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PHYSICS
STANDARD LEVEL
PAPER 3

Wednesday 5 November 2008 (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.

Option A — Mechanics Extension

A1. This question is about gravitational field strength and escape speed.

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

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(b) Deduce from Newton's law of universal gravitation that the gravitational field strength g at the surface of a planet of mass M and radius R is proportional to $\frac{M}{R^2}$. *[2]*

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(c) The gravitational field strength at the surface of Venus g_V is related to the gravitational field strength at the surface of the Earth g_E by

$$g_V = 0.87 \times g_E.$$

The radius of Venus R_V is related to the radius of the Earth R_E by

$$R_V = 0.96 \times R_E.$$

Calculate the mass of Venus M_V in terms of the mass of the Earth M_E. *[2]*

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(This question continues on the following page)

(Question A1 continued)

(d) (i) Deduce that the escape speed v from the surface of Venus is

$$v = \sqrt{2 g_V R_V}\,. \qquad [3]$$

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(ii) State whether the escape speed from the surface of Venus is equal to, greater than, **or** less than the escape speed from the surface of the Earth. *[1]*

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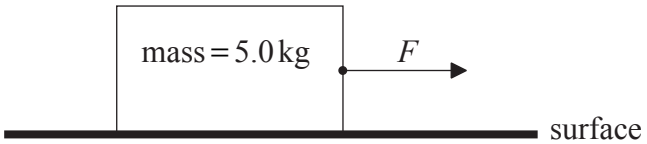
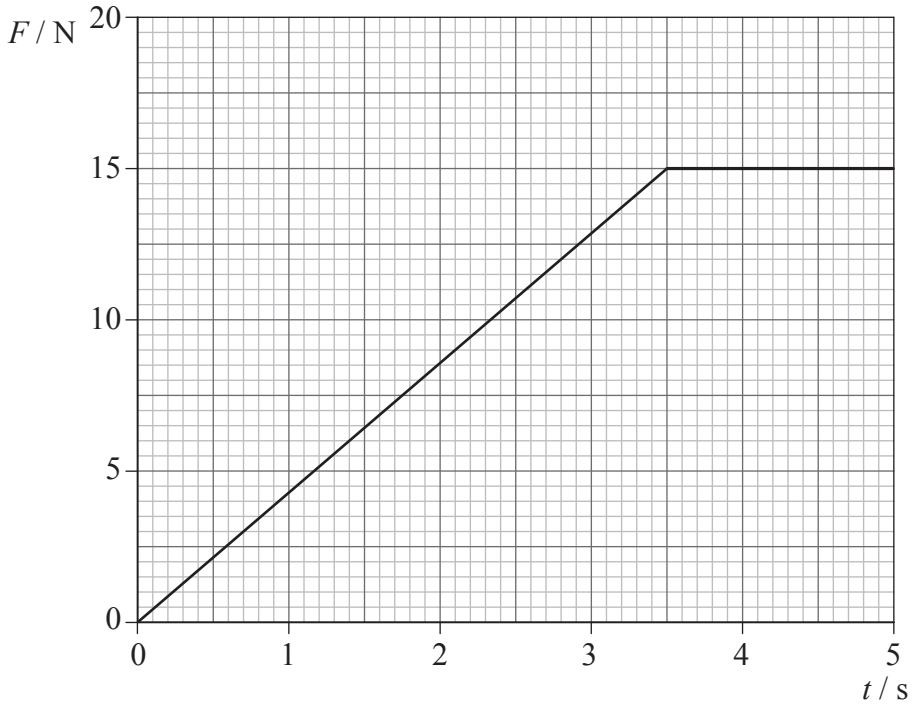
A2. This question is about friction and rotational equilibrium.

A uniform block of mass 5.0 kg is at rest on a horizontal surface. A force F is applied to the block as shown.



The magnitude of F is gradually increased until the block starts to move, after which time F is held constant and the block continues to gain speed. The variation with time t of the force F is shown below.



