PHYSICS
STANDARD LEVEL
PAPER 3

Thursday 3 May 2007 (morning)

1 hour

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.

Option A — Mechanics Extension

A1. This question is about gravitational field strength near the surface of a planet.

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

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(ii) State why gravitational field strength at a point is numerically equal to the acceleration of free fall at that point. *[1]*

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(b) A certain planet is a uniform sphere of mass M and radius R of 5.1×10^{6} m.

(i) State an expression, in terms of M and R, for the gravitational field strength at the surface of the planet. State the name of any other symbol you may use. *[1]*

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(ii) A mountain on the surface of the planet has a height of 2000 m. Suggest why the value of the gravitational field strength at the base of the mountain and at the top of the mountain are almost equal. *[2]*

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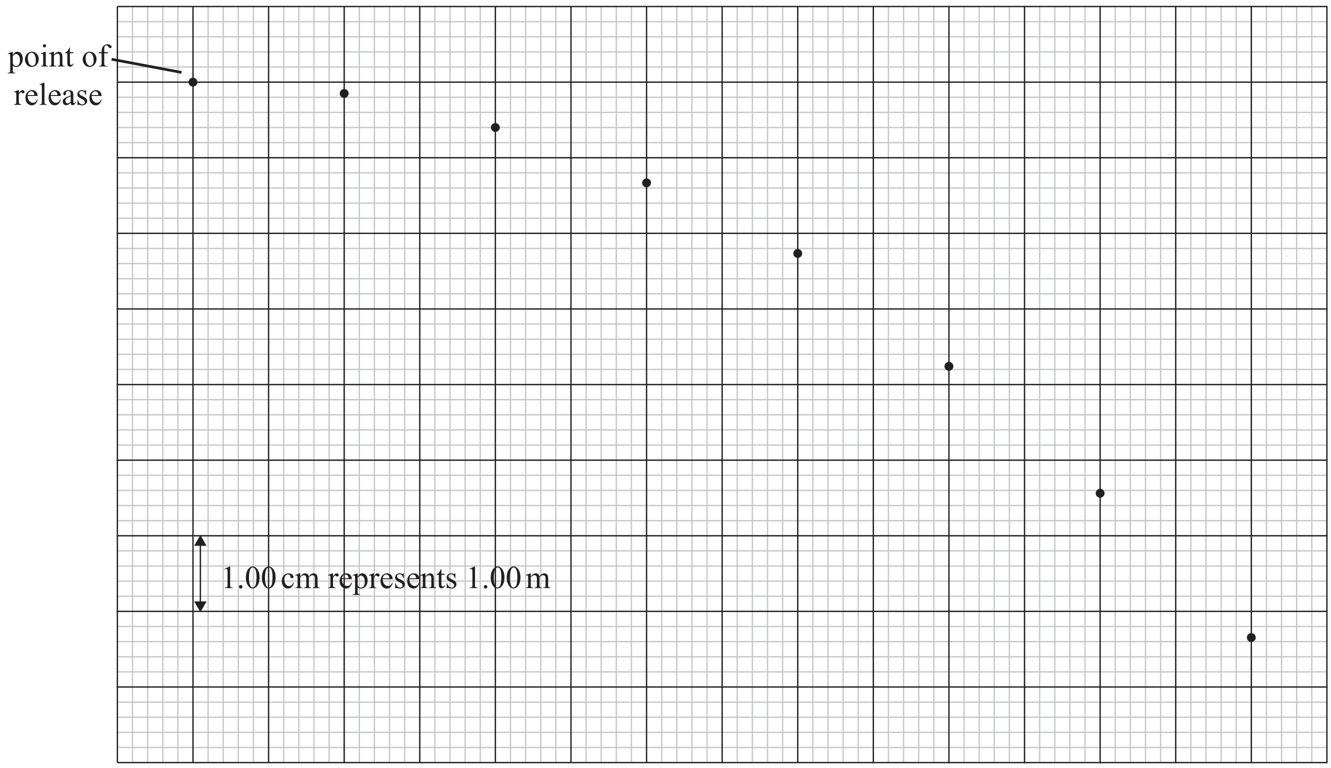
(Question A1 continued)

(c) A small sphere is projected horizontally near the surface of the planet in (b). Photographs of the sphere are taken at time intervals of 0.20 s. The images of the sphere are placed on a grid and the result is shown below.



