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

N02/430/H(3)+

PHYSICS
HIGHER LEVEL
PAPER 3

Wednesday 6 November 2002 (morning)

1 hour 15 minutes

Name

Number

INSTRUCTIONS TO CANDIDATES

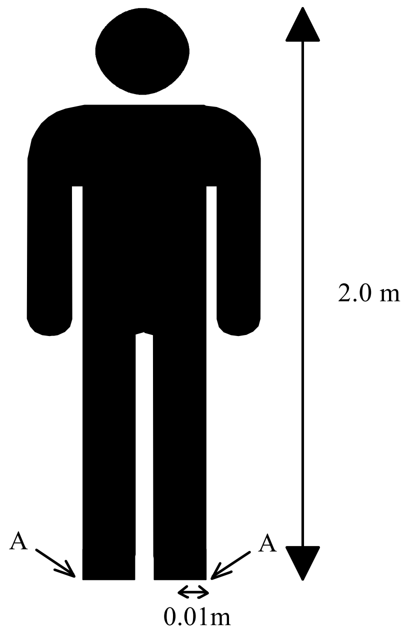
- Write your candidate name and number in the boxes above.
- Do not open this examination paper until instructed to do so.
- Answer all of the questions from two of the Options in the spaces provided.
- At the end of the examination, indicate the letters of the Options answered in the boxes below.

OPTIONS ANSWERED	EXAMINER	TEAM LEADER	IBCA
	/30	/30	/30
	/30	/30	/30
	TOTAL /60	TOTAL /60	TOTAL /60

OPTION D — BIOMEDICAL PHYSICS

D1. This question considers whether or not a human giant is a physical possibility.

The weight of a standing person must be supported by the two leg bones at the points labelled A in the diagram below.



The bones are under compressive stress where stress is defined as $\frac{force}{area}$.

(a) Juan is a large person of height 2.0 m and weight 1000 N. If the radius of Juan's leg bone at point A is 0.01 m show that the stress in one of Juan's leg bones when he is standing upright is $1.6 \times 10^6\ \mathrm{N\,m^{-2}}$. *[2]*

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(b) When Juan runs at top speed the stress in his leg bones is five times greater than when he is standing upright. What is the stress in Juan's leg bones when he is running at top speed? *[1]*

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(This question continues on the following page)

(Question D1 continued)

(c) Suppose now there exists a person whose linear dimensions are x times that of the linear dimensions of Juan such that the height of this person is $2.0x$ m. Deduce, in terms of x, expressions for

(i) the weight of this person. *[2]*

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(ii) the stress in one of this person's leg bones when he is standing upright. *[3]*

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(d) The breaking stress of bone is $1.0 \times 10^{7}\ \text{N m}^{-2}$.

(i) Estimate the maximum height that this person can have such that his legs will not break when he is **running** at his top speed. *[2]*

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(ii) Give **one** reason why in reality the maximum height that a human can have will probably be less than your estimated value. *[1]*

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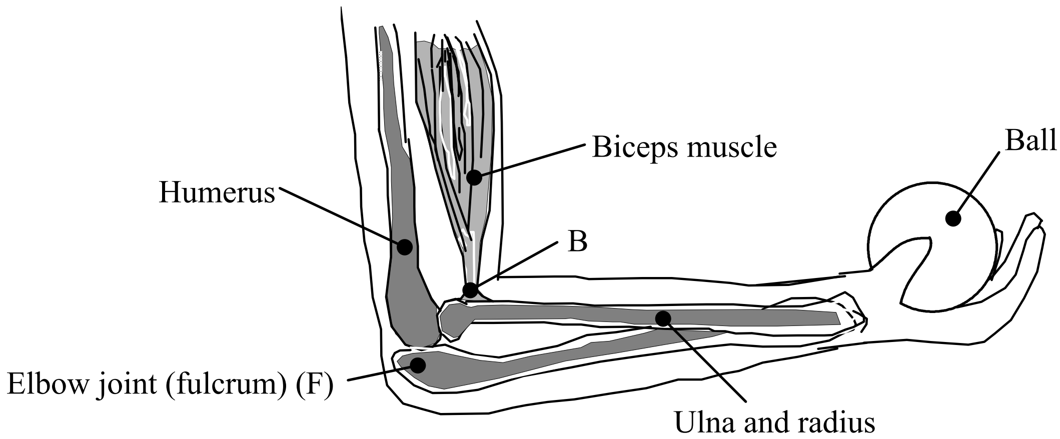
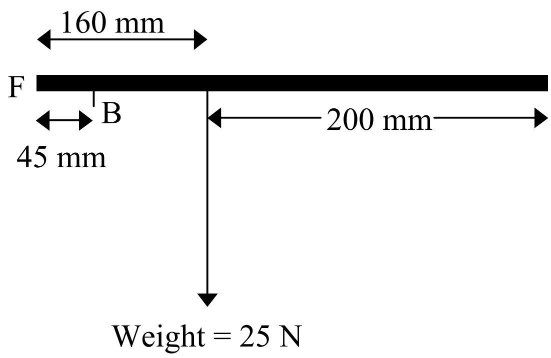
D2. This question is about forces and the arm.

