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

M07/4/PHYSI/HP3/ENG/TZ1/XX+

22076509

PHYSICS
HIGHER LEVEL
PAPER 3

Thursday 3 May 2007 (morning)

1 hour 15 minutes

Candidate session number

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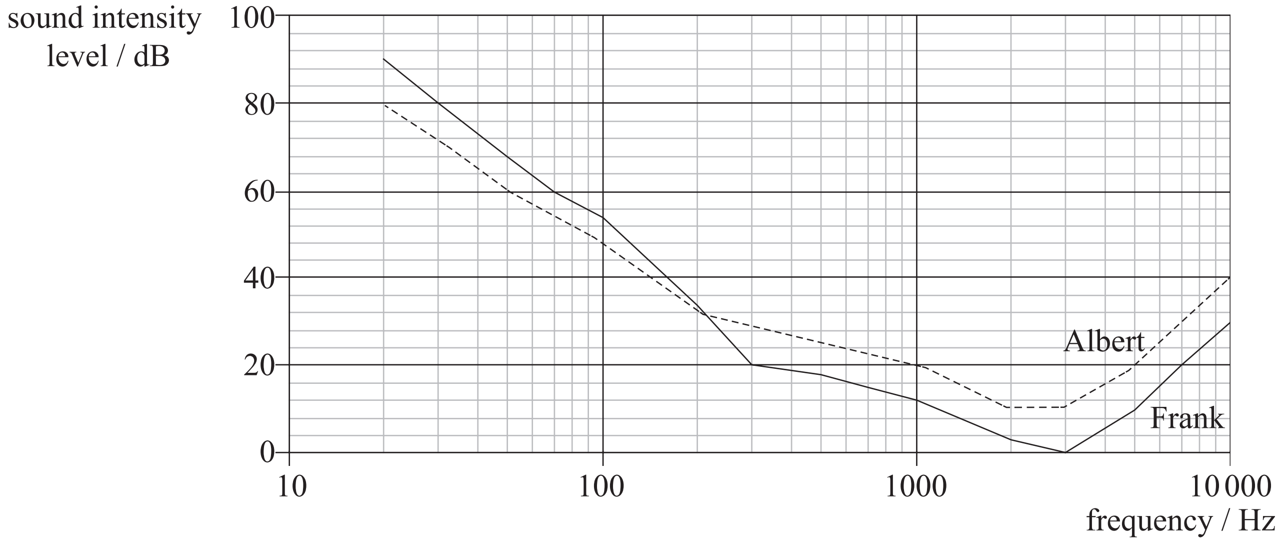
INSTRUCTIONS TO CANDIDATES

- 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 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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(This question continues on the following page)

(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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D4. This question is about energy expenditure.

The table gives values for the rate *R* of loss of thermal energy from a person who is clothed appropriately for working in still air at an air temperature of 32 °C.

Mechanism	***R* / W at 32 °C**	***R* at –10 °C**
Convection	40	
Radiation	30	
Evaporation	320	
Respiration	10	

The person now puts on additional clothing and works at the same rate in a cold room. The air in the room is still and at a temperature of −10 °C.

(a) Complete the table above, by writing **either** "increased" **or** "decreased" **or** "remained the same" to suggest the change in each of the mechanisms. *[4]*

(b) State the effect, if any, on the rate of loss of thermal energy by the mechanisms when the air at a temperature of −10 °C is moving, rather than still. *[2]*

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D5. This question is about dosimetry.

(a) Define *absorbed dose*. *[1]*

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(b) Outline why, when assessing the biological effects of radiation, dose equivalent is used, rather than absorbed dose. *[1]*

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(c) A patient undergoes computerized tomography (CT scanning) and receives a dose equivalent of 2.2 mSv. The increased health risk as a result of exposure to this radiation is estimated to be 5 % per Sv.

(i) Calculate the increased health risk as a result of this CT scan. *[1]*

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(ii) Suggest why patients are prepared to accept this increased health risk. *[1]*

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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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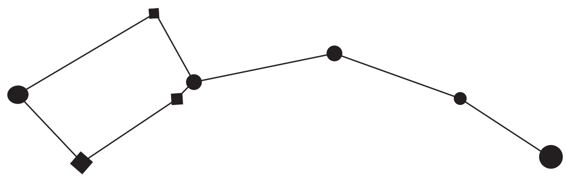
(Question E1 continued)

(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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E5. This question is about atomic spectra.