The first photograph is taken at time $t = 0$. Each 1.00 cm on the grid represents a distance of 1.00 m in both the horizontal and the vertical directions.

Use the diagram to

(i) explain why air resistance on the planet is negligible. *[2]*

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(ii) calculate a value for the acceleration of free fall at the surface of the planet. *[3]*

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(Question A1 continued)

(d) Use your answer to (c)(ii) and data from (b) to calculate the mass of the planet. *[2]*

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A2. This question is about centre of gravity.

(a) Describe what is meant by the *centre of gravity* of an object. *[2]*

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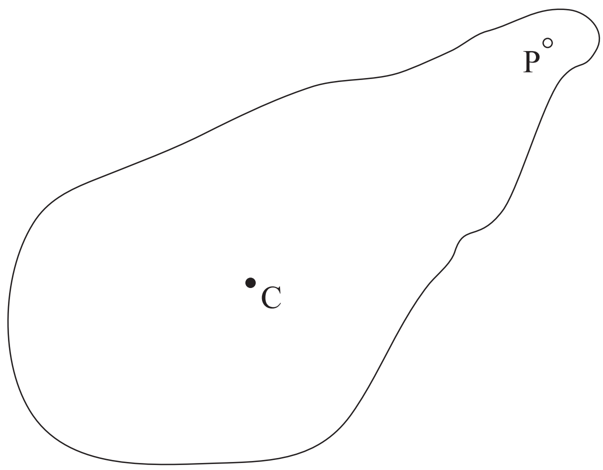
(b) A sheet of cardboard is pivoted at point P and is held in the position shown in the diagram below.



The centre of gravity of the sheet is at point C.

(i) On the diagram above, draw an arrow labelled *W* to represent the weight of the cardboard. *[1]*

(ii) The cardboard sheet is now released. Explain why, using energy principles, the cardboard will eventually come to rest. *[2]*

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(iii) Explain why, when the sheet comes to rest, point C will be below point P. *[2]*

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Option B — Quantum Physics and Nuclear Physics

B1. This question is about photoelectric emission.

A piece of metal is placed in an evacuated container. Light of wavelength 444 nm is incident on the surface of the metal. The surface has a work function of 4.60 eV.

(a) (i) Calculate the energy, in joule, of a photon of light of wavelength 444 nm. *[1]*

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(ii) Deduce whether photoelectric emission of electrons will occur. *[3]*

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(b) The wavelength of the light incident on the surface is now reduced to 222 nm. State and explain why electrons having a range of kinetic energy from zero to approximately 1.0 eV will be emitted. *[4]*

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B2. This question is about radioactive decay.

A cobalt-60 nucleus decays with the emission of a β^- -particle to form a nucleus of nickel-60. The nickel nucleus then decays with the emission of two γ-ray photons of energies 1.17 MeV and 1.33 MeV.

(a) Explain why the decay of nickel-60 leads to the conclusion that atomic nuclei have discrete energy levels. *[2]*

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(b) A fresh sample of cobalt-60 contains N_0 cobalt nuclei. Initially, there are no nickel-60 nuclei in the sample. After 3.0 years, the ratio

$$\frac{\text{number of nickel-60 nuclei}}{\text{number of cobalt-60 nuclei}}$$

is $\frac{1}{2}$.

(i) Deduce that the number of cobalt-60 nuclei remaining after 3.0 years is $\frac{2}{3}N_0$ *[2]*

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(ii) Calculate the half-life of cobalt-60. *[3]*

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B3. This question is about fundamental particles.

Particle production and annihilation are subject to conservation laws. Two of these laws are conservation of mass-energy and conservation of momentum.

(a) State the names of **three** other conservation laws. *[3]*

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2. . . . .

3. . . . .

(b) Free neutrons are unstable. A neutron may decay to become a proton with the emission of an electron. A student represents the decay by the following equation.

$$ {}^{1}_{0}n \rightarrow {}^{1}_{1}p + {}^{0}_{-1}e $$

(i) State, by reference to conservation laws, why the student's equation is not correct. *[1]*

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(ii) Write down the correct decay equation. *[1]*

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Option C — Energy Extension

C1. This question is about the first law of thermodynamics.

(a) Describe what is meant by the *internal energy* of an ideal gas. *[2]*

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(b) The internal energy of an ideal gas increases by an amount ΔU. During this process, an amount q of thermal energy is transferred to the gas and the gas does an amount w of external work.

