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

Wednesday 6 November 2019 (morning)

Candidate session number

1 hour 15 minutes

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**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

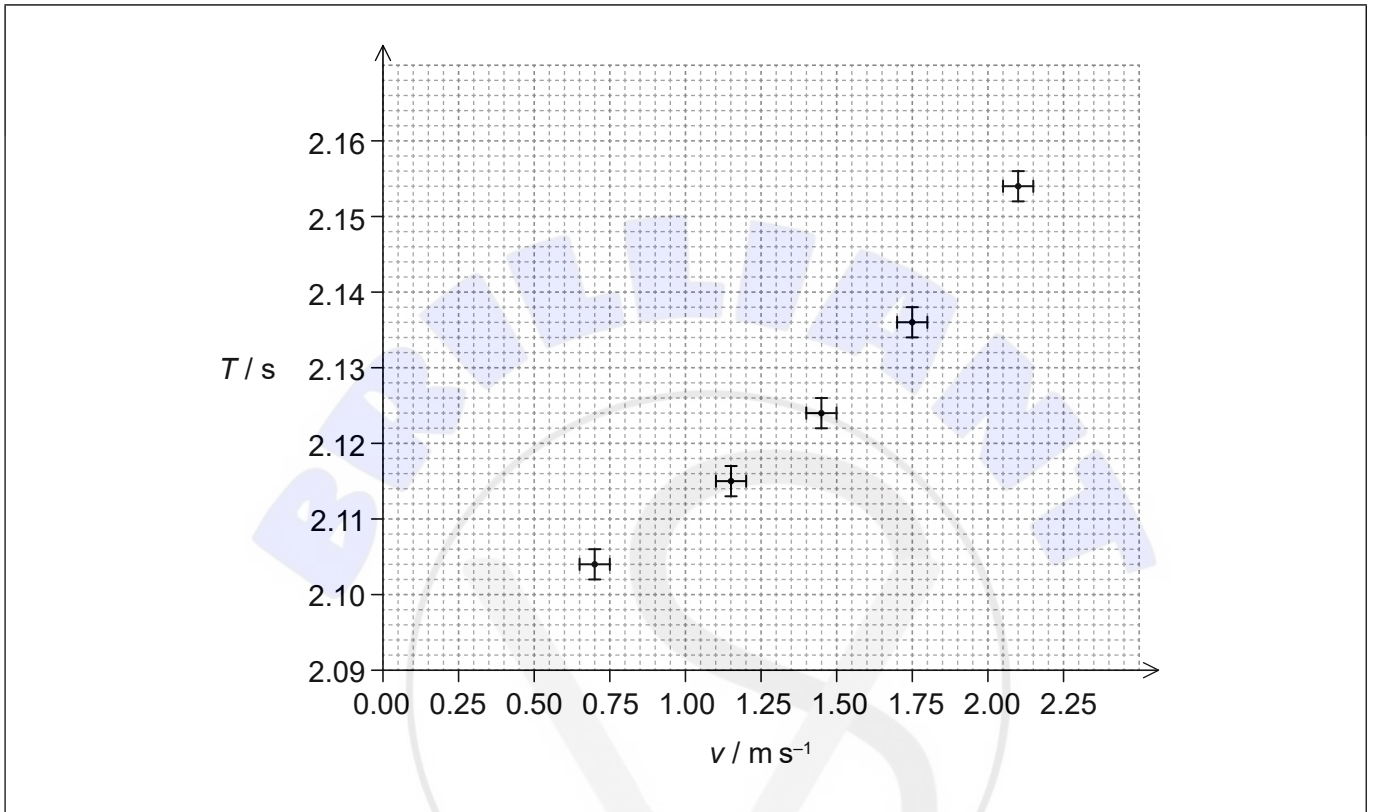
Section B	Questions
Answer all of the questions from one of the options.	
Option A — Relativity	3 – 6
Option B — Engineering physics	7 – 10
Option C — Imaging	11 – 14
Option D — Astrophysics	15 – 17



### 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]

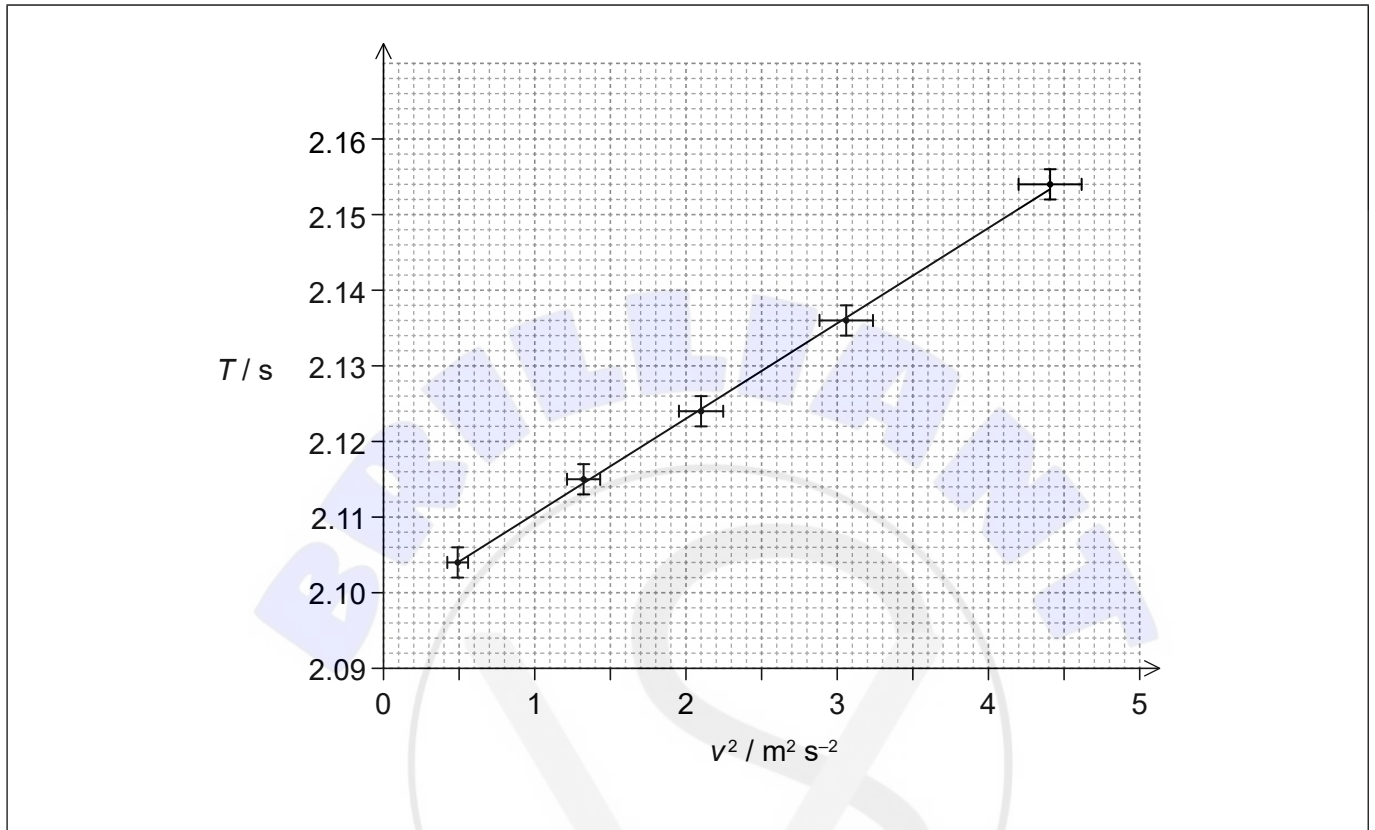
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(Question 1 continued)

