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

N02/430/S(3)+

**PHYSICS**
**STANDARD LEVEL**
**PAPER 3**

Wednesday 6 November 2002 (morning)

1 hour

Name

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Number

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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.

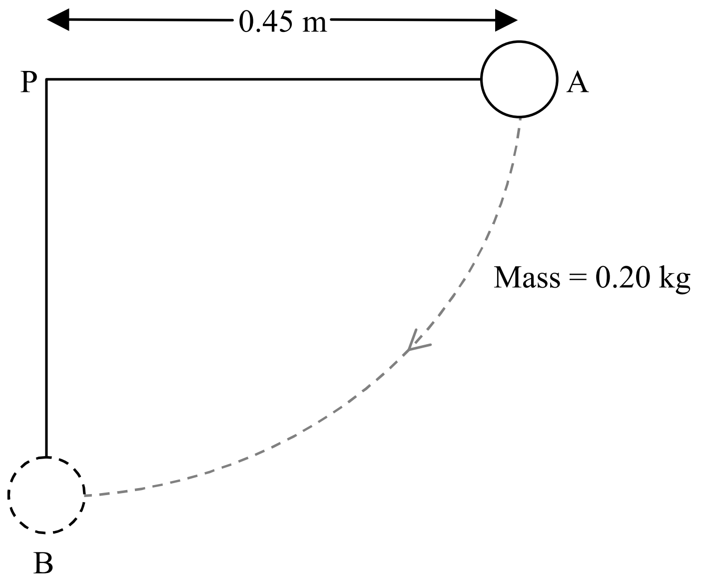
| OPTIONS ANSWERED | EXAMINER | TEAM LEADER | IBCA |
|---|---|---|---|
| | /20 | /20 | /20 |
| | /20 | /20 | /20 |
| | TOTAL /40 | TOTAL /40 | TOTAL /40 |

## OPTION A — MECHANICS EXTENSION

**A1.** This question is about a swinging ball.

In the diagram below a ball of mass 0.20 kg is tied by a string to the point P and is held at the position A with the string horizontal. The distance from P to the centre of the ball is 0.45 m.

The ball is released and it swings down in a circular arc passing through the point B which is vertically below P.




The following questions all refer to the ball at the instant when it is at position B.

You may take the acceleration due to gravity $g = 10\ \text{m s}^{-2}$.

(a) Explain whether the net force acting on the ball is zero **or** not when it is at position B. *[2]*

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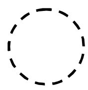
*(This question continues on the following page)*

*(Question A1 continued)*

(b) In the space below draw a labelled free body diagram showing the forces acting on the ball when it is at position B of its motion. *[3]*



B

(c) When the ball is in position B

(i) show that the speed of the ball is $3.0\ \mathrm{m\,s^{-1}}$. *[2]*

(ii) determine the acceleration of the ball. *[2]*

(iii) determine the tension in the string. *[3]*

**A2.** This question is about the oscillations of a mass on a spring.

Diagram 1 below shows a mass *M* suspended from a vertically supported spring. The mass is pulled down to the position marked A and released such that it oscillates with simple harmonic motion between the positions A and B. The equilibrium position of the mass is at the labelled position E.

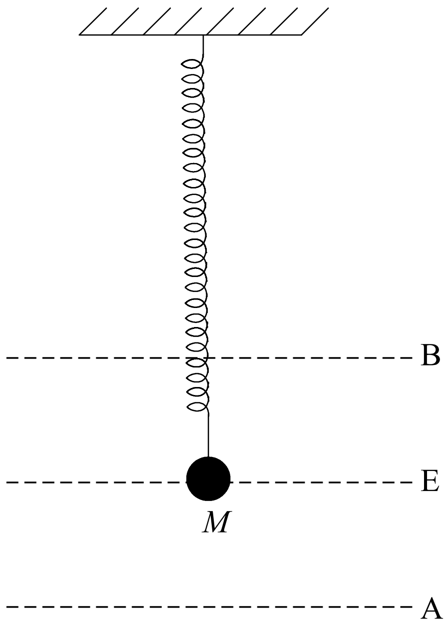



Diagram 1

The time period of the oscillation is 0.80 s. The sketch graph below, diagram 2, shows how the acceleration of the mass varies with time over one time period.