(i) Use the first law of thermodynamics to state a relation between ΔU, q and w. *[1]*

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(ii) Suggest how the state of an ideal gas may be changed such that each of the following conditions is met separately. *[3]*

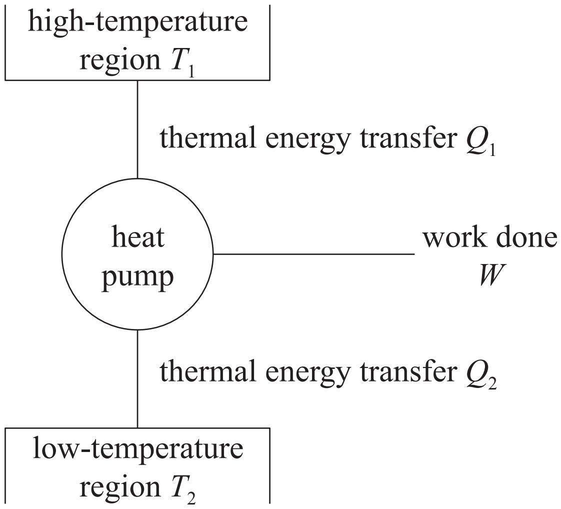
$\Delta U = 0$ . . . .

$w = 0$ . . . .

$q = 0$ . . . .

C2. This question is about heat pumps.

The diagram illustrates an ideal heat pump that operates between a high-temperature region and a low-temperature region.



(a) On the diagram above, draw arrows to indicate the directions of energy transfer for the heat pump. *[1]*

(b) The energy transfers between the heat pump and the high-temperature and the low-temperature regions are Q_1 and Q_2 respectively when an amount W of work is done.

(i) State the relation between Q_1, Q_2 and W. *[1]*

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(ii) State an expression, in terms of Q_1 and Q_2, for the ratio $\frac{W}{Q_2}$. *[1]*

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(Question C2 continued)

(c) The kelvin temperatures of the high-temperature and low-temperature regions are T_1 and T_2 respectively.

(i) Derive an expression, in terms of T_1 and T_2, for the ratio $\dfrac{W}{Q_2}$. *[2]*

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(ii) A refrigerator has an ice compartment at a temperature of $-3\,^\circ\text{C}$. Thermal energy is removed from the back of the refrigerator which is at a temperature of $37\,^\circ\text{C}$. The rate of transfer of thermal energy from the ice compartment is 95 W. Using your expression in (i), calculate the input power to the refrigerator. *[2]*

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(iii) State **one** reason why the actual input power for this refrigerator would have to be greater than that calculated in (c)(ii). *[1]*

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C3. This question is about solar heaters.

(a) An active solar heater (solar panel) is installed on the roof of a building in the southern hemisphere. Suggest why the panel should be facing northwards at noon. *[2]*

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(b) At one particular location, the average power received from the Sun during a six-hour period each day is $840\,\mathrm{W\,m^{-2}}$. The solar heater has an overall efficiency of 35 %. It is required that, during the six-hour period, the solar heater raises the temperature of 140 kg of water by 25 K. The specific heat capacity of water is $4.2\,\mathrm{kJ\,kg^{-1}\,K^{-1}}$. Calculate the minimum effective area of the solar heater. *[4]*