(a) State and explain the value of the maximum frictional force acting between the object and the surface. *[2]*

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(This question continues on the following page)

(Question A2 continued)

(b) The value of the maximum frictional force can be used to calculate the coefficient of friction between the block and the surface. Explain whether the value calculated would be the coefficient of static friction **or** the coefficient of dynamic friction. *[2]*

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(c) At $t = 4.0\,\text{s}$, the acceleration of the block is $0.60\,\text{m s}^{-2}$. Calculate the coefficient of friction acting at that time between the block and the surface. *[3]*

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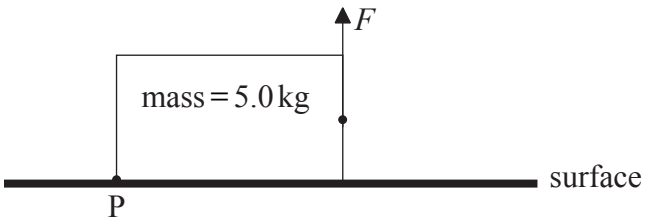
(d) The block is brought to rest and the force F now acts vertically on the block as shown. The magnitude of F is gradually increased but its direction remains vertical. When the block begins to move it rotates about the edge P.



(i) Calculate the minimum value of F that will just cause the block to begin to rotate. *[2]*

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(ii) State the value of F for which the block completely loses contact with the surface. *[1]*

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Option B — Quantum Physics and Nuclear Physics

B1. This question is about the evidence for the quantization of energy in atoms.

(a) State what is meant by the phrase *the quantization of energy in atoms*. *[2]*

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(b) By means of a labelled diagram, outline an experimental set-up by which X-rays can be emitted from a sample of tungsten. *[3]*

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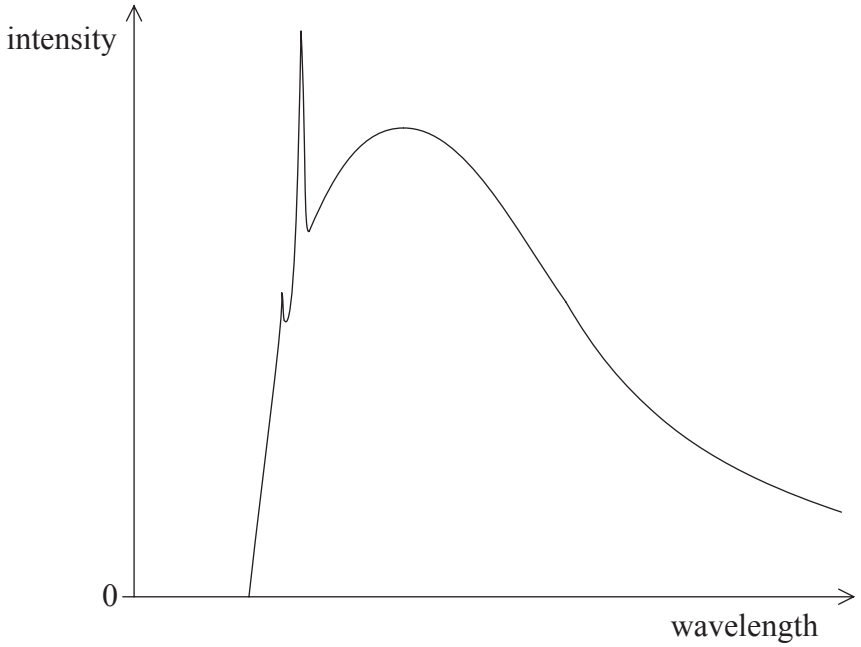
(Question B1 continued)

(c) The graph below shows the X-ray spectrum of a sample of tungsten.



Explain which features of this X-ray spectrum provide evidence for the quantization of energy levels in tungsten atoms. *[2]*

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(d) One of the lines in the emission spectrum of atomic hydrogen has a wavelength of 410 nm. Determine what quantitative information can be deduced about some of the energy levels in the hydrogen atom from this wavelength value. *[3]*

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B2. This question is about β^+-decay.

A nucleus of nitrogen-13, ${}^{13}_{7}\mathrm{N}$, undergoes β^+-decay to produce an isotope of carbon.

(a) Determine the **three** particles that result from the decay of a nucleus of nitrogen-13. State the mass number and the atomic number for each particle. *[3]*

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2. . . . . .

3. . . . . .

(b) Identify which particle from your answer to (a) contains quarks. *[1]*

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(c) The half-life of nitrogen-13 is 10 minutes. Determine the decay constant for nitrogen-13. *[2]*

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(d) A sample initially contains 0.13 mg of nitrogen-13.