(a) Explain what is meant by the *Rydberg constant*. *[3]*

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(b) In 1885, Balmer demonstrated that the wavelength λ of light in the visible line spectrum of atomic hydrogen may be expressed as

$$\lambda = A\frac{m^2}{m^2 - 4}$$

where m is an integer greater than two and A has the value 3.65×10^{-7} m. The wavelengths that were observed became known as the Balmer series.

Use this expression to

(i) derive a value for the Rydberg constant. *[2]*

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(ii) determine the longest wavelength in the Balmer series. *[2]*

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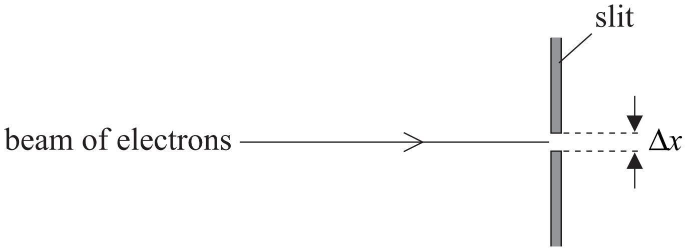
E6. This question is about the Heisenberg uncertainty principle.

A beam of electrons is incident normally to the plane of a narrow slit as shown below.



The slit has width Δx equal to 0.01 mm.

As an electron passes through the slit, there is an uncertainty Δx in its position.

(a) Calculate the minimum uncertainty Δp in the momentum of the electron. *[2]*

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(b) Suggest, by reference to the original direction of the electron beam, the direction of the component of the momentum that has the uncertainty Δp. *[1]*

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Option F — Astrophysics

F1. This question is about luminosity.

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

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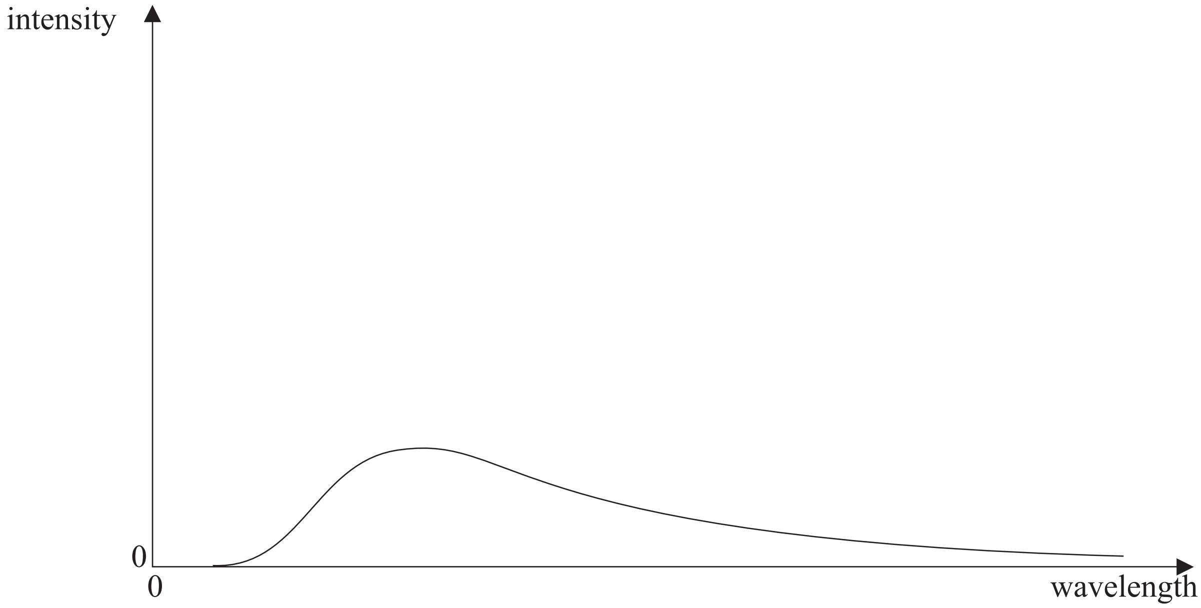
(b) The sketch-graph below shows the intensity spectrum for a black-body at a temperature of 6000 K.