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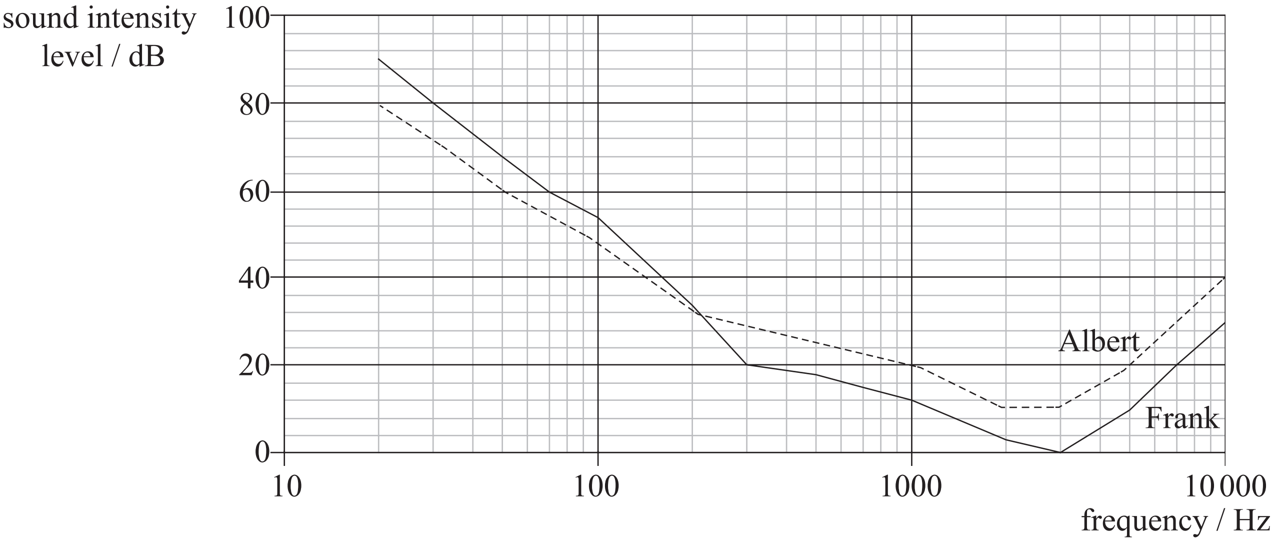
Option D — Biomedical Physics

D1. This question is about sound and hearing.

The following graph shows the variation with frequency of the threshold of hearing for Frank and for Albert.



A sound source produces a note of frequency 70 Hz. The sound power output of the source is 0.027 W. The sound is emitted uniformly in all directions. Frank and Albert both walk towards the source. Frank stops when he first hears the sound. Albert stops when he first hears the sound.

(a) Use the graph to state and explain whether Albert **or** Frank stops closest to the source. *[3]*

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(Question D1 continued)

(b) Deduce that the distance from the speaker at which Frank first hears the sound is 46 m. You may assume there is no reflected sound. The surface area of a sphere of radius r is $4\pi r^2$. *[3]*

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(c) The frequency of the sound emitted by the source is changed to 4000 Hz while Albert remains at the same location as he was in (a), and the power output is maintained at the same level as in (a). Use the graph to state and explain the changes, if any, of the loudness of the sound heard by Albert. *[2]*

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D2. This question is about scaling.

The bodies of a lion and a domestic cat are similar in shape and density. The linear dimensions of the body of a particular lion are 4.0 times larger than those of a particular domestic cat.

(a) Estimate the ratio

$$\frac{\text{mass of body of the lion}}{\text{mass of body of the domestic cat}}.$$ *[2]*

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(b) The breaking stress of the leg bones is defined as the force per unit area that just breaks the bone. The minimum diameter of the leg bone is the diameter that will just support the weight of the body without breaking. Assume that the animals have similar bone material.

(i) Use your answer to (a) to determine the ratio

$$\frac{\text{minimum diameter of the leg bone of the lion}}{\text{minimum diameter of the leg bone of the domestic cat}}.$$ *[2]*

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(ii) Use your answers to (a) and (b)(i) to explain why the lion has legs that are not 4.0 times the diameter of those of the domestic cat. *[2]*

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D3. This question is about medical imaging.

(a) Outline the basis of computerized tomography (CT scanning). *[4]*

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(b) State and explain **one** disadvantage of the use of computerized tomography. *[2]*

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Option E — The History and Development of Physics

E1. This question is about models of the Universe.

(a) Explain the model proposed by Aristarchus to account for the observed motion of the stars. *[2]*

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(b) State **two** ways in which Ptolemy's model differs from the Aristarchus model of the Universe. *[2]*

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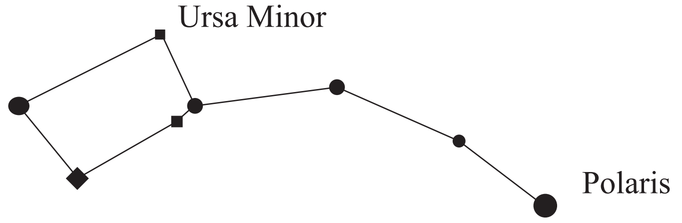
(Question E1 continued)

(c) The diagram below shows the positions of some of the stars in the constellation Ursa Minor. The star Polaris may be taken to be at the northern celestial pole.



