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

M05/4/PHYSI/SP3/ENG/TZ2/XX+

22056518

PHYSICS
STANDARD LEVEL
PAPER 3

Friday 20 May 2005 (morning)

1 hour

Candidate session number

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INSTRUCTIONS TO CANDIDATES

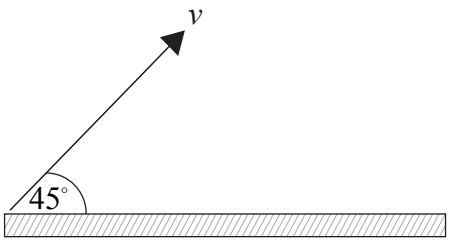
- Write your session number in the boxes above.
- Do not open this examination paper until instructed to do so.
- Answer all of the questions from two of the Options in the spaces provided.
- At the end of the examination, indicate the letters of the Options answered in the candidate box on your cover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

0135

Option A — Mechanics Extension

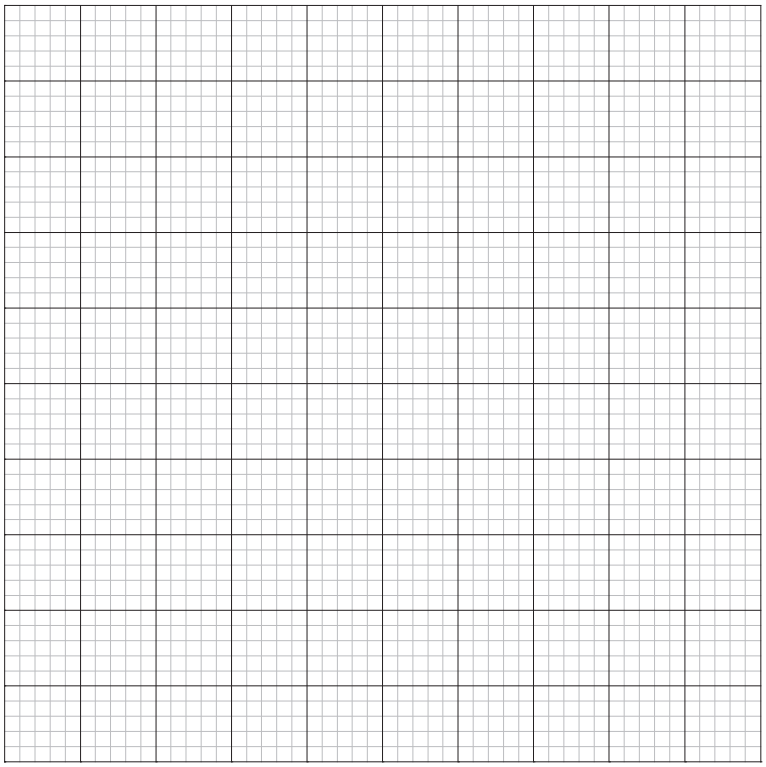
A1. This question is about projectile motion.

A projectile is fired at an angle of 45° to horizontal ground such that its speed immediately after leaving the ground is v.



The projectile leaves the ground at time $t = 0$ and returns to the ground at time $t = T$. Air resistance is negligible.

(a) Draw a sketch-graph, using the same set of axes, to show the variation with time t (x-axis) of the horizontal velocity v_H and vertical velocity v_V of the projectile from time $t = 0$ to time $t = T$. Label the horizontal velocity with the letter v_H and the vertical velocity with the letter v_V. *[4]*



(b) On your sketch-graph, mark with the letter P, the time that corresponds to the projectile at its maximum height. *[1]*

(This question continues on the following page)

(Question A1 continued)

(c) The angle at which the projectile is fired is increased to more than 45°. Explain in terms of conservation of energy, why the maximum height reached by the projectile increases. *[2]*

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A2. This question is about gravitational fields.