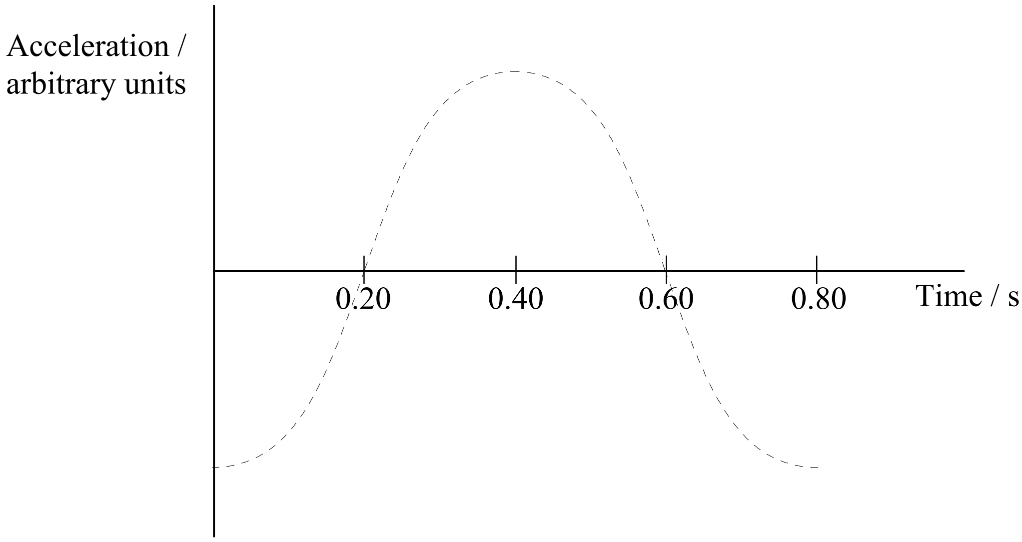


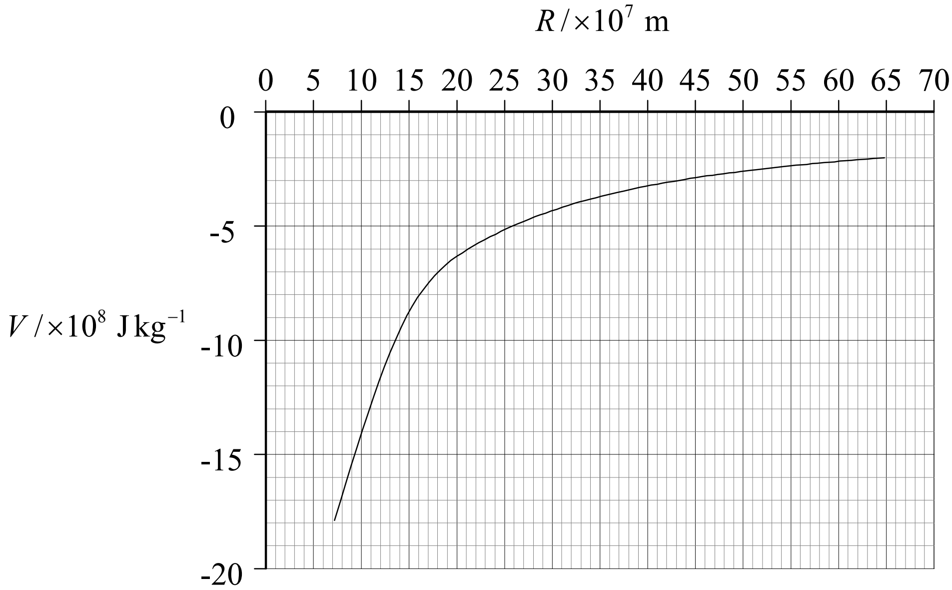

Diagram 2

Mark on the graph above all the points that correspond to the positions A, B and E on diagram 1. *[3]*

**A3.** This question is about gravitational potential and gravitational field.

The graph below shows how the gravitational potential $V$ varies above the surface of a planet measured as a function of distance $R$ from the centre of the planet. Values of the potential from the centre of the planet to the surface are not plotted.

The radius of the planet is $7.2 \times 10^7$ m.




(a) One of the moons of the planet is at a distance of $22 \times 10^7$ m from the centre of the planet. A spaceship of mass $2.0 \times 10^4$ kg is fired towards this moon from the surface of the planet.