Calculate the

(i) initial rate of emission of β^+ particles from the sample. *[2]*

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(ii) mass of nitrogen-13 remaining after 15 minutes. *[2]*

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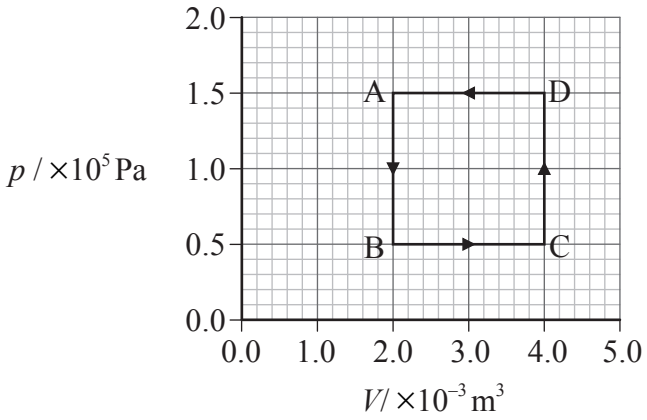
Option C — Energy Extension

C1. This question is about the thermodynamics of an ideal gas.

The diagram below shows the pressure-volume (p-V) relation of a fixed mass of an ideal gas undergoing a thermodynamic cycle.



(a) During the change A → B, explain whether

(i) the internal energy of the gas increases, decreases **or** stays the same. *[2]*

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(ii) thermal energy is transferred between the gas and its surroundings. *[2]*

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(b) During the change B → C, explain whether work is done **either** by the gas on its surroundings **or** by the surroundings on the gas. *[2]*

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(This question continues on the following page)

(Question C1 continued)

(c) Calculate the overall energy transferred during one cycle. *[2]*

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(d) Explain whether, after a complete cycle, the internal energy of the gas overall increases, decreases **or** stays the same. *[2]*

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C2. This question is about the generation of electrical power.

Fossil fuel power stations and solar power stations can be used for the generation of electrical power.

(a) State and explain whether the sources of energy in each of these power stations is classified as renewable or non-renewable. *[2]*

Fossil fuel power:

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Solar power:

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(b) Discuss the main energy **transformations** that are involved in the use of fossil fuels to generate electrical energy. *[4]*

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(c) Photovoltaic cells and active solar heaters are both solar power devices. Outline the difference between these two devices. *[2]*

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(This question continues on the following page)

(Question C2 continued)

(d) State **one** disadvantage of fossil fuel power production and **one** disadvantage of solar power devices. *[2]*

Fossil fuel power production:

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Solar power devices:

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Option D — Biomedical Physics

D1. This question is about scaling.

Two mammals, X and Y, have similar body shapes. The mass of mammal X is 40 kg, whereas the mass of mammal Y is 10 kg.

(a) (i) Deduce that the ratio

$$\frac{\text{length of mammal X}}{\text{length of mammal Y}}$$

has a value of 1.6. *[2]*

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(ii) State **one** assumption made in the calculation in (a)(i). *[1]*

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(b) Mammal X and mammal Y are both exposed to a very cold environment. Explain why the body temperature of mammal X would fall more slowly than that of mammal Y. *[3]*