On the diagram above, draw a sketch showing the positions of the stars as they would be seen six hours later. *[3]*

(d) State how the Aristarchus model explains your sketch in (c). *[1]*

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E2. This question is about caloric theory.

In 1798, Rumford published a paper in support of an alternate view to the caloric theory, based on observations involving the boring of cannons.

(a) Outline Rumford's observations. *[1]*

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(b) Explain how Rumford's observations are inconsistent with the caloric theory. *[2]*

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E3. This question is about electric charge.

Priestley and Franklin attempted to establish an inverse-square law for electrostatic force, as did Coulomb. Compare the **two** approaches. *[3]*

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E4. This question is about investigations of electrons and neutrons.

(a) State and explain why the properties of electrons can be determined more easily than those of neutrons. *[2]*

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(b) Experimentation in the 1930s showed that the radiation produced by the α-bombardment of beryllium could penetrate several centimetres of lead. This radiation ejects high-energy protons from paraffin wax. Discuss how these observations led Chadwick to conclude that this radiation is neutrons. *[4]*

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Option F — Astrophysics

F1. This question is about luminosity.

(a) Define *luminosity*. *[1]*

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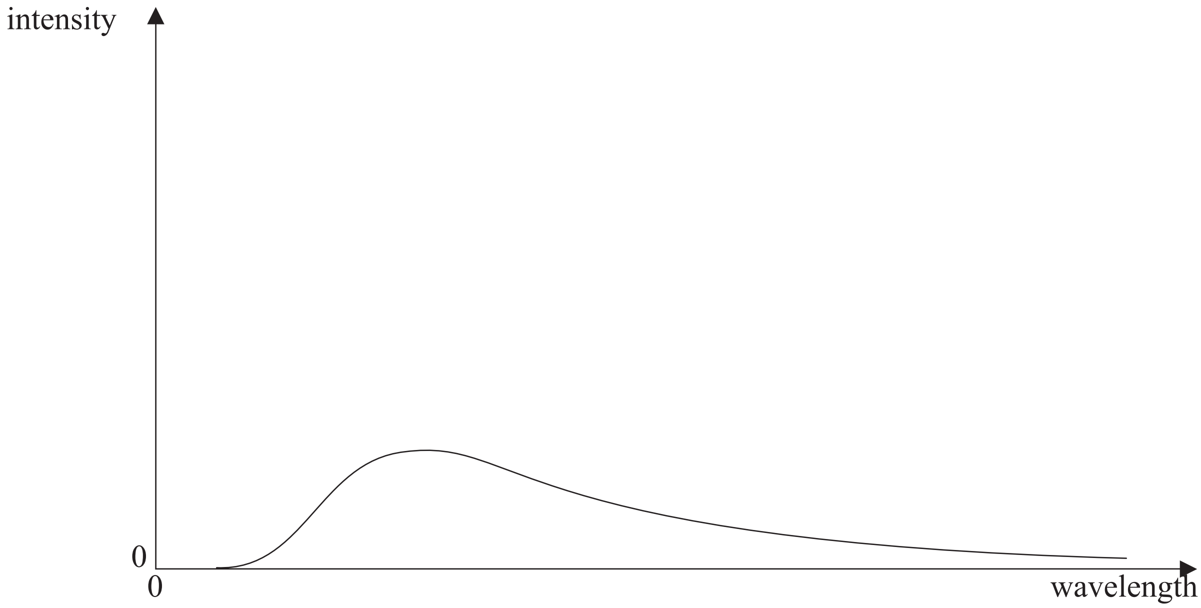
(b) The sketch-graph below shows the intensity spectrum for a black-body at a temperature of 6000 K.



On the axes above, draw a sketch-graph showing the intensity spectrum for a black-body at 8000 K. *[2]*