Assuming that the mass of the moon is much less than that of the planet, use data from the above graph to find the minimum amount of energy that the spaceship would require in order to just reach this moon. *[4]*

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(b) If the mass of the moon is **not** small compared to the mass of the planet would more energy **or** less energy be required for the spaceship to just reach the moon? Explain. *[1]*

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## OPTION B — ATOMIC AND NUCLEAR PHYSICS EXTENSION

**B1.** This question is about radioactive decay of an isotope of uranium, $^{235}_{92}U$.

When the nuclide $^{235}_{92}U$ undergoes decay the resulting nuclide is radioactive. A series of successive decays can subsequently occur. The position of $^{235}_{92}U$ is shown in the grid below. The grid is labelled with the numbers *N*, *Z* and the symbols for the associated nuclides.

| *N* | Fr | Ra | Ac | Th | Pa | U | Np | Pu |
|---|---|---|---|---|---|---|---|---|
| 143 | | | | | | $^{235}_{92}U$ • | | |
| 142 | | | | | | | | |
| 141 | | | | | | | | |
| 140 | | | | | | | | |
| 139 | | | | | | | | |
| 138 | | | | | | | | |
| *Z* | 87 | 88 | 89 | 90 | 91 | 92 | 93 | 94 |

(a) What does the number 143 represent for the nuclide $^{235}_{92}U$? *[1]*

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$^{235}_{92}U$ decays by alpha emission to a radioactive isotope *P*.
*P* then decays by negative beta emission to another radioactive nuclide *Q*.
*Q* then decays by alpha emission to a nuclide *R*.

(b) Mark on the above grid the positions of the nuclides *P*, *Q* and *R*. *[3]*

(c) What are the atomic number and mass number of the nuclide *R*? *[2]*

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**B2.** This question is about the particle nature of light and the wave nature of electrons.

(a) In the photoelectric effect it is observed that the energy of the electrons emitted from the surface of a metal depends on the frequency of the incident light. Explain why this observation is not consistent with the wave properties associated with light? *[2]*

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(b) Light of wavelength 400 nm is incident on the surface of a metal. The work function of the metal is 2.0 eV.

(i) Define the term *work function*. *[2]*

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(ii) Show that the maximum kinetic energy of the electrons emitted from the surface of the metal is $1.8 \times 10^{-19}$ J. *[5]*

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(c) Show that electrons with this maximum kinetic energy will have a de Broglie wavelength of about 1 nm. *[5]*

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## OPTION C — ENERGY EXTENSION

**C1.** This question is about a heat engine.

(a) Explain the difference between a *heat engine* and a *heat pump*. *[3]*

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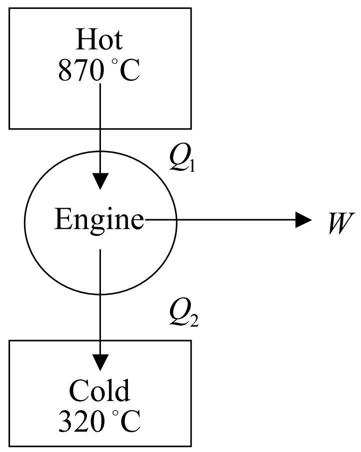
The diagram below represents an idealized heat engine. The engine operates in a Carnot cycle between a hot reservoir at temperature $870\,^{\circ}\mathrm{C}$ and a cold reservoir at temperature $320\,^{\circ}\mathrm{C}$.




During one cycle, $Q_1$ is the energy transferred from the hot reservoir, $Q_2$ is the energy transferred into the cold reservoir and $W$ is the work done by the engine.

(b) Name the law that determines the relationship between $Q_1$, $Q_2$ and $W$. *[1]*

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*(This question continues on the following page)*

*(Question C1 continued)*

(c) The power output for this engine is 100 kW. Determine the rate at which energy is transferred

(i) from the hot reservoir. *[4]*

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(ii) to the cold reservoir. *[2]*

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**C2.** This question is about an active solar heater that uses solar panels.

(a) Outline the principle of operation of an active solar heater that uses solar heating panels. *[3]*

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(b) Estimate, using the data below, the area of solar panels required to raise the temperature of 1000 kg of water by 25 K in 3.0 hours.

