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

M05/4/PHYSI/HP3/ENG/TZ2/XX+

22056515

PHYSICS
HIGHER LEVEL
PAPER 3

Friday 20 May 2005 (morning)

1 hour 15 minutes

Candidate session number

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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.

Option D — Biomedical Physics

D1. This question is about scaling.

Two balls A and B are made of the same material. Ball A has mass M_A and radius R_A. Ball B has mass M_B and radius R_B.

(a) Write down an expression for the ratio $\frac{M_A}{M_B}$ in terms of the radii of the balls, R_A and R_B. *[1]*

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The balls are now heated until the surface temperature of each ball is the same. The thermal power loss from ball A is Q_A and that from ball B is Q_B.

(b) State an expression for the ratio $\frac{Q_A}{Q_B}$ in terms of R_A and R_B. *[1]*

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The power loss per unit mass from ball A is P_A and that from ball B is P_B.

(c) Use your answers in (a) and (b) to determine an expression for the ratio $\frac{P_A}{P_B}$ in terms of R_A and R_B. *[3]*

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(d) Use your answer to (c) to suggest why babies are more at risk than adults of death from exposure in cold weather. *[1]*

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D2. This question is about hearing loss and audiograms.

(a) Distinguish between conductive and sensory hearing loss. *[2]*

Conductive: . . . .

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Sensory: . . . .

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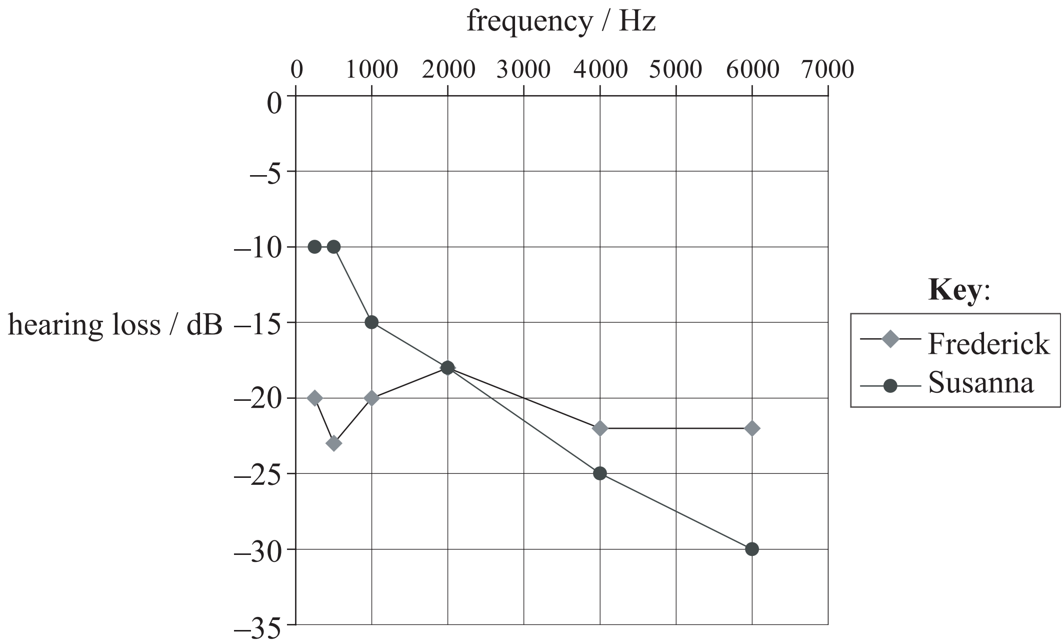
The diagram below shows the audiograms for two people, Frederick and Susanna, both of whom are suffering from hearing loss. The hearing loss is measured in decibels, a unit that measures sound intensity level.



(b) Outline how sound intensity level is related to sound intensity. *[2]*

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(This question continues on the following page)

(Question D2 continued)

(c) Suggest the type of hearing loss from which each person could be suffering and state a possible cause of the hearing loss. *[4]*

Frederick: . . . .

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Susanna: . . . .

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D3. This question is about X-rays.

(a) State what is meant by X-ray quality. *[1]*

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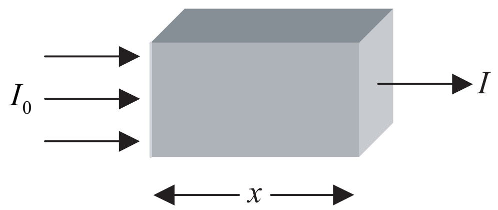
A parallel beam of X-rays of intensity I_0 is incident on a material of thickness x as shown below. The intensity of the emergent beam is I.