The diagram below shows the arm of a person holding a ball in the palm of his/her hand with the forearm horizontal. The weight of the forearm is 25 N and the weight of the ball is 8.0 N.



The diagram below is a representation of the forearm showing relevant distances. B is the point where the bicep muscles are attached to the forearm.



(a) On the diagram above draw labelled arrows to represent all the forces acting on the forearm when the ball is held in the hand. *(One force, namely the weight, has already been drawn for you).* *[3]*

(b) Calculate the force that the biceps muscle exerts on the forearm. *[2]*

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D3. This question is about hearing loss.

(a) Explain the terms *air conduction* and *conductive hearing loss*. *[2]*

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(b) As a result of conductive hearing loss a person suffers a loss in hearing of 50 dB at a frequency of 1000 Hz. A person with normal hearing can just hear a sound of intensity $10^{-12}\ \text{W m}^{-2}$ at a frequency of 1000 Hz. Calculate the intensity of sound at frequency 1000 Hz that can be just heard by the person suffering the hearing loss. *[2]*

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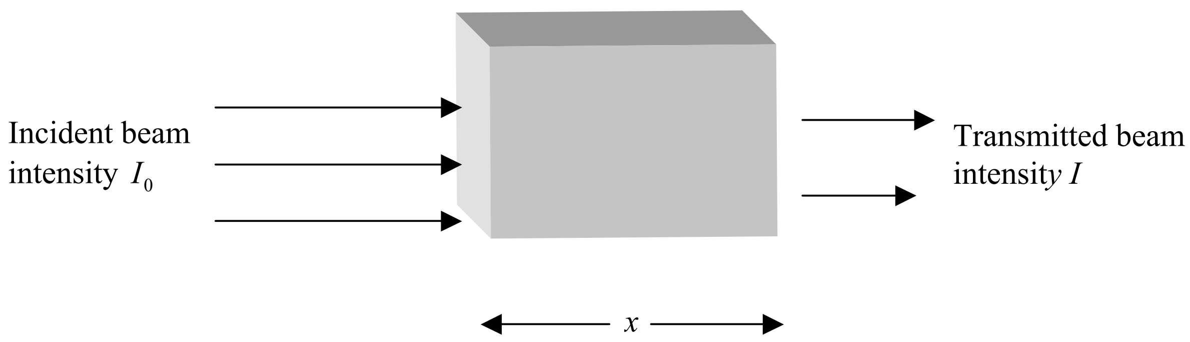
D4. This question is about X-rays.

The diagram below shows a beam of X-rays of intensity I_0 incident on a slab of a particular material of thickness x.



The intensity of the beam is attenuated as it passes through the material. For different values of thickness x of the material the intensity I of the transmitted beam is given by

$$I = I_0 e^{-\mu x}$$

where μ is a constant.

(a) State **two** mechanisms that can cause the attenuation of X-rays in matter. *[2]*

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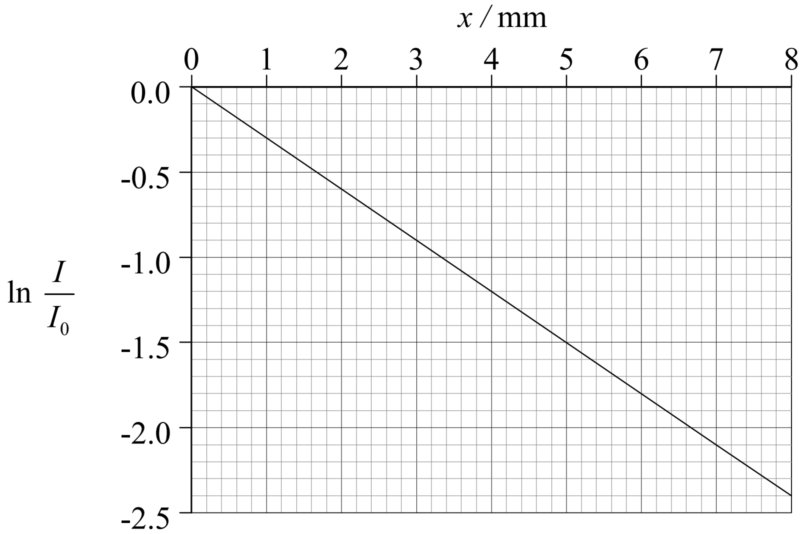
(This question continues on the following page)

(Question D4 continued)

The intensity of transmitted X-rays is measured for lead of different thickness x. The graph below is obtained when $\ln\frac{I}{I_0}$ is plotted against x.



(b) Using information from the graph, determine the constant μ for X-rays of this initial intensity. *[3]*

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(c) X-rays of this initial intensity are used in an X-ray security device at an airport.

