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**Physics**  
**Higher level**  
**Paper 3**

Thursday 29 October 2020 (morning)

Candidate session number

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1 hour 15 minutes

**Instructions to candidates**

- Write your session number in the boxes above.
- Do not open this examination paper until instructed to do so.
- Answers must be written within the answer boxes provided.
- A calculator is required for this paper.
- A clean copy of the **physics data booklet** is required for this paper.
- The maximum mark for this examination paper is **[45 marks]**.

Section A	Questions
Answer all questions.	1 – 2

Section B	Questions
Answer all of the questions from one of the options.	
Option A — Relativity	3 – 7
Option B — Engineering physics	8 – 12
Option C — Imaging	13 – 18
Option D — Astrophysics	19 – 24



### Section A

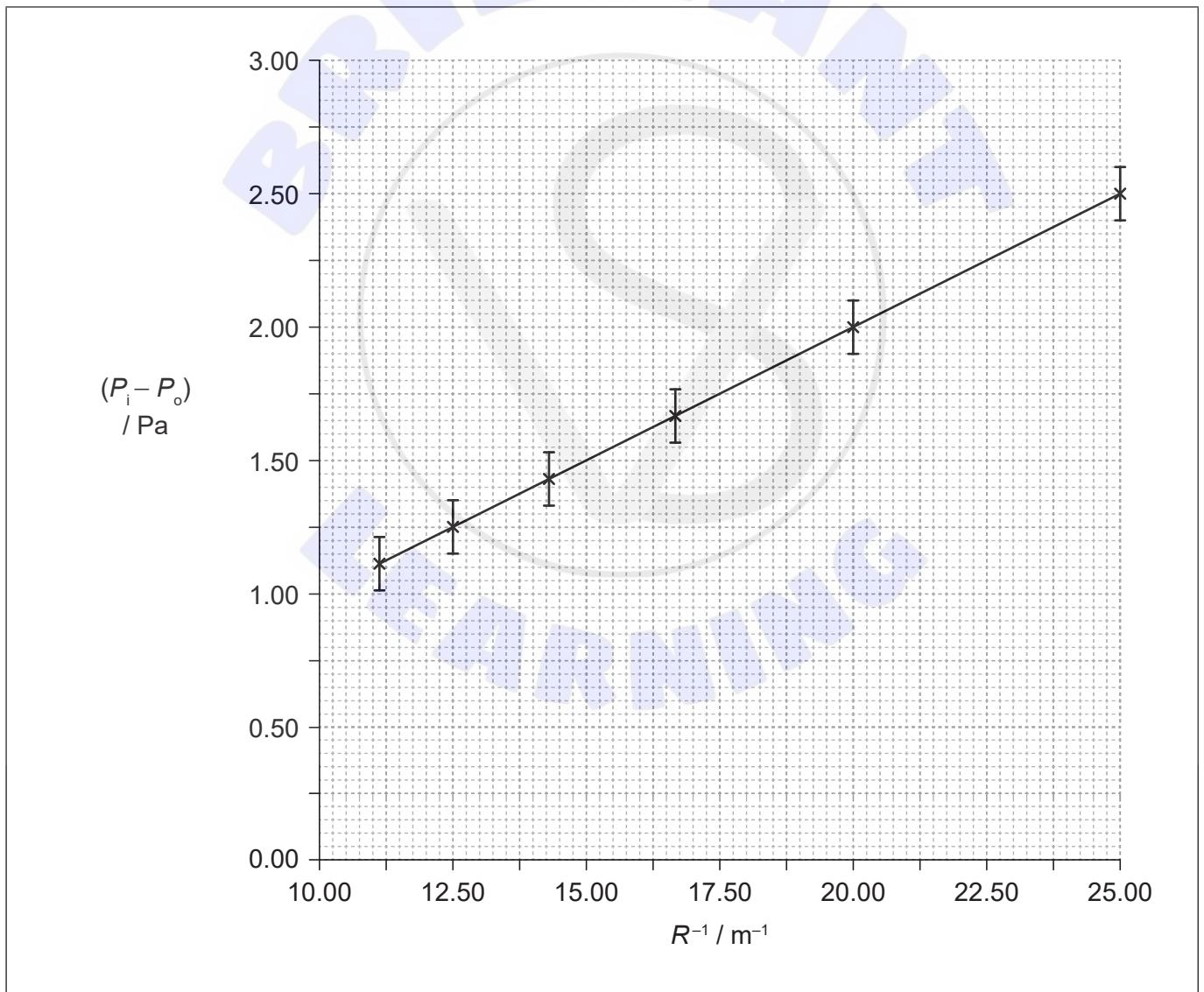
Answer **all** questions. Answers must be written within the answer boxes provided.

1. A spherical soap bubble is made of a thin film of soapy water. The bubble has an internal air pressure  $P_i$  and is formed in air of constant pressure  $P_o$ . The theoretical prediction for the variation of  $(P_i - P_o)$  is given by the equation

$$(P_i - P_o) = \frac{4\gamma}{R}$$

where  $\gamma$  is a constant for the thin film and  $R$  is the radius of the bubble.

Data for  $(P_i - P_o)$  and  $R$  were collected under controlled conditions and plotted as a graph showing the variation of  $(P_i - P_o)$  with  $\frac{1}{R}$ .



(This question continues on the following page)



**(Question 1 continued)**

(a) Suggest whether the data are consistent with the theoretical prediction. [2]

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(b) (i) Show that the value of  $\gamma$  is about 0.03. [2]

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(ii) Identify the fundamental units of  $\gamma$ . [1]

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(iii) In order to find the uncertainty for  $\gamma$ , a maximum gradient line would be drawn. On the graph, sketch the maximum gradient line for the data. [1]

(iv) The percentage uncertainty for  $\gamma$  is 15%. State  $\gamma$ , with its absolute uncertainty. [2]

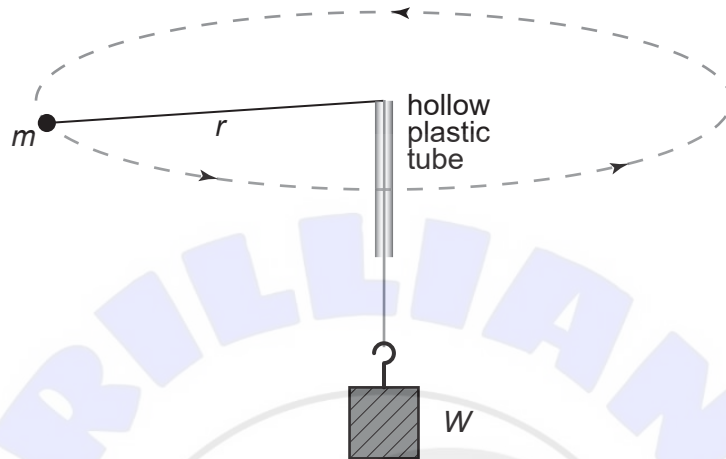
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(v) The expected value of  $\gamma$  is 0.027. Comment on your result. [1]

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2. A student studies the relationship between the centripetal force applied to an object undergoing circular motion and its period  $T$ . The object (mass  $m$ ) is attached by a light inextensible string, through a tube, to a weight  $W$  which hangs vertically. The string is free to move through the tube. A student swings the mass in a horizontal, circular path, adjusting the period  $T$  of the motion until the radius  $r$  is constant. The radius of the circle and the mass of the object are measured and remain constant for the entire experiment.