(b) Define *half-value thickness*. *[1]*

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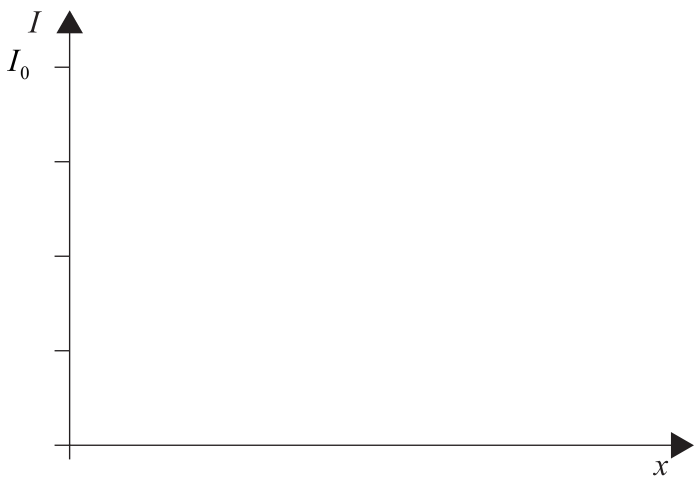
(c) Using the axes below, draw a sketch-graph to show the variation with x of the intensity I. *[2]*



(d) Annotate your sketch-graph to show the half-value thickness $x_{\frac{1}{2}}$. *[1]*

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(e) State the name of **one** of the mechanisms responsible for the attenuation of X-rays in matter. *[1]*

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D4. This question is about maintaining body temperature.

A person is sunbathing in a hot climate.

(a) Complete the table below to show the percentage of energy lost per second from the body due to the various mechanisms available. *[2]*

Mechanism	**% loss**
Conduction and convection	10
Radiation	8
	80
	2

In order to maintain a constant body temperature, a person sunbathing needs to lose about 320 J of thermal energy to the surroundings every second through sweating.

(b) Estimate the amount of sweat evaporated from the skin of the sunbather every hour. (The specific latent heat of sweat is about 2 400 kJ kg^{-1}.) *[2]*

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D5. This question is about dosimetry.

(a) Describe what is meant by the term *relative biological effectiveness* (quality factor). *[2]*

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The whole body of a person of mass 70 kg is exposed to monochromatic X-rays of energy 200 keV. As a result of this exposure, the person receives a dose equivalent of 500 μSv in 2.0 minutes.

(b) Deduce that the person absorbs about 10^{10} X-ray photons per second. *[4]*

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Option E — The History and Development of Physics

E1. This question is about models of the universe.

Here are two observations concerning the stars and the Moon.

I. The stars move across the night sky but the overall pattern of the stars does not change.

II. The Moon moves across the night sky but its position relative to the fixed pattern of the stars continually changes.

(a) Explain how the Ptolemaic model of the universe accounts for these observations. *[4]*

Observation I: . . . .

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Observation II: . . . .

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(b) State the essential difference between the Copernican model and the Ptolemaic model of the universe. *[1]*

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E2. This question is about concepts of motion and force.

A block of stone is dragged along the ground at constant speed.

(a) State how Aristotle proposed that the force dragging the block was related to the speed of the block. *[1]*

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(b) State Galileo's theory that relates a single force acting on an object to the speed of the object. *[1]*

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(c) Describe how Galileo's theory explained the motion of the block of stone dragged at constant speed along the ground. *[2]*

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(d) Compare the methods by which Aristotle and Galileo reached their conclusions. *[2]*

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E3. This question is about the atom and the nucleus.

When cathode rays were first discovered and investigated, some physicists including Hertz, thought that they were waves. However, other physicists including J J Thompson thought that they consisted of particles.

(a) Outline the evidence upon which Hertz and Thompson based their conclusions. *[2]*

Hertz: . . . .

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Thompson: . . . .

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(b) By reference to electrons, compare the principal difference between Thompson's model and Rutherford's model of the atom. *[2]*

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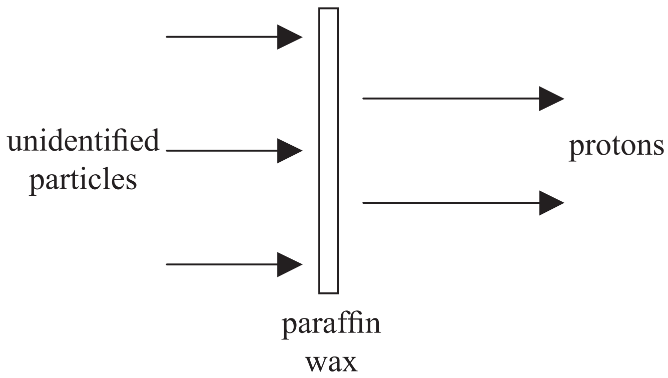
(This question continues on the following page)

(Question E3 continued)

In 1932 Chadwick carried out an experiment in which he discovered the neutron by measuring the mass of an unidentified particle.