Average solar power received per unit area $= 1000 \text{ W m}^{-2}$

Specific heat capacity of water $= 4.2 \times 10^{3} \text{ J kg}^{-1} \text{ K}^{-1}$

Assume that 60 % of the solar energy is used to heat the water. *[5]*

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(c) State **two** disadvantages in using solar panels for heating water. *[2]*

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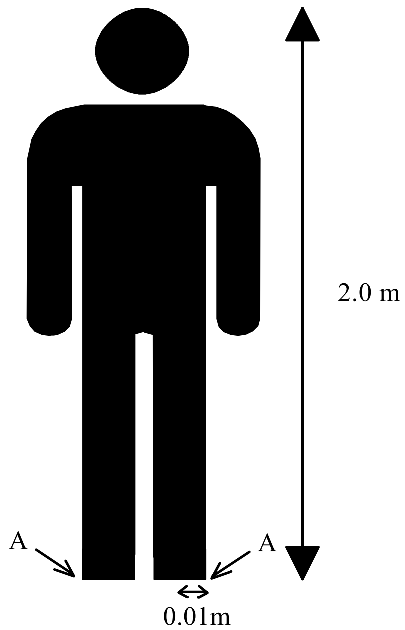
**OPTION D — BIOMEDICAL PHYSICS**

**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 $1.6 \times 10^6\ \text{N m}^{-2}$. *[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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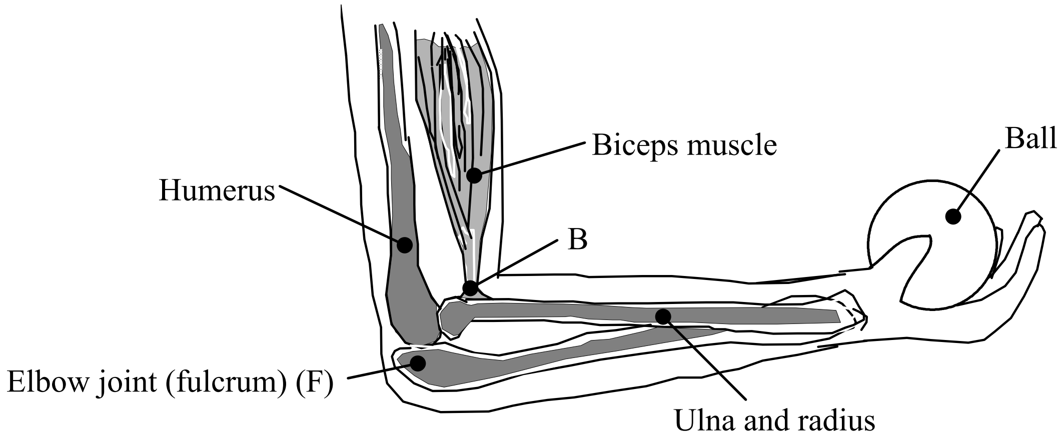
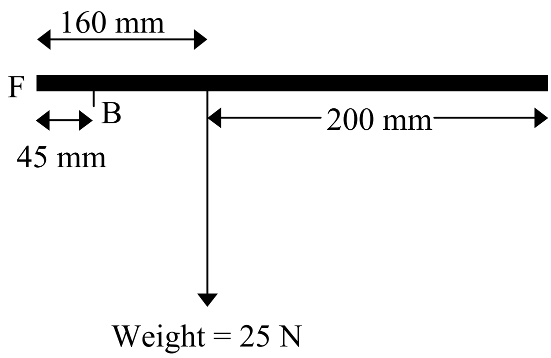
**D2.** This question is about forces and the arm.

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 $10^{-12}$ 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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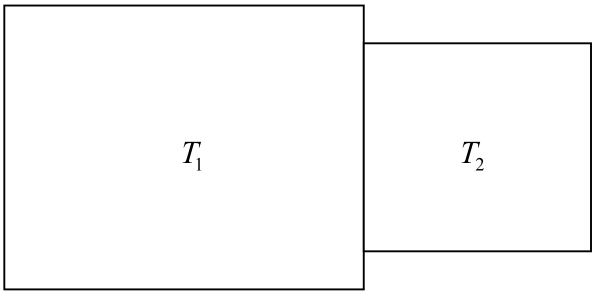
## OPTION E — HISTORICAL PHYSICS

**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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*(This question continues on the following page)*