The student collects the measurements of  $T$  five times, for weight  $W$ . The weight is then doubled ( $2W$ ) and the data collection repeated. Then it is repeated with  $3W$  and  $4W$ . The results are expected to support the relationship

$$W = \frac{4\pi^2 mr}{T^2}.$$

- (a) State why the experiment is repeated with different values of  $W$ . [1]

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In reality, there is friction in the system, so in this case  $W$  is less than the total centripetal force in the system. A suitable graph is plotted to determine the value of  $mr$  experimentally. The value of  $mr$  was also calculated directly from the measured values of  $m$  and  $r$ .

- (b) Predict from the equation whether the value of  $mr$  found experimentally will be larger, the same or smaller than the value of  $mr$  calculated directly. [2]

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(This question continues on the following page)



**(Question 2 continued)**

- (c) (i) The measurements of  $T$  were collected five times. Explain how repeated measurements of  $T$  reduced the random error in the final experimental value of  $mr$ . [2]

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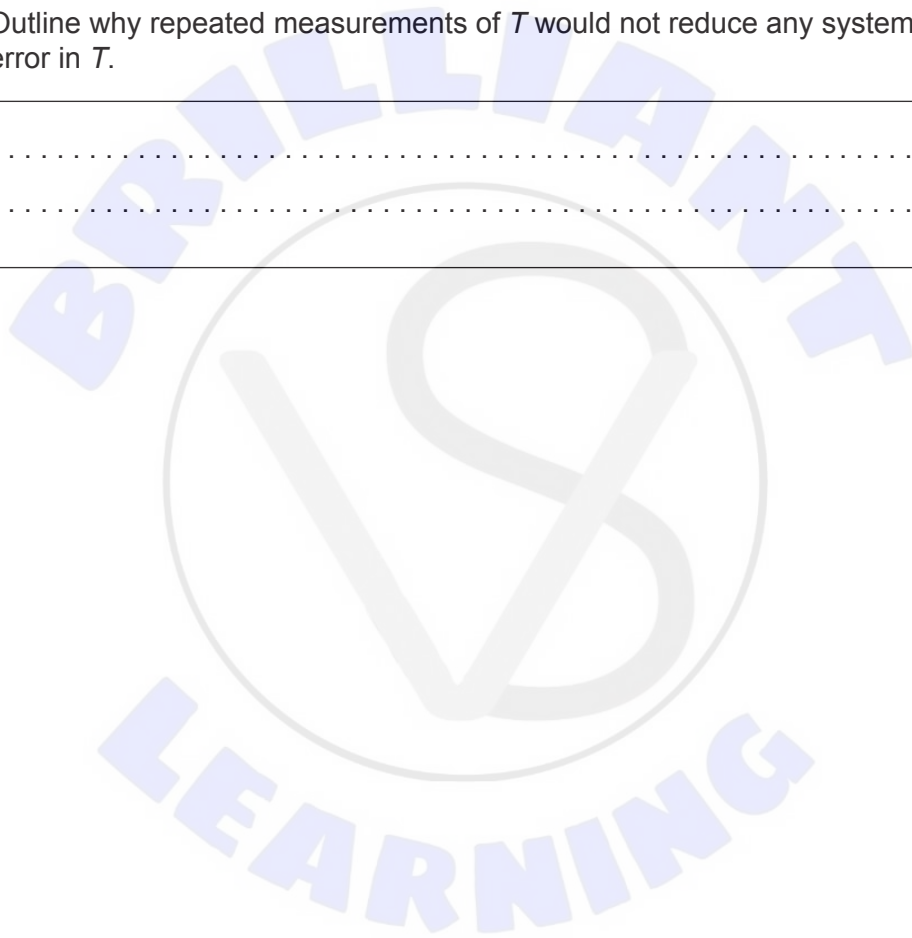
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- (ii) Outline why repeated measurements of  $T$  would not reduce any systematic error in  $T$ . [1]

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### Section B

Answer **all** of the questions from **one** of the options. Answers must be written within the answer boxes provided.

#### Option A — Relativity

3. (a) Maxwell's equations led to the constancy of the speed of light. Identify what Maxwell's equations describe. [1]

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- (b) State a postulate that is the same for both special relativity and Galilean relativity. [1]

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- (c) Two parallel current-carrying wires have equal currents in the same direction. There is an attractive force between the wires. [1]
- (i) Identify the nature of the attractive force recorded by an observer stationary with respect to the wires. [1]

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- (ii) A second observer moves at the drift velocity of the electron current in the wires. Discuss how this observer accounts for the force between the wires. [3]

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(Option A continues on the following page)



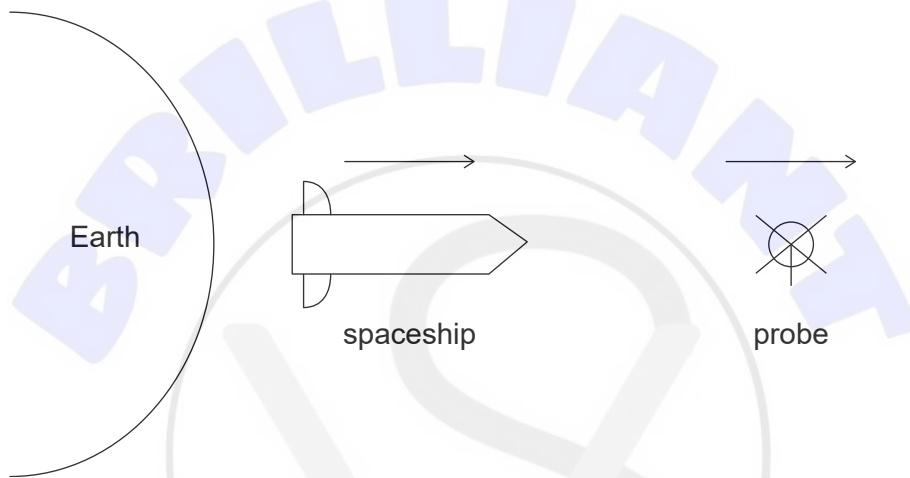
(Option A continued)

4. (a) The Lorentz transformations assume that the speed of light is constant. Outline what the Galilean transformations assume. [1]

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- (b) A spaceship is travelling at  $0.80c$ , away from Earth. It launches a probe away from Earth, at  $0.50c$  relative to the spaceship. An observer on the probe measures the length of the probe to be  $8.0\text{m}$ .



