Diploma Programme
Programme du diplôme
Programa del Diploma

Physics
Standard level
Paper 3

Wednesday 6 November 2019 (morning)

Candidate session number

1 hour

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 **[35 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 – 4
Option B — Engineering physics	5 – 6
Option C — Imaging	7 – 9
Option D — Astrophysics	10 – 11

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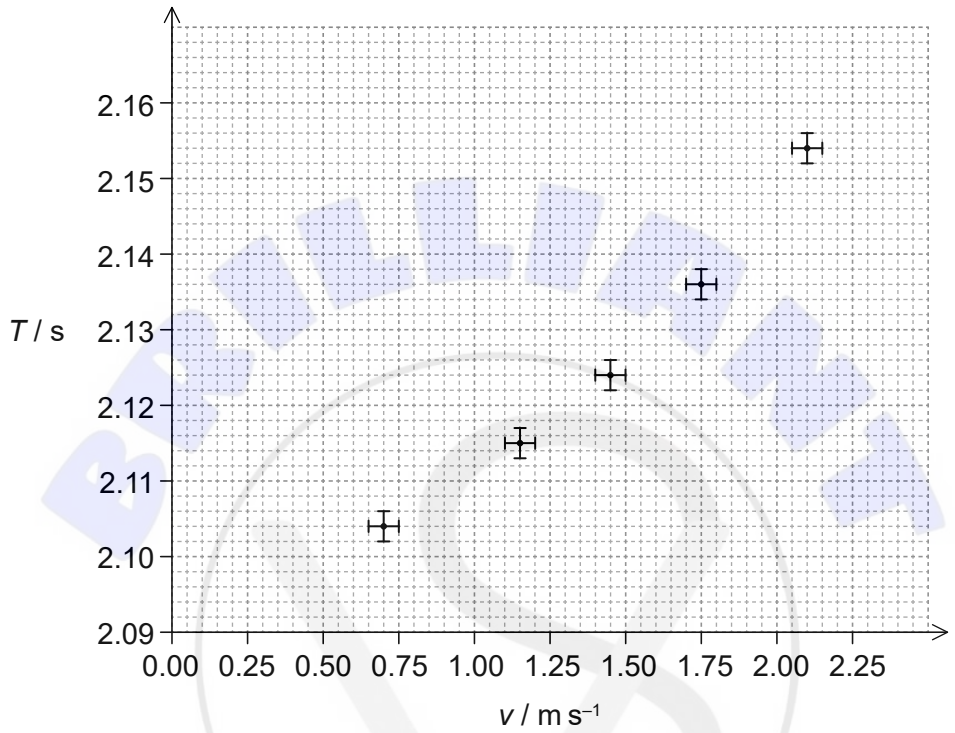
25 pages

Section A

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

1. A student investigates how the period T of a simple pendulum varies with the maximum speed v of the pendulum's bob by releasing the pendulum from rest from different initial angles. A graph of the variation of T with v is plotted.



(a) Suggest, by reference to the graph, why it is unlikely that the relationship between T and v is linear. [1]

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(b) Determine the fractional uncertainty in v when $T = 2.115\,\text{s}$, correct to **one** significant figure. [2]

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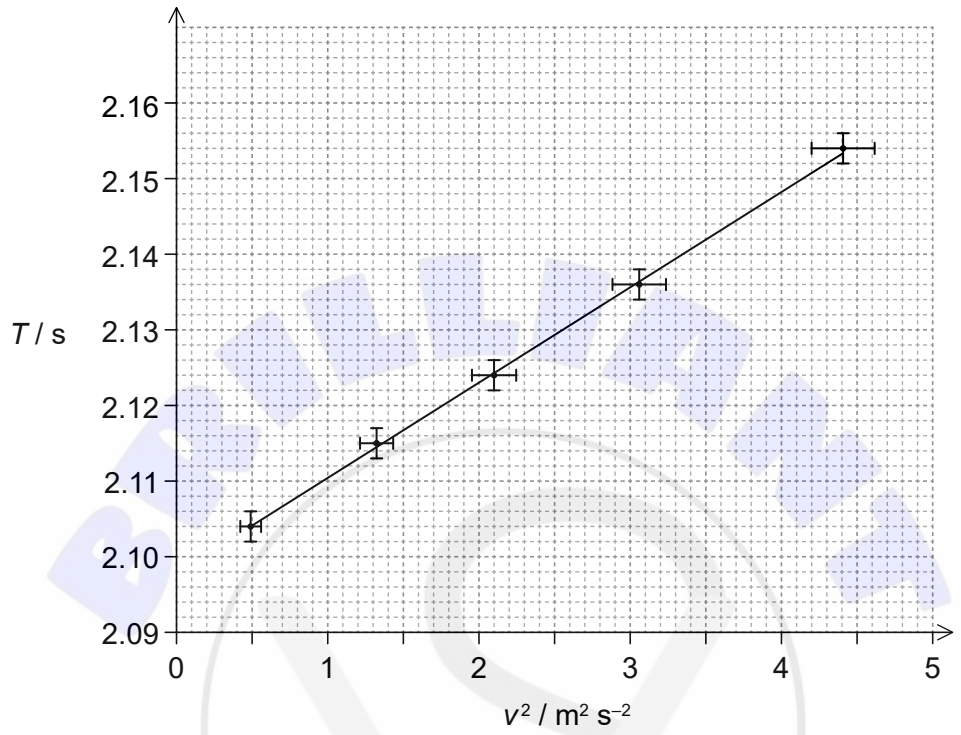
(Question 1 continued)

