Diploma Programme
Programme du diplôme
Programa del Diploma

Physics
Higher level
Paper 3

Thursday 29 October 2020 (morning)

Candidate session number

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

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Section A

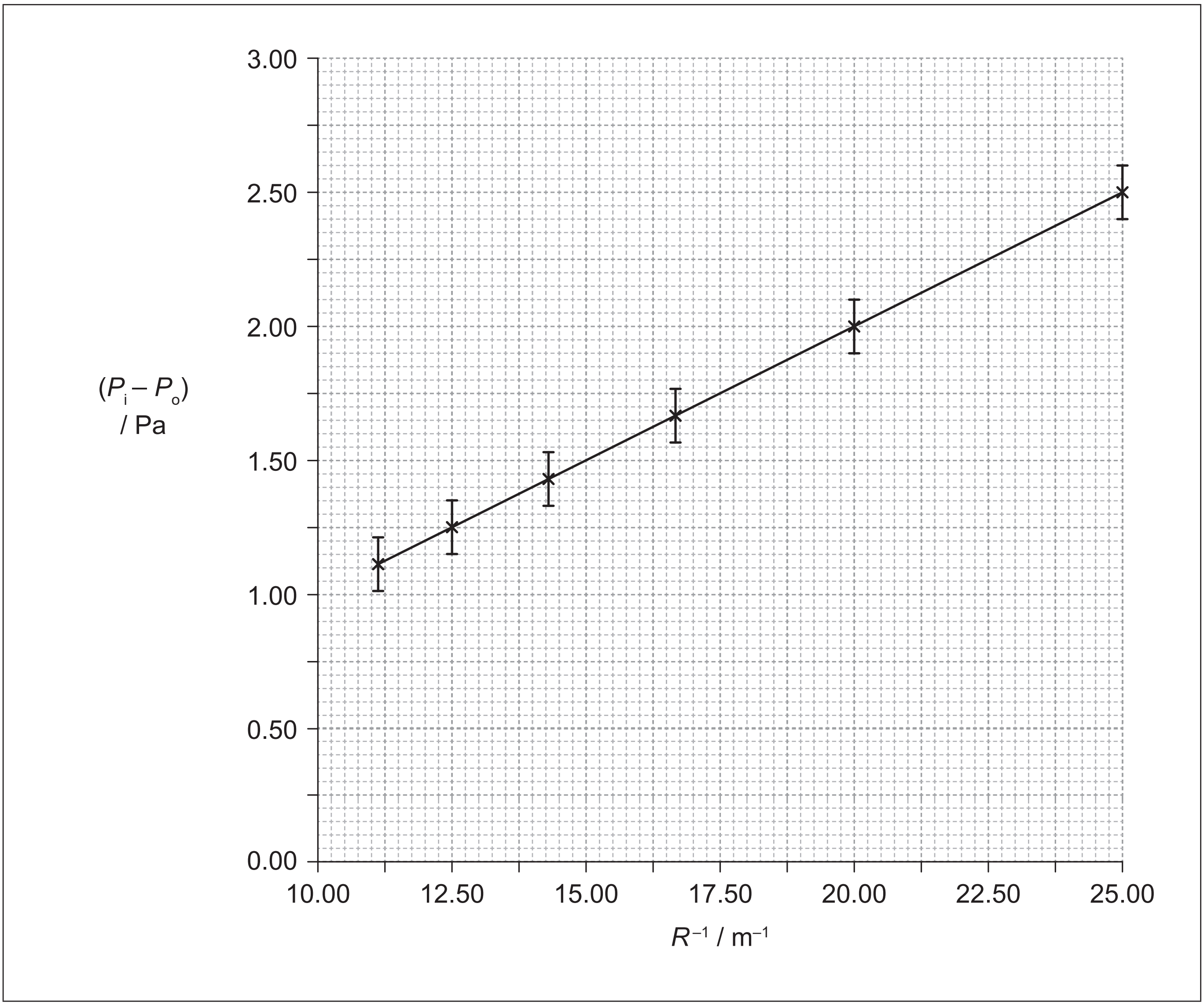
Answer **all** questions. Answers must be written within the answer boxes provided.

