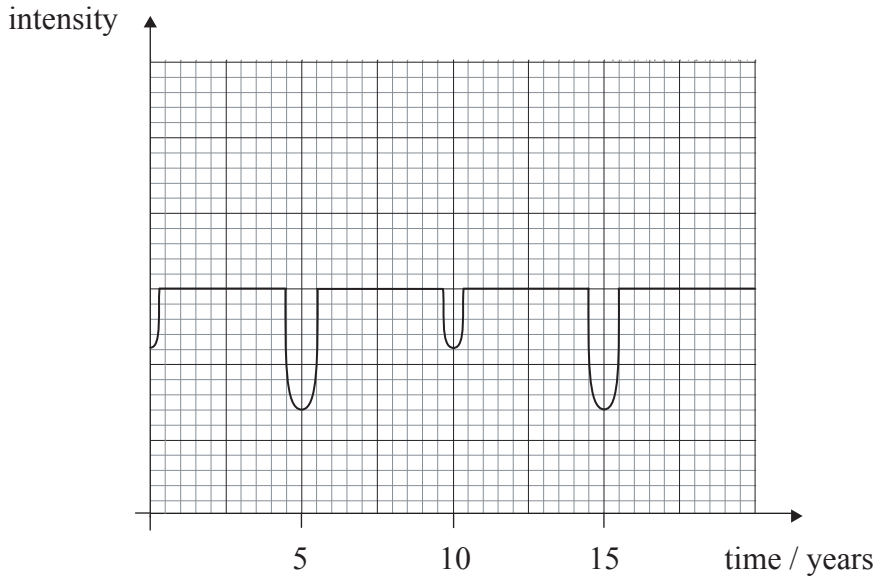
(Question F1 continued)

(b) The graph below shows the variation with time of the intensity of light received on Earth from the two stars.



(i) The diagrams below each show the orbits of the two stars. Star A is in the inner orbit. Annotate the diagrams to show the relative positions of stars A and B as seen from Earth, that correspond to the intensity-time graph opposite at times of 5 and 10 years. *[2]*

Diagram at 5 years

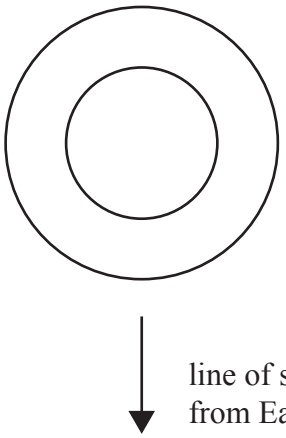
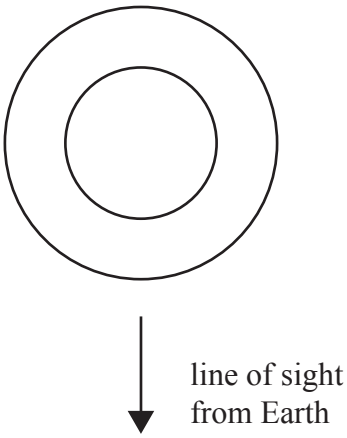


Diagram at 10 years



(ii) State the period of this binary star system. *[1]*

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(iii) State what can be deduced from knowing the period of the binary and the separation of the stars. *[1]*

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F2. This question is about cosmology.

(a) State what is meant by *critical density*. *[1]*

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(b) Recent measurements suggest that the mass density of the universe is likely to be less than the critical density. State what this observation implies for the evolution of the universe in the context of the Big Bang model. *[1]*

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(c) (i) Outline what is meant by *dark matter*. *[2]*

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(ii) Give **two** possible examples of dark matter.

1. . . . . *[1]*

2. . . . . *[1]*

F3. This question is about cosmic background radiation.