(c) The student hypothesizes that the relationship between T and v is $T = a + bv^2$, where a and b are constants. To verify this hypothesis a graph showing the variation of T with v^2 is plotted. The graph shows the data and the line of best fit.



Determine b, giving an appropriate unit for b. [3]

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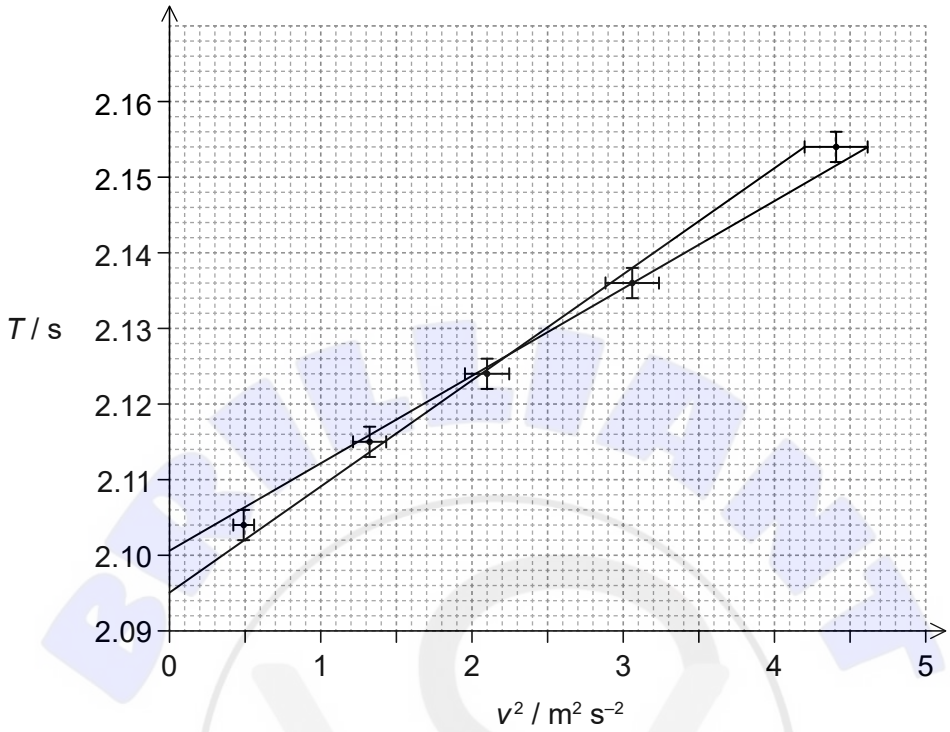
(Question 1 continued)

(d) The lines of the minimum and maximum gradient are shown.



Estimate the absolute uncertainty in *a*. [2]