(a) Define *gravitational field strength*. *[2]*

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The gravitational field strength at the surface of Jupiter is $25\,\text{N}\,\text{kg}^{-1}$ and the radius of Jupiter is $7.1\times10^{7}\,\text{m}$.

(b) (i) Derive an expression for the gravitational field strength at the surface of a planet in terms of its mass M, its radius R and the gravitational constant G. *[2]*

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(ii) Use your expression in (b) (i) above to estimate the mass of Jupiter. *[2]*

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(Option A is continued on page 6)

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(Option A continued)

A3. This question examines the principle of a weighing device.

(a) State the conditions for a body to be in both translational and rotational equilibrium. *[2]*

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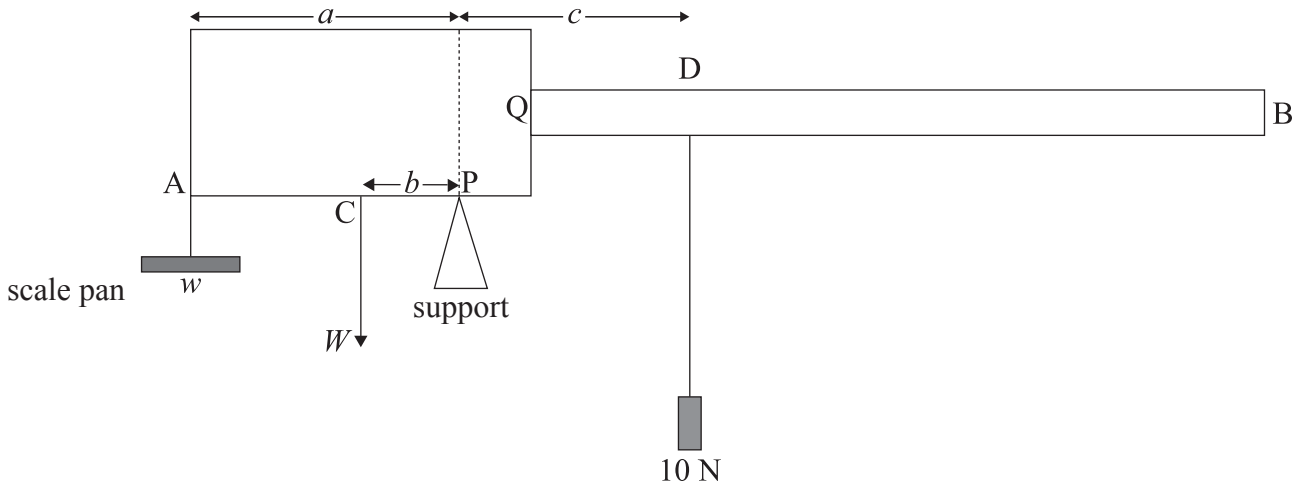
The diagram below shows a non-uniform horizontal rod AB of weight W supported at a point P. A scale pan of weight w is suspended from end A and a 10 N weight can be moved along the thinner part of the rod QB.



The weight W of the rod acts through the point C.

In the situation shown, the 10 N weight is at the point D and the rod is horizontal and in equilibrium. The distances AP = a, CP = b and PD = c

(b) State an expression relating the forces and the distances shown in the diagram and explain how you arrived at this expression. *[2]*

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(This question continues on the following page)

(Question A3 continued)

(c) An object of unknown weight X is added to the scale pan. To maintain equilibrium, the 10 N weight has to be moved a distance $2.4a$ to the right of point D. Determine the weight X of the object. *[3]*