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

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

where γ 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 γ is about 0.03. [2]

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(ii) Identify the fundamental units of γ. [1]

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

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

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

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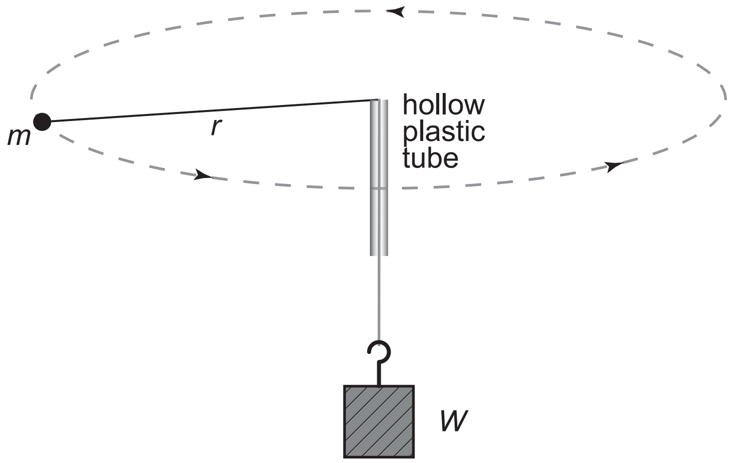
2. A student studies the relationship between the centripetal force applied to an object undergoing circular motion and its period *T*.
The object (mass *m*) is attached by a light inextensible string, through a tube, to a weight *W* which hangs vertically. The string is free to move through the tube. 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 (2*W*) and the data collection repeated. Then it is repeated with 3*W* and 4*W*.
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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(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.

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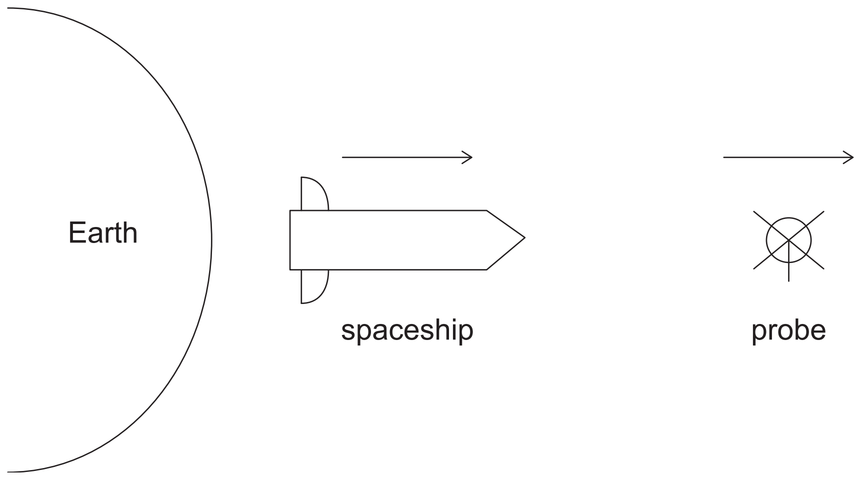
(b) A spaceship is travelling at 0.80*c*, away from Earth. It launches a probe away from Earth, at 0.50*c* relative to the spaceship. An observer on the probe measures the length of the probe to be 8.0 m.