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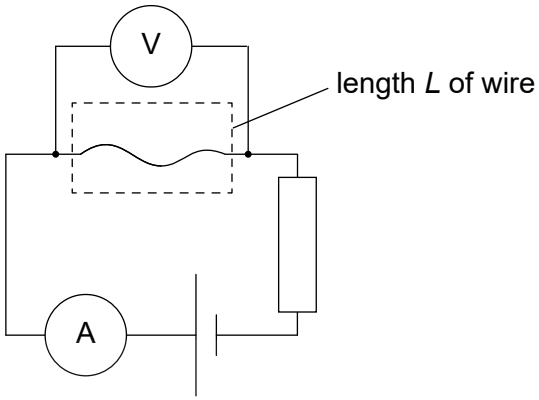
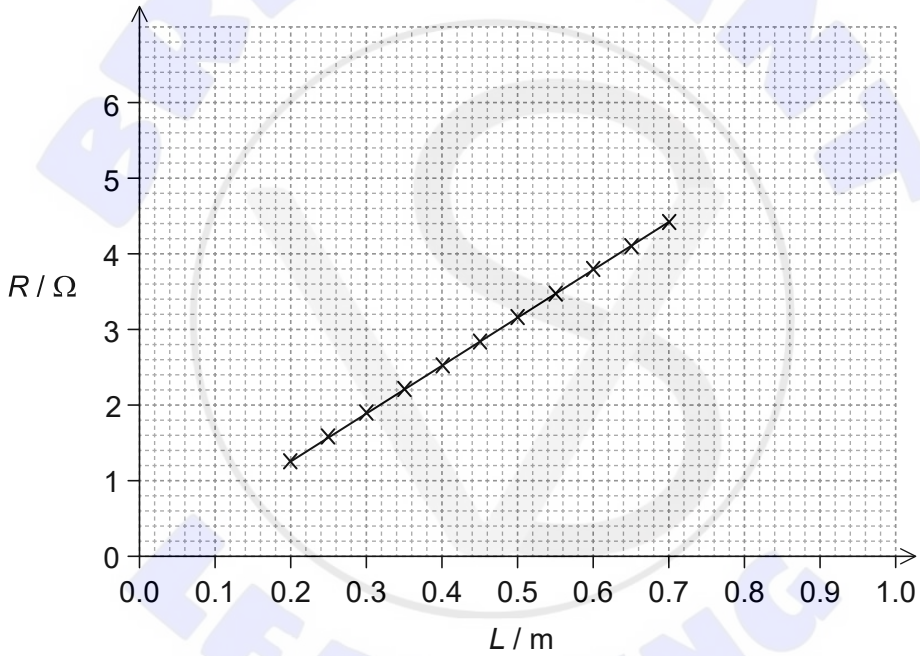
2. The resistance R of a wire of length L can be measured using the circuit shown.



(a) In one experiment the wire has a uniform diameter of $d = 0.500\,\text{mm}$. The graph shows data obtained for the variation of R with L.



The gradient of the line of best fit is $6.30\,\Omega\,\text{m}^{-1}$.

(i) Estimate the resistivity of the material of the wire. Give your answer to an appropriate number of significant figures. [2]

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(This question continues on the following page)

(Question 2 continued)

(ii) Explain, by reference to the power dissipated in the wire, the advantage of the fixed resistor connected in series with the wire for the measurement of *R*. [3]

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(b) The experiment is repeated using a wire made of the same material but of a larger diameter than the wire in part (a). On the axes in part (a), draw the graph for this second experiment. [2]

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) One of the two postulates of special relativity states that the speed of light in a vacuum is the same for all observers in inertial reference frames. State the other postulate of special relativity. [1]

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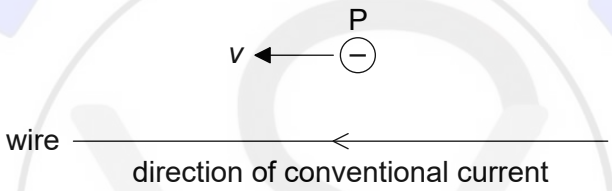
(b) A long straight current-carrying wire is at rest in a laboratory. A negatively-charged particle P outside the wire moves parallel to the current with constant velocity v relative to the laboratory.



In the reference frame of the laboratory the particle P experiences a repulsive force away from the wire.

(i) State the nature of the force on the particle P in the reference frame of the laboratory. [1]

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(ii) Deduce, using your answer to part (a), the nature of the force that acts on the particle P in the rest frame of P. [2]

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(Option A continues on the following page)

(Option A, question 3 continued)

(iii) Explain how the force in part (b)(ii) arises. [2]

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(iv) The velocity of P is 0.30*c* relative to the laboratory. A second particle Q moves at a velocity of 0.80*c* relative to the laboratory.

Calculate the speed of Q relative to P. [2]

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(Option A continues on the following page)

(Option A continued)

4. A train is moving across a bridge with a speed $v = 0.40c$. Observer A is at rest in the train. Observer B is at rest with respect to the bridge.

The length of the bridge L_B according to observer B is 2.0 km.