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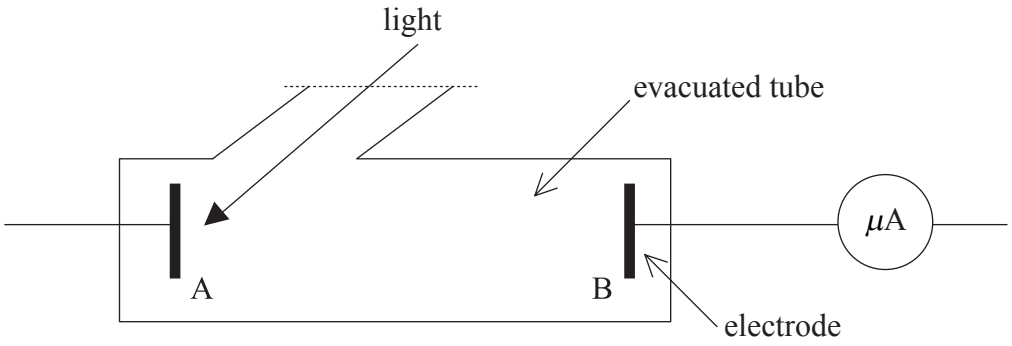
Option B — Quantum Physics and Nuclear Physics

B1. This question is about the photoelectric effect.

In an experiment to investigate the photoelectric effect, light of frequency f is incident on the metal surface A shown in the diagram below. A potential difference is applied between A and electrode B. The photoelectric current is measured by the microammeter. *(**Note**: the complete electrical circuit is not shown.)*



(a) Indicate on the diagram the polarity of A and of B. *[1]*

(b) The frequency f of the light is reduced and it is found that there is a frequency f_0, the threshold frequency, below which the microammeter does not indicate a current. Explain how Einstein's photoelectric theory accounts for this observation. *[4]*

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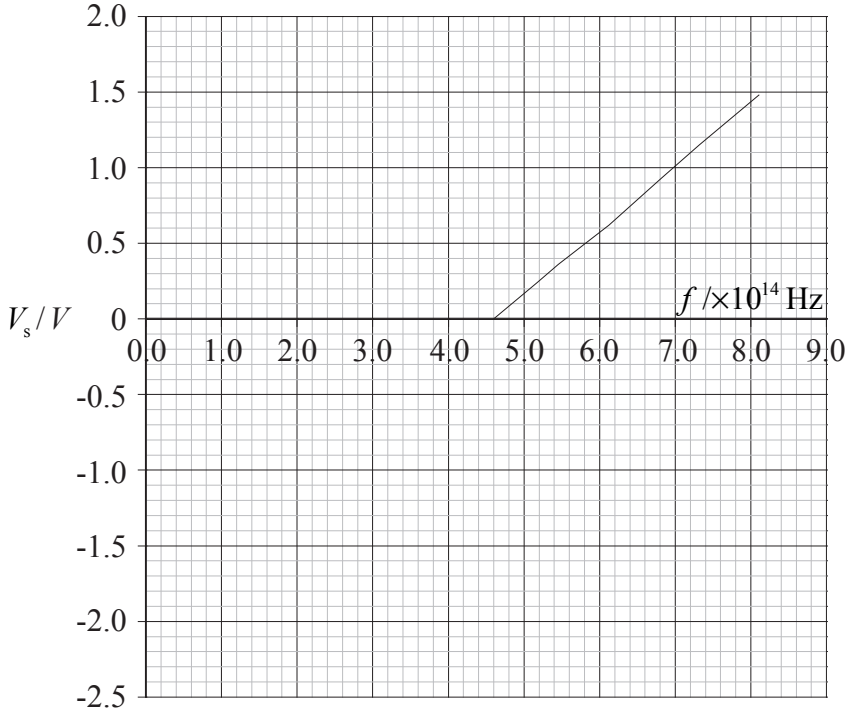
(This question continues on the following page)

(Question B1 continued)

The potential difference between A and B is now reversed. For a particular frequency of the light, the potential difference is changed until there is zero current in the circuit. The graph below shows the variation of frequency f of the light with the potential difference V_s for zero current.



(c) Explaining your working, use the graph to determine

(i) the threshold frequency. *[1]*

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(ii) the work function, in eV, of the metal. *[2]*

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B2. This question is about radioactive decay and the age of rocks.