(a) Describe what is meant by *cosmic background radiation*. *[2]*

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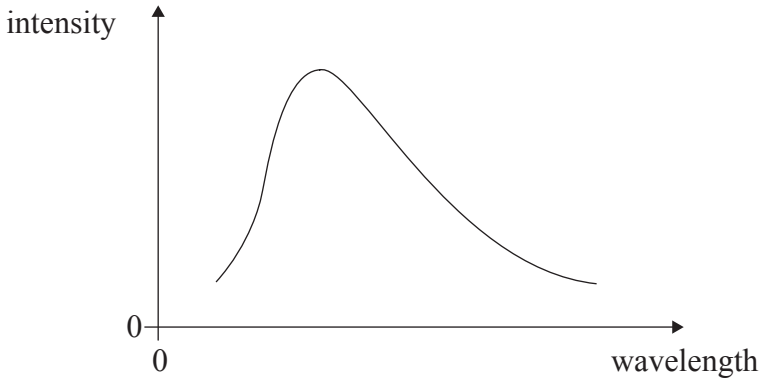
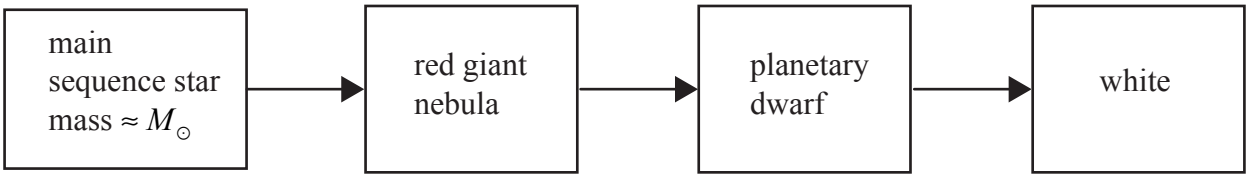
(b) The graph below shows the spectrum of the cosmic background radiation *i.e.* the variation, with wavelength, of the intensity of the cosmic background radiation.



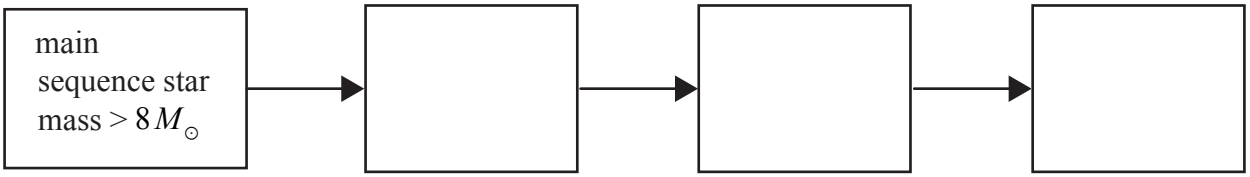
There is evidence to suggest that the universe will expand forever. On the diagram above, sketch a graph to show the spectrum of the background radiation for the universe many millions of years from now. *[2]*

F4. This question is about the evolution of stars.

The diagram below is a flow chart that shows the stages of evolution of a main sequence star such as the Sun. (Mass of the Sun, the solar mass = $M_\odot$)



(a) Complete the boxes below to show the stages of evolution of a main sequence star that has a mass greater than $8\,M_\odot$. *[3]*



(b) Outline why

(i) white dwarf stars cannot have a greater mass than $1.4\,M_\odot$. *[2]*

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(ii) it is possible for a main sequence star with a mass equal to $8\,M_\odot$ to evolve to a white dwarf. *[1]*

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F5. This question is about Hubble's law.

The light received from many distant galaxies is red-shifted.

(a) State the cause of this red-shift. *[1]*

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

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(c) Deduce the relationship between the age of the universe T and the Hubble constant H. State any assumptions you have made. *[2]*

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Option G — Relativity

G1. This question is about the postulates of special relativity.