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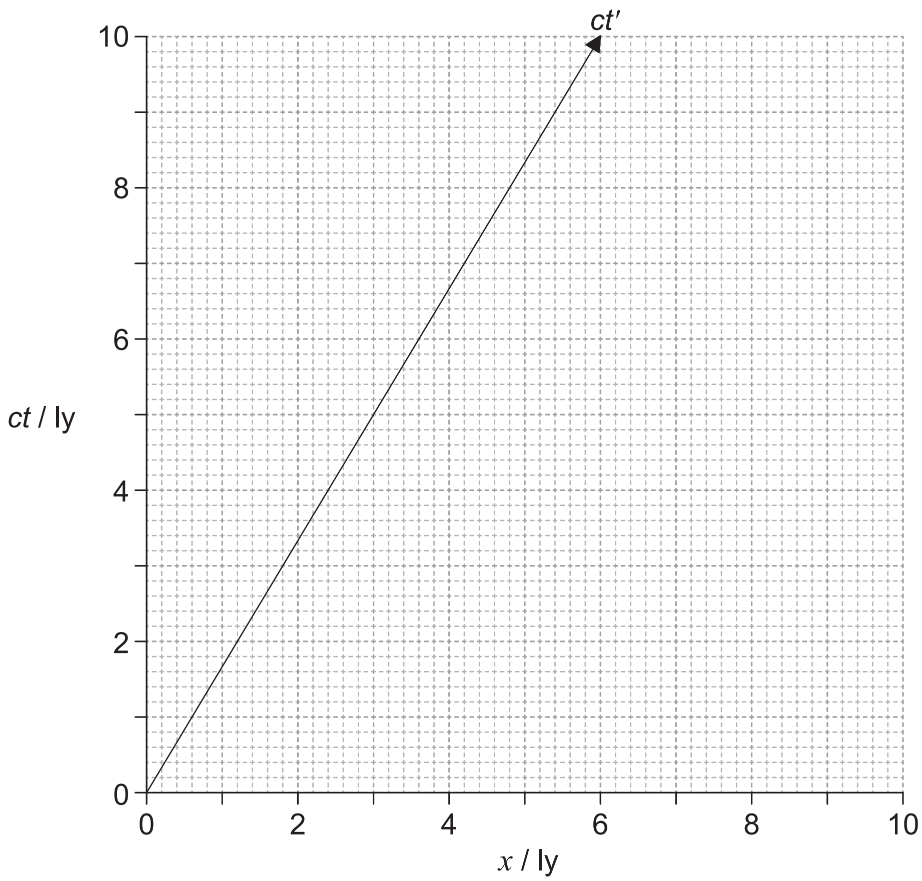
5. The spacetime diagram is in the reference frame of an observer O on Earth. Observer O and spaceship A are at the origin of the spacetime diagram when time $t = t' = 0$. The worldline for spaceship A is shown.



(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 $\left({}^2_1H\right)$ nucleus (rest mass 2.014 u) is accelerated by a potential difference of 2.700×10^2 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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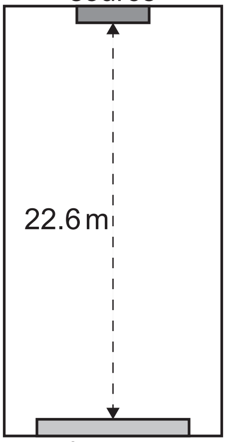
(Option A continues on the following page)

(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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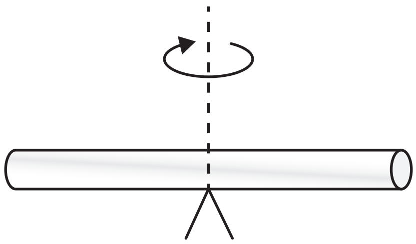
End of Option A

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 rad s^{-2}. The moment of inertia of the bar about the axis of rotation is 0.0216 kg m^2.



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

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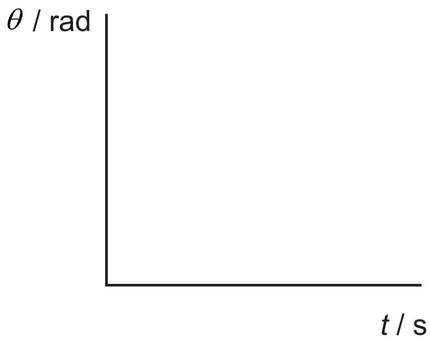
(b) Draw the variation with time t of the angular displacement θ of the bar during the acceleration. [1]