*(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 °C. (The specific heat capacity of water = 4200 J $kg^{-1}$ $K^{-1}$ and $g$ = 10 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 | . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . | . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . |

## 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 | $3.0 \times 10^{-10}$ |
| Procyon B | 11.4 | + 10.7 | $1.5 \times 10^{-14}$ |

(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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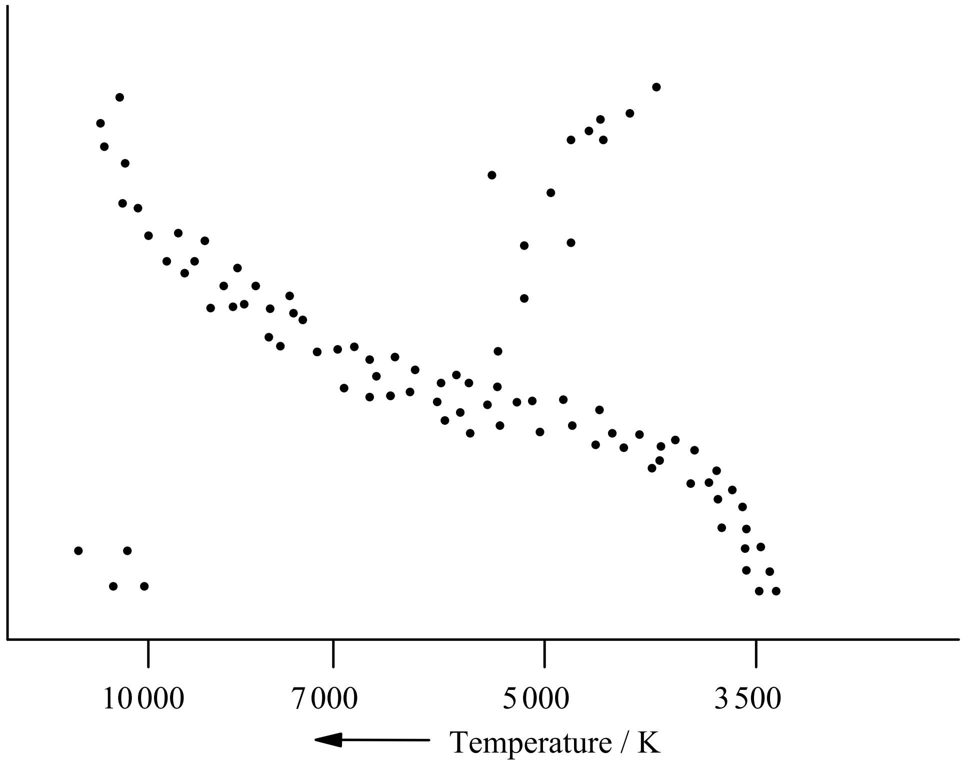
*(This question continues on the following page)*

*(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 $1.4\times10^{3}\ \text{W m}^{-2}$. Using information in the table at the start of the question, show that the Sun is about $2\times10^{5}$ times more luminous than Procyon B. (1 light year = $6.3\times10^{4}$ 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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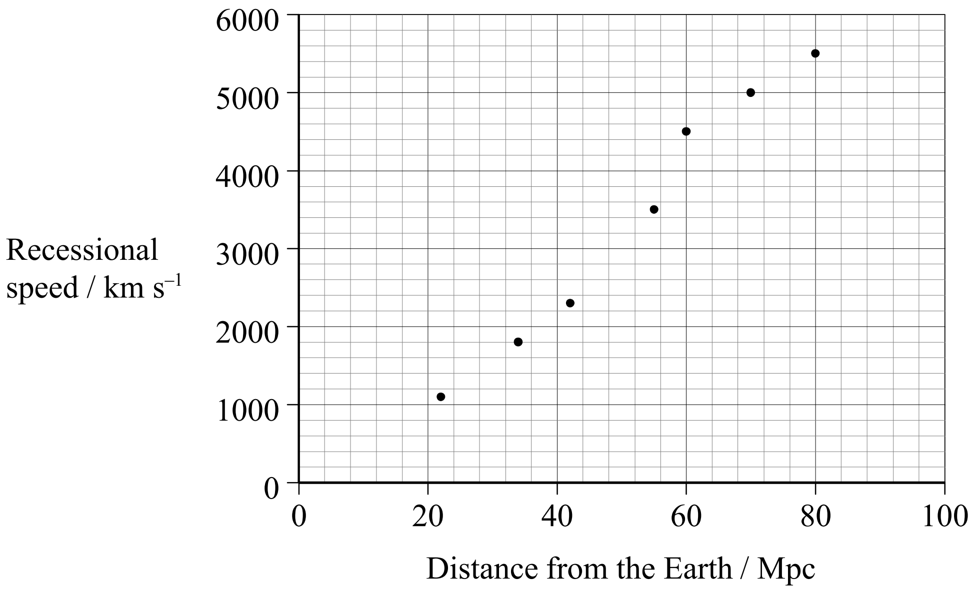
In the graph below the recessional speed of some galaxies is plotted against their distance from the Earth.