- (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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(This question continues on page 5)



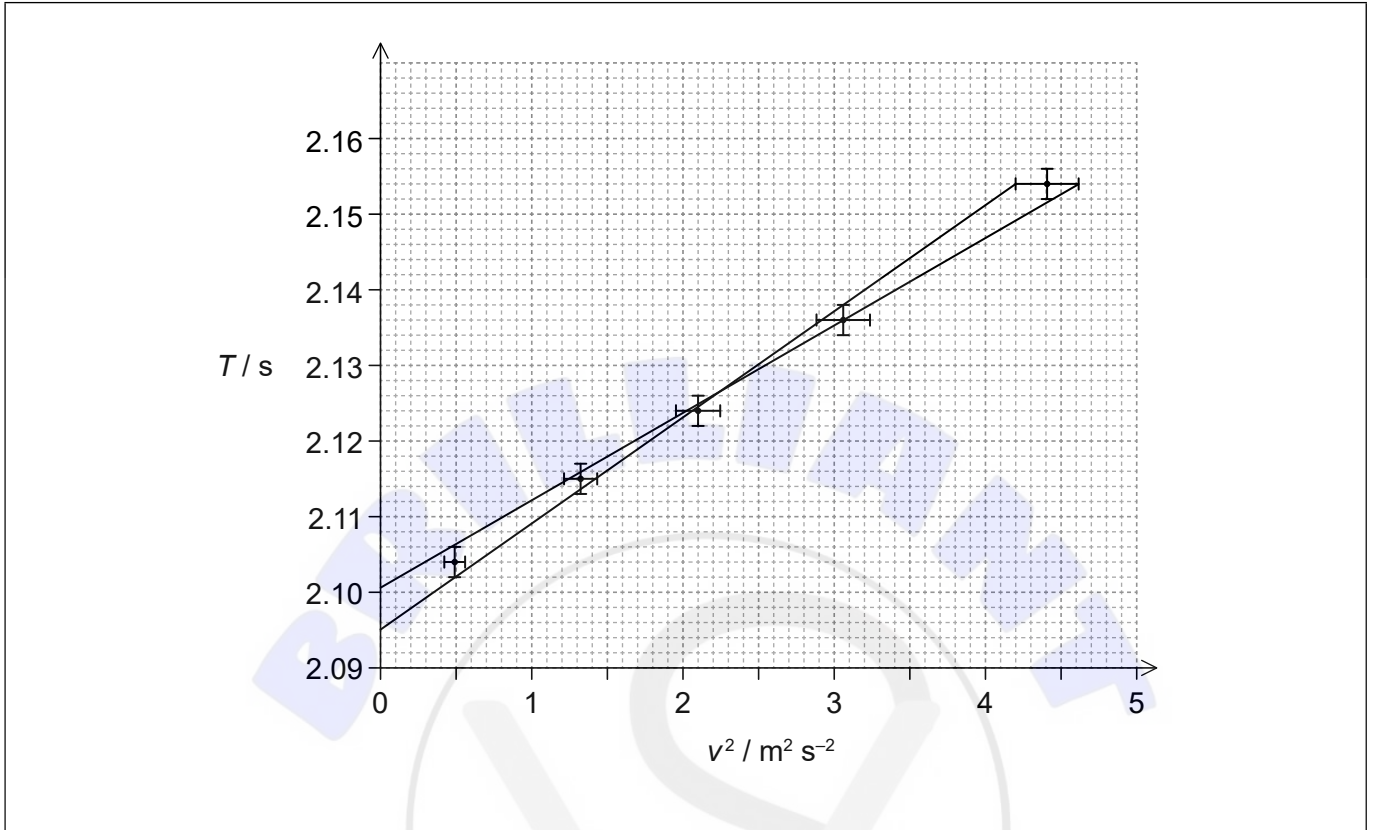


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Answers written on this page  
will not be marked.