- (i) Deduce the length of the probe as measured by an observer in the spaceship. [2]

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- (ii) Explain which of the lengths is the proper length. [2]

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(Option A continues on the following page)



**(Option A, question 4 continued)**

(c) Calculate the speed of the probe in terms of  $c$ , relative to Earth.

[2]

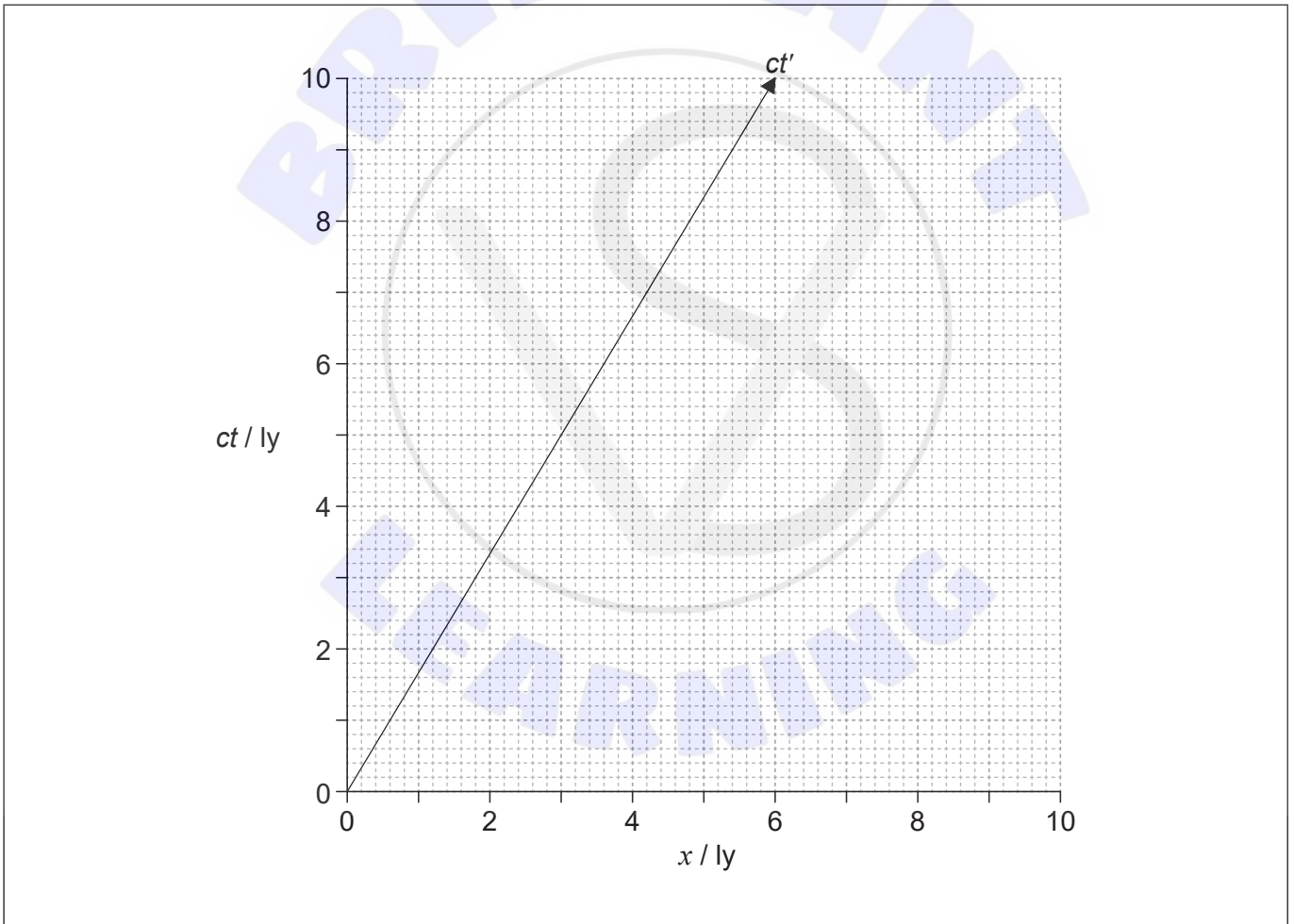
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5. The spacetime diagram is in the reference frame of an observer O on Earth. Observer O and spaceship A are at the origin of the spacetime diagram when time  $t = t' = 0$ . The worldline for spaceship A is shown.



**(Option A continues on the following page)**



**(Option A, question 5 continued)**

- (a) (i) Calculate in terms of  $c$  the velocity of spaceship A relative to observer O. [1]

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- (ii) Draw the  $x'$  axis for the reference frame of spaceship A. [1]

- (b) Event E is the emission of a flash of light. Observer O sees light from the flash when  $t = 9$  years and calculates that event E is 4 ly away, in the positive  $x$  direction.

- (i) Plot the event E on the spacetime diagram and label it E. [2]

- (ii) Determine the time, according to spaceship A, when light from event E was observed on spaceship A. [3]

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**(Option A continues on the following page)**



**(Option A continued)**

6. A deuterium ( ${}^2_1\text{H}$ ) nucleus (rest mass 2.014 u) is accelerated by a potential difference of  $2.700 \times 10^2$  MV.

(a) Define rest mass.

[1]

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(b) Calculate the total energy of the deuterium particle in MeV.

[2]

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(c) In relativistic reactions the mass of the products may be less than the mass of the reactants. Suggest what happens to the missing mass.

[2]

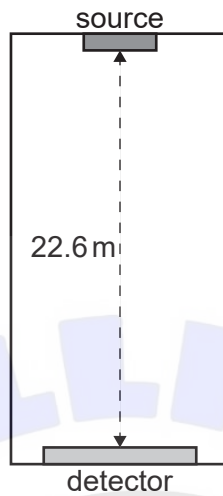
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**(Option A continues on the following page)**



(Option A continued)

7. In the Pound–Rebka–Snider experiment, a source of gamma rays was placed 22.6 m vertically above a gamma ray detector, in a tower on Earth.



- (a) Calculate the fractional change in frequency of the gamma rays at the detector. [1]

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- (b) Explain the cause of the frequency shift for the gamma rays in your answer in (a)  
(i) in the Earth’s gravitational field. [2]

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- (ii) if the tower and detector were accelerating **towards** the gamma rays in free space. [2]

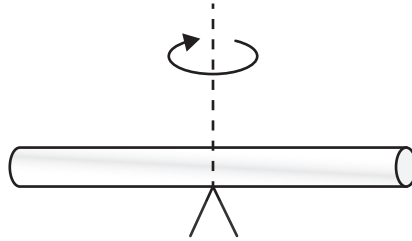
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**End of Option A**



**Option B — Engineering physics**

8. A bar rotates horizontally about its centre, reaching a maximum angular velocity in six complete rotations from rest. The bar has a constant angular acceleration of  $0.110 \text{ rad s}^{-2}$ . The moment of inertia of the bar about the axis of rotation is  $0.0216 \text{ kg m}^2$ .