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

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## 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 $2.55 \times 10^{-8}$ 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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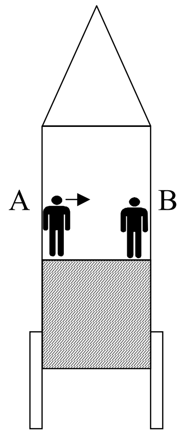
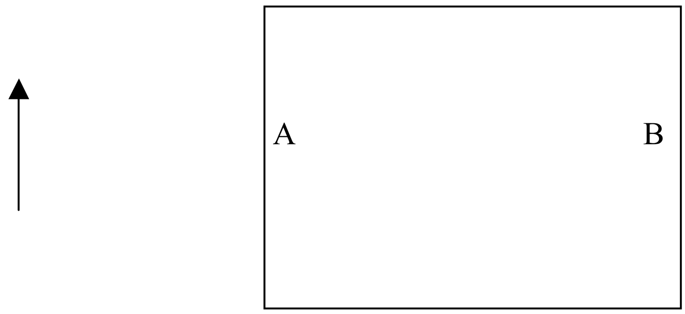
The diagram below shows a spaceship that is far away from any large masses such as planets or stars. The spaceman at position A throws a ball towards another spaceman at position B.

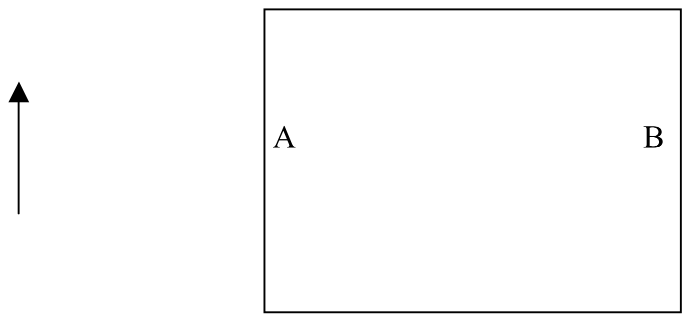



(b) Sketch on the following diagrams the path of the ball as seen by the spacemen if the spaceship is

(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]*




*(This question continues on the following page)*

*(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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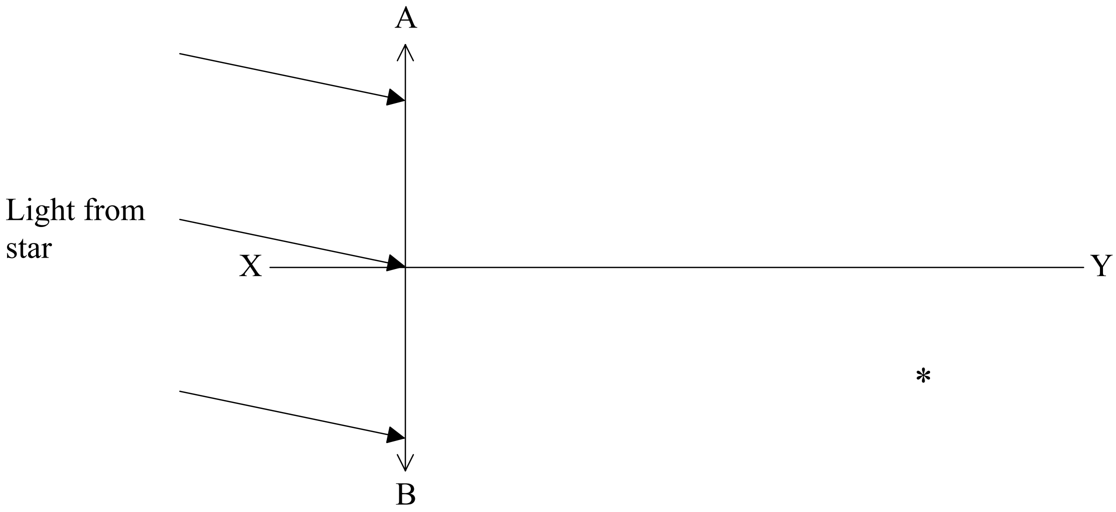
## OPTION H — OPTICS