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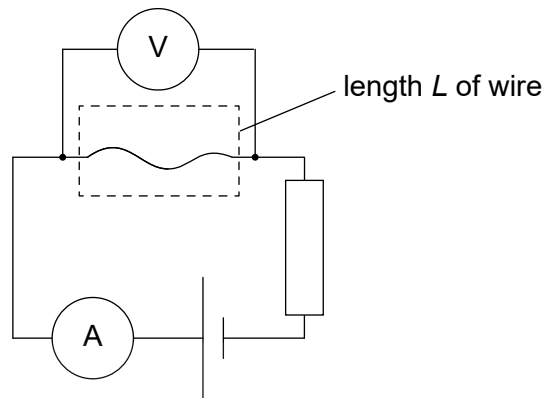
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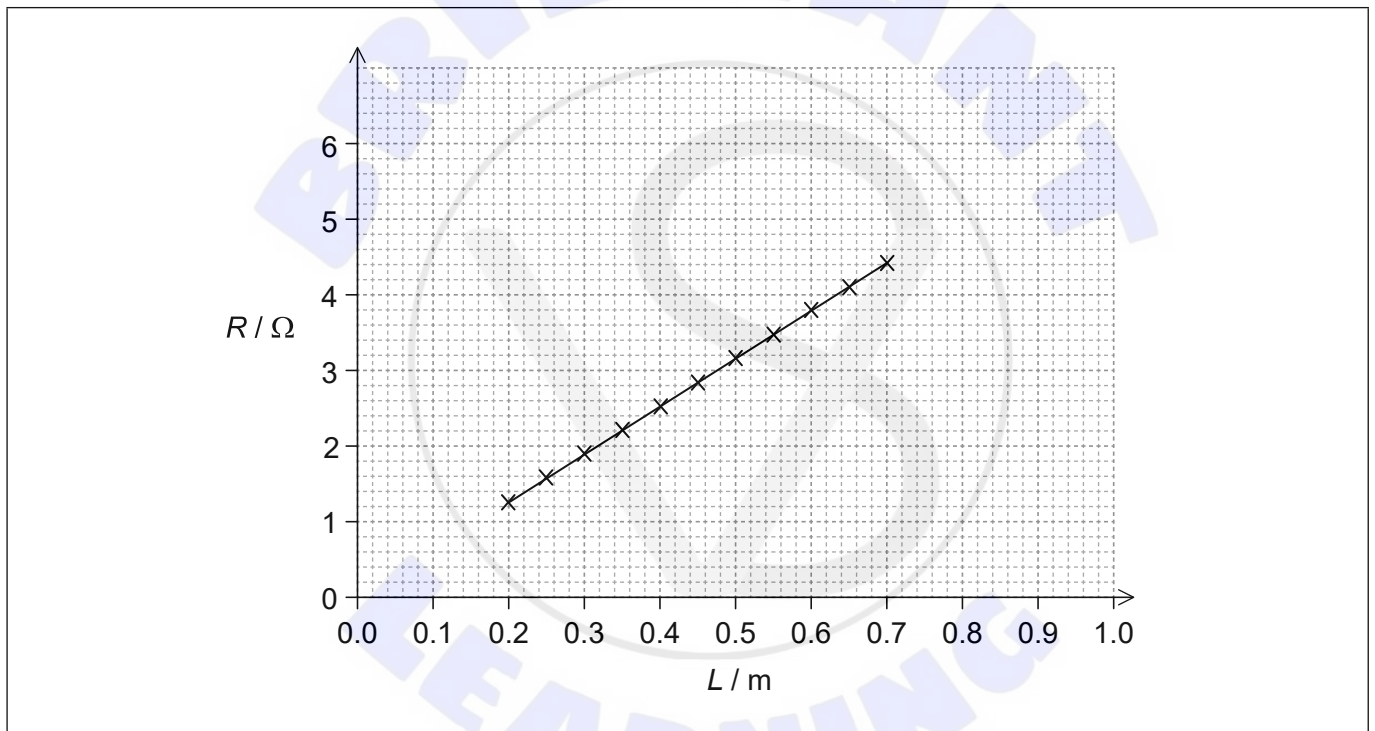
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2. The resistance  $R$  of a wire of length  $L$  can be measured using the circuit shown.



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



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

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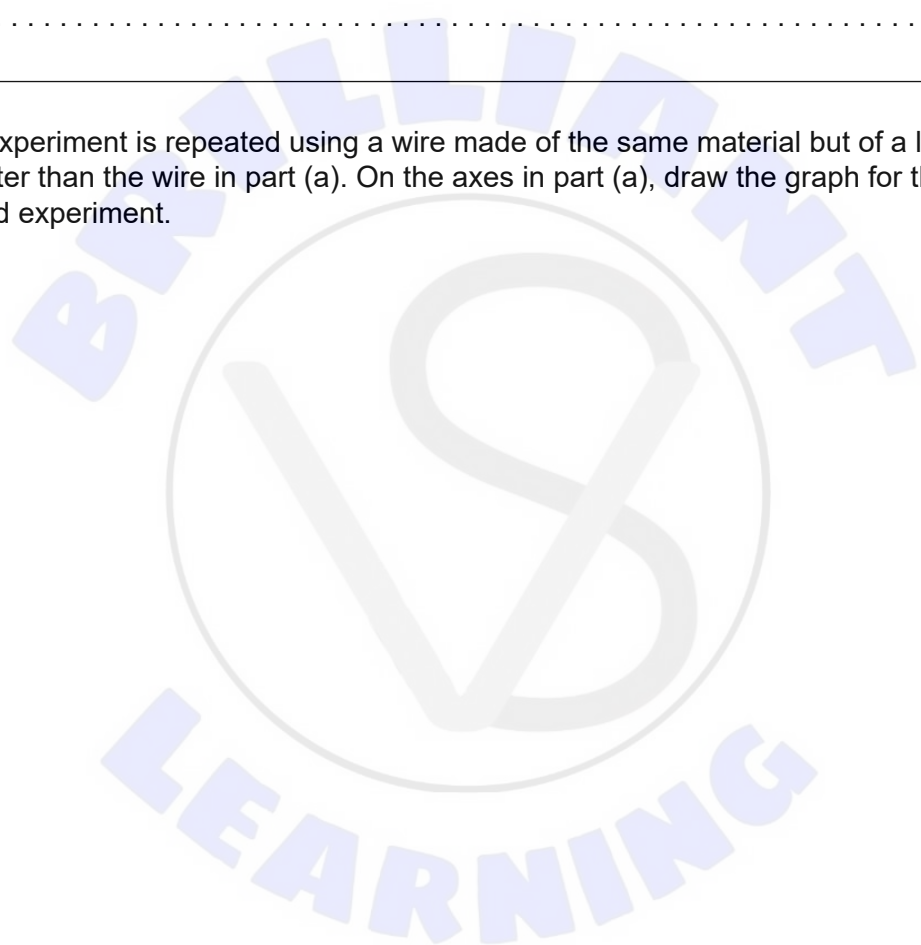
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- (b) The experiment is repeated using a wire made of the same material but of a larger diameter than the wire in part (a). On the axes in part (a), draw the graph for this second experiment.