- (a) Show that the final angular velocity of the bar is about  $3 \text{ rad s}^{-1}$ . [2]

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- (b) Draw the variation with time  $t$  of the angular displacement  $\theta$  of the bar during the acceleration. [1]

$\theta / \text{rad}$

$t / \text{s}$

- (c) Calculate the torque acting on the bar while it is accelerating. [1]

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(Option B continues on the following page)



**(Option B, question 8 continued)**

- (d) The torque is removed. The bar comes to rest in 30 complete rotations with constant angular deceleration. Determine the time taken for the bar to come to rest. [2]

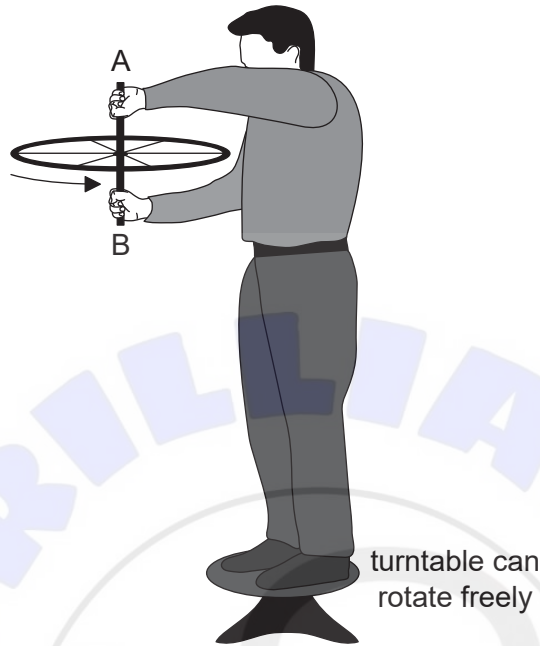
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**(Option B continues on the following page)**

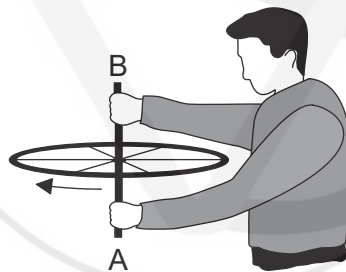


**(Option B continued)**

9. The first diagram shows a person standing on a turntable which can rotate freely. The person is stationary and holding a bicycle wheel. The wheel rotates anticlockwise when seen from above.



The wheel is flipped, as shown in the second diagram, so that it rotates clockwise when seen from above.



- (a) Explain the direction in which the person-turntable system starts to rotate. [3]

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**(Option B continues on the following page)**



**(Option B, question 9 continued)**

(b) Explain the changes to the rotational kinetic energy in the person-turntable system. [2]

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10. A solid sphere of radius  $r$  and mass  $m$  is released from rest and rolls down a slope, without slipping. The vertical height of the slope is  $h$ . The moment of inertia  $I$  of this sphere about an axis through its centre is  $\frac{2}{5}mr^2$ .



Show that the linear velocity  $v$  of the sphere as it leaves the slope is  $\sqrt{\frac{10gh}{7}}$ . [3]

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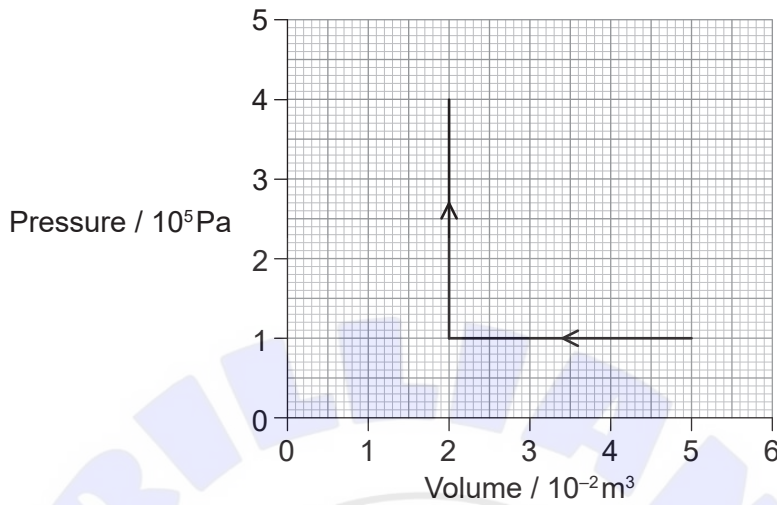
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**(Option B continues on the following page)**



**(Option B continued)**

11. The diagram represents an ideal, monatomic gas that first undergoes a compression, then an increase in pressure.



(a) Calculate the work done during the

(i) compression.

[1]

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(ii) increase in pressure.

[1]

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(b) An adiabatic process then increases the volume of the gas to  $5.0 \times 10^{-2} \text{ m}^3$ .

(i) Calculate the pressure following this process.

[2]

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**(Option B continues on the following page)**



**(Option B, question 11 continued)**

- (ii) Outline how an approximate adiabatic change can be achieved. [2]

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- 12.** (a) State **two** properties of an ideal fluid. [2]

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- (b) A sphere is dropped into a container of oil.  
The following data are available.

Density of oil =  $915 \text{ kg m}^{-3}$   
Viscosity of oil =  $37.9 \times 10^{-3} \text{ Pa s}$   
Volume of sphere =  $7.24 \times 10^{-6} \text{ m}^3$   
Mass of sphere = 12.6 g

Determine the terminal velocity of the sphere. [3]

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**(Option B continues on the following page)**



**(Option B, question 12 continued)**

(c) The sphere is now suspended from a spring so that the sphere is below the surface of the oil.