In the experiment, the particles were produced by bombarding beryllium with α-particles. In order to determine the mass of the particles, Chadwick collided them with the atoms of two different elements. He then measured the speeds of these atoms as a result of these collisions.

He first directed the particles at a slab of paraffin wax so that they collided with the hydrogen atoms in the paraffin wax producing a beam of protons.



(c) (i) Describe how Chadwick measured the speed of the protons. *[2]*

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Chadwick now arranged for the particles to enter a nitrogen bubble chamber such that they collided with nitrogen atoms.

(ii) State how Chadwick measured the speeds of the nitrogen atoms after the unidentified particles had collided with them. *[1]*

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(This question continues on the following page)

(Question E3 continued)

Knowing the speeds of the protons and the nitrogen atoms and also their masses, Chadwick was able to apply two laws of physics in order to determine the mass of the unidentified particles.

(iii) Identify the **two** laws applied by Chadwick. *[2]*

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E4. This question is about models of the hydrogen atom.

In 1913 Neils Bohr developed a model of the hydrogen atom which successfully explained many aspects of the spectrum of atomic hydrogen.

(a) State **one** aspect of the spectrum of atomic hydrogen that Bohr's model did not explain. *[1]*

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Bohr proposed that the electron could have only certain stable orbits. These orbits are specified by the relation

$$mvr = \frac{nh}{2\pi} \text{ with } n = 1, 2, 3..........$$

where m is the mass of the electron, v its speed, r the radius of the orbit and h the Planck constant. This is sometimes known as Bohr's first postulate.

(b) State the other postulate proposed by Bohr. *[2]*

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(This question continues on the following page)

(Question E4 continued)

By using Newton's second law and the Coulomb law in combination with the first postulate, it can be shown that

$$r = \frac{n^2 h^2}{4\pi^2 mke^2}$$

where $k = \dfrac{1}{4\pi\varepsilon_0}$.

It can also be shown that the total energy E_n of the electron in a stable orbit is given by

$$E_n = -\frac{ke^2}{2r}.$$

(c) Using these two expressions, deduce that the total energy E_n may be given as

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

where K is a constant. *[3]*

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(d) State and explain what physical quantity is represented by the constant K. *[2]*

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(e) Outline how the Schrödinger model of the hydrogen atom leads to the concept of energy levels. *[2]*

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Option F — Astrophysics

F1. The question is about stellar radiation and the star Betelgeuse.

(a) Explain the term *black-body radiation*. *[1]*

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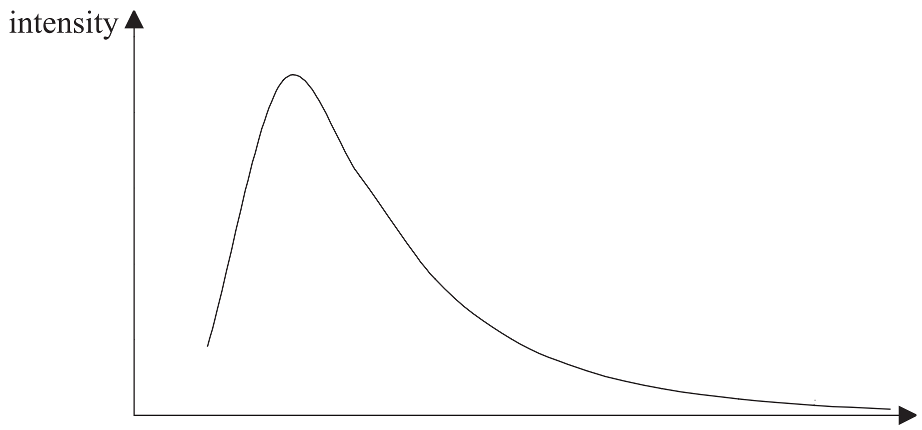
The diagram below is a sketch graph of the black-body radiation spectrum of a certain star.



(b) Label the x-axis of the graph. *[1]*

(c) On the graph, sketch the black-body radiation spectrum of a star that has a lower surface temperature and lower apparent brightness than this star. *[2]*

The star Betelgeuse in the Orion constellation emits black-body radiation that has a maximum intensity at a wavelength of 0.97 μm.

(d) Deduce that the surface temperature of Betelgeuse is about 3000 K. *[1]*

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(This question continues on the following page)

(Question F1 continued)

The apparent brightness of Betelgeuse is 2.10×10^{-8} W m^{-2} and its luminosity is 4.10×10^{4} times that of the Sun. The apparent brightness of the Sun is 1.37×10^{3} W m^{-2}.

(e) Describe what is meant by

(i) *luminosity*. *[1]*

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(ii) *apparent brightness*. *[2]*

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(iii) Determine, using the above data, the distance in AU of the star Betelgeuse from the Earth. *[4]*

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F2. This question is about Olbers' paradox.

