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

N06/4/PHYSI/SP3/ENG/TZ0/XX+

88066506

PHYSICS
STANDARD LEVEL
PAPER 3

Monday 6 November 2006 (morning)

1 hour

Candidate session number

0	0							

INSTRUCTIONS TO CANDIDATES

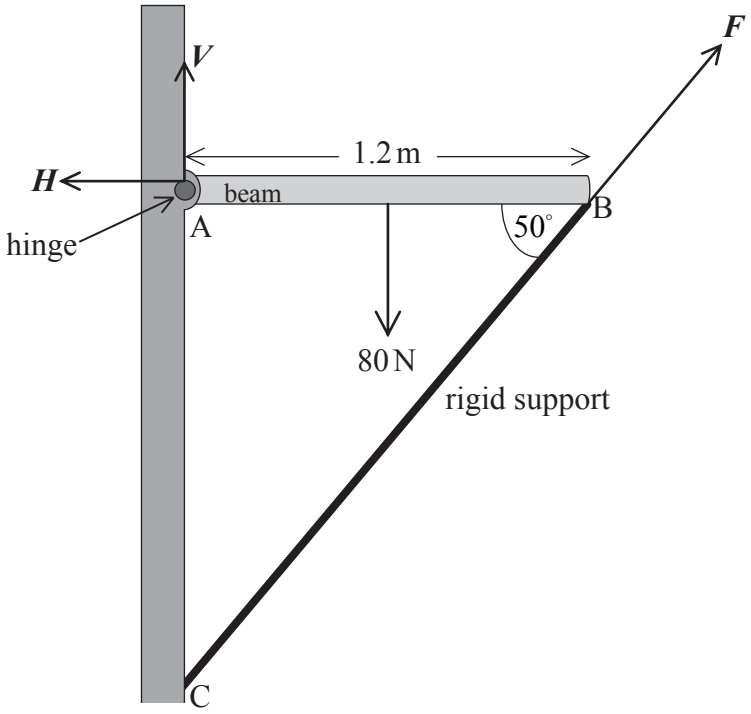
- Write your session number code in the boxes above.
- Do not open this examination paper until instructed to do so.
- Answer all of the questions from two of the Options in the spaces provided.
- At the end of the examination, indicate the letters of the Options answered in the candidate box on your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

0130

Option A — Mechanics Extension

A1. This question is about supporting a beam of wood.

A uniform beam of wood AB is hinged at point A to a vertical wall. The beam is kept horizontal by a rigid support BC of negligible weight.



The length of the beam AB is 1.2 m and its weight is 80 N. The angle between the rigid support and the beam is 50°. The force that the hinge exerts on the beam at A may be resolved into a vertical component ***V*** and a horizontal component ***H*** as shown on the diagram. The force ***F*** is the force that the support BC exerts on the beam.

(This question continues on the following page)

(Question A1 continued)

(a) Deduce that the magnitude of the force ***F*** is 52 N. *[3]*

. . . . . .

. . . . . .

. . . . . .

. . . . . .

. . . . . .

(b) Calculate the magnitude and direction of the resultant reaction force at A. *[4]*

. . . . . .

. . . . . .

. . . . . .

. . . . . .

. . . . . .

. . . . . .

A2. This question is about the energy of orbiting satellites.

(a) Define the term *gravitational potential* at a point in a gravitational field. *[2]*

. . . . . .

. . . . . .

. . . . . .

(b) A satellite is in orbit about Earth at a distance R from the centre of Earth. The Earth may be regarded as a point mass situated at its centre.

Deduce that the kinetic energy of the satellite is numerically equal to half the potential energy of the satellite. *[3]*

. . . . . .

. . . . . .

. . . . . .

. . . . . .

. . . . . .

(c) The distance between the centre of the Moon and the centre of Earth is about 4.0×10^{8} m. The Moon may also be regarded as a point mass situated at its centre. The orbital period of the Moon about the Earth is 2.4×10^{6} s.

(i) Calculate the orbital speed of the Moon. *[2]*

. . . . . .

. . . . . .

. . . . . .

. . . . . .