(i) Using information from the graph, determine the thickness of lead that will reduce the initial intensity of the X-ray beam by 90 %. *[3]*

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(ii) Explain why it is important to know the thickness of the lead that will reduce the intensity of the X-ray beam by 90 %. *[2]*

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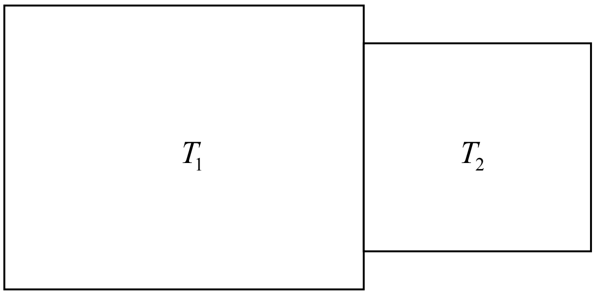
OPTION E — HISTORICAL PHYSICS

E1. This question is about theories of heat.

Prior to about 1840 phenomena associated with heating were explained in terms of the caloric theory.

The diagram below shows two objects at different temperatures T_1 and T_2 $(T_1 > T_2)$ that have just been placed in thermal contact with each other.



(a) Describe how the caloric theory accounted for the two bodies eventually reaching the same temperature. *[4]*

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(b) When you rub your hands together they get warm. How did the caloric theory account for this phenomenon? *[1]*

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(Question E1 continued)

(c) James Joule, a nineteenth-century scientist, suggested that heat is not caloric but a form of energy. In order to test his idea he measured the temperature of water at the top and bottom of a waterfall.

(i) Why did Joule expect there to be a difference in temperature between the water at the top and at the bottom of the waterfall? *[2]*

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(ii) Estimate the height of a waterfall for which the difference in temperature would be $1\,^{\circ}\mathrm{C}$. (The specific heat capacity of water = $4200\ \mathrm{J\,kg^{-1}\,K^{-1}}$ and $g = 10\ \mathrm{m\,s^{-2}}$.) *[3]*

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E2. This question is about models of the Universe.

(a) Astronomers often refer to stars as “fixed stars”. Given the fact that many stars move east to west across the night sky what do they mean by the term *fixed stars*? *[2]*

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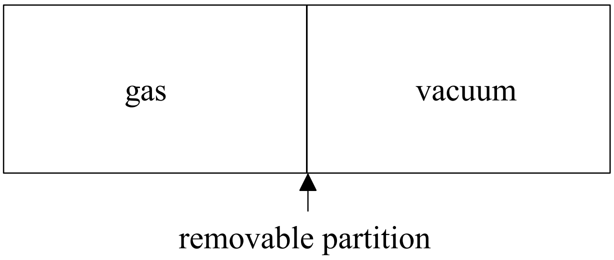
(b) The nightly pattern of the fixed stars changes and so does the annual pattern. The Aristotelian model of the Universe and the Copernican model of the Universe each offer different explanations for these observed changes. Complete the table below describing how each model explains each observed change. *[8]*

Observation	**Explanation of observation in terms of the Aristotelian model**	**Explanation of observation in terms of the Copernican model**
Change in the pattern of the fixed stars over a period of one night	. . . .	. . . .
Change in the pattern of the fixed stars over a period of one year	. . . .	. . . .

E3. The diagram below shows a container which is divided in two by a partition. In one side there is a gas and on the other side a vacuum.



(a) The partition is now removed such that the gas now fills the whole container.

(i) State and explain what has happened to the entropy of the gas. *[2]*

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(ii) State how the second law of thermodynamics relates to this situation. *[1]*

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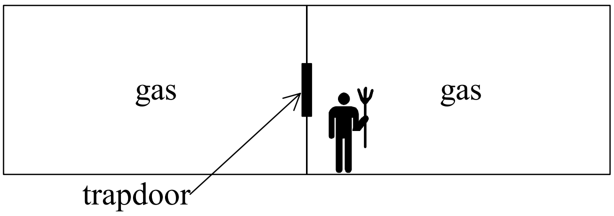
(Question E3 continued)

(b) Maxwell devised a "thought experiment" based on an idea similar to the situation described above to demonstrate how the second law of thermodynamics might be violated. However, in Maxwell's experiment the partition now separates two gases each at the same temperature, pressure and volume. The partition is now fitted with a trapdoor that can be operated by a "demon". *(See the diagram shown below.)*



(i) Outline Maxwell's thought experiment and explain how the result can be seen to violate the second law. *[3]*

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(ii) Suggest a flaw in Maxwell's thought experiment that indicates that the second law is in fact not violated. *[1]*

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E4. This question is about the fundamental interactions and their exchange particles.

Fill in the blank rows in the table below listing the four **fundamental** interactions and their exchange particles. *(Please note that the first row has been completed for you.)* *[3]*

Interaction	**Exchange particle**
Gravity	Graviton

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OPTION F — ASTROPHYSICS

F1. This question is about the apparent magnitude, apparent brightness and luminosity of two stars.

The table below gives some information about two stars Aldebaran and Procyon B.