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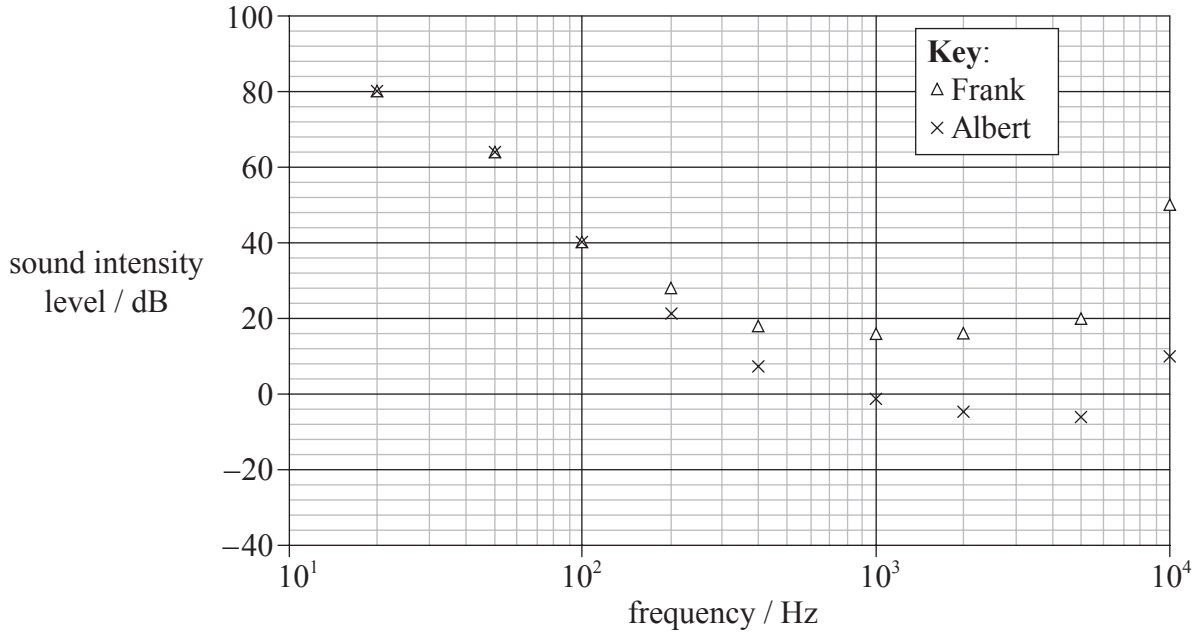
D2. This question is about hearing.

The graph below shows the variation with frequency of the threshold of hearing for two identical twin brothers, Frank and Albert.



Frank and Albert have worked in different places for many years. One workplace was very quiet and the other was very noisy.

(a) Suggest, with reference to the graph, which brother is likely to have worked in the noisy workplace. *[2]*

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(b) For a frequency of 10 000 Hz, calculate the ratio

$$\frac{\text{intensity of the sound just detectable by Frank}}{\text{intensity of the sound just detectable by Albert}}.$$ *[2]*

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(Question D2 continued)

(c) State **one** feature of the graph that suggests one of the brothers suffers from sensory hearing loss. *[1]*

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(d) A person with a damaged cochlea will have loss of hearing at selected narrow frequency ranges. Explain how this phenomenon leads to a loss of speech discrimination. *[3]*

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D3. This question is about X-ray imaging.

(a) Outline how a CT (Computed Tomography) X-ray image is produced and state the nature of the image. *[3]*

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(b) Describe the use of barium in X-ray imaging. *[3]*

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Option E — The History and Development of Physics

E1. This question is about the motion of stars and planets.

Three observations that can be made concerning the apparent relative motion of planets and stars are:

- stars do not move relative to each other
- planets move relative to the fixed stars
- planets change direction in their motion.

(a) Explain, with the aid of a diagram, how the Aristotelian model **or** the Ptolemaic model accounted for these three observations. *[4]*

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(b) Discuss the differences between the Ptolemaic model and Kepler's model of the solar system. *[3]*

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E2. This question is about the caloric theory.

(a) Describe how the caloric theory accounted for thermal conduction. *[2]*

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(b) Discuss the observations and deductions, made by Count Rumford in 1798, that disproved the caloric theory. *[3]*

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E3. This question is about theories of electric charge.

(a) A piece of plastic when rubbed with a cloth becomes electrically charged. Outline how this phenomenon is explained by the

(i) two fluid model of Du Fay. *[2]*

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(ii) modern atomic model of matter. *[3]*

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(b) In the late 19th century, J J Thomson measured the charge-to-mass ratio for an electron. Outline how this measurement was made. *[3]*

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Option F — Astrophysics

F1. This question is about measuring stellar distances.

(a) Describe what is meant by

(i) apparent brightness. *[1]*

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(ii) apparent magnitude. *[2]*

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(iii) absolute magnitude. *[1]*

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(b) State the property of a star that is most closely related to its absolute magnitude. *[1]*

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(c) The star Ross 128 has an apparent magnitude that is less than its absolute magnitude. Explain, with reference to this statement, why the method of stellar parallax may be used to measure the distance of Ross 128 from Earth. *[3]*

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(Question F1 continued)

(d) Describe how the observed spectrum of very distant stars can be used to estimate their absolute magnitude. *[4]*

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(e) The apparent brightness of Ross 128 is $7.9\times10^{-15}\,\mathrm{W\,m^{-2}}$ and its luminosity is $1.1\times10^{21}\,\mathrm{W}$. Determine in parsecs, the distance of Ross 128 from Earth. *[3]*

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F2. This question is about the Doppler shift and the expansion of the universe.