(ii) Use your answer in (b) and (c)(i) to calculate a value for the gravitational potential due to Earth at a distance of 4.0×10^{8} m from its centre. *[2]*

. . . . . .

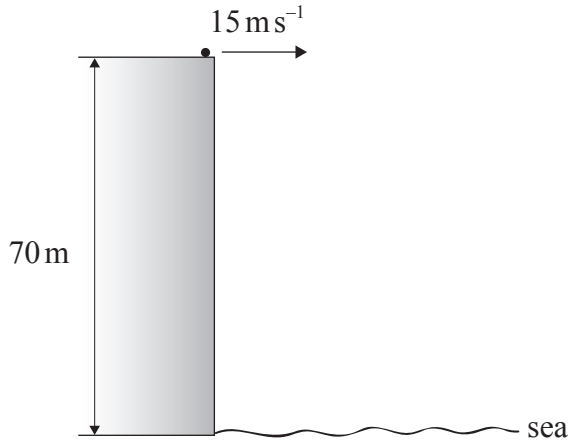
. . . . . .

. . . . . .

. . . . . .

A3. This question is about projectile motion.

A stone is projected horizontally from the top of a cliff with a speed $15\,m\,s^{-1}$.



The height of the cliff is 70 m and the acceleration of free fall is $10\,m\,s^{-2}$. The stone strikes the surface of the sea at velocity V.

(a) Ignoring air resistance, deduce that the stone strikes the sea at a speed of $40\,m\,s^{-1}$. *[2]*

. . . . . .

. . . . . .

. . . . . .

. . . . . .

(b) Use your answer in (a) to calculate the angle that the velocity V makes with the surface of the sea. *[2]*

. . . . . .

. . . . . .

. . . . . .

. . . . . .

Option B — Quantum Physics and Nuclear Physics

B1. This question is about energy levels and atomic models.

(a) Diagram 1 below shows some of the energy levels (measured in electron-volts) of the hydrogen atom. Diagram 2 is a representation of part of the visible spectrum of atomic hydrogen (not to scale).

Diagram 1

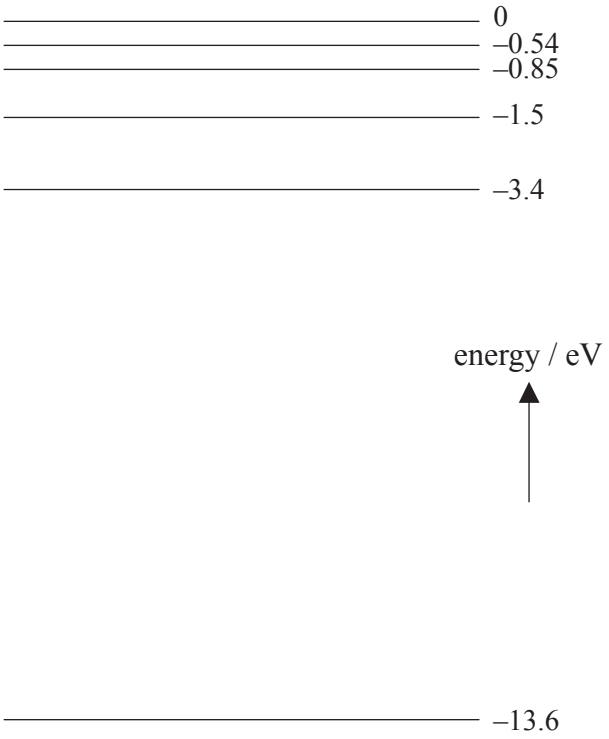
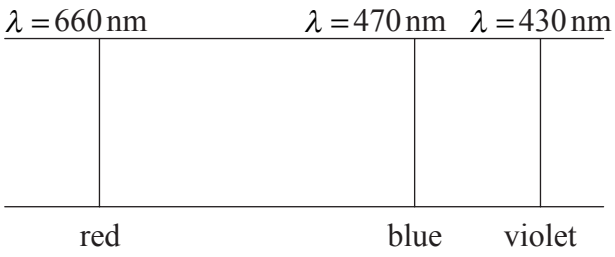


Diagram 2



(i) State the value of the ionization energy of hydrogen. *[1]*

. . . . . .