Star	**Distance from Earth (light years)**	**Apparent magnitude**	**Apparent brightness $W\,m^{-2}$**
Aldebaran	65.1	+ 0.87	3.0×10^{-10}
Procyon B	11.4	+ 10.7	1.5×10^{-14}

(a) Explain the difference between *apparent magnitude* and *apparent brightness*. *[3]*

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(b) As viewed from Earth, explain which star in the above table will appear the brightest. *[2]*

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(c) Explain which star has the greatest luminosity. *[2]*

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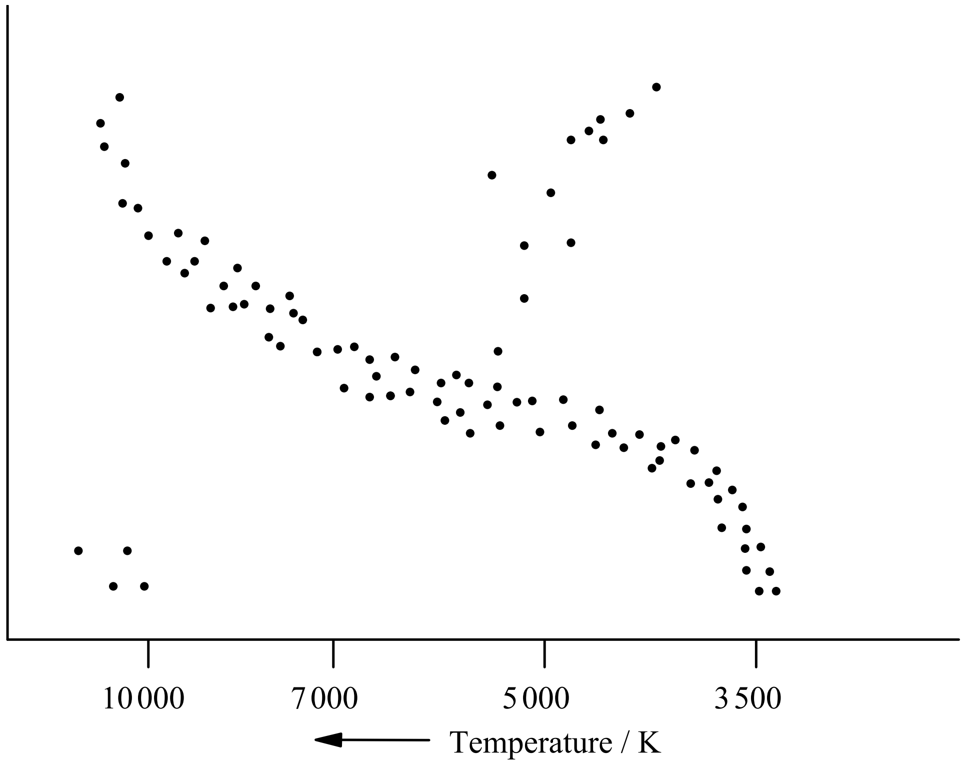
(Question F1 continued)

(d) A Hertzsprung-Russell diagram is shown below.



(i) Label the vertical axis of the above diagram. *[1]*

(ii) Aldebaran is a Red Giant and Procyon B is a White Dwarf. Mark the approximate positions of these two stars on the diagram above. *[2]*

(e) The apparent brightness of the Sun is $1.4 \times 10^3\ \text{W m}^{-2}$. Using information in the table at the start of the question, show that the Sun is about 2×10^5 times more luminous than Procyon B. (1 light year = 6.3×10^4 AU). *[4]*

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F2. This question is about galaxies.

(a) Most galaxies are moving **away** from the Earth. How do astronomers deduce that the galaxies are moving and how do they deduce that they are moving away from the Earth? *[3]*

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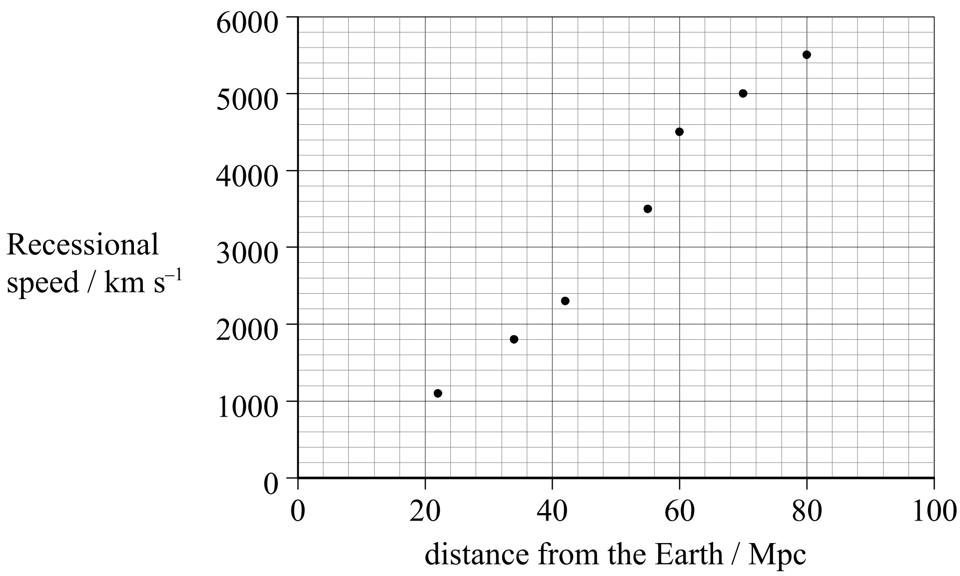
In the graph below the recessional speed of some galaxies is plotted against their distance from the Earth.