(a) Calculate, for observer A,

(i) the length L_A of the bridge [2]

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(ii) the time taken to cross the bridge. [2]

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(b) Outline why L_B is the proper length of the bridge. [1]

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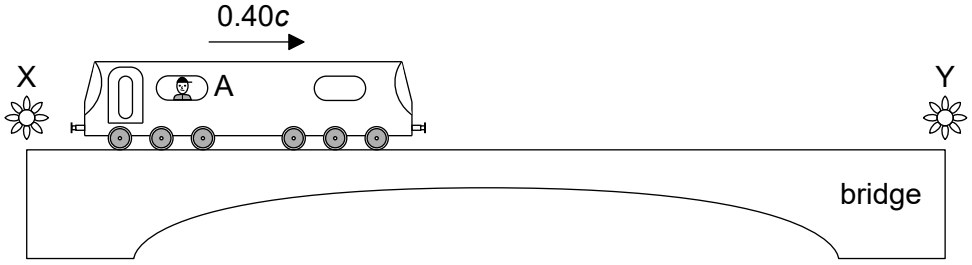
(c) According to observer B, two lamps at opposite ends of the bridge are turned on simultaneously as observer A crosses the bridge. Event X is the lamp at one end of the bridge turning on. Event Y is the lamp at the other end of the bridge turning on.

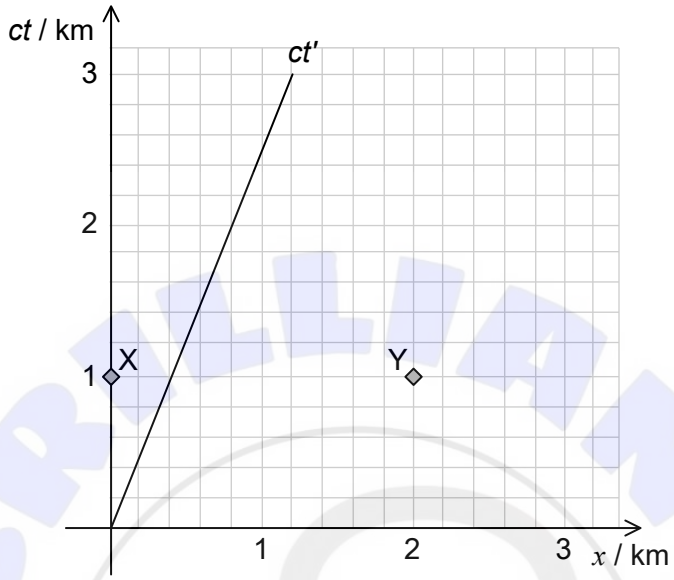
not to scale



(Option A continues on the following page)

(Option A, question 4 continued)

Events X and Y are shown on the spacetime diagram. The space and time axes of the reference frame for observer B are x and ct. The line labelled ct' is the worldline of observer A.



(i) Draw, on the spacetime diagram, the space axis for the reference frame of observer A. Label this axis x'. [1]

(ii) Demonstrate using the diagram which lamp, according to observer A, was **turned on** first. [2]

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(iii) Demonstrate, using the diagram, which lamp observer A **observes** to light first. [2]

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(iv) Determine the time, according to observer A, between X and Y. [2]

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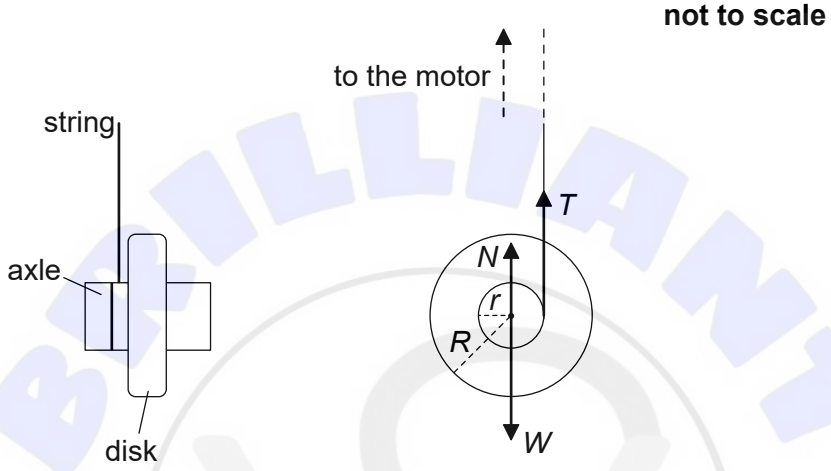
End of Option A

Option B — Engineering physics

5. A flywheel is made of a solid disk with a mass M of 5.00 kg mounted on a small radial axle. The mass of the axle is negligible. The radius R of the disk is 6.00 cm and the radius r of the axle is 1.20 cm.