(ii) The wavelength corresponding to the red line in the visible spectrum of atomic hydrogen is 660 nm. Deduce that the energy of a photon of wavelength 660 nm is 1.9 eV. *[3]*

. . . . . .

. . . . . .

. . . . . .

. . . . . .

. . . . . .

(This question continues on the following page)

(Question B1 continued)

(iii) On **diagram 1**, draw an arrow to show the electron transition between energy levels that gives rise to a photon of energy 1.9 eV. Label this arrow with the letter R. *[1]*

(iv) On **diagram 1** and using your answer to (iii), draw arrows to show the electron transitions that give rise to the blue line and to the violet line in the visible spectrum of atomic hydrogen. Label these arrows B and V respectively. *[1]*

(b) The kinetic energy of an electron in the ground state of a hydrogen atom is 13.6 eV. Deduce that an electron in the ground state of the hydrogen atom has a de Broglie wavelength of approximately 3.3×10^{-10} m (mass of electron $= 9.1\times10^{-31}$ kg). *[4]*

. . . . . .

. . . . . .

. . . . . .

. . . . . .

. . . . . .

. . . . . .

(c) The "radius" of the hydrogen atom is of the order of 10^{-10} m. Outline how the value of the de Broglie wavelength in (b) is consistent with the Schrödinger model of the hydrogen atom. *[3]*

. . . . . .

. . . . . .

. . . . . .

. . . . . .

B2. This question is about radioactive decay.

(a) Define the term *decay constant*. *[1]*

. . . . . .

. . . . . .

(b) The isotope potassium-40 undergoes beta decay to form the isotope calcium-40.

State the name of the

(i) interaction responsible for this decay process. *[1]*

. . . . . .

(ii) exchange particle associated with the interaction in (i). *[1]*

. . . . . .

(c) The mass of potassium-40 and the mass of calcium-40 in a sample of some rocks is measured. The following data are available:

mass of potassium-40	$= 5.0\,\text{mg}$
mass of calcium-40	$= 24\,\text{mg}$
decay constant of potassium-40	$= 5.3 \times 10^{-10}\,\text{year}^{-1}$

When the rocks were created they contained no calcium-40 but did contain potassium-40. By determining the time that has elapsed since there was only potassium-40 in the sample, calculate the age of the rocks. *[4]*

. . . . . .

. . . . . .

. . . . . .

. . . . . .

. . . . . .

. . . . . .

Blank page

Option C — Energy Extension

C1. This question is about the first law of thermodynamics and about a steam engine.

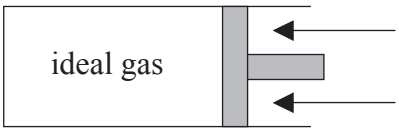
(a) State the first law of thermodynamics. *[2]*

. . . . . .

. . . . . .

. . . . . .

(b) An ideal gas in a cylinder is compressed by a piston.



The work done on the gas is 250 J and the change in internal energy of the gas is 150 J. Explain how these energy changes are consistent with the first law of thermodynamics. *[3]*

. . . . . .