A nucleus of the radioactive isotope potassium-40 decays into a stable nucleus of argon-40.

(a) Complete the equation below for the decay of a potassium-40 nucleus. *[2]*

$$^{40}_{19}\mathrm{K} \rightarrow {}^{40}_{18}\mathrm{Ar} +$$

A certain sample of rocks contains 1.2×10^{-6} g of potassium-40 and 7.0×10^{-6} g of trapped argon-40 gas.

(b) Assuming that all the argon originated from the decay of potassium-40 and that none has escaped from the rocks, calculate what mass of potassium was present when the rocks were first formed. *[1]*

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The half-life of potassium-40 is 1.3×10^{9} years.

(c) Determine

(i) the decay constant of potassium-40. *[2]*

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(ii) the age of the rocks. *[2]*

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B3. This question is about fundamental particles and conservation laws.

Nucleons are considered to be made of quarks.

(a) State the name of

(i) the force (interaction) between quarks. *[1]*

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(ii) the particle that gives rise to the force between quarks. *[1]*

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(b) Outline in terms of conservations laws, why the interaction $\bar{v} + p = n + e^+$ is observed but the interaction $v + p = n + e^+$ has never been observed. *(You may assume that mass-energy and momentum are conserved in both interactions.)* *[3]*

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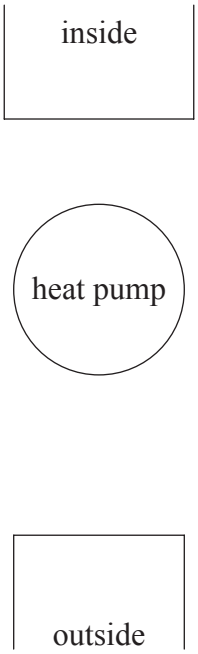
Option C — Energy Extension

C1. This question is about a heat pump and thermodynamic processes.

Heat pumps can be used to heat houses by transferring energy from the outside of the house to the inside of the house, the outside of the house being at a lower temperature than the inside of the house.

During one cycle, a particular heat pump absorbs Q_C units of energy from the outside and delivers Q_H units into the inside of the house. This process requires W units of work to be done.

(a) Annotate the diagram below to show these energy transfers. *[3]*



(b) The power input to the heat pump is 1.0 kW and the efficiency of the heat pump is 25 %. Calculate the rate at which the heat pump delivers energy to the inside of the house. *[2]*

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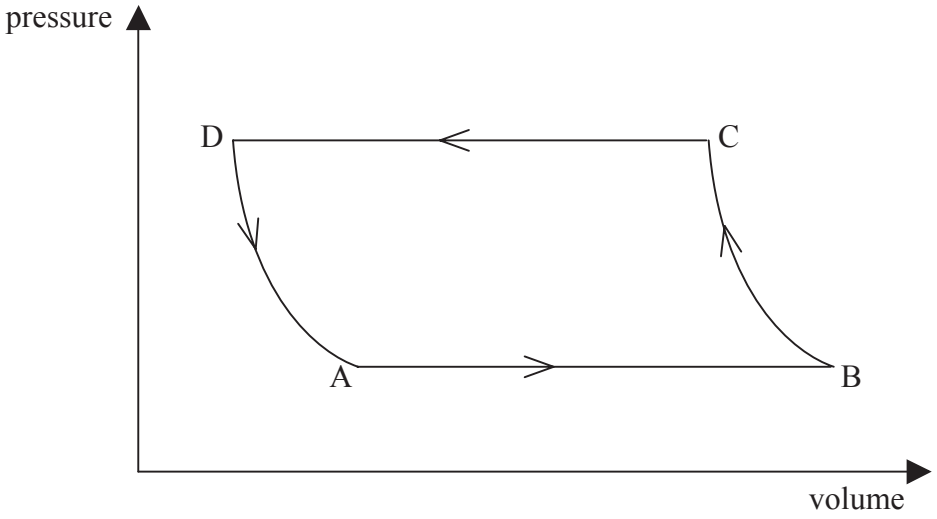
(This question continues on the following page)

(Question C1 continued)

The diagram below shows the relation between the pressure and the volume of the working substance of the heat pump for one cycle ABCD of operation of the heat pump. During the cycle there are two adiabatic processes and two isothermal-isobaric processes.