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

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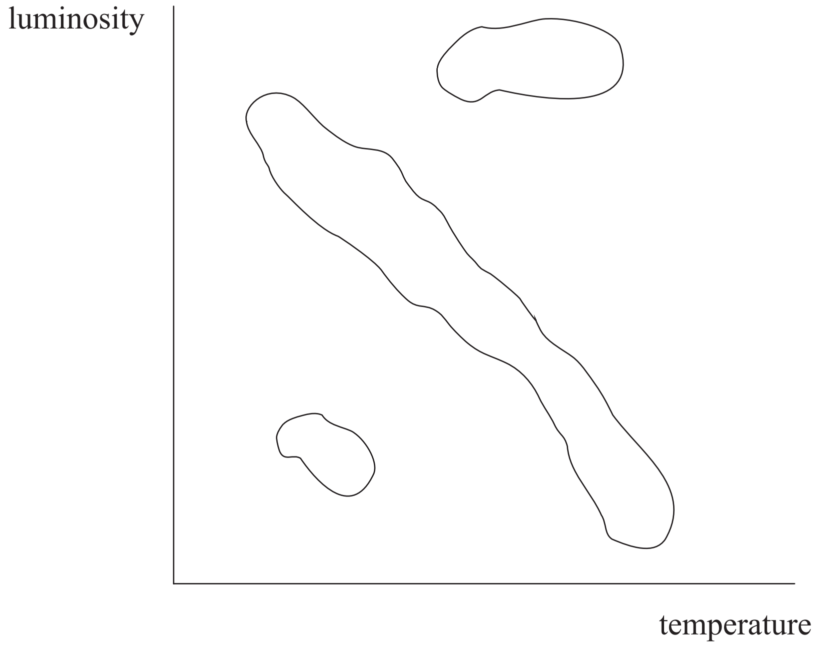
(Question F1 continued)

(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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F4. This question is about stellar evolution.

(a) Outline the late stages in the evolution of a high-mass star that leads it to end its life as a neutron star. *[3]*

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(b) Outline the mechanism that enables a neutron star to be detected from Earth. *[3]*

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F5. This question is about galactic motion.

The K-line of light from singly ionised calcium has a wavelength of 393.3 nm when measured in a laboratory. The same line in the spectrum of galaxy NGC 4889 has a wavelength of 401.8 nm. The value of the Hubble constant may be assumed to be $70\,\text{km}\,\text{s}^{-1}\,\text{Mpc}^{-1}$.