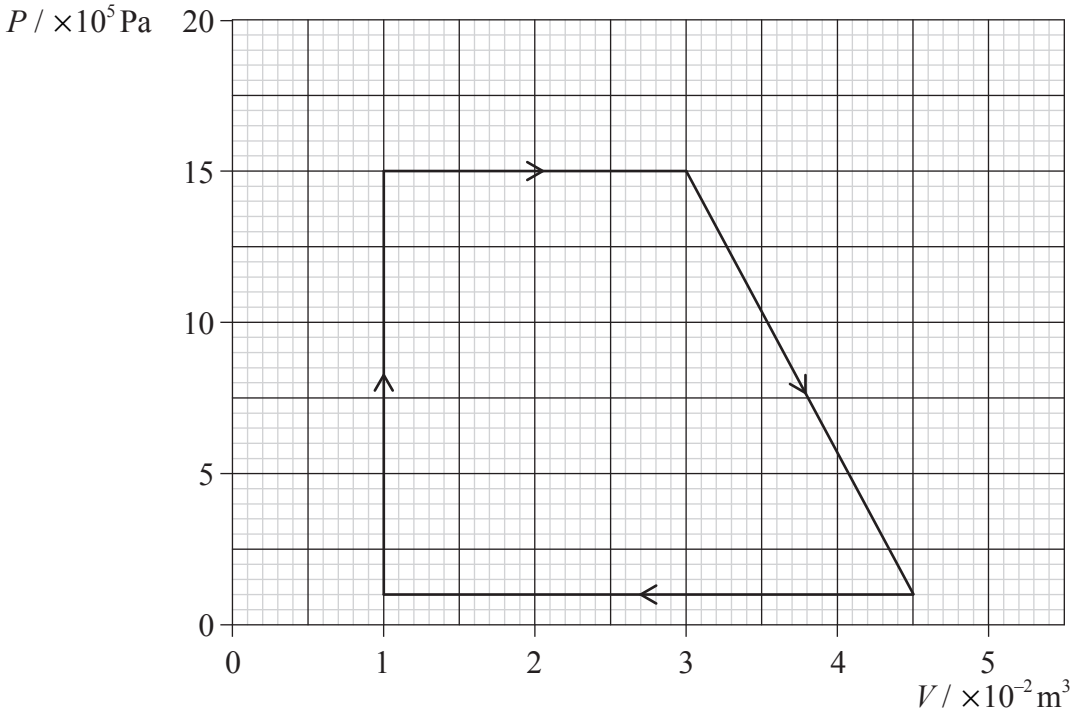
. . . . . .

. . . . . .

(This question continues on the following page)

(Question C1 continued)

(c) In one cycle of a steam engine, water is heated at high pressure until changed into steam at a very high temperature. This steam expands and is then compressed such that it turns back to water. The graph below shows the idealised relationship between the pressure P and volume V of the water and steam for one cycle of this steam engine.



(i) Use the graph above to deduce that the work done by the engine in one cycle is approximately 4×10^4 J. *[2]*

. . . . . .

. . . . . .

. . . . . .

. . . . . .

(ii) As a result of compressing the steam, the energy transferred to the surroundings is approximately 1×10^5 J. Estimate the efficiency of the steam engine. *[3]*

. . . . . .

. . . . . .

. . . . . .

. . . . . .

. . . . . .

C2. This question is about solar power.

(a) Describe, in terms of energy transformations, the difference between a photovoltaic cell and an active solar heater. *[2]*

. . . . . .

. . . . . .

. . . . . .

. . . . . .

(b) A photovoltaic cell of area $6.5 \times 10^{-4}\,m^2$ is situated on the roof of a house. The cell has an efficiency of 8 %. At a time when the power of the solar radiation incident on the photovoltaic cell is a maximum, the cell delivers a power of 47 mW to the external circuit.

(i) Deduce that the maximum value of the power of the solar radiation incident on the cell is approximately $0.90\,kW\,m^{-2}$. *[2]*

. . . . . .

. . . . . .

. . . . . .

. . . . . .

(ii) State **one** reason why the power of solar radiation at any particular region does not have a constant value. *[1]*

. . . . . .

. . . . . .

(This question continues on the following page)

(Question C2 continued)

(c) A power of 3.0 kW is required to produce adequate hot water for the house.

(i) Use the data from (b) to determine the minimum area of the photovoltaic cells required to generate this power. *[2]*

. . . . . .

. . . . . .

. . . . . .

. . . . . .

(ii) The efficiency of energy conversion in an active solar heater is 24 %. Calculate the minimum area of this solar heater required to generate this power. *[1]*

. . . . . .

. . . . . .

(iii) State and explain whether it is more practical to use photovoltaic cells or an active solar heater to provide hot water for the house. *[2]*

. . . . . .

. . . . . .

. . . . . .

. . . . . .

Option D — Biomedical Physics

D1. This question is about scaling.

Two insects have the same shape. The linear dimensions of insect A are 2.0 times the linear dimensions of insect B.