(i) Determine the force exerted by the spring on the sphere when the sphere is at rest. [2]

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(ii) The sphere oscillates vertically within the oil at the natural frequency of the sphere-spring system. The energy is reduced in each cycle by 10%. Calculate the Q factor for this system. [1]

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(iii) Outline the effect on Q of changing the oil to one with greater viscosity. [2]

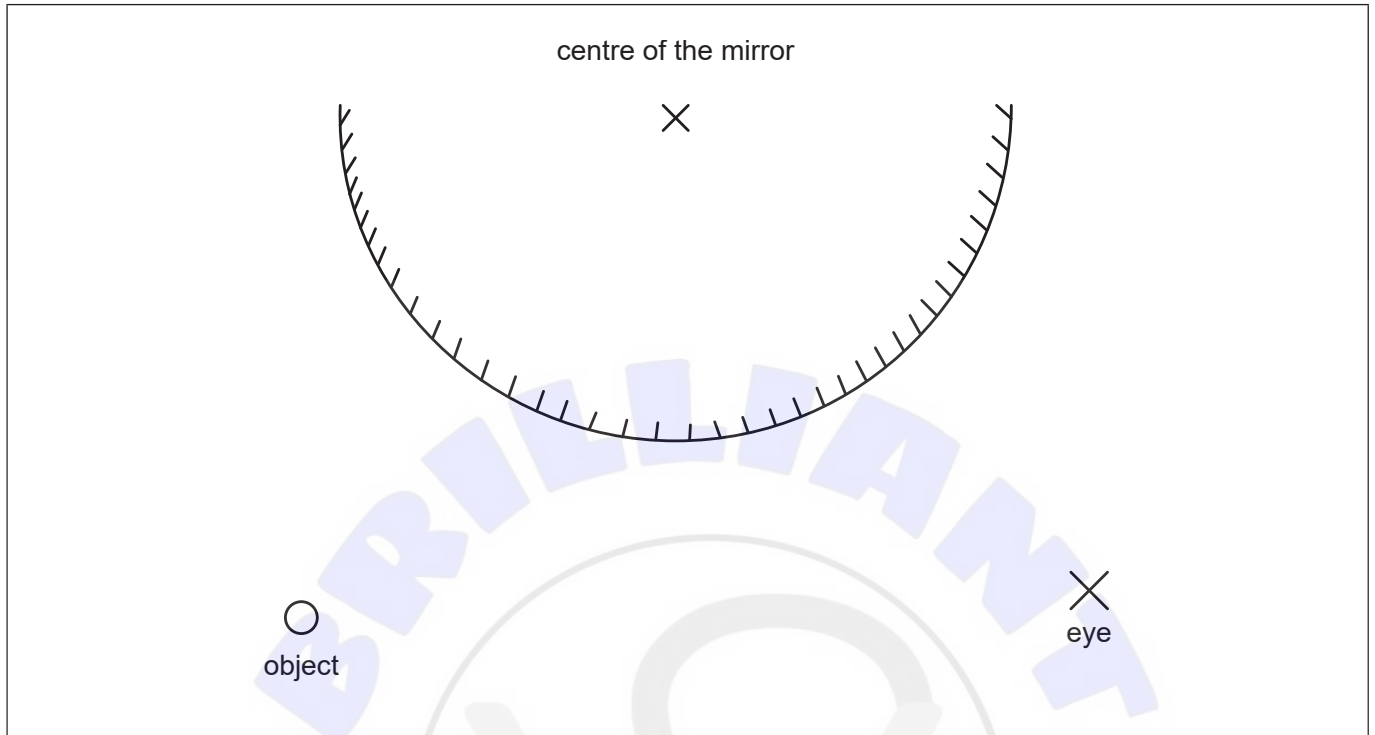
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**End of Option B**



**Option C — Imaging**

13. The diagram represents a diverging mirror being used to view an object.



- (a) Construct a single ray showing one path of light between the eye, the mirror and the object, to view the object. [2]
- (b) The image observed is virtual. Outline the meaning of virtual image. [1]

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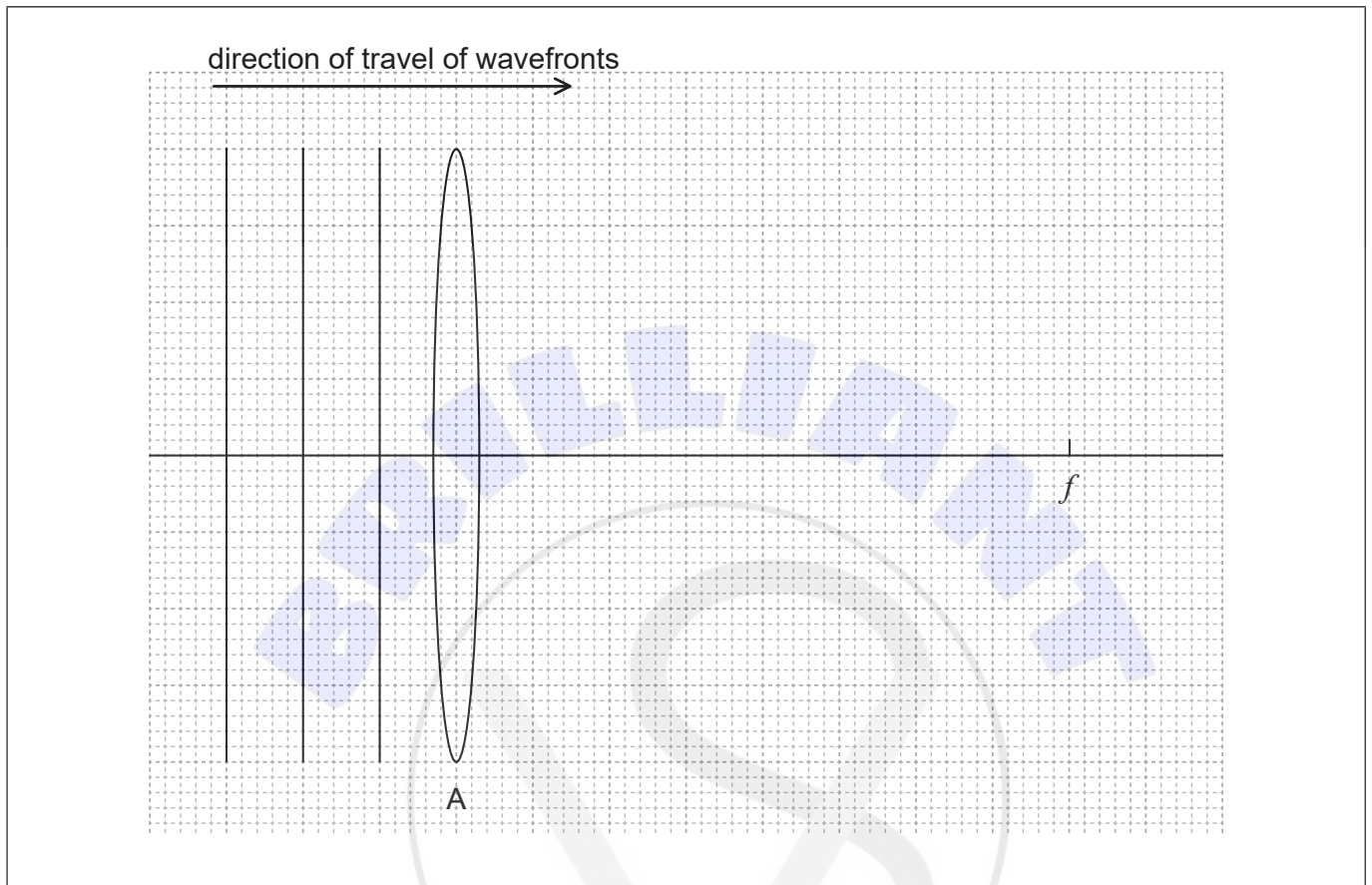
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(Option C continues on the following page)



(Option C continued)

14. A beam of monochromatic light from infinity is incident on a converging lens A. The diagram shows three wavefronts of the light and the focal point  $f$  of the lens.