Deduce a value for the distance of NGC 4889 from Earth. *[4]*

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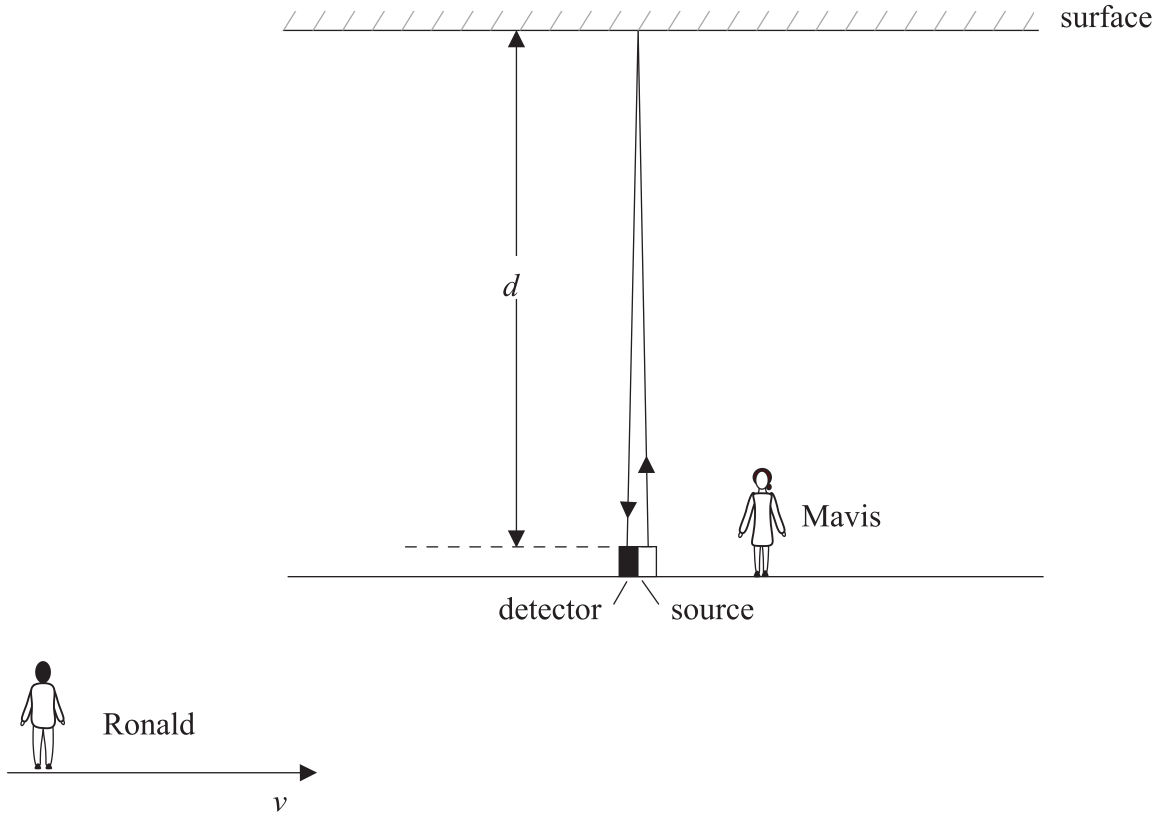
Option G — Relativity

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 $t = \frac{t_0}{\sqrt{1 - \frac{v^2}{c^2}}}$. *[3]*

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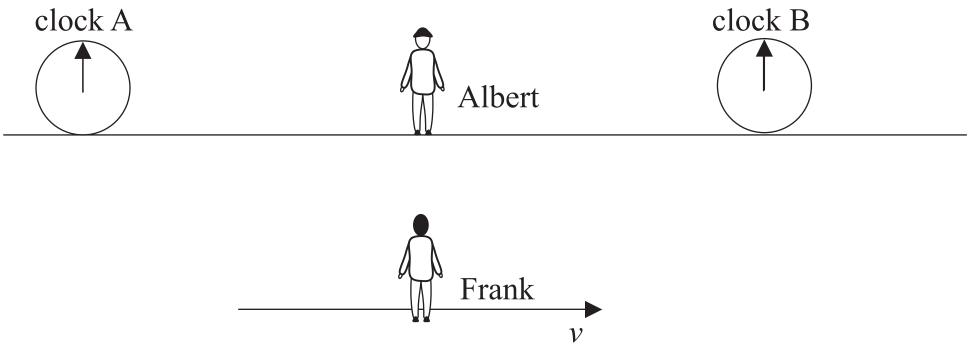
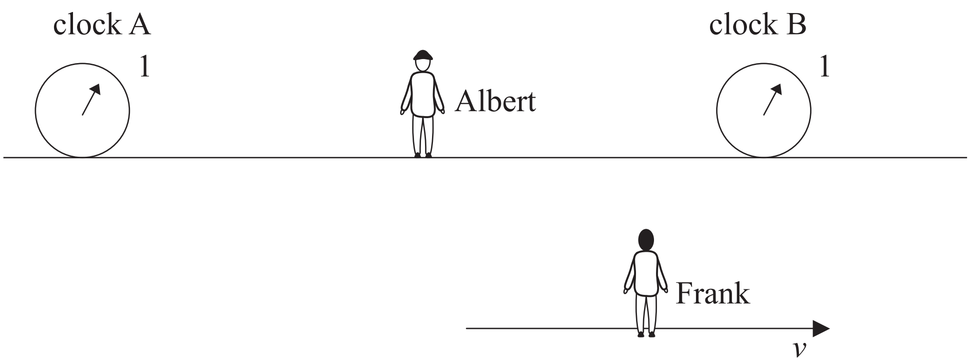
G2. This question is about the observation of clocks.

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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G4. This question is about relativistic energy and momentum.