[2]



### Section B

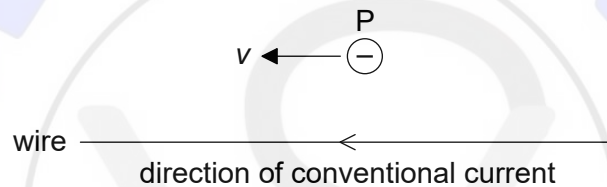
Answer **all** of the questions from **one** of the options. Answers must be written within the answer boxes provided.

#### 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  $0.30c$  relative to the laboratory. A second particle Q moves at a velocity of  $0.80c$  relative to the laboratory.



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

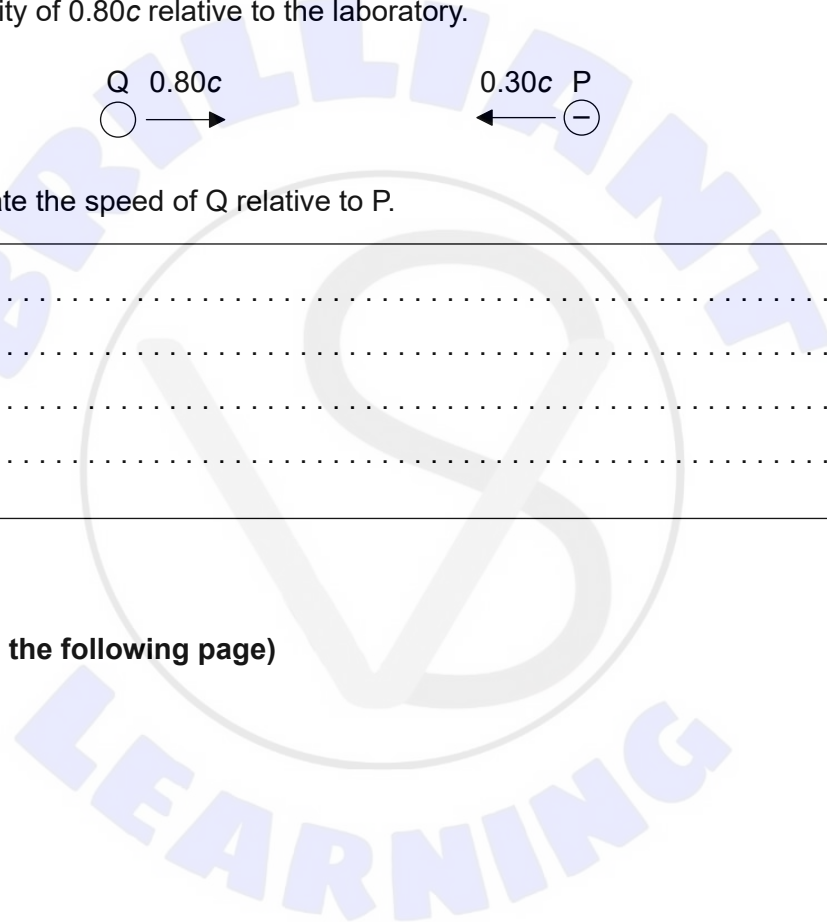
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**(Option A continues on the following page)**



**(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]

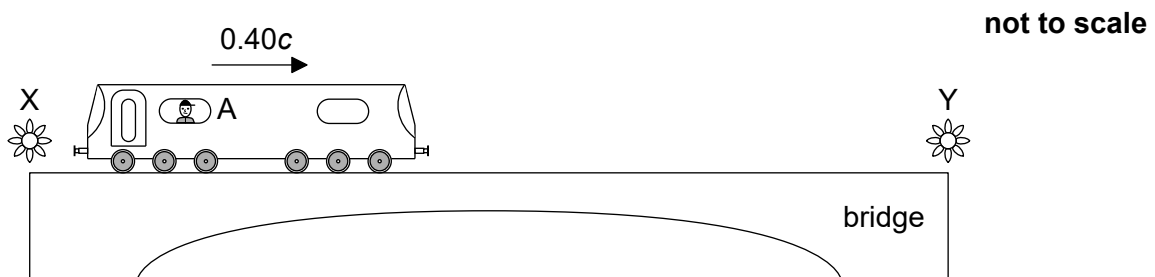
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- (b) Outline why  $L_B$  is the proper length of the bridge.

[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.