(a) State the **two** postulates of the special theory of relativity. *[2]*

Postulate 1

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Postulate 2

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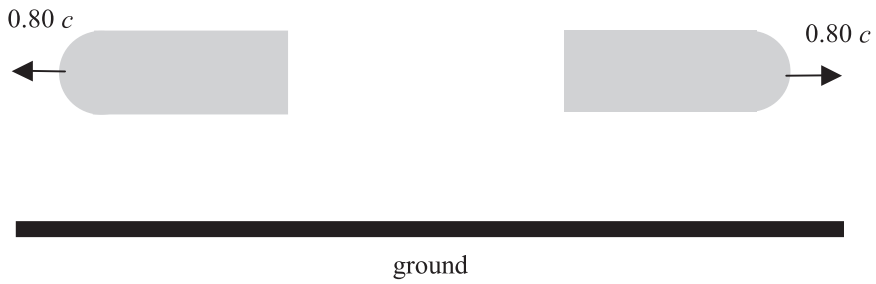
(b) Two identical spacecraft are moving in opposite directions each with a speed of 0.80 *c* as measured by an observer at rest relative to the ground. The observer on the ground measures the **separation** of the spacecraft as increasing at a rate of 1.60 *c*.



(i) Explain how this observation is consistent with the theory of special relativity. *[1]*

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(ii) Calculate the speed of one spacecraft relative to an observer in the other. *[3]*

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G2. This question is about relativistic kinematics.

(a) Muons are unstable particles that have an average lifetime of 2.2×10^{-6} s as measured in a reference frame in which they are at rest. Muons that are created at a height of 3.0 km above the Earth's surface move vertically downward with a speed of $0.98\,c$ as measured by an observer at rest on the Earth's surface.

(i) Calculate the average lifetime of a muon as measured by the observer on Earth. *[2]*

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(ii) Calculate the distance travelled by a muon during a time equal to the average lifetime of the muon according to the observer at rest relative to the Earth's surface. *[2]*

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(iii) Calculate the distance travelled by the Earth during a time equal to the average lifetime of the muon according to an observer at rest relative to the muon. *[2]*

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(This question continues on the following page)

(Question G2 continued)

(iv) Muons created at a height of 3.0 km above the Earth's surface are in fact detected on the surface of the Earth. Use your answers to (ii) and (iii) together with any other relevant calculations to explain this observation according to

1. the observer at rest on the surface of the Earth. *[2]*

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2. the observer at rest relative to the muon. *[3]*

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(b) The rest mass of the muon is 106 MeVc^{-2}. Calculate the potential difference through which a muon at rest in the lab must be accelerated in order to have a speed of 0.98 c. (The electric charge of the muon is identical to that of the electron.) *[3]*

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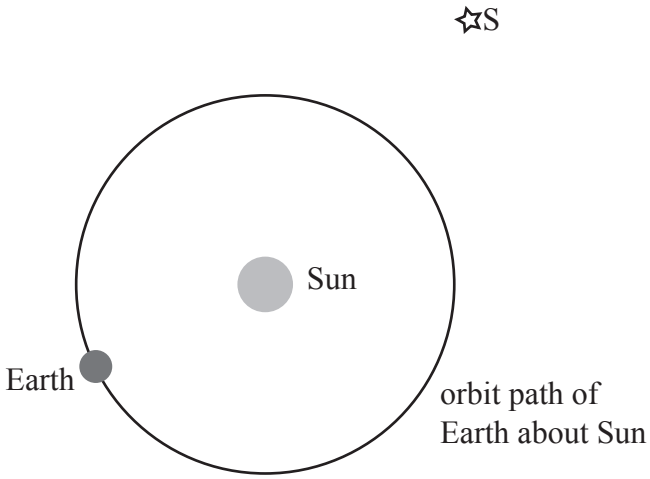
G3. This question is about General Relativity and experimental evidence to support it.

On 29 March 1919, an experiment was carried out by Eddington to provide evidence to support Einstein's General Theory of Relativity. The diagram below (not to scale) shows the relative position of the Sun, Earth and a star S on this date.



This particular date was chosen because at the place where the experiment was carried out, there was a total eclipse of the Sun.

Eddington measured the apparent position of the star and six months later, he again measured the position of the star from Earth.