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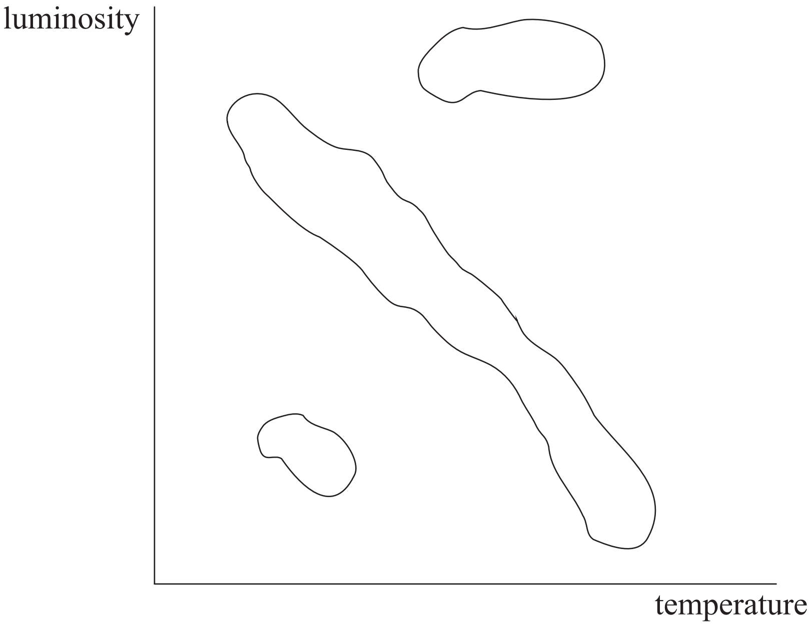
(Question F1 continued)

(c) A sketch of a Hertzsprung-Russell diagram is shown below.



On the diagram above, identify the

(i) main sequence (label this M),
(ii) red giant region (label this R),
(iii) white dwarf region (label this W). *[2]*

(d) In a Hertzsprung-Russell diagram, luminosity is plotted against temperature. Explain why the diagram alone does not enable the luminosity of a particular star to be determined from its temperature. *[3]*

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F2. This question is about stellar magnitudes and stellar distances.

(a) Define

(i) *apparent magnitude*. *[1]*

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(ii) *absolute magnitude*. *[1]*

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(b) Star A has an apparent magnitude of 5.0 and is 100 pc from Earth. The luminosity of star A is 4.0 times the luminosity of star B. The apparent brightness of star A is 100 times greater than the apparent brightness of star B.

Deduce that

(i) star B is 500 pc from Earth. *[3]*

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(ii) the absolute magnitude of star A is 0. *[2]*

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F3. This question is about cosmology.

(a) State **one** piece of evidence that indicates that the Universe is expanding. *[1]*

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(b) The rate at which the Universe is expanding depends on the density of the Universe.

(i) Define *critical density*. *[1]*

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(ii) Explain the importance of comparing the density of the Universe to the critical density in predicting the future of the Universe. *[3]*

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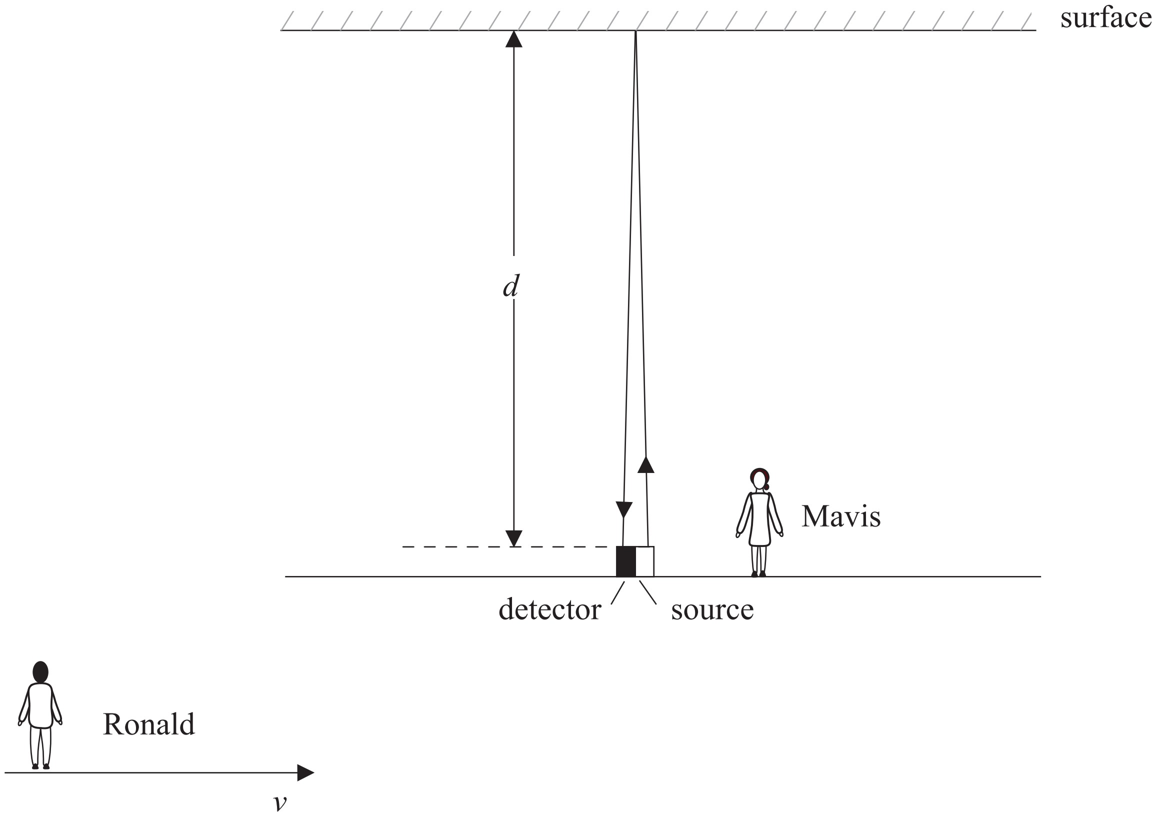
Option G — Relativity