(b) Draw a line of best-fit and hence determine a value of Hubble's constant. *[3]*

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(c) A certain spectral line as measured in the laboratory has a wavelength of 390.0 nm. When measured in the spectrum of a galaxy the wavelength is found to be 395.8 nm.

(i) Determine the recession speed of the galaxy. *[3]*

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(ii) Using the above graph estimate the distance of the galaxy from Earth. *[1]*

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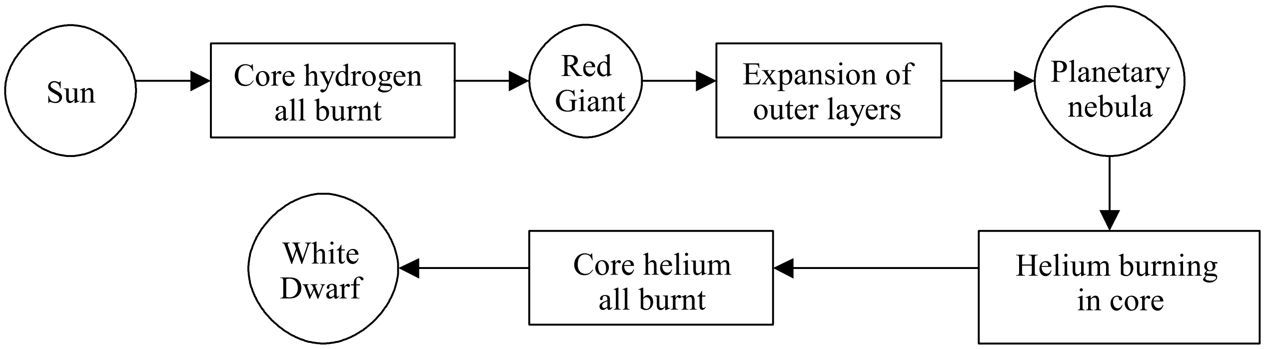
F3. This question is about stellar evolution.

The flow chart below shows some of the principal stages that occur as the Sun evolves to a White Dwarf. Circles are used for the different types of objects that occur during the evolution and boxes are used for the processes which lead to the formation of the different types of objects.



Complete the flow diagram below, using circles for the different types of object formed and boxes for the processes, to show the principal stages of the evolution and final fate of a star which is about ten times more massive than the Sun. *[6]*

Final type of object

OPTION G — SPECIAL AND GENERAL RELATIVITY

G1. This question is about the relativistic motion of particles called pions.

(a) One of the two postulates of Einstein's theory of Special Relativity can be stated as *all inertial observers will measure the same value for the free space velocity of light.*

(i) Explain what is meant by the term *inertial observer*. *[1]*

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(ii) State the other postulate of Special Relativity. *[1]*

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(b) The accelerator at the Brookhaven National Laboratory produces a beam of pions. The pions are unstable and last on average 2.55×10^{-8} s before decaying. This time is a proper time. Explain what is meant by the term *proper time* in this context. *[1]*

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(This question continues on the following page)

(Question G1 continued)

(c) After pions are produced they travel along a tube with a speed of 0.98c as measured in the laboratory frame of reference.

Determine, as measured in the laboratory frame of reference,

(i) the average time that the pions last before decaying. *[3]*

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(ii) the average distance the pions travel along the tube before decaying. *[2]*

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(d) From the pions' point of view they are stationary and it is the tube that is moving past them. Confirm by calculation, using appropriate values of distance and time, that the speed of the tube relative to the pions is the same as the speed of the pions relative to the laboratory reference frame. *[5]*

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G2. This question is about the principle of equivalence.

(a) State Einstein's principle of equivalence as used in his theory of General Relativity. *[2]*

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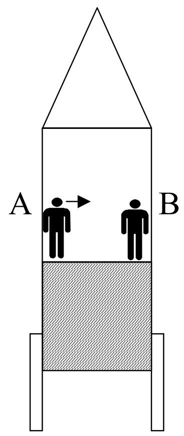
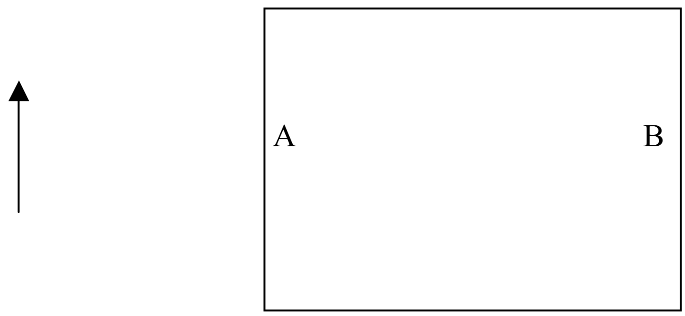
The diagram below shows a spaceship that is far away from any large masses such as planets or stars. The spaceman at position A throws a ball towards another spaceman at position B.