Newton made three assumptions about the nature of the universe. One of these assumptions is that the universe is static.

(a) State the other **two** assumptions. *[2]*

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(b) Explain, using a quantitative argument, how these assumptions led to Olbers' paradox. *[4]*

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(c) Describe **one** piece of evidence that suggests that the universe is not static. *[2]*

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(Option F continues on page 18)

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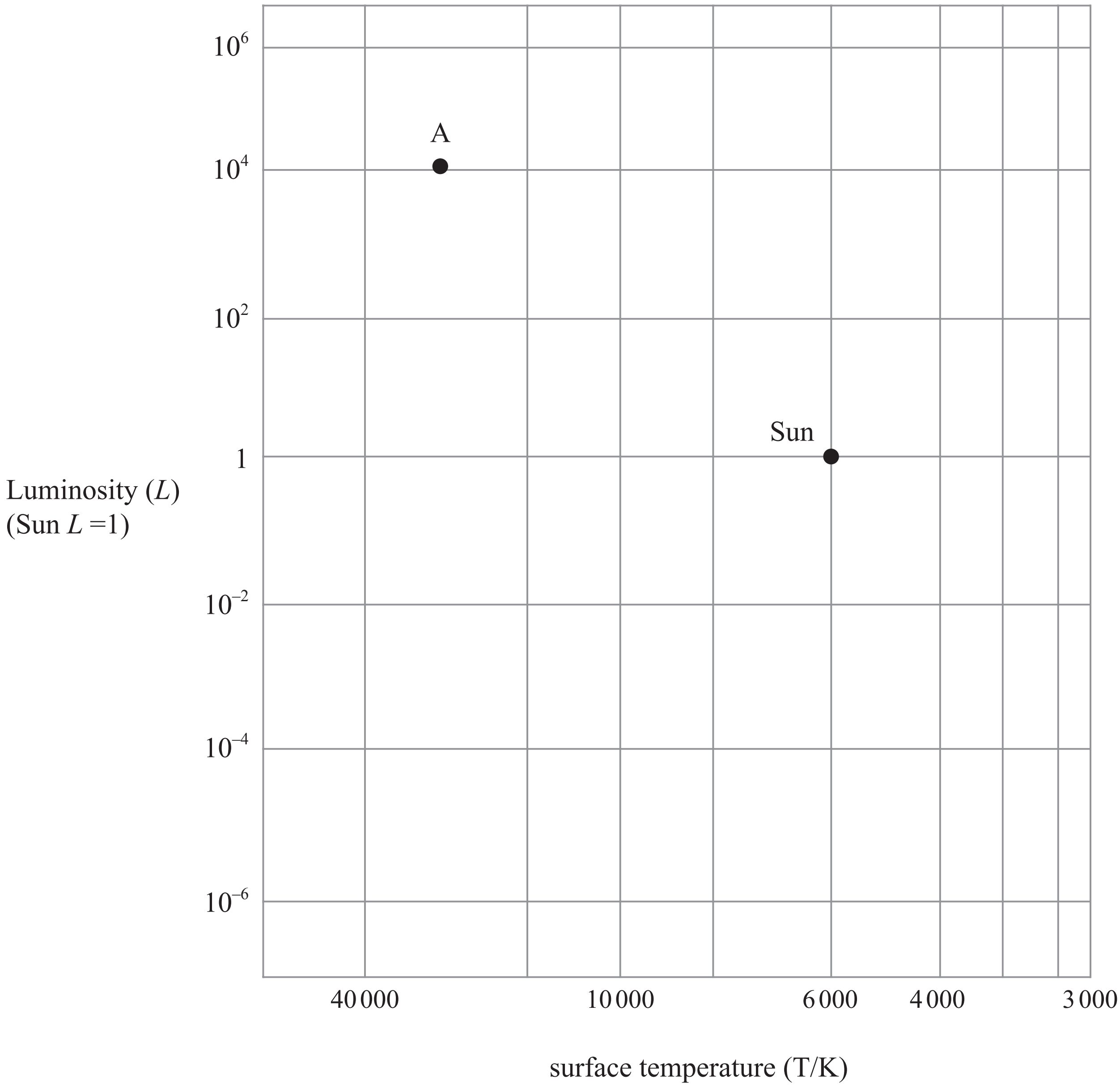
(Option F continued)

F3. This question is about the evolution of stars.

The diagram below shows a grid on which a Hertzsprung-Russell diagram could be drawn. The present positions of the Sun and another Main Sequence star A are shown.



The mass of star A is about 15 times the mass of the Sun.