(a) Calculate the ratio

(i) $\frac{\text{surface area of insect A}}{\text{surface area of insect B}}$. *[1]*

. . . . . .

. . . . . .

(ii) $\frac{\text{volume of insect A}}{\text{volume of insect B}}$. *[1]*

. . . . . .

. . . . . .

(b) The absorption of oxygen by insects depends on their surface areas. The amounts of oxygen needed depend on the volumes of the insects. Use your answers in (a) to suggest why these conditions limit the size of insects. *[2]*

. . . . . .

. . . . . .

D2. This question is about sound intensity levels.

(a) Distinguish between *sound intensity* and *loudness*. *[2]*

. . . . . .

. . . . . .

. . . . . .

. . . . . .

(b) An engine generates 2.4 W of sound power that is emitted uniformly in all directions. For health reasons, the intensity level at the ear must not exceed 82 dB. Calculate the minimum distance that any person must be from the engine unless wearing ear protection. (The surface area of a sphere of radius r is $4\pi r^2$) *[5]*

. . . . . .

. . . . . .

. . . . . .

. . . . . .

. . . . . .

. . . . . .

. . . . . .

. . . . . .

D3. This question is about X-rays.

A parallel beam of X-rays is used to investigate a broken bone. The attenuation coefficient for soft tissue (muscle) is $0.035\,\text{cm}^{-1}$. The X-ray half-value thickness for bone is about 150 times less than that for soft tissue.

(a) Define the term *half-value thickness*. *[1]*

. . . . . .

. . . . . .

(b) Deduce that the attenuation coefficient for bone is $5.3\ \text{cm}^{-1}$. *[2]*

. . . . . .

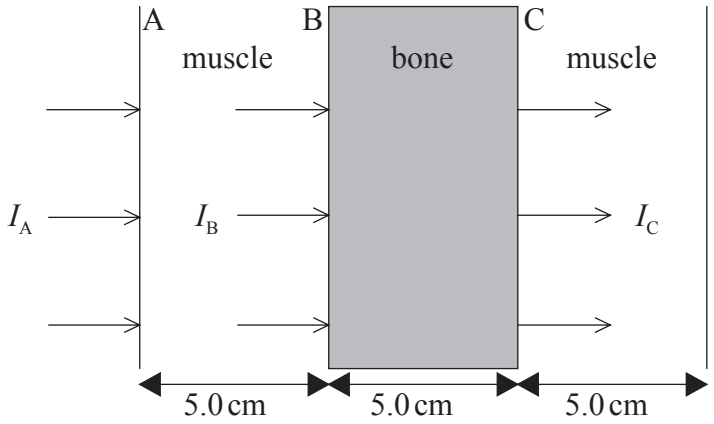
. . . . . .

. . . . . .

(This question continues on the following page)

(Question D3 continued)

(c) A parallel beam of X-rays is incident on the leg of a person. The leg has a bone of diameter 5.0 cm, surrounded by muscle on each side of thickness 5.0 cm. A section through the leg is shown in the diagram below.



The intensity of the X-ray beam at the surface A of the leg is I_A. At the surface B of the bone, the intensity is I_B and the intensity of the beam emerging at surface C of the bone is I_C.

Calculate the ratio

(i) $\frac{I_B}{I_A}$. *[2]*

. . . . . .

. . . . . .

. . . . . .

(ii) $\frac{I_C}{I_B}$. *[1]*

. . . . . .

. . . . . .

(d) Use your answer in (c) to explain how it is possible to obtain a shadow image of the leg and bone. *[3]*

. . . . . .

. . . . . .

. . . . . .

. . . . . .

Option E — The History and Development of Physics

E1. This question is about models of the universe.

(a) When viewed over a period of several years, the Moon and Mars both appear to move relative to the background of the fixed stars. Compare the observed motion of the Moon to that of Mars. *[3]*

Moon:

. . . . . .

. . . . . .

. . . . . .

Mars:

. . . . . .

. . . . . .

. . . . . .

(This question continues on the following page)

(Question E1 continued)

(b) Ptolemy was able to describe precisely and account for the differences in observed motion of the Moon and Mars. Describe the model developed by Ptolemy. *[4]*

. . . . . .