- (a) Draw on the diagram the three wavefronts after they have passed through the lens. [2]
- (b) Lens A has a focal length of 4.00 cm. An object is placed 4.50 cm to the left of A. Show by calculation that a screen should be placed about 0.4 m from A to display a focused image. [2]

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(Option C continues on the following page)



**(Option C, question 14 continued)**

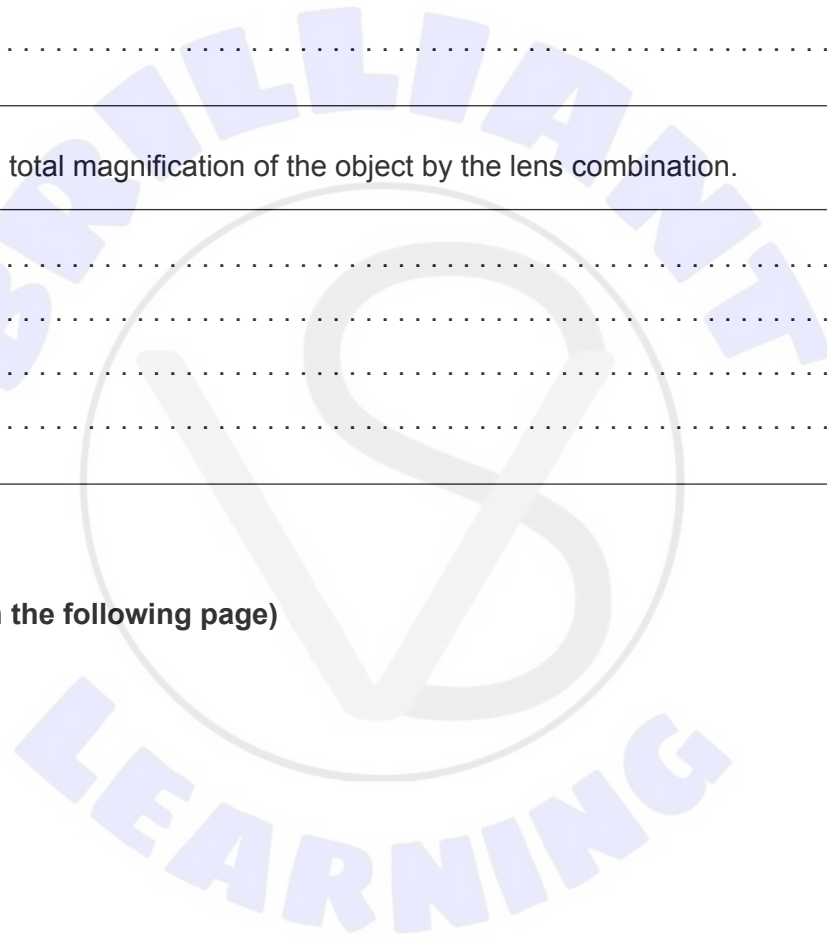
- (c) The screen is removed and the image is used as the object for a second diverging lens B, to form a final image. Lens B has a focal length of 2.00 cm and the final real image is 8.00 cm from the lens. Calculate the distance between lens A and lens B. [3]

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- (d) Calculate the total magnification of the object by the lens combination. [2]

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**(Option C continues on the following page)**

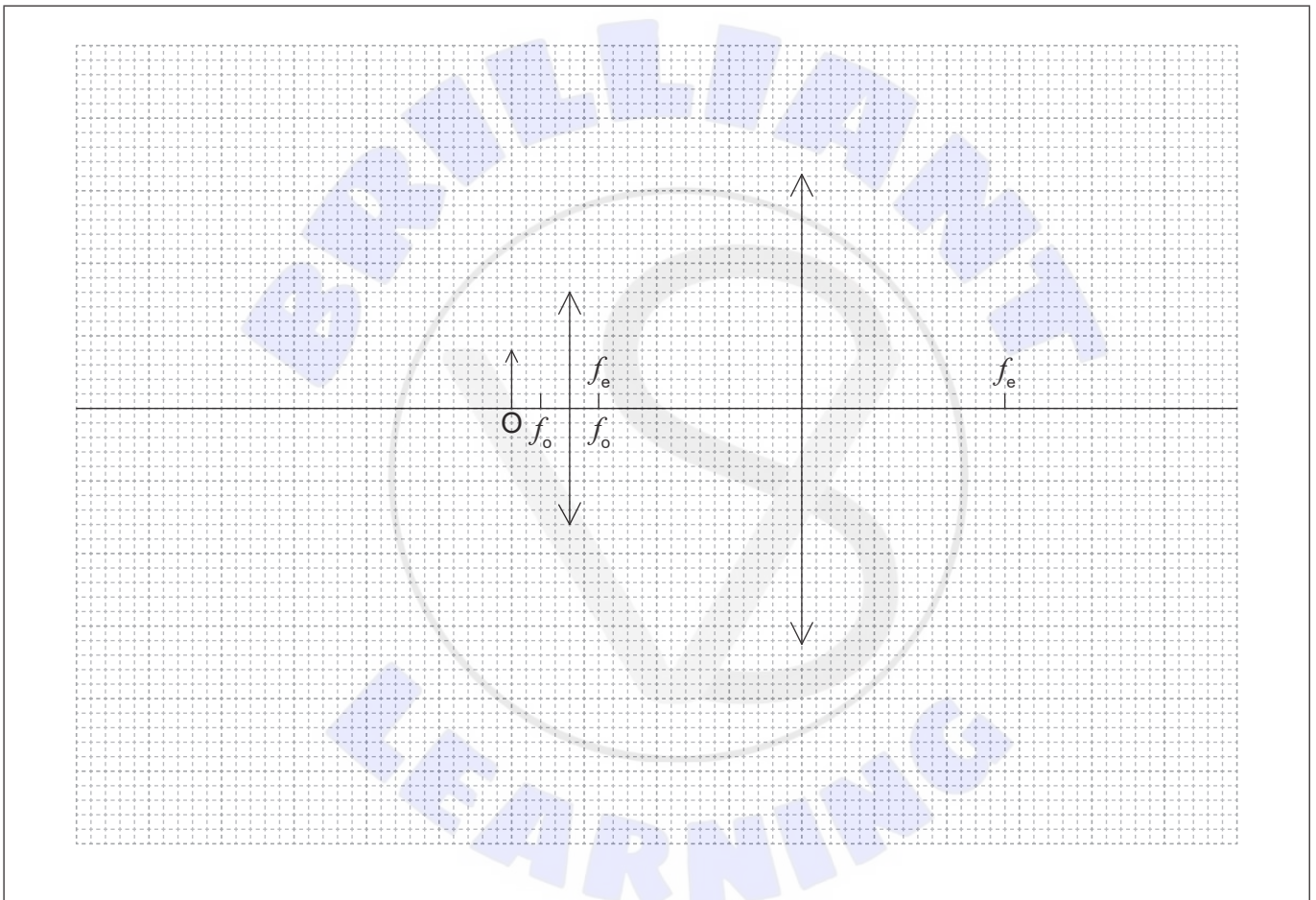


(Option C continued)