(a) On the diagram above, draw the evolutionary path of the Sun and the evolutionary path of star A as both stars leave the Main Sequence. *[4]*

(This question continues on the following page)

(Question F3 continued)

(b) When stars with masses of about eight times that of the Sun leave the Main Sequence, they may end up in the same region of the Hertzsprung-Russell diagram as the Sun when it leaves the Main Sequence. Explain, with reference to the Chandrasekhar limit, why this is so. *[4]*

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(c) State **two** main changes that take place in nucleosynthesis when a star of about eight times the solar mass leaves the Main Sequence. *[2]*

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Option G — Relativity

G1. This question is about frames of reference.

(a) Explain what is meant by a *reference frame*. *[2]*

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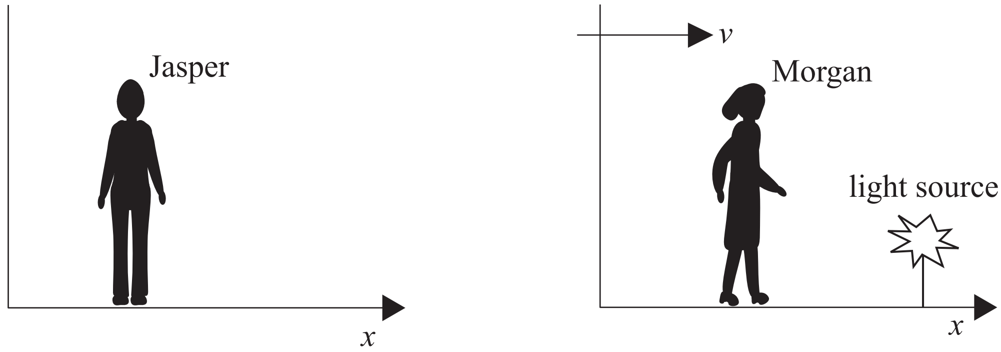
In the diagram below, Jasper regards his reference frame to be at rest and Morgan's reference frame to be moving away from him with constant speed v in the x-direction.



Morgan carries out an experiment to measure the speed of light from a source which is at rest in her reference frame. The value of the speed that she obtains is c.

(b) Applying a Galilean transformation to the situation, state the value that Jasper would be expected to obtain for the speed of light from the source. *[1]*

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(c) State the value that Jasper would be expected to obtain for the speed of light from the source based on Maxwell's theory of electromagnetic radiation. *[1]*

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(This question continues on the following page)

(Question G1 continued)

(d) Deduce, using the relativistic equation for the addition of velocities, that Jasper will in fact obtain a value for the velocity of light from the source consistent with that predicted by the Maxwell theory. *[3]*

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In Morgan's experiment to measure the speed of light she uses a spark as the light source. According to her, the spark lasts for a time interval of 1.5 μs. In this particular situation, the time duration of the spark as measured by Morgan is known in the Special Theory of Relativity as the proper time.

(e) (i) Explain what is meant by *proper time*. *[1]*

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(ii) According to Jasper, the spark lasts for a time interval of 3.0 μs. Calculate the relative velocity between Jasper and Morgan. *[3]*

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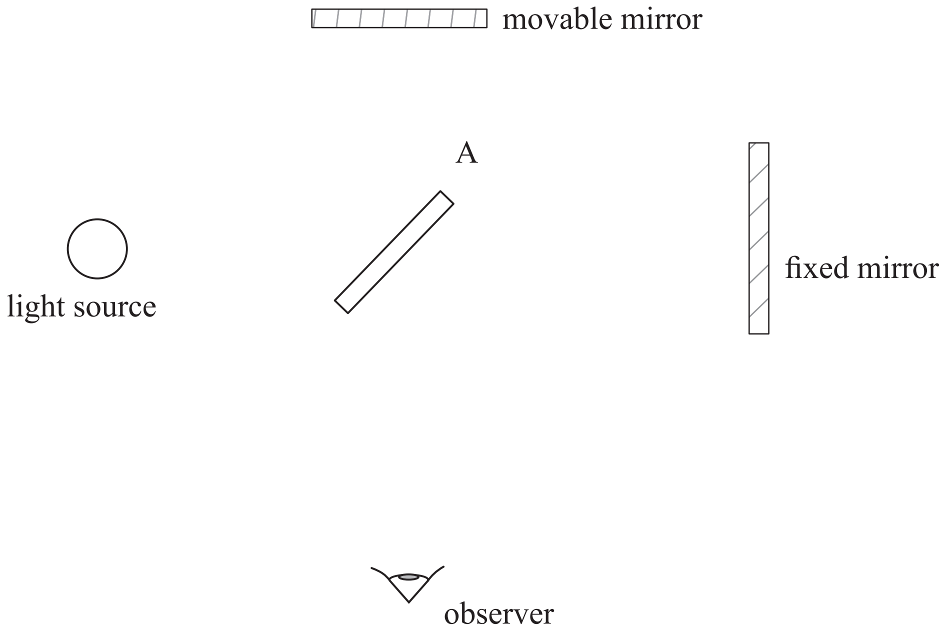
G2. This question is about the Michelson-Morley experiment.