G1. This question is about the measurement of time.

Mavis is stationary with respect to a source that produces a light pulse. The light pulse is reflected at a surface, and returns to a detector located very close to the source. The distance between the source and the surface is d.



Ronald is moving with constant speed v relative to the source in a direction parallel to the surface.

(a) On the diagram above, draw the path of the pulse as seen by Ronald. *[2]*

(This question continues on the following page)

(Question G1 continued)

(b) The time taken for the light to travel from the source to the detector, as measured by Ronald, is t. Use your diagram in (a) to deduce that the distance L travelled by the pulse, as measured by Ronald, is given by the expression

$$L = 2\sqrt{d^2 + \left(\frac{vt}{2}\right)^2}.$$ *[3]*

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(c) The time taken for the pulse to travel from the source to the detector, as measured by Mavis, is t_0.

(i) State the relation between t_0, d and c where c is the speed of light. *[1]*

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(ii) Use your answer in (b) and (c) (i) to deduce that $t = \dfrac{t_0}{\sqrt{1 - \dfrac{v^2}{c^2}}}$. *[3]*

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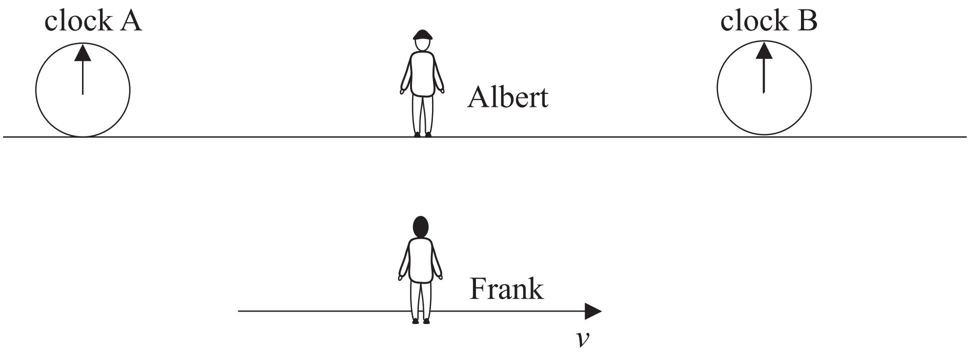
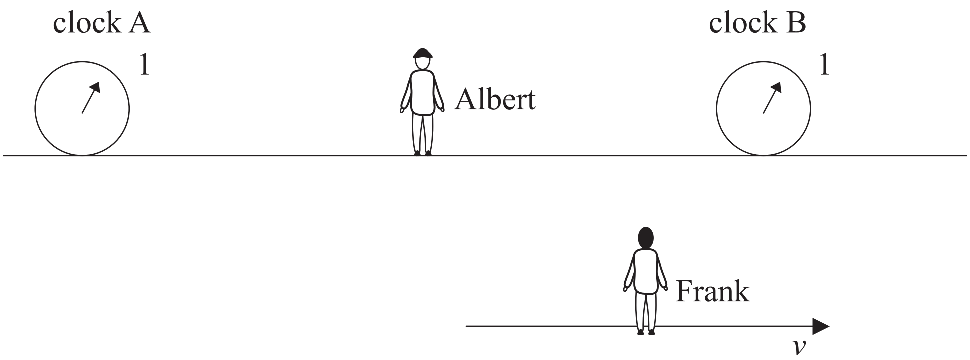
G2. This question is about the observation of clocks.