. . . . . .

. . . . . .

. . . . . .

. . . . . .

. . . . . .

(c) According to Aristotle, the orbital motion of the planets is a natural motion. Outline how Newton's understanding of orbital motion of the planets differed from that of Aristotle. *[2]*

. . . . . .

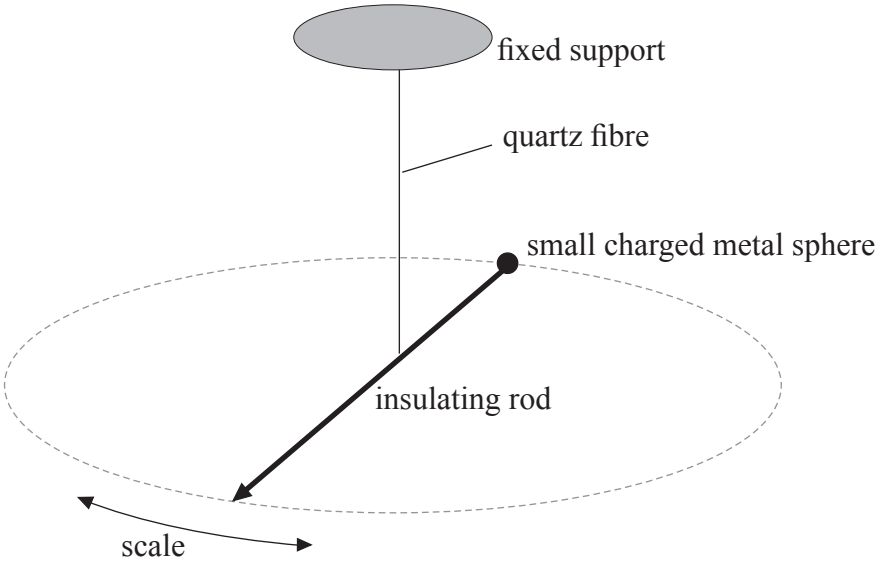
. . . . . .

. . . . . .

. . . . . .

E2. This question is about the force between electrical charges.

The diagram below shows some apparatus, similar to that used by Coulomb, to establish the relation between the force between point charges and their separation.



(a) With the aid of the diagram above, outline how the apparatus may be used to determine the relation between the force between the charges and the separation of the charges. *[4]*

. . . . . .

. . . . . .

. . . . . .

. . . . . .

. . . . . .

. . . . . .

. . . . . .

(b) By knowing the ratio of the charges on the two spheres, Coulomb also established the relation between force and magnitude of charges. Explain how Coulomb determined these ratios. *[2]*

. . . . . .

. . . . . .

. . . . . .

. . . . . .

E3. This question is about cathode rays.

(a) By means of a labelled sketch diagram, outline the discovery of cathode rays. *[3]*

. . . . . .

. . . . . .

. . . . . .

. . . . . .

. . . . . .

(b) Describe how cathode rays were shown to be charged particles. *[2]*

. . . . . .

. . . . . .

. . . . . .

. . . . . .

Option F — Astrophysics

F1. (a) State where in the solar system, with respect to the planetary orbits, the greatest concentration of asteroids is found. *[1]*

. . . . . .

(b) Some constellations are not visible in the night sky for the whole of the year. Suggest **one** reason for this observation. *[2]*

. . . . . .

. . . . . .

. . . . . .

F2. This question is about stellar observations.

(a) Define the following terms.

(i) *Luminosity* *[1]*

. . . . . .

. . . . . .

(ii) *Apparent brightness* *[1]*

. . . . . .

. . . . . .

(b) The spectrum and temperature of a certain star are used to determine its luminosity to be approximately 5.0×10^{31} W. The apparent brightness of the star is 1.4×10^{-9} W m^{-2}. These data can be used to determine the distance of the star from Earth.

(i) State the name of this technique used to determine distances to stars. *[1]*

. . . . . .

. . . . . .

(ii) Calculate the distance of the star from Earth in parsec. *[3]*

. . . . . .

. . . . . .

. . . . . .