(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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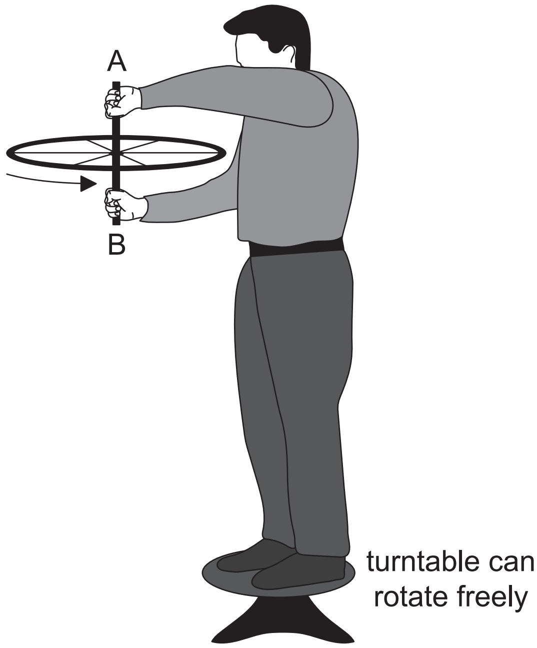
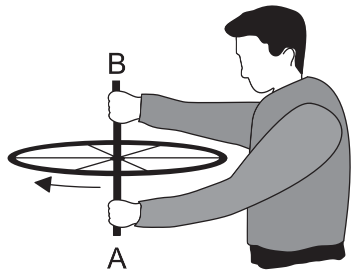
(Option B continues on the following page)

(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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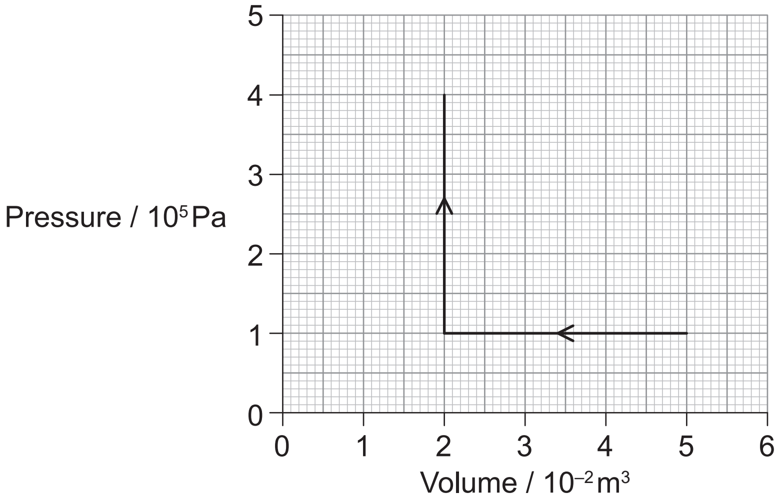
(Option B continues on the following page)

(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 5.0×10^{-2} 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 = $915\,\text{kg}\,\text{m}^{-3}$
Viscosity of oil = $37.9 \times 10^{-3}\,\text{Pa}\,\text{s}$
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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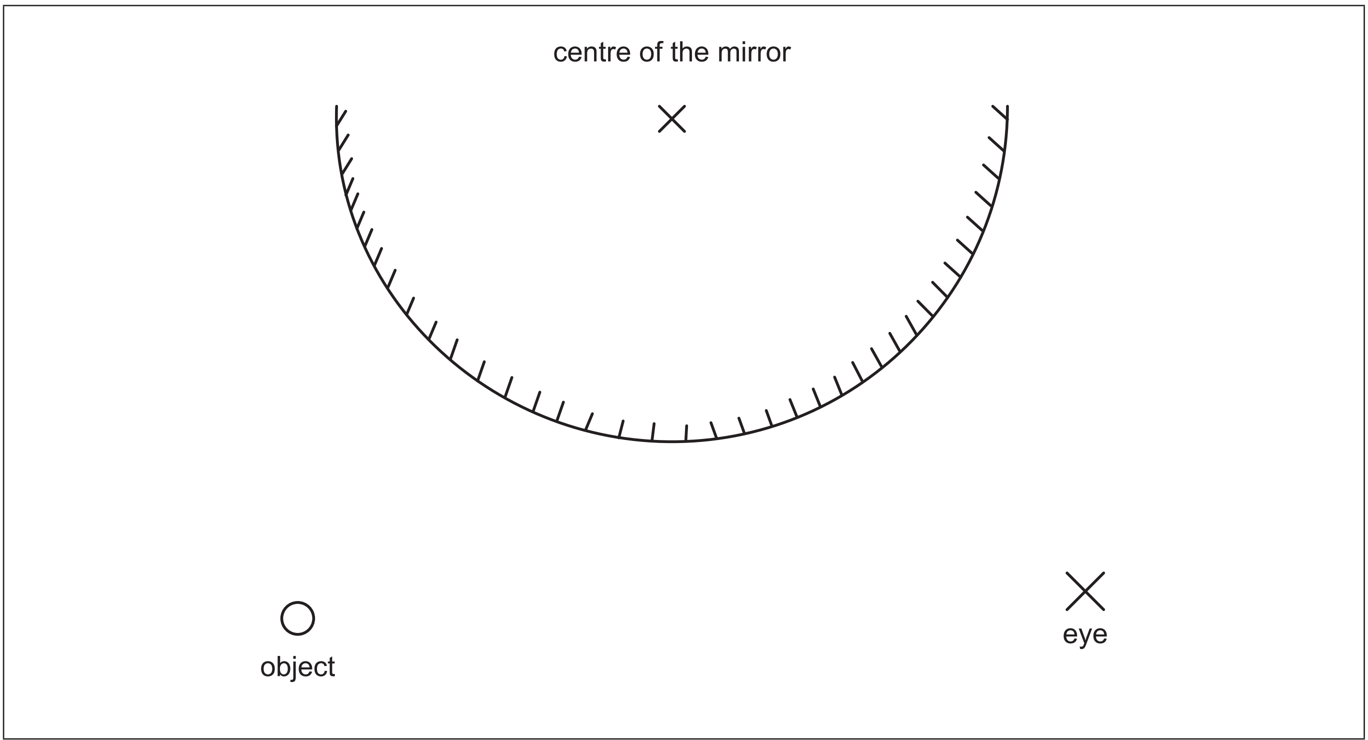
End of Option B