Albert is standing equal distances from two clocks A and B. Frank is moving with constant speed *v* from clock A towards clock B.



At the instant that Frank is opposite Albert, Albert observes the second-hand of both clocks to be at 0.

At some time later, Albert observes the second-hand of both clocks change position to be at 1, as shown in the diagram below. At this instant, Frank is in the position shown in the diagram below.



Discuss whether, at this instant, Frank observes the second-hand of each clock to be at 1. *[4]*

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G3. This question is about muons.

(a) A muon is formed 4500 m above the surface of the Earth, as measured by an observer on Earth. This muon takes 2.2 μs, as measured in its frame of reference, to reach the Earth's surface. Describe how these observations support the concept of length contraction. *[4]*

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(b) A muon created in the laboratory is accelerated from rest through a potential difference of 2.1×10^{8} V. The rest mass of the muon is $105\,\text{MeV}\,\text{c}^{-2}$. Calculate the mass of the accelerated muon, as measured in the laboratory frame of reference. The charge on a muon is the elementary charge *e*. *[3]*

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Option H — Optics

H1. This question is about refraction and dispersion.

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

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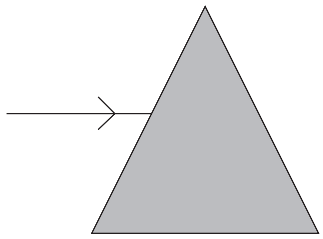
(b) A thin beam of white light is incident on one surface of a glass prism as shown below.



On the diagram above, draw lines to show the approximate paths of the red and of the blue light as it passes through the prism and back into the air. *[3]*

(c) State and explain, with reference to your diagram, whether the refractive index of glass for blue light is greater or less than that for red light. *[3]*

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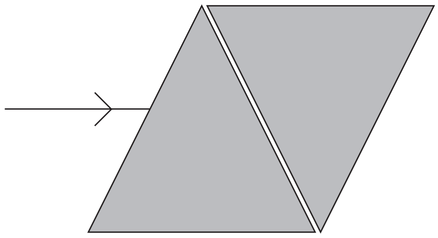
(Question H1 continued)

(d) A second similar prism is placed close to the first prism in (b) as shown below.



Suggest the appearance and the direction of the light that emerges from the second prism. *[2]*

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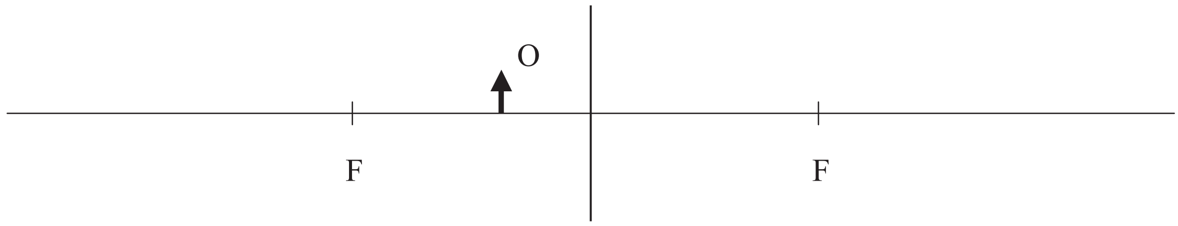
H2. This question is about lenses.

The diagram below shows a thin converging lens and an object, O.



The principal foci of the lens are at F.

(a) Construct rays to locate the position of the image of the object. *[3]*

(b) Describe fully the nature of the image formed. *[2]*

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(This question continues on the following page)

(Question H2 continued)

(c) The diagram below shows the relative positions of the objective lens and eyepiece lens used in a compound microscope in normal adjustment.

An object O is placed in front of the objective lens.

On the diagram above, draw the approximate positions of

(i) the principal foci of the objective lens (label these with the letter A),

(ii) the image formed by the objective lens (label this with the letter B),

(iii) the principal foci of the eyepiece lens (label these with the letter C),

(iv) the position of the final image (label this with the letter D). *[4]*

(d) Suggest why, for large magnifications, a compound microscope is used, rather than a single lens. *[2]*

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