. . . . . .

(This question continues on the following page)

(Question F2 continued)

(c) Distances to some stars can be measured by using the method of stellar parallax.

(i) Outline this method. *[4]*

. . . . . .

. . . . . .

. . . . . .

. . . . . .

. . . . . .

(ii) Modern techniques enable stellar parallax angles as small as 5.0×10^{-3} arc-second to be measured. Calculate the maximum distance that can be measured using the method of stellar parallax. *[1]*

. . . . . .

. . . . . .

. . . . . .

F3. This question is about cosmology.

(a) Describe the observational evidence in support of an expanding universe. *[2]*

. . . . . .

. . . . . .

. . . . . .

(b) Define the term *critical density* of the universe. *[1]*

. . . . . .

. . . . . .

(c) Discuss the significance of comparing the density of the universe to the critical density for determining the future of the universe. *[3]*

. . . . . .

. . . . . .

. . . . . .

. . . . . .

. . . . . .

Option G — Relativity

G1. This question is about relativistic kinematics and mechanics.

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

. . . . . .

. . . . . .

. . . . . .

(b) State the **two** postulates of Special Relativity. *[3]*

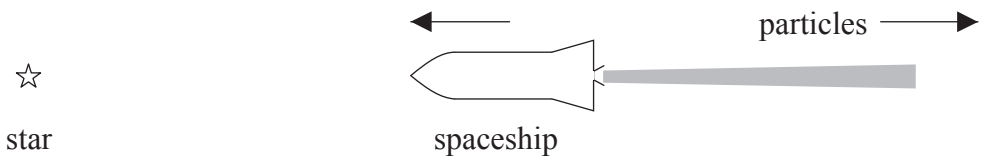
. . . . . .

. . . . . .

. . . . . .

. . . . . .

(c) A spaceship with a proper length of 240 m is travelling towards a star with a speed of 0.80c relative to the star. The exhaust from its rocket engine is a high-energy beam of particles. The particles move at a speed of 0.60c as measured by an observer in the spaceship.



Another observer is in the inertial reference frame of the star.

For this observer

(i) calculate the length of the spaceship. *[2]*

. . . . . .

. . . . . .

. . . . . .

. . . . . .

(ii) calculate the speed of the particles. *[2]*

. . . . . .

. . . . . .

. . . . . .

. . . . . .

(This question continues on the following page)

(Question G1(c) continued)

(iii) state the direction of the relative motion of the particles. *[1]*

. . . . . .

(d) The rest mass of the spaceship is 3.0×10^3 kg. Determine the total energy, in joule, of the spaceship as measured by the observer in the inertial reference frame of the star. *[2]*

. . . . . .

. . . . . .

. . . . . .

G2. This question is about muon decay.

(a) Explain what is meant by *time dilation*. *[2]*

. . . . . .

. . . . . .

. . . . . .

. . . . . .

(b) Discuss how observations of muons created in the upper atmosphere of Earth are used as evidence for time dilation. *[4]*

. . . . . .

. . . . . .

. . . . . .

. . . . . .

. . . . . .

. . . . . .

(c) A particular muon created in the upper atmosphere of Earth has a lifetime of 2.20 μs as measured in the muon's reference frame. The speed, as measured by an observer on the ground, is 0.995c ($\gamma = 10$). Calculate the distance moved by the muon during its lifetime as measured by an observer on the ground. *[2]*

. . . . . .

. . . . . .

. . . . . .

. . . . . .

Option H — Optics

H1. This question is about dispersion and refractive index.

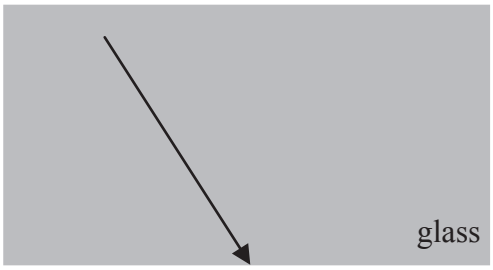
(a) State and explain what is meant by the *dispersion* of white light. *[2]*

. . . . . .

. . . . . .

. . . . . .