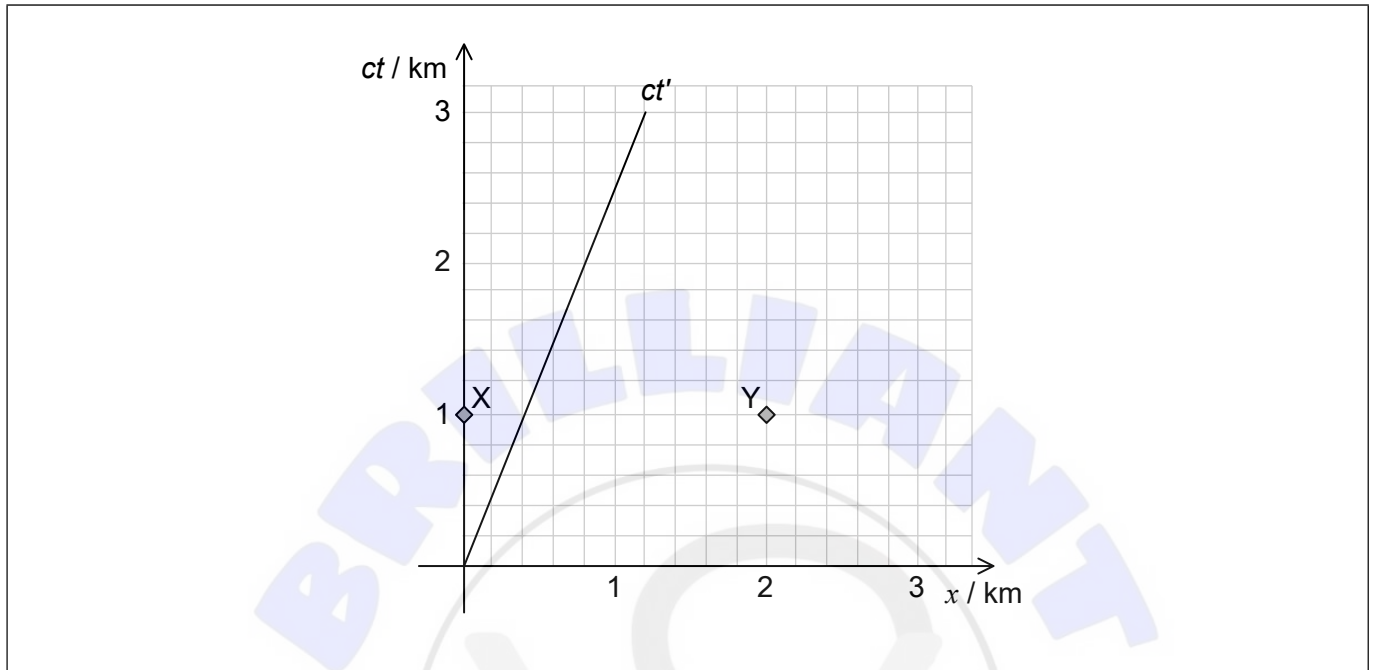


**(Option A continues on the following page)**



(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]

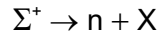
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(Option A continues on the following page)



**(Option A continued)**

5. A  $\Sigma^+$  particle decays from rest into a neutron and another particle X according to the reaction



The following data are available.

$$\begin{aligned} \text{Rest mass of } \Sigma^+ &= 1190 \text{ MeVc}^{-2} \\ \text{Momentum of neutron} &= 185 \text{ MeVc}^{-1} \end{aligned}$$

(a) Calculate, for the neutron,

(i) the total energy.

[1]

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(ii) the speed.

[2]

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(b) Determine the rest mass of X.

[3]

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



**(Option A continued)**

6. A black hole has a Schwarzschild radius  $R$ . A probe at a distance of  $0.5R$  from the event horizon of the black hole emits radio waves of frequency  $f$  that are received by an observer very far from the black hole.

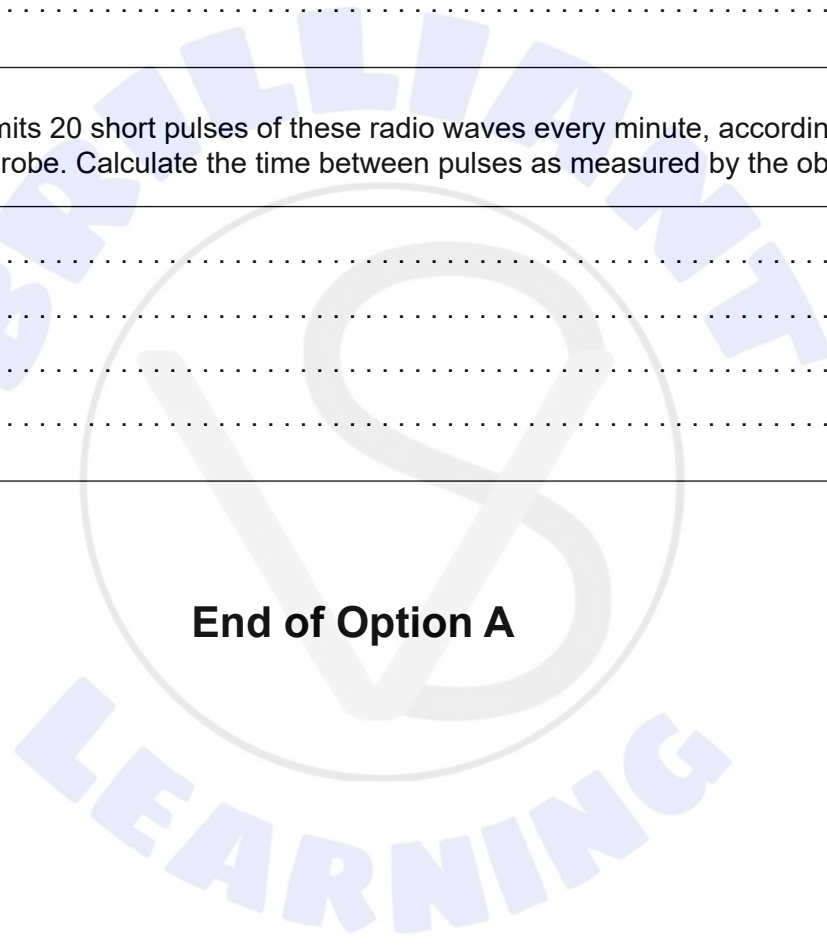
(a) Explain why the frequency of the radio waves detected by the observer is lower than  $f$ . [2]