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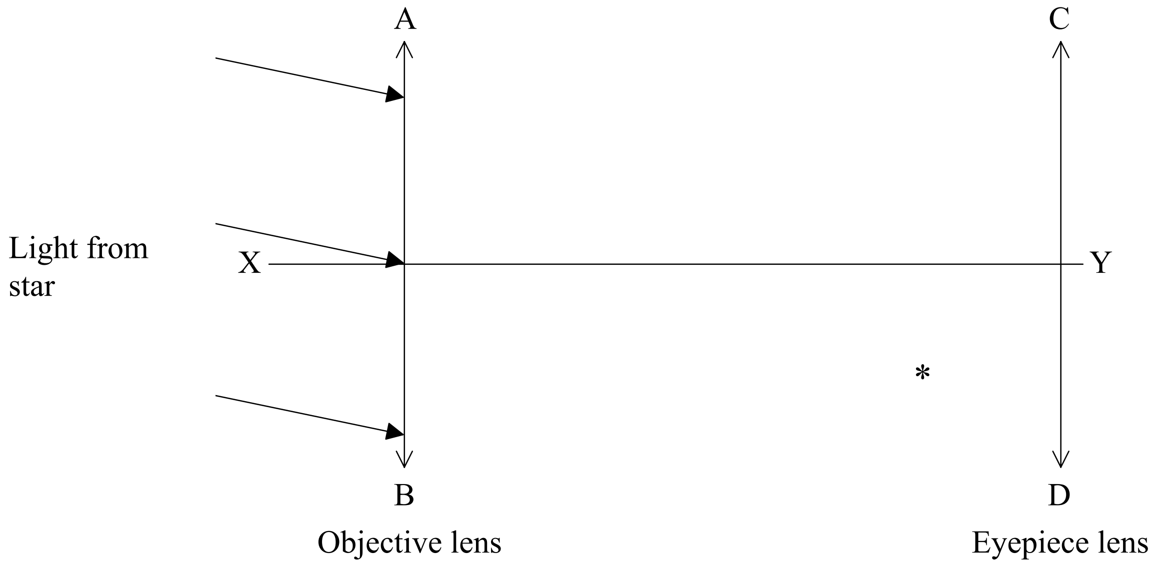
(ii) Complete the ray diagram by showing the path of the three rays after they have passed through the lens. *[1]*

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

*(This question continues on the following page)*

*(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.



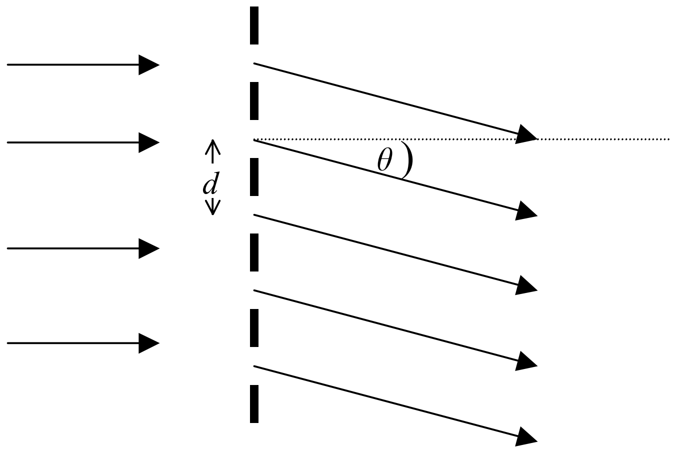

(i) If the final image of the star is formed at infinity, mark on the axis XY the positions of the principal focus $F_E$ of the eyepiece lens and the principal focus $F_O$ of the objective lens. *[1]*

(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 $90^\circ$ to the grating. The light diffracted by the slits at an angle $\theta$ 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 $\theta$ 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]*