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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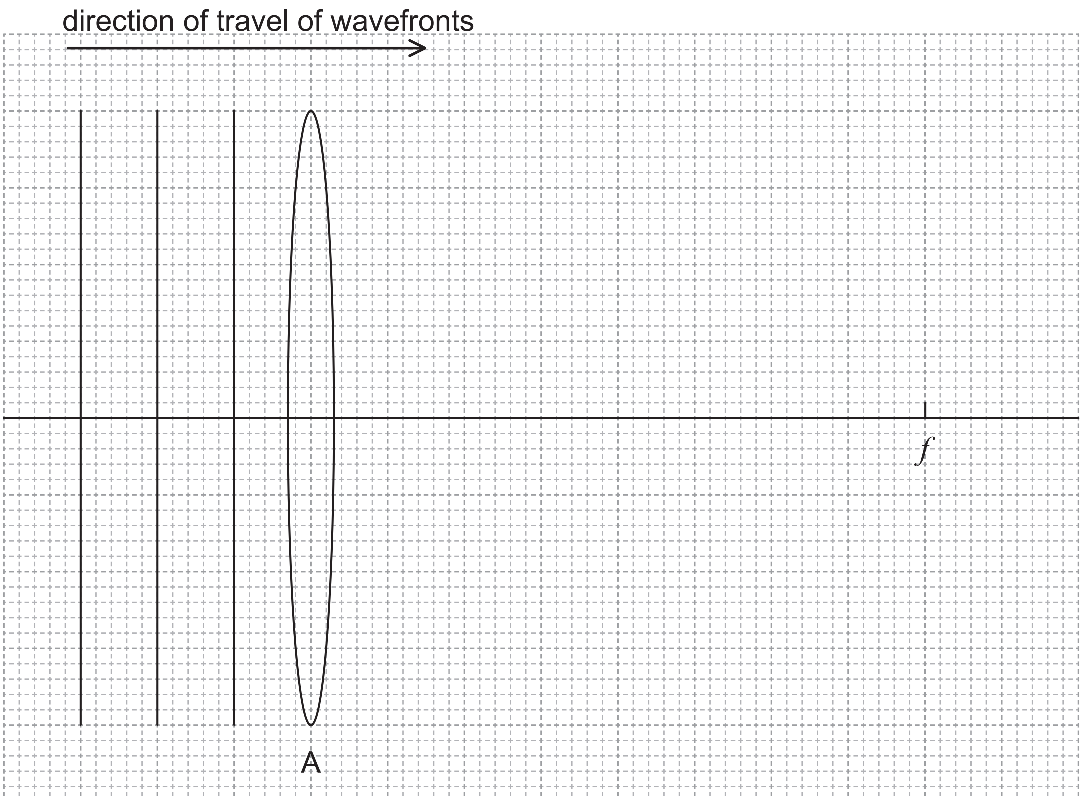
(Option C continues on the following page)