Two protons, each with the same total energy, collide head-on. The following reaction occurs.

$$p^{+} + p^{+} \rightarrow p^{+} + p^{+} + p^{+} + p^{-}$$

p^{+} is a proton and p^{-} is an antiproton. They each have a rest mass of 930 MeV c^{-2}.

(a) Deduce that, for this reaction to occur, the **minimum total** energy of each colliding proton is 1860 MeV. State any assumption you make. *[2]*

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(b) Calculate the momentum, in MeV c^{-1}, of a proton that has a total energy of 1860 MeV. *[4]*

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G5. This question is about spacetime.

Use the concept of spacetime to

(a) explain the gravitational attraction between the Earth and an orbiting satellite. *[2]*

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(b) describe what is meant by a black hole. *[2]*

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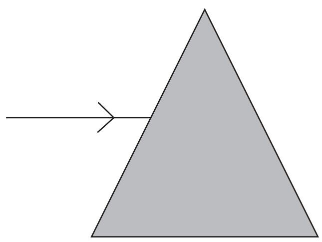
(b) A thin beam of white light is incident on one surface of a glass prism as shown below.



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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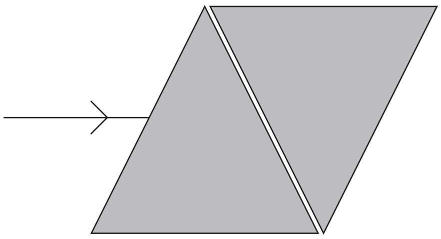
(Question H1 continued)

(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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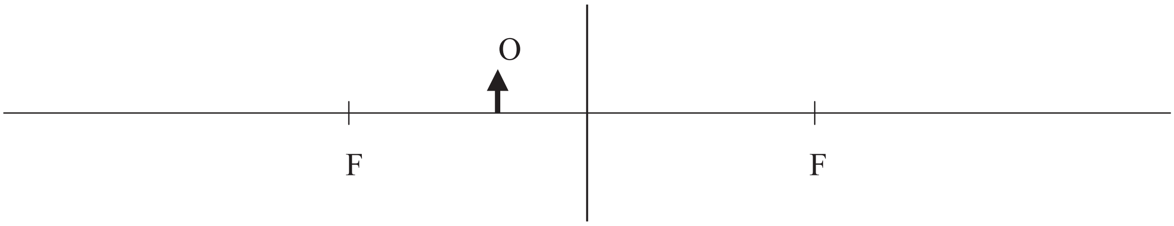
H2. This question is about lenses.

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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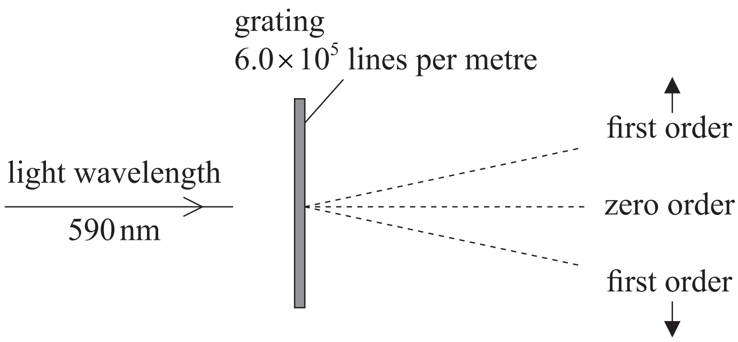
H3. This question is about a diffraction grating.

Light of wavelength 590 nm is incident normally on a diffraction grating, as shown below.



The grating has 6.0×10^5 lines per metre.

(a) Determine the **total** number of orders of diffracted light, including the zero order, that can be observed. *[4]*

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(b) The incident light is replaced by a beam of light consisting of two wavelengths, 590 nm and 589 nm.

State **two** observable differences between a first order spectrum and a second order spectrum of the diffracted light. *[2]*

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H4. This question is about thin films.

A thin film of oil is floating on some water. White light is reflected from the oil film. A series of coloured fringes is seen.

(a) State the name of the wave phenomenon that gives rise to the formation of the coloured fringes. *[1]*

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(b) Describe why the oil film appears to change colour when viewed from different angles of incidence. *[3]*

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