(c) Explain what is meant by

(i) an *adiabatic process*. *[2]*

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(ii) an *isothermal-isobaric process*. *[1]*

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(d) State and explain during which process or processes energy is absorbed from the outside of the house. *[3]*

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C2. This question is about wind energy.

It is required to design wind turbines for a wind farm for which the following information is available.

Total required annual electrical energy output from the wind farm $= 120\,\text{TJ}$
Maximum number of turbines for which there is space on the farm $= 20$
Average annual wind speed at the site $= 9.0\,\text{m s}^{-1}$

(a) Deduce that the average power output required from one turbine is 0.19 MW. *[3]*

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(b) Estimate the blade radius of the wind turbine that will give a power output of 0.19 MW. *[3]*
(Density of air $= 1.2\,\text{kg m}^{-3}$)

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(c) State **one** reason why your answer to (b) is only an estimate. *[1]*

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(d) Discuss briefly **one** disadvantage of generating power from wind energy. *[2]*

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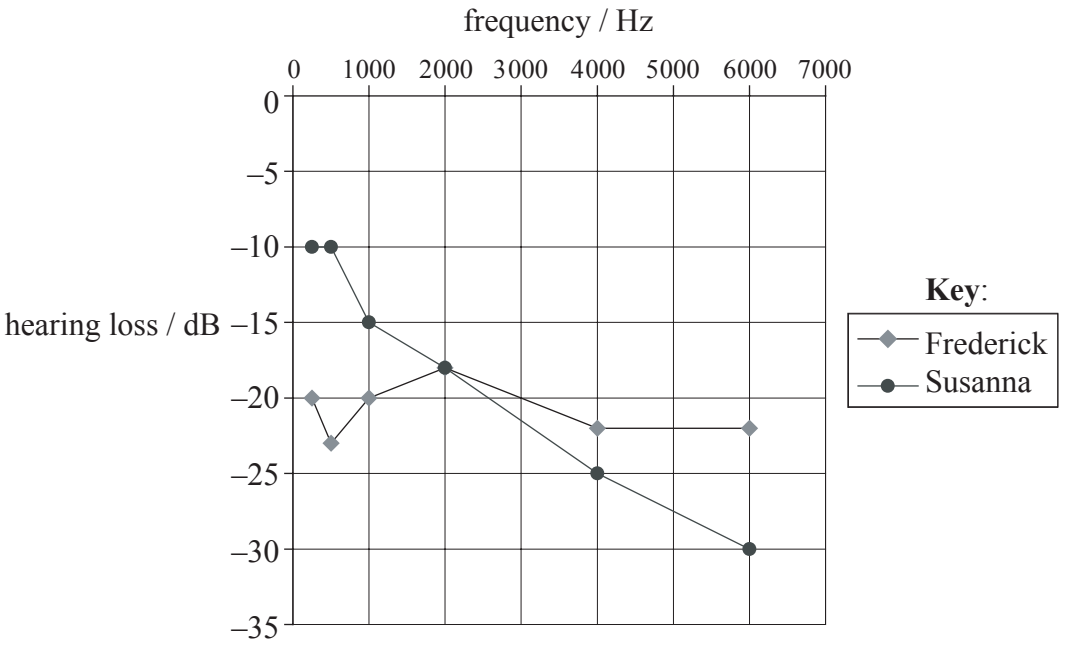
The diagram below shows the audiograms for two people, Frederick and Susanna, both of whom are suffering from hearing loss. The hearing loss is measured in decibels, a unit that measures sound intensity level.