A string of negligible thickness is wound around the axle. The string is pulled by an electric motor that exerts a vertical tension force T on the flywheel. The diagram shows the forces acting on the flywheel. W is the weight and N is the normal reaction force from the support of the flywheel.

not to scale



The moment of inertia of the flywheel about the axis is $I = \frac{1}{2}MR^2$.

(a) State the torque provided by the force W about the axis of the flywheel. [1]

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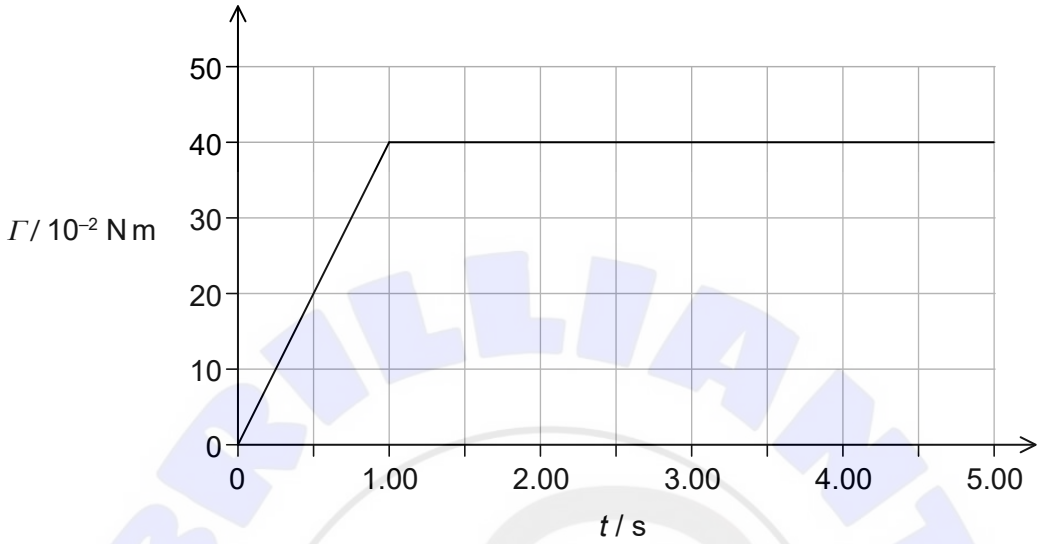
(Option B continues on the following page)

(Option B, question 5 continued)

(b) The flywheel is initially at rest. At time $t = 0$ the motor is switched on and a time-varying tension force acts on the flywheel. The torque Γ exerted on the flywheel by the tension force in the string varies with t as shown on the graph.



(i) Identify the physical quantity represented by the area under the graph. [1]

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(ii) Show that the angular velocity of the flywheel at $t = 5.00\,\text{s}$ is $200\,\text{rad}\,\text{s}^{-1}$. [2]

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(iii) Calculate the maximum tension in the string. [1]

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(Option B continues on the following page)

(Option B, question 5 continued)

(c) At $t = 5.00\,\text{s}$ the string becomes fully unwound and it disconnects from the flywheel. The flywheel remains spinning around the axle.

(i) The flywheel is in translational equilibrium. Distinguish between translational equilibrium and rotational equilibrium. [2]

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(ii) At $t = 5.00\,\text{s}$ the flywheel is spinning with angular velocity $200\,\text{rad}\,\text{s}^{-1}$. The support bearings exert a constant frictional torque on the axle. The flywheel comes to rest after 8.00×10^3 revolutions. Calculate the magnitude of the frictional torque exerted on the flywheel. [3]

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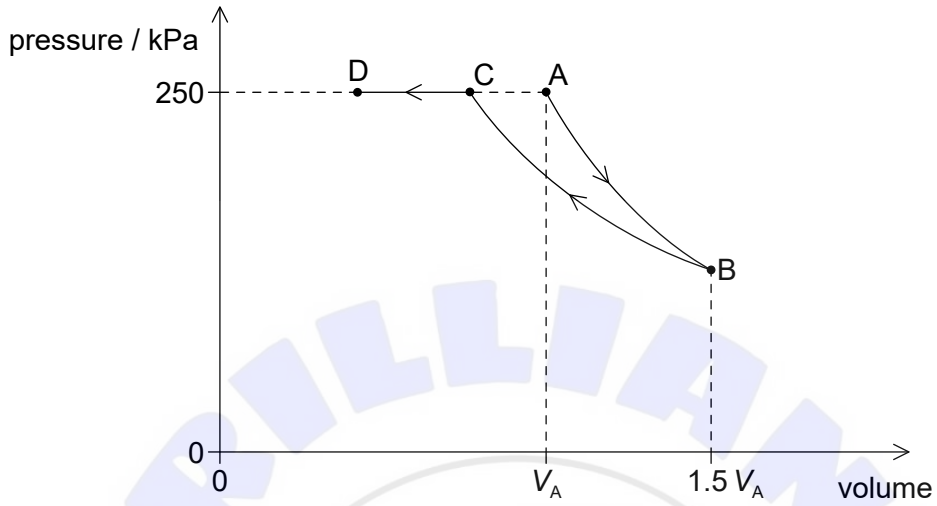
(Option B continues on the following page)