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(b) The probe emits 20 short pulses of these radio waves every minute, according to a clock in the probe. Calculate the time between pulses as measured by the observer. [2]

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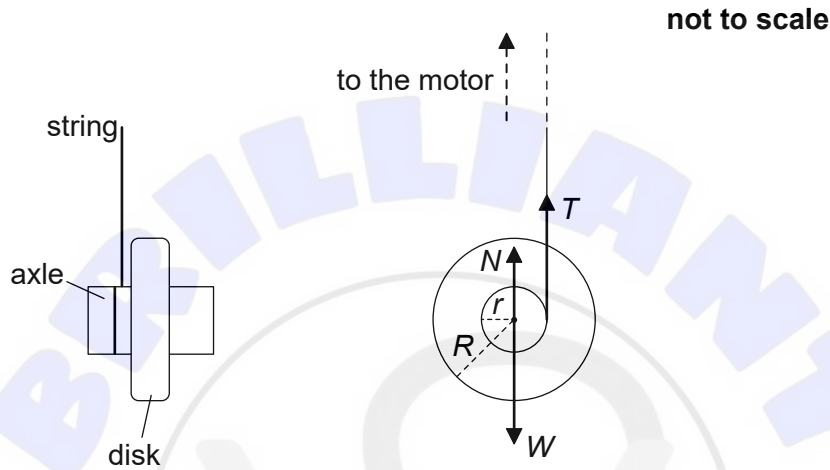
**End of Option A**



**Option B — Engineering physics**

7. 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.



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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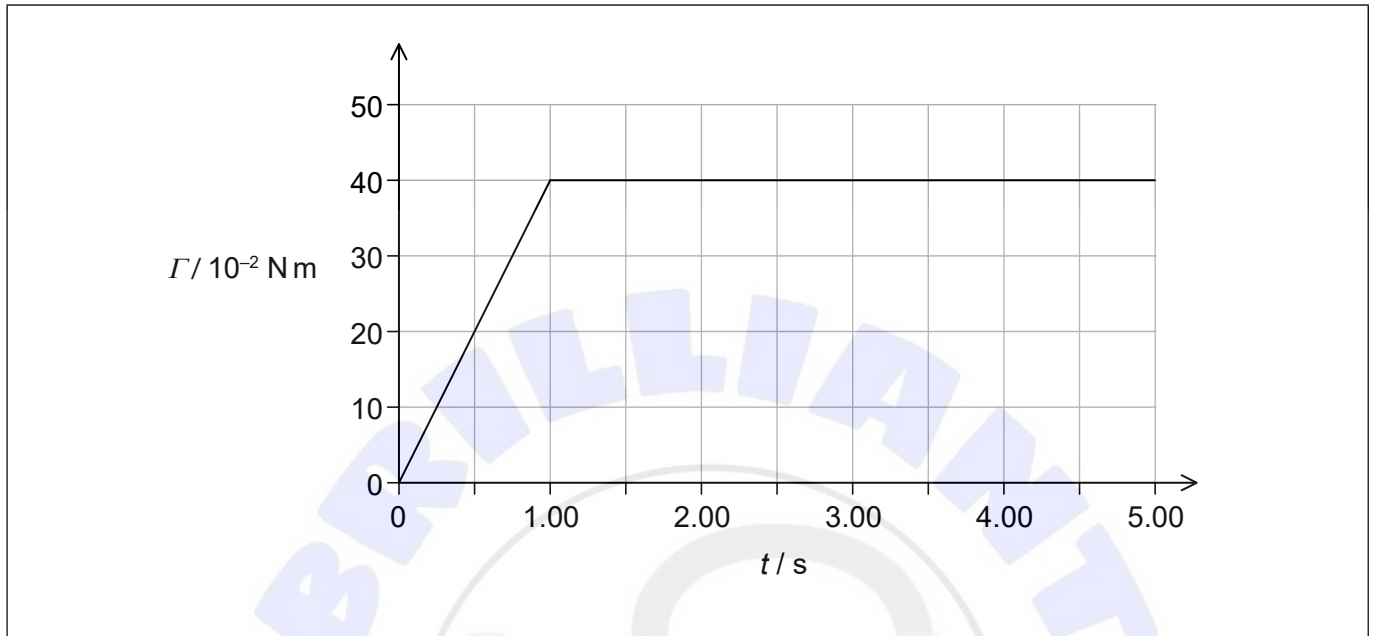
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(Option B continues on the following page)



**(Option B, question 7 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  $\Gamma$  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  $200 \text{ rad s}^{-1}$ . [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 7 continued)**

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

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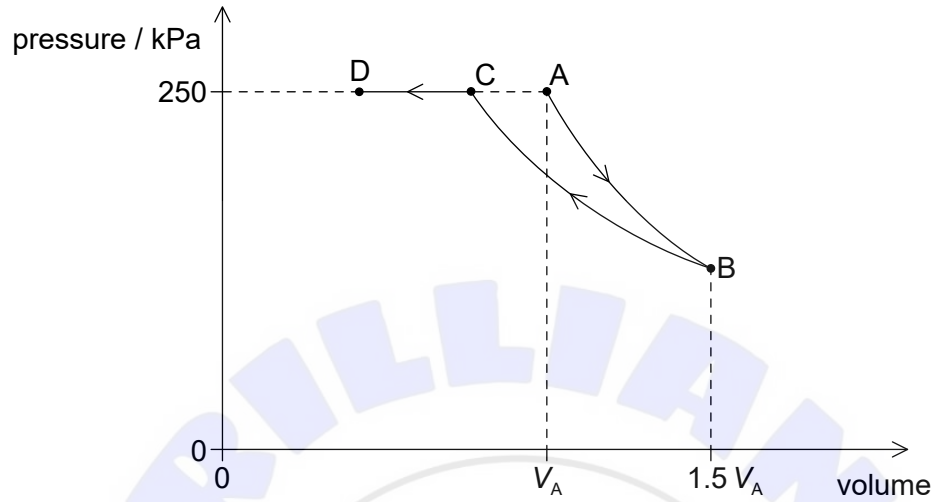
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**(Option B continues on the following page)**