(a) State why it was necessary for there to be a total solar eclipse to carry out the experiment. *[1]*

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(b) Explain why it was necessary to measure the position of the star six months later. *[1]*

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(c) On the diagram, draw the path of a ray of light from S to the Earth as suggested by Einstein's theory. *[1]*

(This question continues on the following page)

(Question G3 continued)

(d) Explain how Einstein's theory accounts for the path of the ray that you have drawn. *[2]*

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(e) On the diagram, label with the letter A, the apparent position of the star as seen from Earth. *[1]*

G4. This question is about relativistic mechanics.

A proton is accelerated from rest through a potential difference. After acceleration the proton has a mass equal to twice its rest mass, m_p.

(a) State an expression in terms of m_p, for the total energy E of the proton after acceleration. *[1]*

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(b) Determine the momentum of the proton after acceleration given that the rest mass $m_p = 930\,\text{MeVc}^{-2}$. *[3]*

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Option H — Optics

H1. This question is about light and the electromagnetic spectrum.

(a) Outline the electromagnetic nature of light. *[2]*

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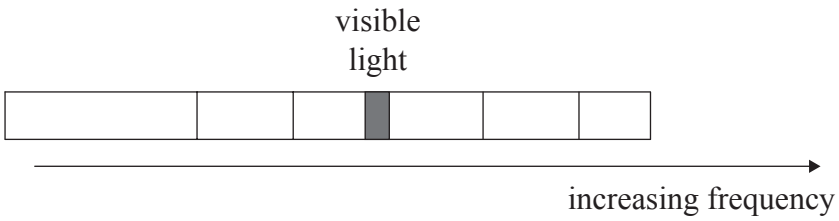
(b) The diagram below is a representation of the electromagnetic spectrum.



In the diagram the region of visible light has been indicated.

Indicate on the diagram above the approximate position occupied by

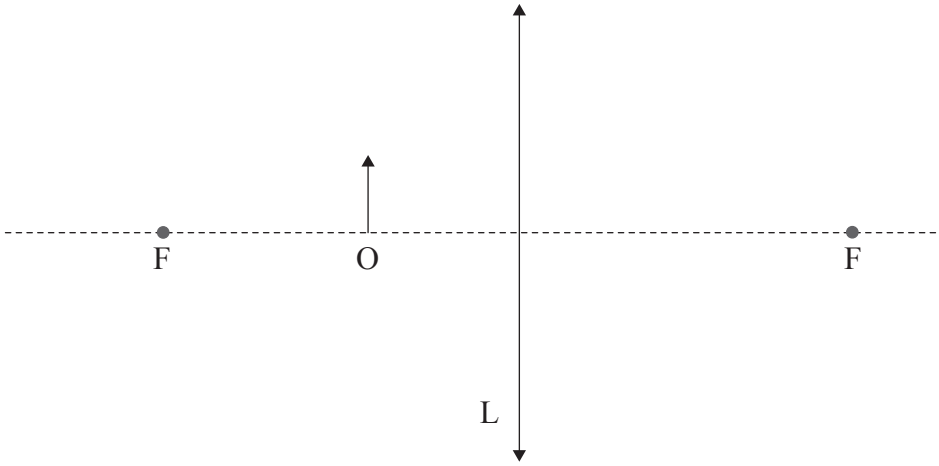
(i) infrared waves (label this I). *[1]*

(ii) microwaves (label this M). *[1]*

(iii) gamma rays (label this G). *[1]*

H2. This question is about converging lenses.

(a) The diagram shows a small object O represented by an arrow placed in front of a *converging* lens L. The focal points of the lens are labelled F.



(i) Define the *focal point* of a converging lens. *[2]*

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(ii) On the diagram above, draw rays to locate the position of the image of the object formed by the lens. *[3]*

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

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(This question continues on the following page)

(Question H2 continued)

(b) A convex lens of focal length 6.25 cm is used to view an ant of length 0.80 cm that is crawling on a table. The lens is held 5.0 cm above the table.