(Option B continued)

6. An ideal gas consisting of 0.300 mol undergoes a process ABCD. AB is an adiabatic expansion from the initial volume V_A to the volume $1.5\,V_A$. BC is an isothermal compression. The pressures at C and D are the same as at A.



The following data are available.

Pressure at A = 250 kPa
Volume at C = 3.50×10^{-3} m^3
Volume at D = 2.00×10^{-3} m^3

(a) (i) Show that the pressure at B is about 130 kPa. [2]

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(ii) Calculate the ratio $\frac{V_A}{V_C}$. [1]

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(Option B continues on the following page)

(Option B, question 6 continued)

(b) The gas at C is further compressed to D at a constant pressure. During this compression the temperature decreases by 150 K.

For the compression CD,

(i) determine the thermal energy removed from the system. [3]

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(ii) explain why the entropy of the gas decreases. [2]

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(iii) state and explain whether the second law of thermodynamics is violated. [2]

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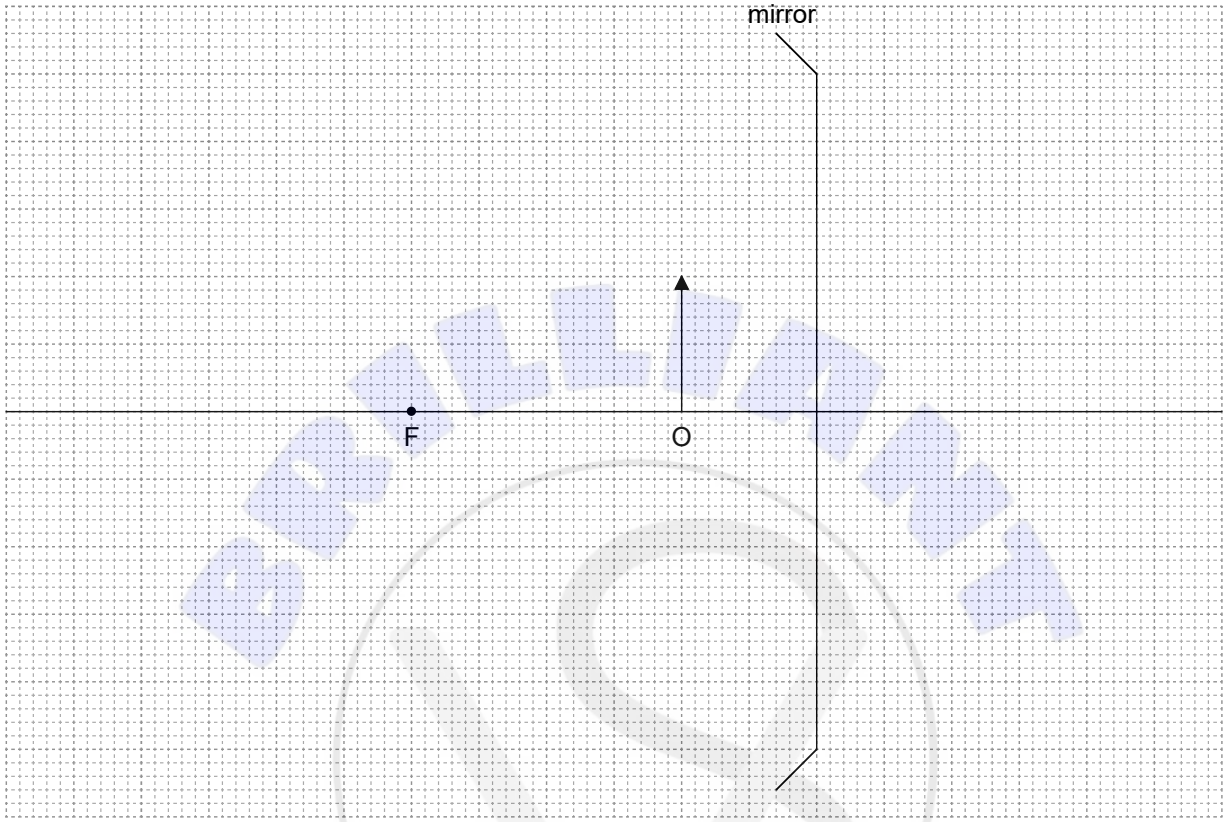
End of Option B

Option C — Imaging

7. (a) The diagram, drawn to scale, shows an object O placed in front of a converging mirror. The focal point of the mirror is labelled F.