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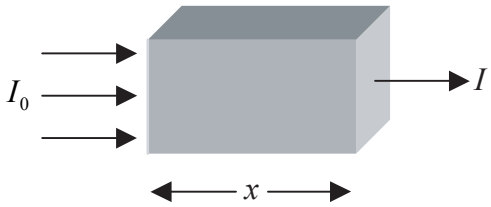
A parallel beam of X-rays of intensity I_0 is incident on a material of thickness x as shown below. The intensity of the emergent beam is I.



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

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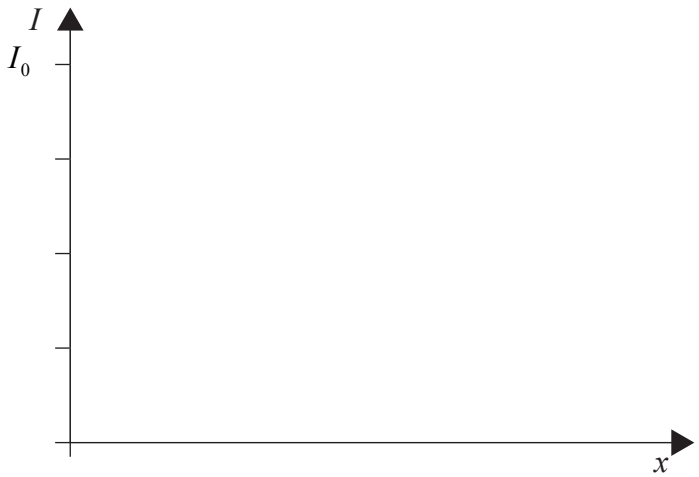
(c) Using the axes below, draw a sketch-graph to show the variation with x of the intensity I. *[2]*



(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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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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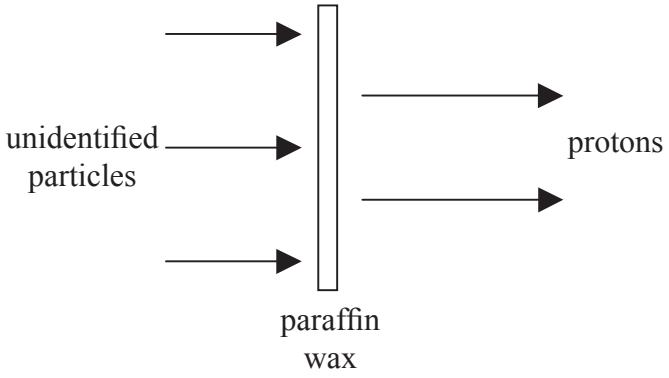
(This question continues on the following page)

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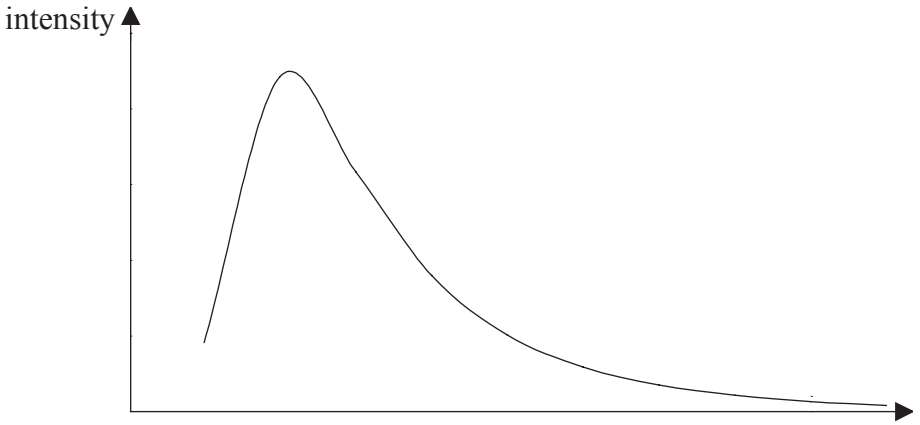
The diagram below is a sketch graph of the black-body radiation spectrum of a certain star.