(b) A narrow beam of light is incident from glass on a boundary between glass and air as shown below.



The beam consists of a mixture of red and blue light.

(i) On the diagram above, draw labelled rays to show the path of the red and blue light in air. *[2]*

(ii) The refractive index of glass for the red light is 1.52. Calculate the maximum angle of incidence on the glass air boundary for the red light to pass into the air. *[2]*

. . . . . .

. . . . . .

. . . . . .

(iii) Explain whether the blue light would pass into the air for the angle calculated in (ii). *[2]*

. . . . . .

. . . . . .

. . . . . .

H2. This question is about an astronomical telescope.

(a) Angular magnification M of a lens or system of lenses may be defined using the expression

$$M = \frac{\theta_i}{\theta_o}.$$

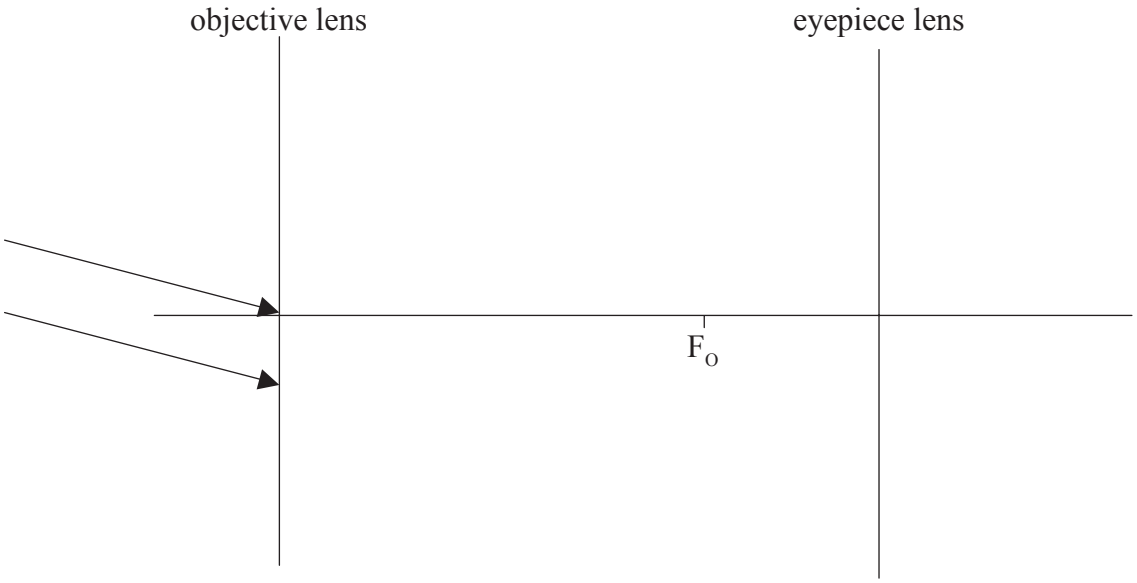
Explain what is represented by the angles θ_i and θ_o. *[2]*

. . . . . .

. . . . . .

(b) The diagram below represents the objective lens and the eyepiece lens of an astronomical telescope in normal adjustment (final image formed at infinity). The point F_O is in the focal plane of the objective lens.

Two parallel rays from a distant point source are shown incident on the objective lens.



On the diagram above

(i) draw the positions of the principal foci of the eyepiece lens (label these points F_E). *[1]*

(ii) construct rays to locate the position of the final image. *[3]*

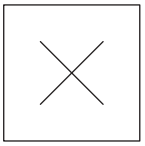
(iii) draw the position of the eye (label this with the letter E). *[1]*

(iv) label the angles θ_i and θ_o. *[1]*

(This question continues on the following page)

(Question H2 continued)

(c) A telescope is used to view a distant flat, square shaped object on which a cross has been drawn. The outline of the object is shown below.



Describe the appearance of the image of the object, including the cross, due to the lens having

(i) spherical aberration only. *[2]*

. . . . . .

. . . . . .

. . . . . .

(ii) chromatic aberration only. *[2]*

. . . . . .

. . . . . .

. . . . . .