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



A is a half-silvered mirror.

(a) State the purpose of the experiment. *[1]*

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(b) On the diagram above, draw rays to show the paths of the light from the source that produce the interference pattern seen by the observer. *[3]*

(c) For part of the experiment, the whole apparatus was rotated though 90°. Explain why. *[2]*

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(This question continues on the following page)

(Question G2 continued)

(d) Explain the function of the moveable mirror. *[1]*

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(e) Describe the results of the experiment and explain how the result supports the Special Theory of Relativity. *[2]*

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G3. This question is about relativistic dynamics.

(a) A charged particle of rest mass m_0 and carrying charge e, is accelerated from rest through a potential difference V. Deduce that

$$\gamma = 1 + \frac{Ve}{m_0 c^2}$$

where $\gamma = \frac{1}{\sqrt{1 - \frac{v^2}{c^2}}}$ and c is the free space speed of light. *[3]*

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(b) Calculate the speed, in terms of c, attained by a proton accelerated from rest through a potential difference of 500 MV. (Rest mass of a proton $= 938\,\text{MeVc}^{-2}$.) *[2]*

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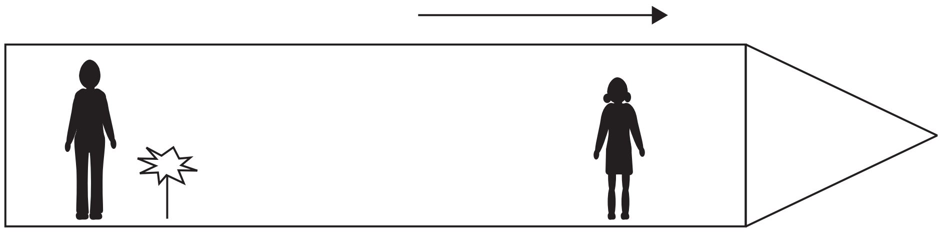
G4. This question is about gravitational redshift.

Alex and Elspeth are in a spaceship that is moving with constant speed in the direction shown. Close to Alex is a light source fixed to the floor of the spaceship. Both Alex and Elspeth measure the same value for the frequency of the light emitted by the source.



The spaceship now starts to accelerate.

(a) Explain why, to Elspeth, the light from the source close to Alex will now be observed to emit light of a lower frequency. *[3]*

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(b) Outline how the situation described in (a) leads to the idea of gravitational redshift. *[2]*

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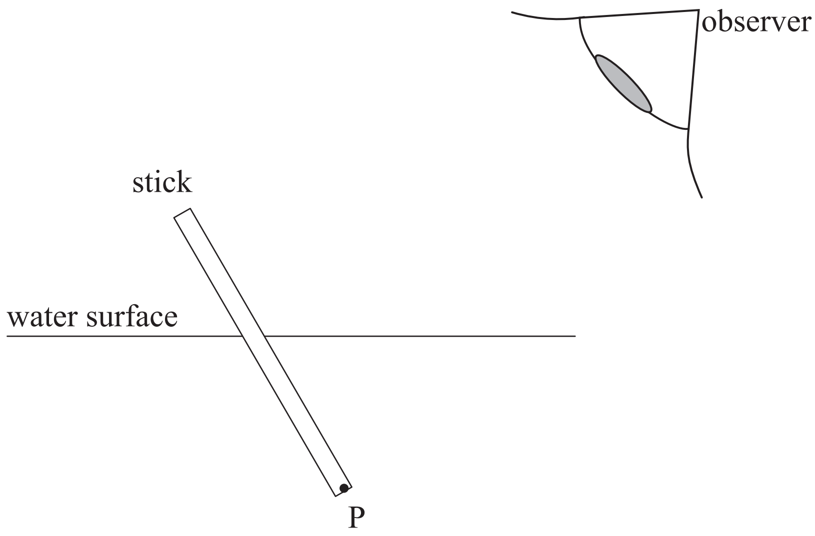
Option H — Optics

H1. This question is about refraction and critical angle.

The diagram below shows a stick that is partially immersed in water.

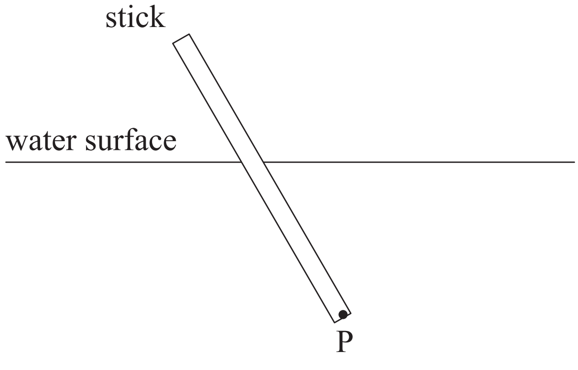


(a) On the diagram above,

(i) draw rays to locate the position of the image of the end P of the stick. *[2]*

(ii) draw the apparent shape of the stick as seen by the observer. *[1]*

(b) On the diagram below, draw the path of a ray of light that comes from end P of the stick and is incident on the water surface at the critical angle. On your diagram, label with a letter C, the critical angle for this ray of light. *[2]*



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(Question H1 continued)

(c) A fish is swimming at a depth of 2.0 m below the water surface. Determine the radius of the circular field of view that the fish has of the "world" above the water surface. (Refractive index of water = 1.3) *[4]*

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H2. This question is about an astronomical telescope.