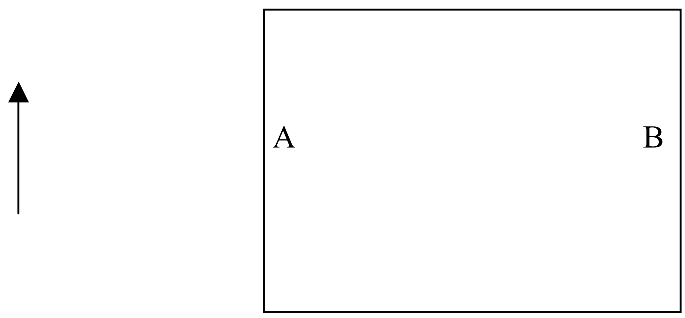


(b) Sketch on the following diagrams the path of the ball as seen by the spacemen if the spaceship is

(i) moving with constant speed in the direction shown by the arrow. *[1]*



(ii) moving with positive acceleration in the direction shown by the arrow. *[2]*



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(Question G2 continued)

(c) The spacemen actually observe the path followed by the ball when the spaceship is accelerating. However, they reach the conclusion that the spaceship is not accelerating but is in fact stationary on the surface of a planet. Could the spacemen be correct? Explain. *[2]*

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G3. This question is about the energy and momentum of colliding protons.

Two beams of protons travelling in opposite directions are made to collide.

The protons in **each** beam have the **same total energy**. The following reaction takes place when a proton in one beam collides with a proton in the other beam

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

where $\tilde{p}^-$ is an antiproton.

The rest mass of a proton and the rest mass of an antiproton is 930 MeV c^{-2}.

(a) Show, stating any assumptions that you have made, that the minimum **total** energy required by a proton in each beam in order for the above reaction to take place is 1860 MeV. *[2]*

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(b) Determine

(i) the potential difference through which each proton must be accelerated in order to obtain a total energy of 1860 MeV. *[2]*

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(ii) the momentum of a proton that has a total energy of 1860 MeV. *[4]*

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(Question G3 continued)

(c) The reaction $p^+ + p^+ \rightarrow p^+ + p^+ + p^+ + \tilde{p}^-$ can also be brought about by colliding an accelerated beam of protons with stationary protons.

By considering the conservation of momentum explain why, even if the protons in the accelerated beam have a total energy of 3720 MeV, when they strike stationary protons, this reaction cannot take place. *[2]*

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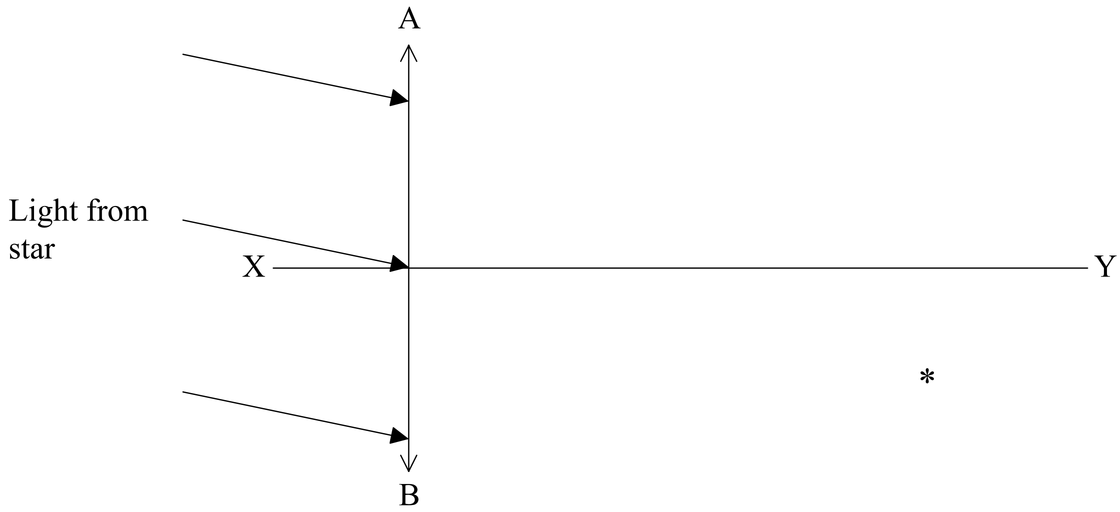
OPTION H — OPTICS

H1. This question is about an astronomical telescope.

(a) Light from a star is incident on a bi-convex lens, AB. The diagram below shows three rays of light from the star incident on the lens. The image of the star is formed at the point marked *.



(i) Explain why the light rays from the star are essentially parallel. *[1]*

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(ii) Complete the ray diagram by showing the path of the three rays after they have passed through the lens. *[1]*

(iii) Mark on the axis XY the position of the principal focus F of the lens. *[1]*