(i) Calculate the distance of the image from the lens. *[2]*

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

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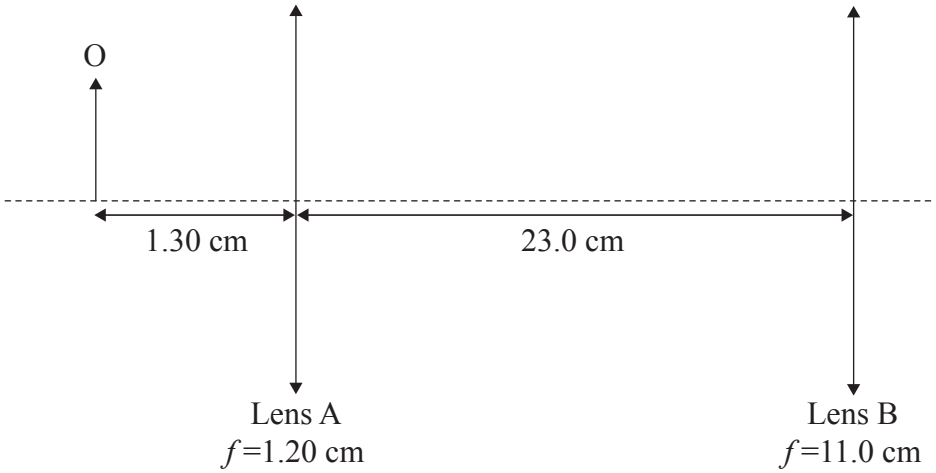
H3. This question is about a compound microscope.

A compound microscope consists of two convex lenses of focal lengths 1.20 cm (lens A) and 11.0 cm (lens B). The lenses are separated by a distance of 23.0 cm as shown below. (The diagram is not drawn to scale.)



An object O is placed 1.30 cm from lens A. An image of O in lens A is formed a distance of 15.6 cm from A.

(a) This image forms an object for lens B. Calculate the object distance for lens B. *[1]*

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(b) Calculate the distance from lens B of the image as produced by the lens B. *[2]*

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(c) Calculate the magnification of the microscope. *[2]*

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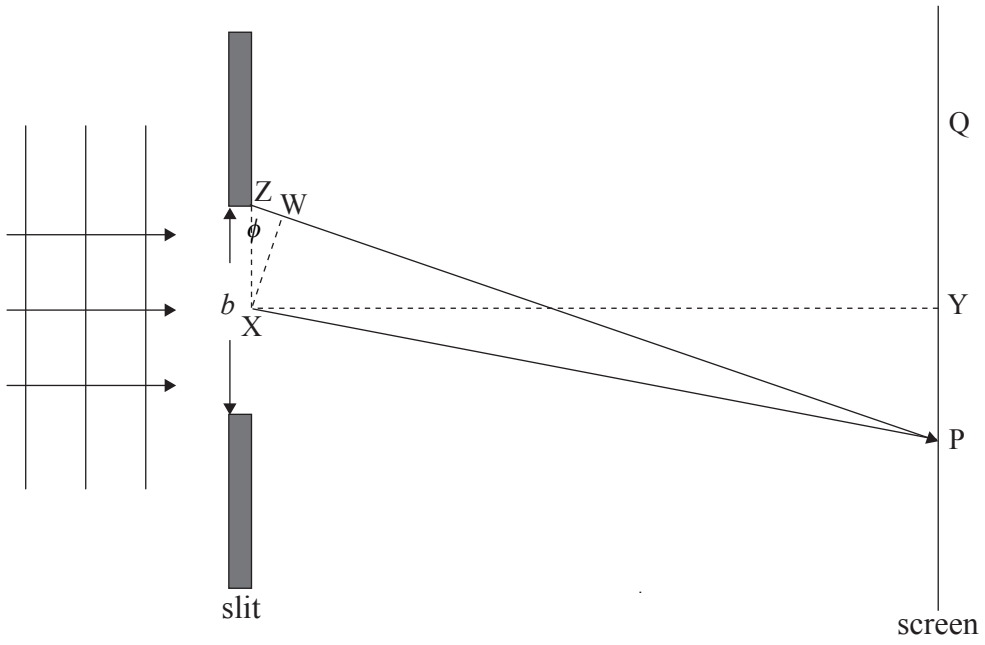
H4. This question is about diffraction at a single slit.