When light from distant galaxies is analysed, the spectral lines are observed to have been Doppler shifted.

(a) State the reason for this Doppler shift. *[1]*

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(b) Penzias and Wilson discovered that there was a uniform source of microwave radiation from every direction in the universe. Explain how this discovery supports the theory that the universe is expanding. *[2]*

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(c) It is suggested that the rate of expansion of the universe might have been gradually increasing since the Big Bang. State and describe the effect, if any, that this theory would predict about the observed Doppler shift of light from distant galaxies. *[2]*

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Option G — Relativity

G1. This question is about Special Relativity.

Two inertial observers, Alice and Bob, are moving towards each other along the same straight line with constant relative speed v. On either side of Alice are two lamps, X and Y, equal distances away from Alice and at rest in her reference frame.

The diagram below represents the situation according to Bob's reference frame.

Alice has a switch that controls each of the lamps. The lamps are initially switched off.

(a) Describe what is meant by an inertial reference frame. *[1]*

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(b) Alice closes the switch, producing an electromagnetic signal that travels from her to the lamps. When either lamp receives the electromagnetic signal it turns on. State and explain the order in which the signal arrives at the lamps (X first, Y first **or** simultaneously)

(i) according to Alice. *[2]*

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(ii) according to Bob. *[2]*

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(This question continues on the following page)

(Question G1 continued)

(c) Explain, in terms of the path taken by electromagnetic waves from the switch to Bob, why Bob receives light from lamp Y before light from lamp X. *[2]*

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(d) Two events are defined as follows:

- event P: the switch for lamp X is closed
- event Q: the light from lamp X arrives at Alice.

Alice measures a time t_A and Bob measures a time t_B between these two events.

(i) Discuss, with reference to proper time, the difference in value between t_A and t_B. *[3]*

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(ii) State and explain whether your answer to (d)(i) would be different for the situation in which Alice was moving away from Bob at speed v as measured by Bob. *[2]*

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(This question continues on the following page)

(Question G1 continued)

(e) Alice measures the distance between the lamps to be 30.0 m. The speed v is 0.90 c.

(i) Explain whether the proper length between the two lamps is greater than, equal to **or** less than 30.0 m. *[1]*

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(ii) Calculate the distance between the lamps, as measured by Bob. *[2]*

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G2. This question is about relativistic velocity addition and relativistic mass.

A particle, P, is moving at constant velocity 0.950c along the x-axis, with respect to an inertial laboratory reference frame. The diagram below represents this situation according to the laboratory reference frame.

The particle decays. One of the decay products is a smaller particle Q of rest mass 940 MeV c^{-2} that is ejected at velocity 0.900c along the x-axis relative to P's reference frame.

The diagram below represents the situation according to P's reference frame. The other decay products are not shown.

(a) Calculate the velocity of particle Q as measured in the laboratory reference frame. *[2]*

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(b) Calculate the difference between the mass of particle Q in P's reference frame and the laboratory reference frame. *[3]*

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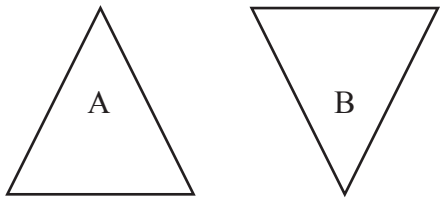
Option H — Optics

H1. This question is about dispersion.

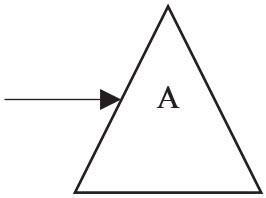
Diagram 1 below shows two identical prisms A and B. Prism B is inverted with respect to prism A.

Diagram 1



A narrow beam of white light is incident on a glass prism A as shown in diagram 2.

Diagram 2



(This question continues on the following page)

(Question H1 continued)

All the light incident on prism A passes through prism B.