(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 Olber's 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 G — Relativity

G1. This question is about frames of reference.

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

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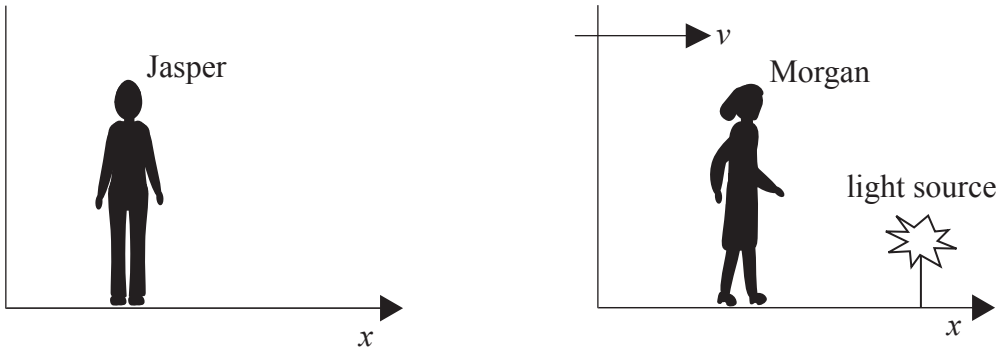
In the diagram below, Jasper regards his reference frame to be at rest and Morgan's reference frame to be moving away from him with constant speed v in the x-direction.



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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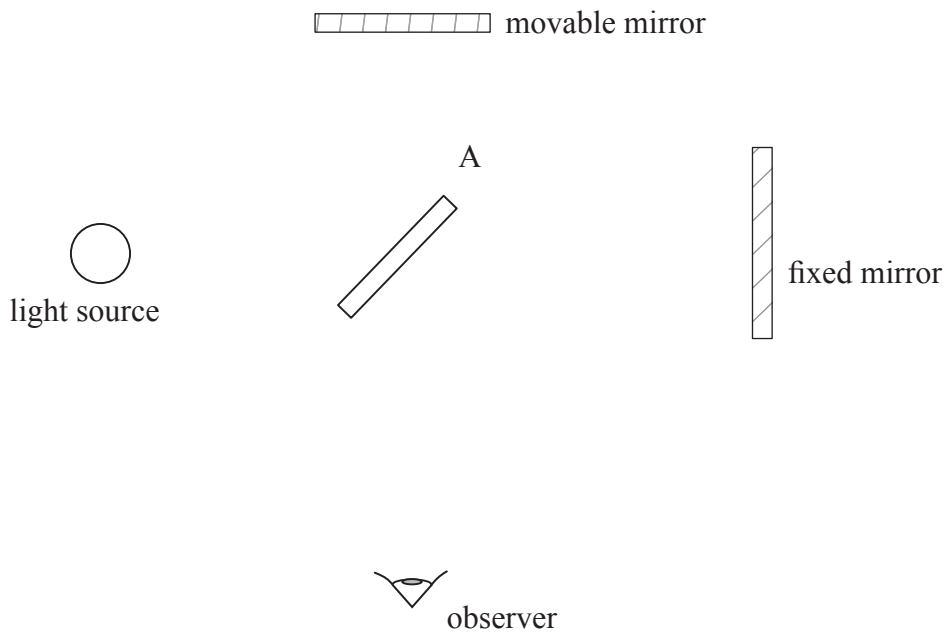
G2. This question is about the Michelson Morley experiment.