(i) Construct a ray diagram in order to locate the position of the image formed by the mirror. Label the image I. [2]

(ii) Estimate the linear magnification of the image. [1]

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(iii) Describe **two** features of the image. [1]

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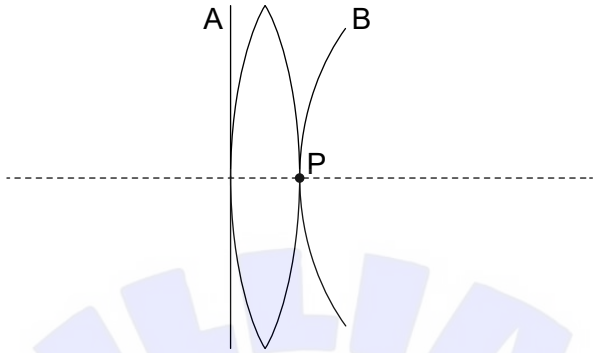
(Option C continues on the following page)

(Option C, question 7 continued)

(b) A planar wavefront of white light, labelled A, is incident on a converging lens. Point P is on the surface of the lens and the principal axis. The **blue** component of the transmitted wavefront, labelled B, is passing through point P.



(i) Sketch, on the diagram, the wavefront of **red** light passing through point P. Label this wavefront R. [1]

(ii) Explain chromatic aberration, with reference to your diagram in (b)(i). [2]

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(Option C continues on the following page)

(Option C, question 7 continued)

(iii) An achromatic doublet reduces the effect of chromatic aberration. Describe an achromatic doublet. [2]

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8. A small object is placed at a distance of 2.0 cm from the objective lens of an optical compound microscope in normal adjustment.

The following data are available.

Magnification of the microscope = 70
Focal length of the eyepiece = 3.0 cm
Near point distance = 24 cm

(a) State what is meant by normal adjustment when applied to a compound microscope. [1]

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(b) Calculate, in cm, the distance between the eyepiece and the image formed by the objective lens. [2]

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(Option C continues on the following page)

(Option C, question 8 continued)

(c) Determine, in cm, the focal length of the objective lens. [3]

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9. Communication signals are transmitted over long distances through optic fibres.

(a) Describe why a higher data transfer rate is possible in optic fibres than in twisted pair cables. [2]

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(b) A signal is transmitted along an optic fibre with attenuation per unit length of $0.40\,\text{dB}\,\text{km}^{-1}$. The signal must be amplified when the power of the signal has fallen to 0.02 % of the input power.

(i) State **one** cause of attenuation in the optic fibre. [1]

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(Option C continues on the following page)

(Option C, question 9 continued)

(ii) Determine the distance at which the signal must be amplified. [2]

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End of Option C

Option D — Astrophysics

10. Eta Cassiopeiae A and B is a binary star system located in the constellation Cassiopeia.

(a) Distinguish between a constellation and a stellar cluster. [2]

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(b) The following data are available.

Apparent brightness of Eta Cassiopeiae A $= 1.1 \times 10^{-9}\,\text{Wm}^{-2}$
Apparent brightness of Eta Cassiopeiae B $= 5.4 \times 10^{-11}\,\text{Wm}^{-2}$
Luminosity of the Sun, $L_\odot$ $= 3.8 \times 10^{26}\,\text{W}$

(i) The peak wavelength of radiation from Eta Cassiopeiae A is 490 nm. Show that the surface temperature of Eta Cassiopeiae A is about 6000 K. [1]

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(ii) The surface temperature of Eta Cassiopeiae B is 4100 K. Determine the ratio $\frac{\text{radius of Eta Cassiopeiae A}}{\text{radius of Eta Cassiopeiae B}}$. [3]

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(Option D continues on the following page)

(Option D, question 10 continued)

(iii) The distance of the Eta Cassiopeiae system from the Earth is 1.8×10^{17} m. Calculate, in terms of $L_\odot$, the luminosity of Eta Cassiopeiae A. [2]