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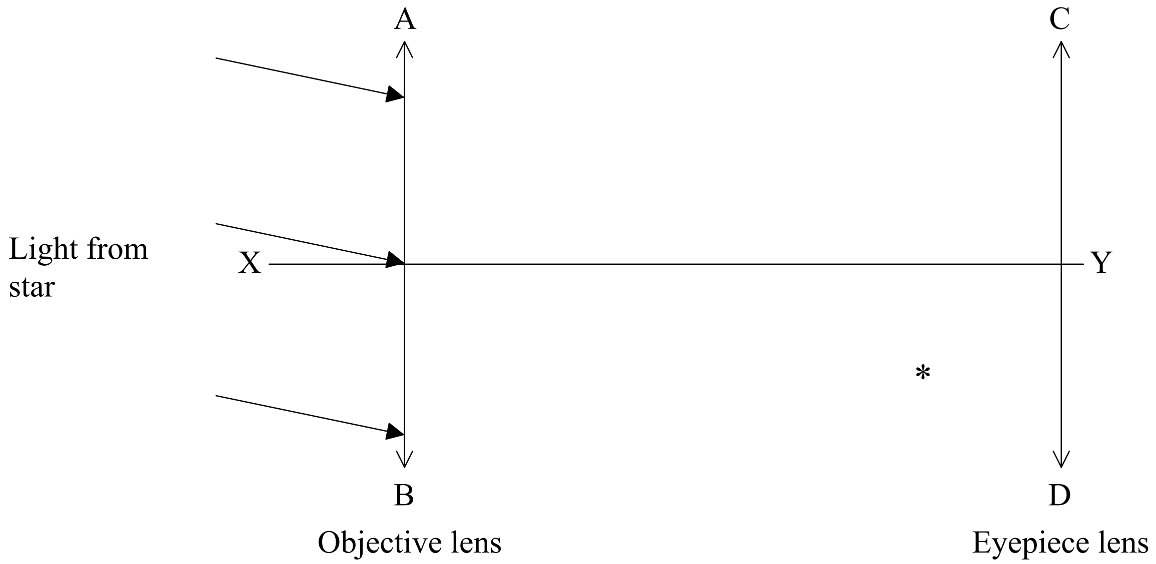
(Question H1 continued)

(b) The lens, AB, in part (a) is used as the objective lens of an astronomical telescope. The diagram below shows the relative positions of the objective and eyepiece lens, CD, and the position of the * image formed by the objective lens when the telescope is used to view the star.



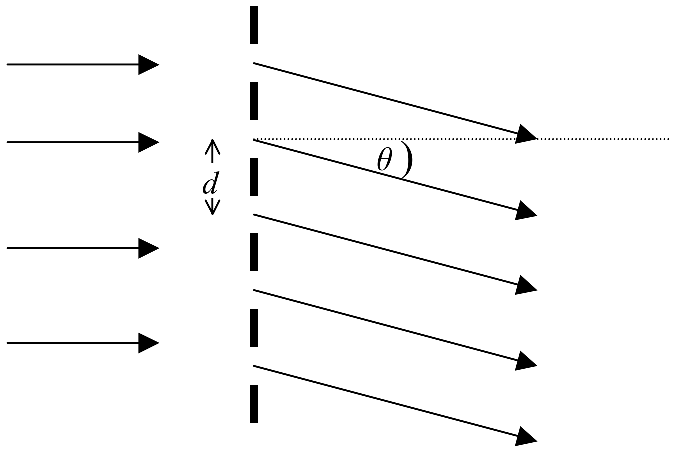
(i) If the final image of the star is formed at infinity, mark on the axis XY the positions of the principal focus F_E of the eyepiece lens and the principal focus F_O of the objective lens. *[1]*

(ii) Complete the ray diagram to determine the direction in which the final image is formed. *[3]*

(iii) Show on the above diagram where the eye should be placed in order to view the final image. *[1]*

H2. This question is about a diffraction grating.

The diagram below shows some of the slits of a diffraction grating upon which a parallel beam of monochromatic light is incident at 90° to the grating. The light diffracted by the slits at an angle θ is also shown.



(a) After passing through the slits the light is brought to a focus on a screen.

(i) Mark on the diagram the path difference between any two adjacent rays. *[1]*

(ii) Hence show that light diffracted at θ will form a principal maximum if the condition $d\sin\theta = n\lambda$ is satisfied where d is the separation between the slits. *[2]*

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(This question continues on the following page)

(Question H2 continued)

(b) The wavelength of the incident light is 500 nm and the diffraction grating has 800 slits per mm.

(i) Determine the angle at which the first principal maximum is formed. *[3]*

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(ii) Determine the number of principal maxima that will be produced on the screen on either side of the central maximum when parallel light is incident on the grating as shown in the diagram opposite. *[3]*

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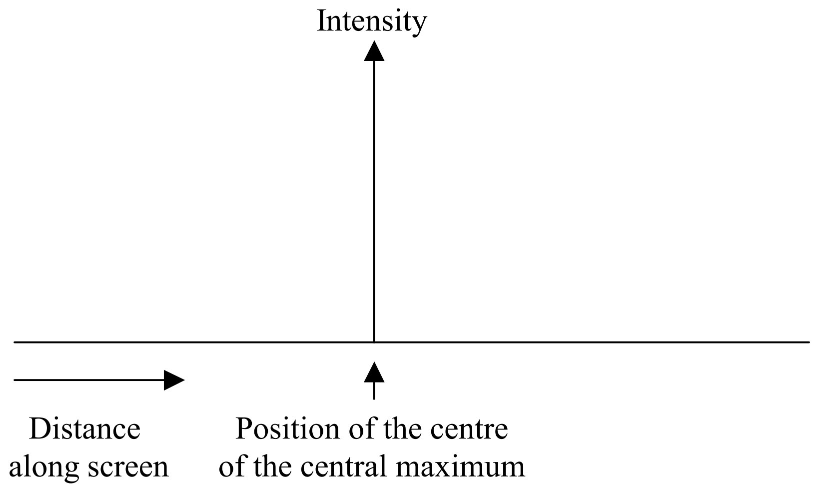
(iii) Using the axes below sketch a diagram to show the intensity distribution of the light on the screen. *(Note that this is a sketch graph; there is no need to add values to the axes).* *[3]*



H3. This question is about short-sightedness and its correction.