(Option B continued)

8. 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 =  $3.50 \times 10^{-3} \text{ m}^3$
- Volume at D =  $2.00 \times 10^{-3} \text{ m}^3$

- (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 8 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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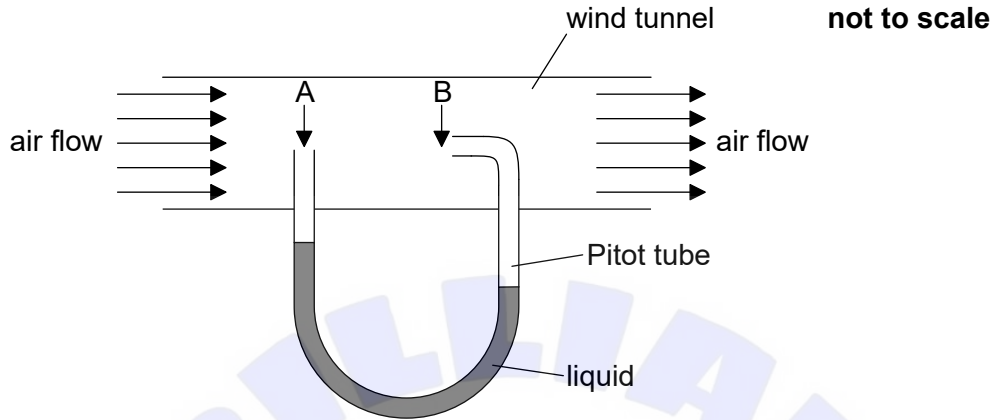
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**(Option B continues on the following page)**



**(Option B continued)**

9. A Pitot tube shown in the diagram is used to determine the speed of air flowing steadily in a horizontal wind tunnel. The narrow tube between points A and B is filled with a liquid. At point B the speed of the air is zero.



- (a) Explain why the levels of the liquid are at different heights. [3]

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- (b) The density of the liquid in the tube is  $8.7 \times 10^2 \text{ kg m}^{-3}$  and the density of air is  $1.2 \text{ kg m}^{-3}$ . The difference in the level of the liquid is 6.0 cm. Determine the speed of air at A. [3]

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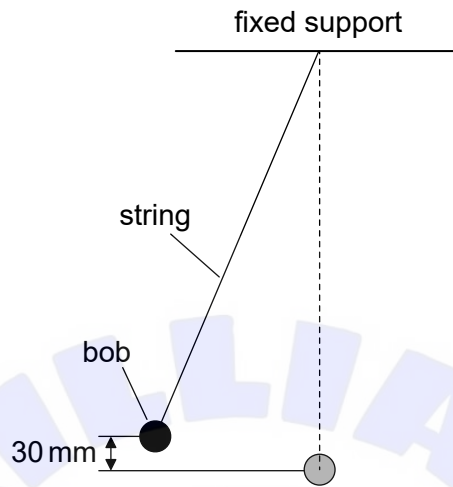
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(Option B continues on the following page)



**(Option B continued)**

10. A pendulum bob is displaced until its centre is 30 mm above its rest position and then released. The motion of the pendulum is lightly damped.



- (a) Describe what is meant by damped motion.

[1]

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- (b) After one complete oscillation, the height of the pendulum bob above the rest position has decreased to 28 mm. Calculate the Q factor.

[1]

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



**(Option B, question 10 continued)**

- (c) The point of suspension now vibrates horizontally with small amplitude and frequency 0.80 Hz, which is the natural frequency of the pendulum. The amount of damping is unchanged.



When the pendulum oscillates with a constant amplitude the energy stored in the system is 20 mJ. Calculate the average power, in W, delivered to the pendulum by the driving force.

[2]