15. (a) Outline the meaning of normal adjustment for a compound microscope. [1]

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- (b) Sketch a ray diagram to find the position of the images for both lenses in the compound microscope at normal adjustment. The object is at O and the focal lengths of the objective and eyepiece lenses are shown. [4]



(Option C continues on the following page)



**(Option C continued)**

**16.** A single pulse of light enters an optic fibre which contains small impurities that scatter the light. Explain the effect of these impurities on the pulse. [3]

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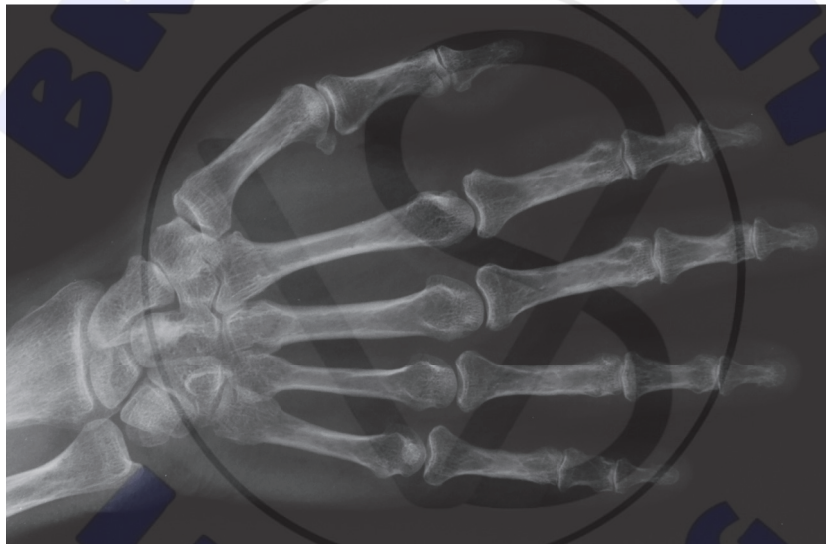
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**17.** The photograph shows an X-ray image of a hand.



(a) Explain how attenuation causes the contrast between soft tissue and bone in the image. [3]

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**(Option C continues on the following page)**



**(Option C, question 17 continued)**

- (b) X-ray images of other parts of the body require the contrast to be enhanced. State **one** technique used in X-ray medical imaging to enhance contrast. [1]

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18. (a) Explain the cause of the radio-frequency emissions from a patient's body during nuclear magnetic resonance (NMR) imaging. [3]

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- (b) Outline how a gradient field allows NMR to be used in medical resonance imaging. [2]

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- (c) Identify **one** advantage of NMR over ultrasound in medical situations. [1]

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**End of Option C**

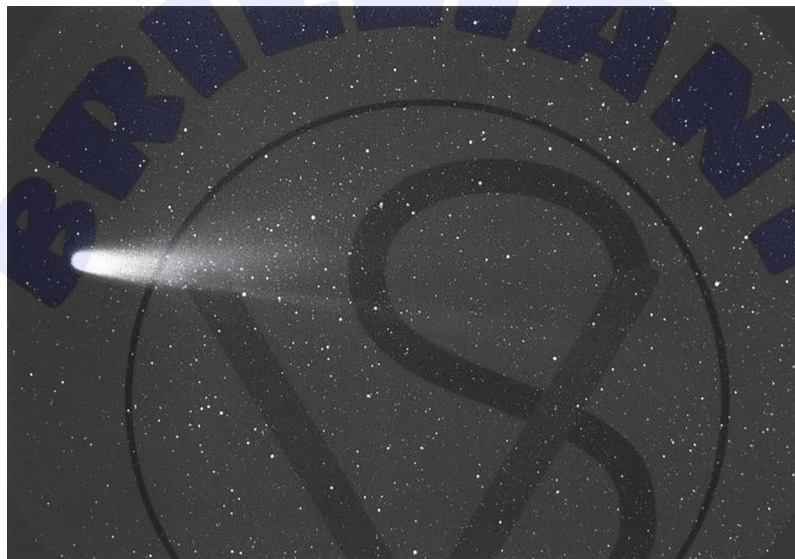


**Option D — Astrophysics**

19. (a) The astronomical unit (AU) and light year (ly) are convenient measures of distance in astrophysics. Define each unit. [2]

AU: .....
.....
ly: .....
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(b) An image of a comet is shown.



(i) Comets develop a tail as they approach the Sun. Identify **one** other characteristic of comets. [1]

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(ii) Identify **one** object visible in the image that is outside our Solar System. [1]

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**(Option D continues on the following page)**



**(Option D continued)**

20. (a) Show that the apparent brightness  $b \propto \frac{AT^4}{d^2}$ , where  $d$  is the distance of the object from Earth,  $T$  is the surface temperature of the object and  $A$  is the surface area of the object. [1]

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- (b) Two of the brightest objects in the night sky seen from Earth are the planet Venus and the star Sirius. Explain why the equation  $b \propto \frac{AT^4}{d^2}$  is applicable to Sirius but not to Venus. [2]

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21. (a) The light from a distant galaxy shows that  $z = 0.11$ .  
Calculate the ratio  $\frac{\text{size of the universe when the light was emitted}}{\text{size of the universe at present}}$ . [1]

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- (b) Outline how Hubble's law is related to  $z$ . [1]

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**(Option D continues on the following page)**



(Option D, question 21 continued)

- (c) Hubble originally linked galactic redshift to a Doppler effect arising from galactic recession. Hubble's law is now regarded as being due to cosmological redshift, not the Doppler effect. Explain the observed galactic redshift in cosmological terms. [3]

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22. The data for the star Eta Aquilae A are given in the table.

	Value
Mean luminosity	$2630 L_{\odot}$
Mass	$5.70 M_{\odot}$
Parallax angle	$2.36 \times 10^{-3}$ arcsec
Apparent brightness	$7.20 \times 10^{-10} \text{ W m}^{-2}$

$L_{\odot}$  is the luminosity of the Sun and  $M_{\odot}$  is the mass of the Sun.

- (a) Show by calculation that Eta Aquilae A is not on the main sequence. [2]

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(Option D continues on the following page)



**(Option D, question 22 continued)**

(b) Estimate, in pc, the distance to Eta Aquilae A

(i) using the parallax angle in the table.