(a) (i) On **diagram 2** opposite, draw lines to show the path of a ray of red light and the path of a ray of blue light as it passes through and emerges from prism A. Label the paths *R* for red and *B* for blue. *[2]*

(ii) On **diagram 2** opposite, draw prism B in the path of the light that has passed through prism A. Draw lines, continuing from those from (a), to show the path of the ray of red light and the path of the ray of blue light as they pass through and emerge from prism B. *[2]*

(b) A screen is placed in the path of the light emerging from prism B. Describe the appearance of the light on the screen. *[2]*

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H2. This question is about the reflection and refraction of laser light.

(a) Define *refractive index*. *[1]*

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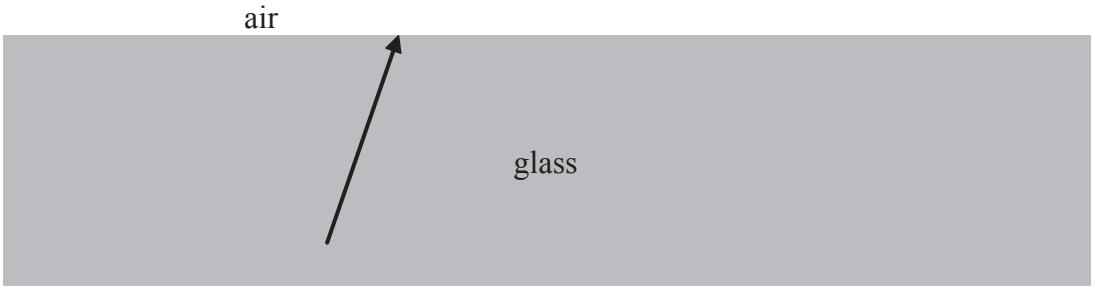
(b) A beam of laser light is incident on a glass/air boundary.



(i) On the diagram above, draw rays to show the reflected ray (label this L) and the refracted ray (label this R). *[1]*

(ii) The angle of incidence of the beam is gradually increased. Deduce how the path of the laser light would change for angles of incidence up to 80°. The refractive index of the glass is 1.5. *[4]*

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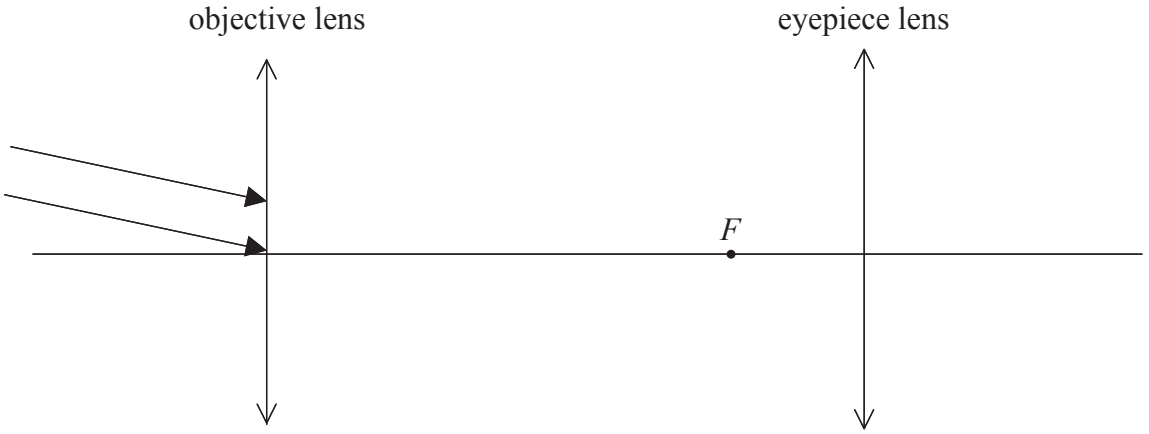
(Option H continued)

H3. The following question is about an astronomical telescope.

A telescope in normal adjustment is pointed at a distant object. Parallel light rays are incident on the objective lens, as shown in the diagram below.



The lenses are positioned so that their focal points are at the same location, labelled *F* on the diagram.

(a) (i) On the diagram above, construct a ray diagram to locate the final image. *[3]*

(ii) On the diagram above, label with the letter E where the eye should be placed in order to view the image. *[1]*

(iii) State, with a brief explanation, the location of the final image. *[1]*

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(This question continues on the following page)

(Question H3 continued)

(b) Use your diagram to explain why the image produced by a telescope is

(i) magnified. *[2]*

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(ii) inverted. *[1]*

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