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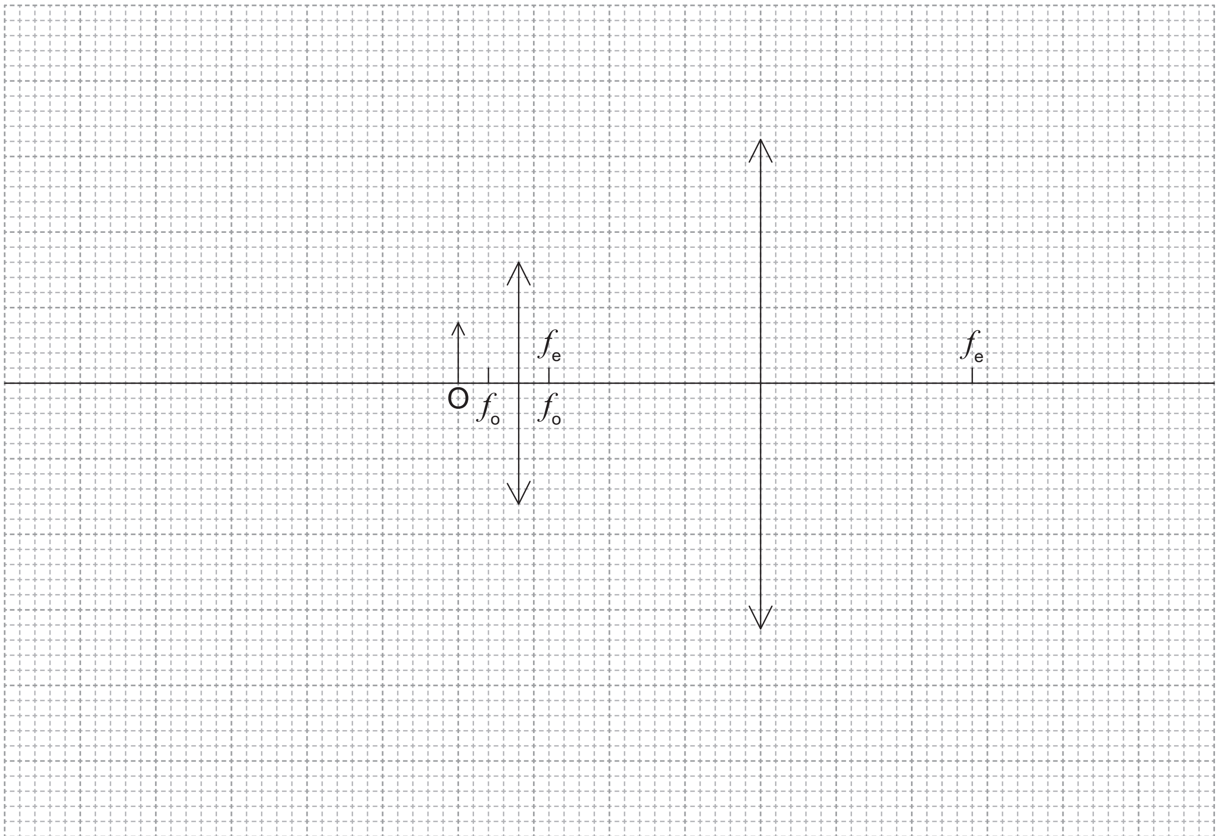
(b) Sketch a ray diagram to find the position of the images for both lenses in the compound microscope at normal adjustment. The object is at O and the focal lengths of the objective and eyepiece lenses are shown. [4]



(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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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)

Turn over

(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: . . . .

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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	2.36×10^{-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 $L_{\odot} = 3.83 \times 10^{26}$ 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:

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.