Diagram 1 shows light from a distant object incident on the pupil of one eye of a short-sighted person.

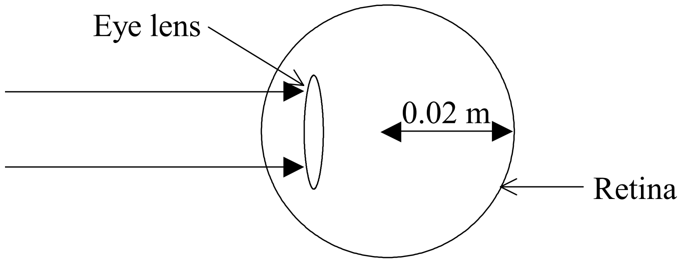


Diagram 1

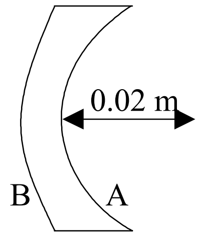


Diagram 2

(a) On diagram 1 show the approximate point P where the rays will be brought to a focus. *[1]*

(b) In order to correct short-sightedness in a particular person a contact lens maker has to make a diverging meniscus lens of focal length 1.00 m. The inner surface A of this lens as shown in diagram 2 has the same radius of curvature as the eye. The refractive index of the material used to make the lens is 1.49 and the radius of curvature of the person's eye is 0.02 m. Determine the radius of curvature of the other surface B of the lens. *[4]*

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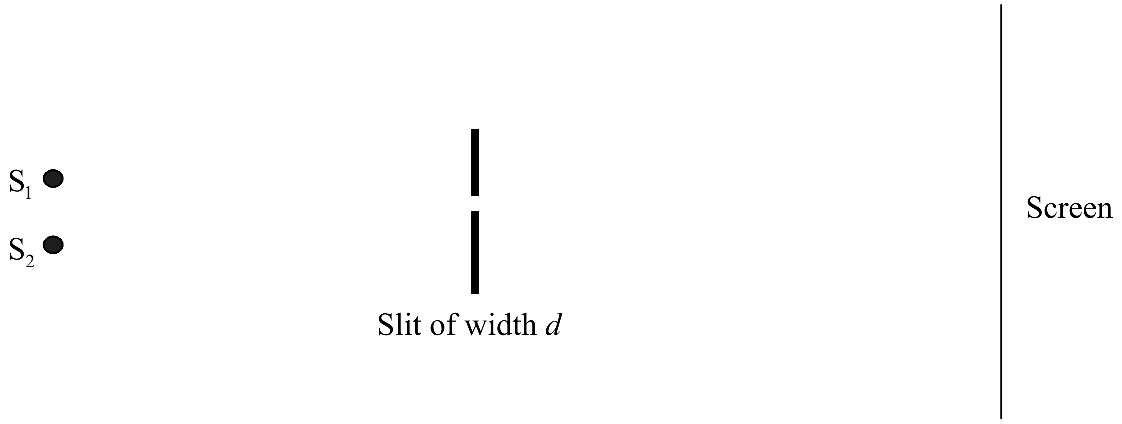
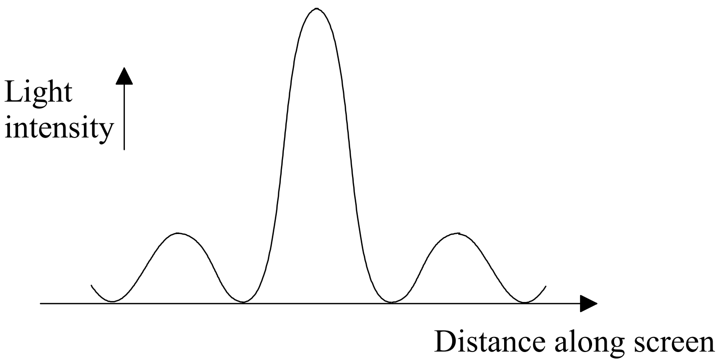
H4. This question is about optical resolution.

Light of wavelength λ from two monochromatic point sources S_1 and S_2 is incident on a narrow slit. After passing through the slit the light is incident on a screen. Both the sources and screen are a long way from the slit. The situation is shown in the diagram below.



The diagram below shows part of the intensity distribution of the image produced on the screen by the source S_1.



(a) Using the diagram above sketch the intensity distribution of the image produced on the screen by the source S_2 when the images of each source are just resolved according to the Rayleigh criterion. *[2]*

(b) The two point sources each emit light of wavelength 500 nm and are at distance of 1.0 m from the slit. The width of the slit is 1.0 mm. Determine the separation of the sources when their respective images are just resolved. *[3]*

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