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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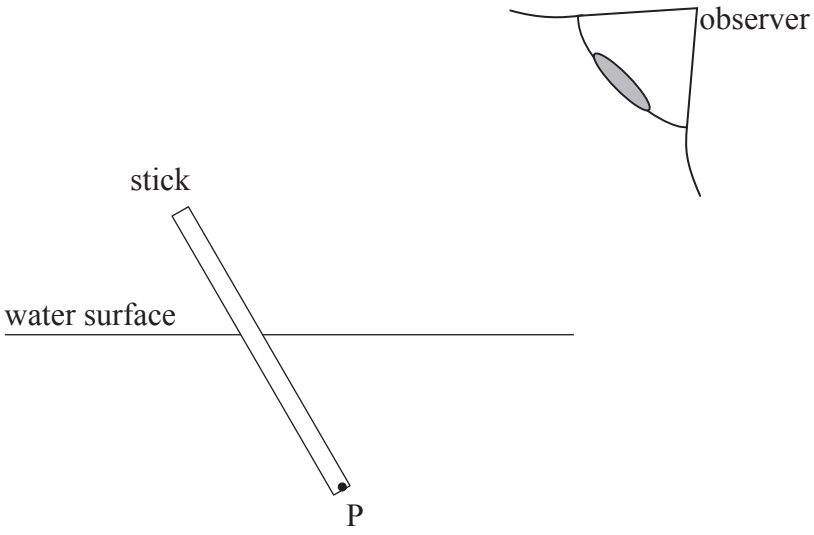
Option H — Optics

H1. This question is about refraction and critical angle.

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

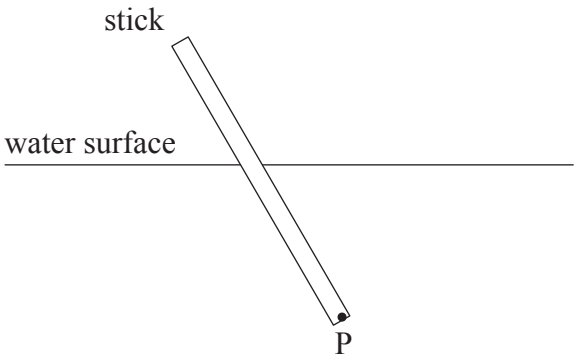


(a) On the diagram above,

(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]*



(This question continues on the following page)

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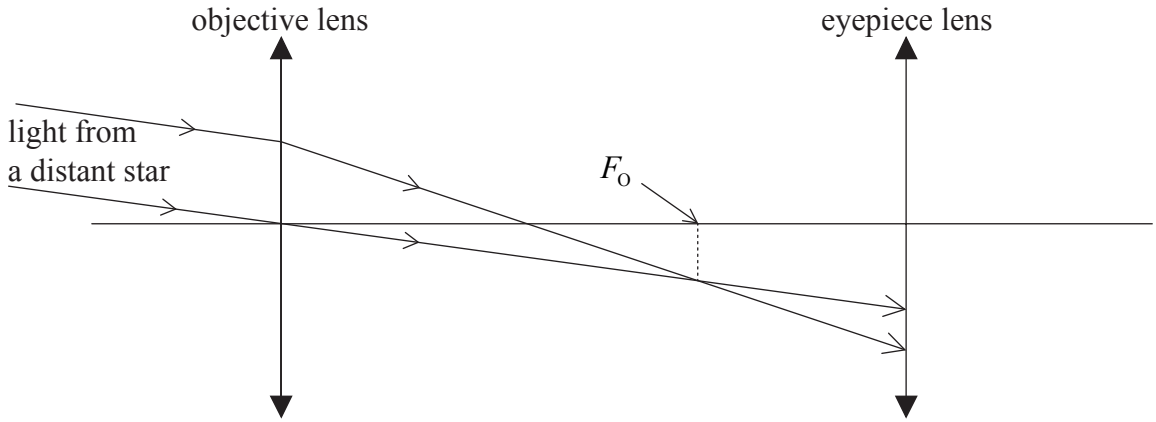
The diagram below shows two rays of light from a distant star incident on the objective lens of an astronomical telescope. The paths of the rays are also shown after they pass through the objective lens and are incident on the eyepiece lens of the telescope.



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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