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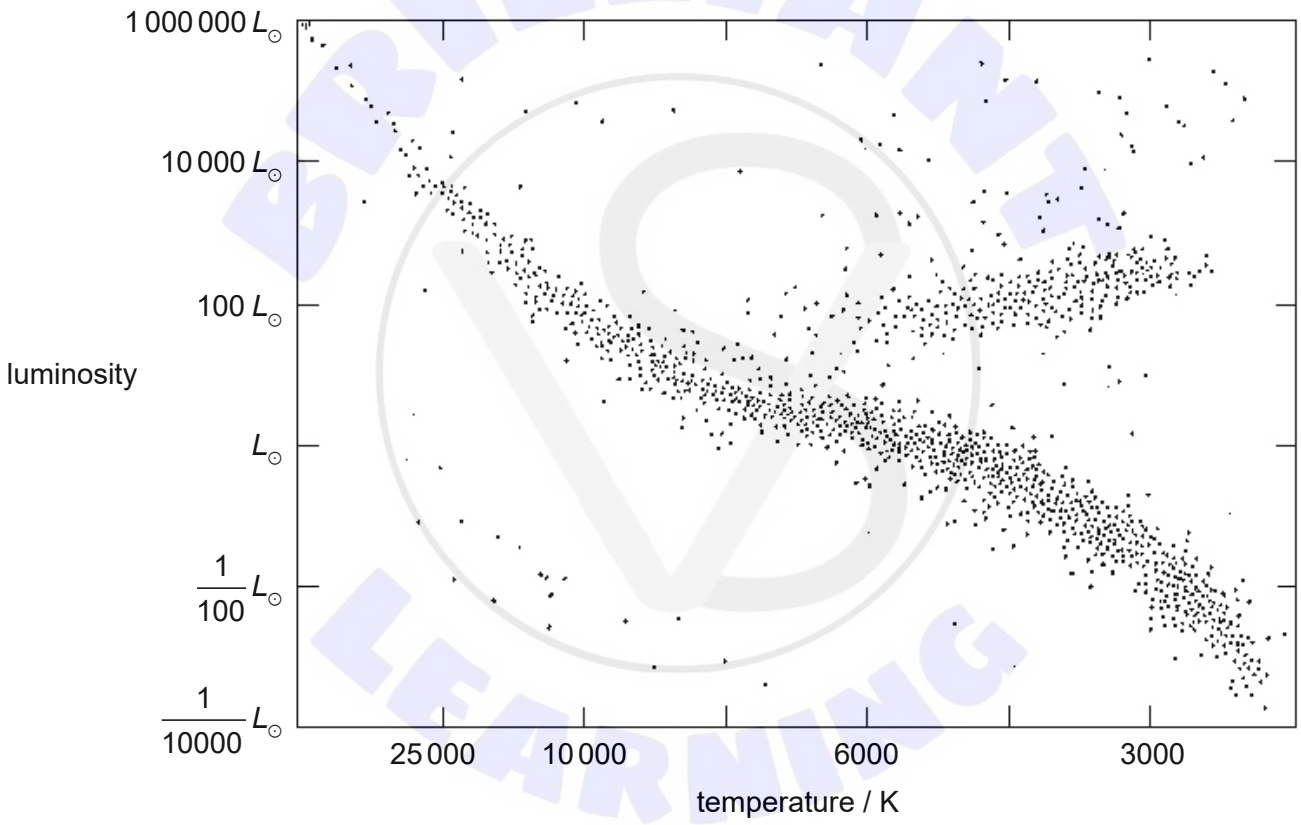
(c) A Hertzsprung–Russell (HR) diagram is shown.



(i) On the HR diagram, draw the present position of Eta Cassiopeiae A. [1]

(ii) State the star type of Eta Cassiopeiae A. [1]

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(Option D continues on the following page)

(Option D, question 10 continued)

(iii) Calculate the ratio $\frac{\text{mass of Eta Cassiopeiae A}}{\text{mass of the Sun}}$. [1]

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(iv) Deduce the final evolutionary state of Eta Cassiopeiae A. [2]

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11. (a) (i) Outline how the light spectra of distant galaxies are used to confirm hypotheses about the expansion of the universe. [2]

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(ii) Light from a hydrogen source in a laboratory on Earth contains a spectral line of wavelength 122 nm. Light from the same spectral line reaching Earth from a distant galaxy has a wavelength of 392 nm. Determine the ratio of the present size of the universe to the size of the universe when the light was emitted by the galaxy. [2]

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(Option D continues on the following page)

(Option D, question 11 continued)

(b) (i) Estimate the age of the universe in seconds using the Hubble constant $H_0 = 70\,\text{km}\,\text{s}^{-1}\,\text{Mpc}^{-1}$. [2]

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(ii) Outline why the estimate made in (b)(i) is unlikely to be the actual age of the universe. [1]

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End of Option D

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