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

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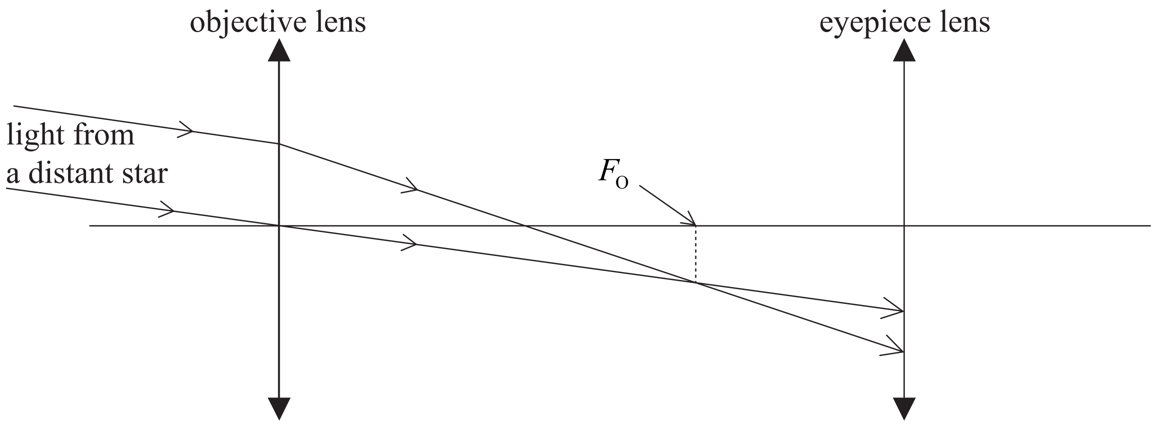
The diagram below shows two rays of light from a distant star incident on the objective lens of an astronomical telescope. The paths of the rays are also shown after they pass through the objective lens and are incident on the eyepiece lens of the telescope.



The principal focus of the objective lens is F_O .

(b) On the diagram above, mark

(i) the position of principal focus of the eyepiece lens (label this F_E). *[1]*

(ii) the position of the image of the star formed by the objective lens (label this I). *[1]*

(c) State where the final image is formed when the telescope is in normal adjustment. *[1]*

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(d) Complete the diagram above to show the direction in which the final image of the star is formed for the telescope in normal adjustment. *[2]*

(This question continues on the following page)

(Question H2 continued)

The eye ring of an astronomical telescope is a device that is placed outside the eyepiece lens of the telescope at the position where the image of the objective lens is formed by the eyepiece lens. The diameter of the eye ring is the same as the diameter of the image of the objective lens. This ensures that all the light passing through the telescope passes through the eye ring.

(e) A particular astronomical telescope has an objective lens of focal length 98.0 cm and an eyepiece lens of focal length 2.00 cm (*i.e.* $f_0 = 98.0\,\text{cm}$, $f_e = 2.00\,\text{cm}$). Determine the position of the eye ring. *[4]*