[1]

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(ii) using the luminosity in the table, given that  $L_{\odot} = 3.83 \times 10^{26} \text{ W}$ .

[3]

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(c) Suggest why your answers to (b)(i) and (b)(ii) are different.

[2]

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(d) Eta Aquilae A is a Cepheid variable. Explain why the brightness of Eta Aquilae A varies.

[3]

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**(Option D continues on the following page)**



**(Option D, question 22 continued)**

- (e) Eta Aquilae A was on the main sequence before it became a variable star. Compare, without calculation, the time Eta Aquilae A spent on the main sequence to the total time the Sun is likely to spend on the main sequence. [2]

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- 23. In 2017, two neutron stars were observed to merge, forming a black hole. The material released included chemical elements produced by the r process of neutron capture. Describe **two** characteristics of the elements produced by the r process. [2]

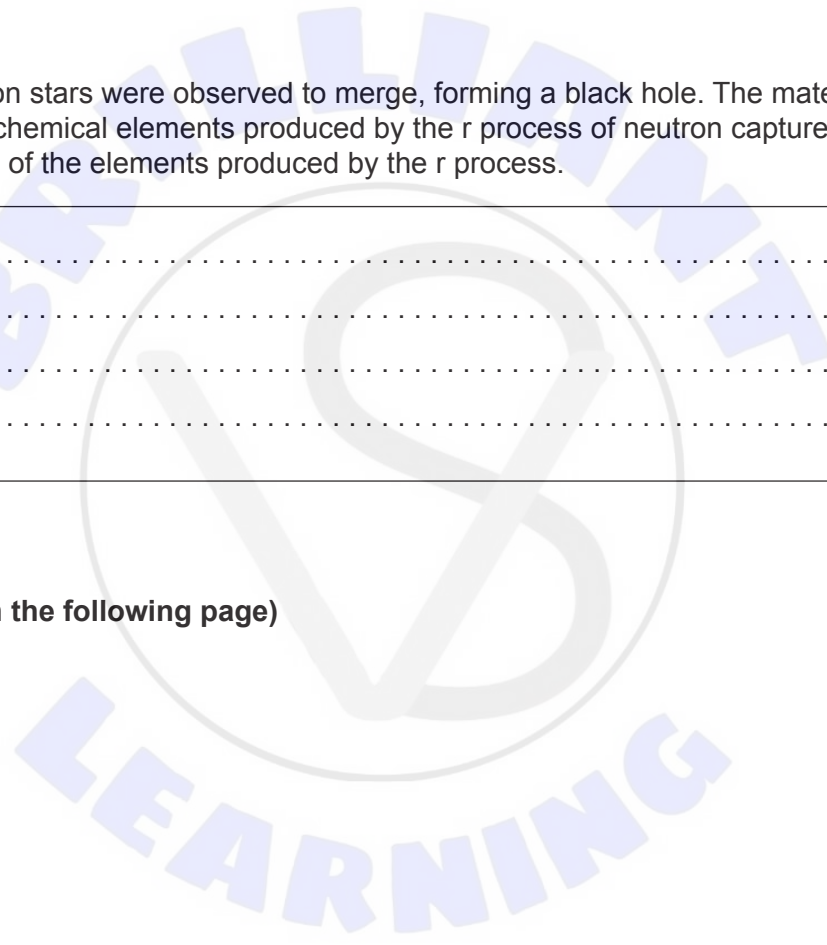
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**(Option D continues on the following page)**



**(Option D continued)**

**24.** The cosmic microwave background (CMB) radiation is observed to have anisotropies.

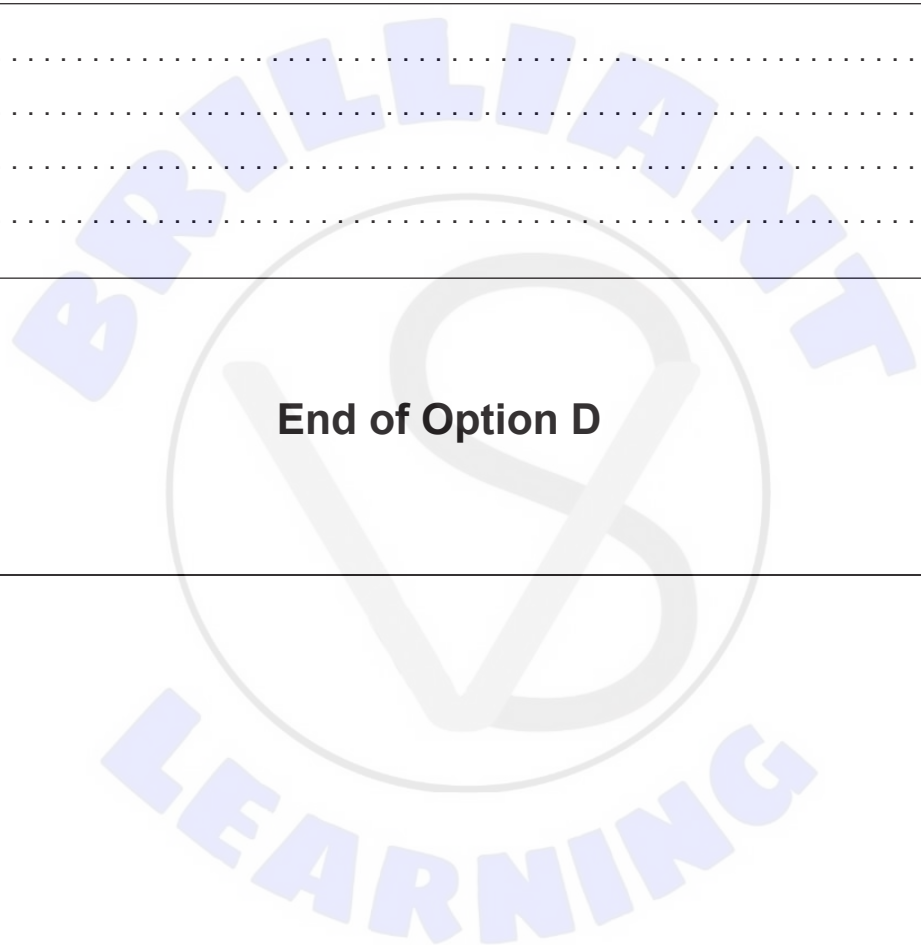
(a) State the nature of the anisotropies observed in the CMB radiation. [1]

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(b) Identify **two** possible causes of the anisotropies in (a). [2]

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**End of Option D**





**References:**

- Q2.** © International Baccalaureate Organization 2020.
- Q9.** © International Baccalaureate Organization 2020.
- Q17.** © International Baccalaureate Organization 2020.
- Q19.** Comet P/Halley as taken March 8, 1986 by W. Liller, Easter Island, part of the International Halley Watch (IHW) Large Scale Phenomena Network.





Please **do not** write on this page.

Answers written on this page  
will not be marked.