Plane wavefronts of monochromatic light are incident on a narrow, rectangular slit whose width b is comparable to the wavelength λ of the light. After passing through the slit, the light is brought to a focus on a screen.



The line XY, normal to the plane of the slit, is drawn from the centre of the slit to the screen and the points P and Q are the first points of minimum intensity as measured from point Y.

The diagram also shows two rays of light incident on the screen at point P. Ray ZP leaves one edge of the slit and ray XP leaves the centre of the slit.

The angle ϕ is small.

(a) On the diagram, label the half angular width θ of the central maximum of the diffraction pattern. *[1]*

(b) State and explain an expression, in terms of λ for the path difference ZW between the rays ZP and XP. *[2]*

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(This question continues on the following page)

(Question H4 continued)

(c) Hence deduce that the half angular width θ is given by the expression

$$\theta = \frac{\lambda}{b}.$$ *[3]*

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(d) In a particular demonstration of single slit diffraction, λ = 450 nm, b = 0.15 mm and the screen is a long way from the slits.

Calculate the angular width of the central maximum of the diffraction pattern on the screen. *[2]*

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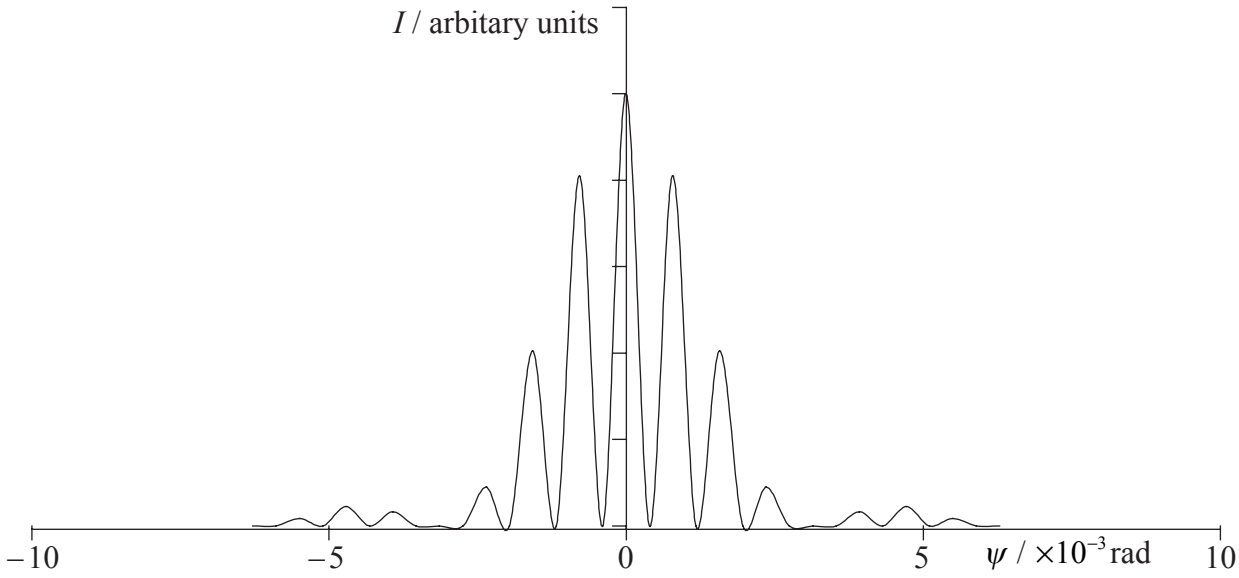
(This question continues on the following page)

(Question H4 continued)

Using light of the same wavelength as above (450 nm), an arrangement is set up to demonstrate diffraction by a double slit. Each slit has the same width as that above (0.15 mm) and the slit separation is d. The graph below shows the variation with the angle of diffraction ψ of the intensity I of the diffraction pattern on the screen.



From the graph it can be seen that a maximum is missing at the angle $\psi = 3.0 \times 10^{-3}$ rad.

(e) Calculate the slit separation d. *[2]*

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