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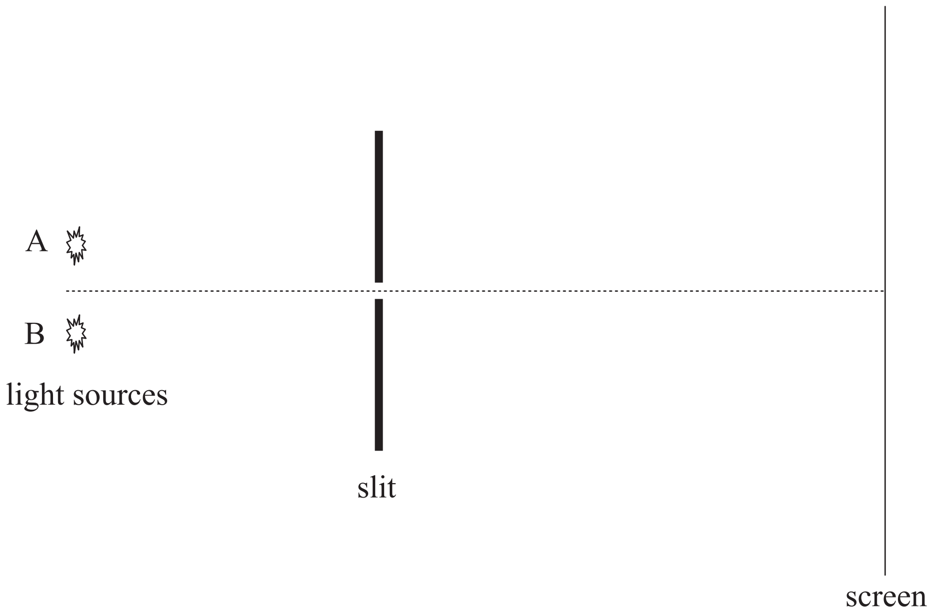
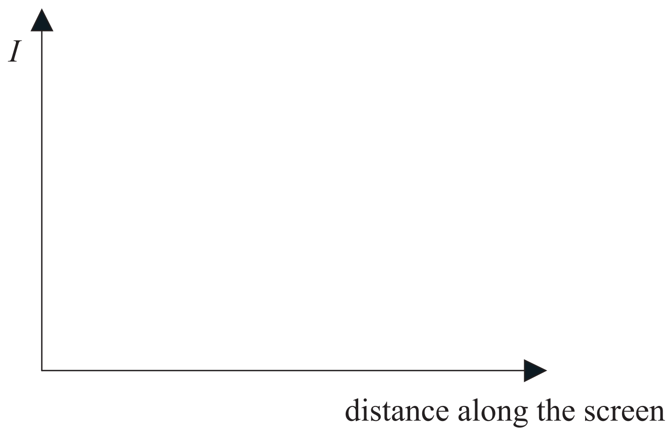
H3. This question is about optical resolution.

The two point sources shown in the diagram below (not to scale) emit light of the same frequency. The light is incident on a rectangular, narrow slit and after passing through the slit, is brought to a focus on the screen.



Source B is covered.

(a) Using the axes below, draw a sketch graph to show how the intensity *I* of the light from A varies with distance along the screen. Label the curve you have drawn A. *[2]*



Source B is now uncovered. The images of A and B on the screen are just resolved.

(b) Using the same axes as in (a), draw a sketch graph to show how the intensity *I* of the light from B varies with distance along the screen. Label this curve B. *[1]*

(This question continues on the following page)

(Question H3 continued)

The bright star Sirius A is accompanied by a much fainter star, Sirius B. The mean distance of the stars from Earth is 8.1×10^{16} m. Under ideal atmospheric conditions, a telescope with an objective lens of diameter 25 cm can just resolve the stars as two separate images.

(c) Assuming that the average wavelength emitted by the stars is 500 nm, estimate the apparent, linear separation of the two stars. *[3]*

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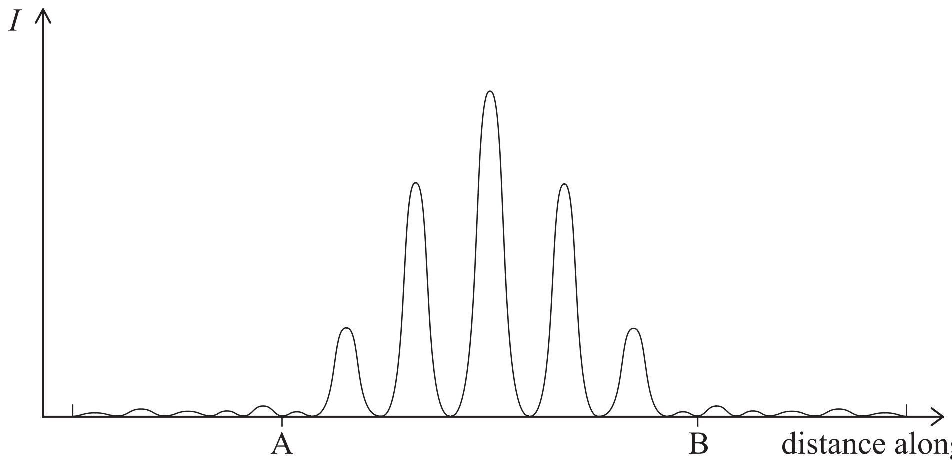
H4. Monochromatic parallel light is incident on two slits of equal width and close together. After passing through the slits, the light is brought to a focus on a screen. The diagram below shows the intensity distribution of the light on the screen.



(a) Light from the same source is incident on many slits of the same width as the widths of the slits above. Draw on the above diagram, a possible new intensity distribution of the light on the screen between the points A and B on the screen. *[2]*

A parallel beam of light of wavelength 450 nm is incident at right angles on a diffraction grating. The slit spacing of the diffraction grating is 1.25×10^{-6} m.

(b) Determine the angle between the central maximum and first order principal maximum formed by the grating. *[2]*

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