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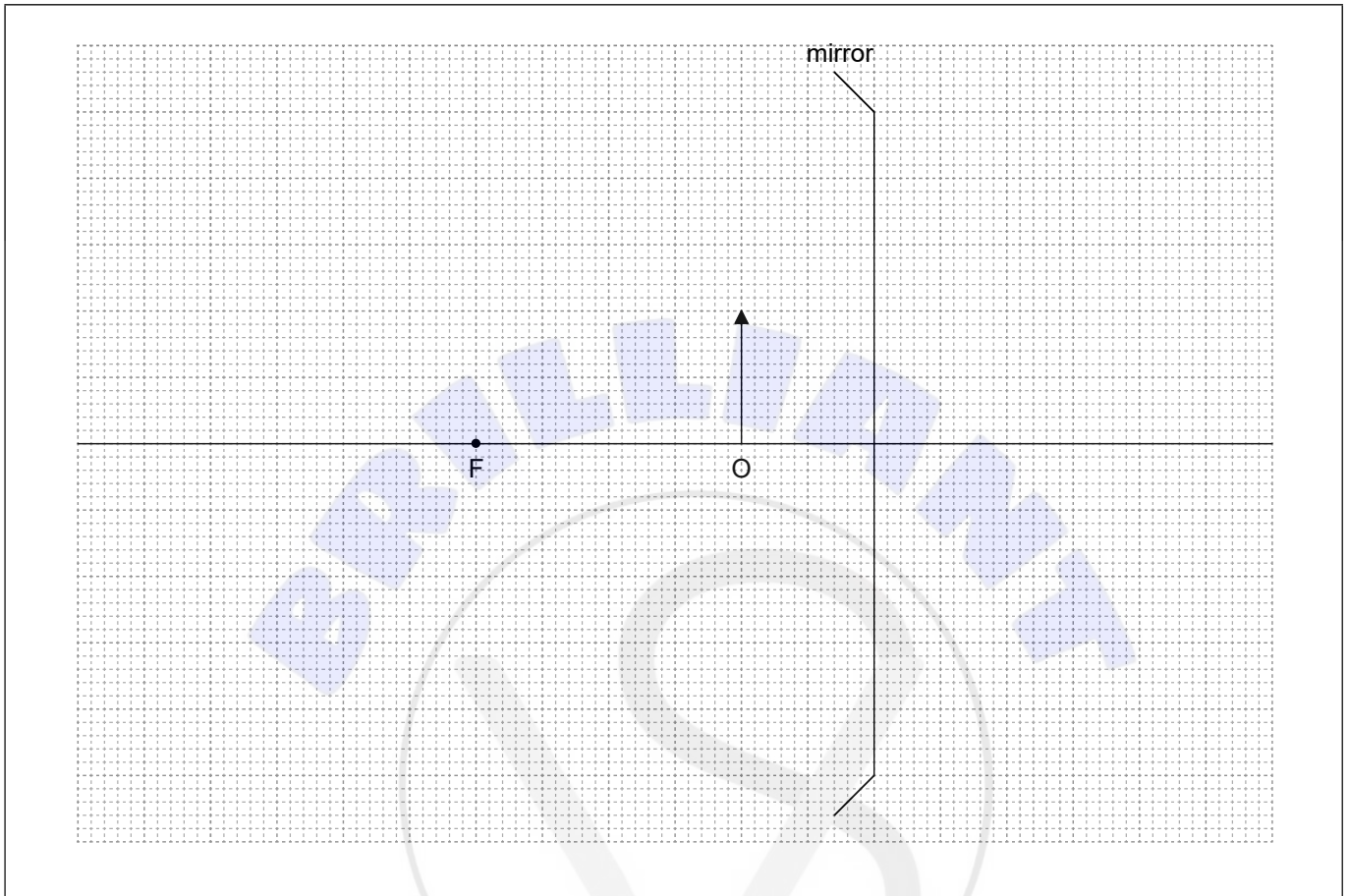
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**End of Option B**



**Option C — Imaging**

11. (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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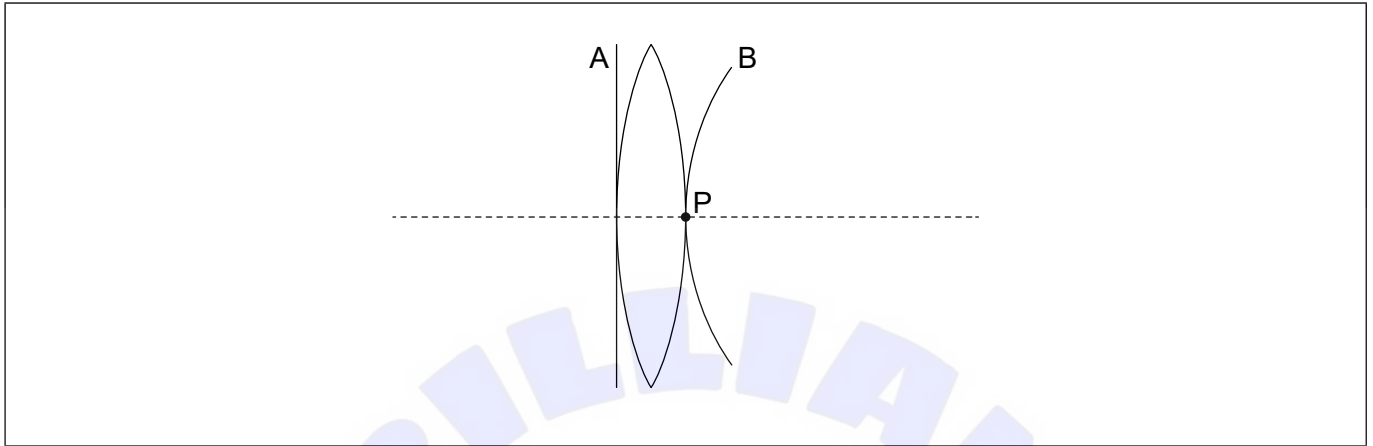
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(Option C continues on the following page)



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

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

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- 12.** 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 12 continued)

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

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13. 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  $0.40 \text{ dB km}^{-1}$ . 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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- (ii) Determine the distance at which the signal must be amplified. [2]

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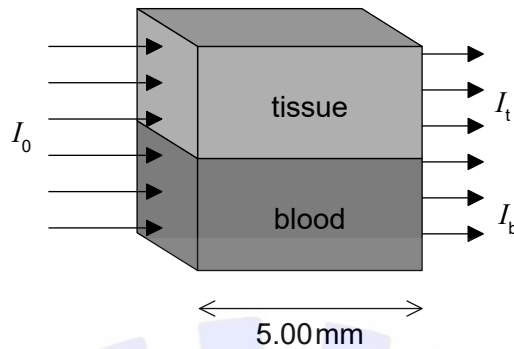
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(Option C continues on the following page)



(Option C continued)

14. (a) An X-ray beam, of intensity  $I_0$ , is used to examine the flow of blood through an artery in the leg of a patient. The beam passes through an equal thickness of blood and soft tissue.



The thickness of blood and tissue is 5.00 mm. The intensity of the X-rays emerging from the tissue is  $I_t$  and the intensity emerging from the blood is  $I_b$ .

The following data are available.

Mass absorption coefficient of tissue	$= 0.379 \text{ cm}^2 \text{ g}^{-1}$
Mass absorption coefficient of blood	$= 0.385 \text{ cm}^2 \text{ g}^{-1}$
Density of tissue	$= 1.10 \times 10^3 \text{ kg m}^{-3}$
Density of blood	$= 1.06 \times 10^3 \text{ kg m}^{-3}$

- (i) Show that the ratio  $\frac{I_b}{I_t}$  is close to 1. [3]

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(Option C continues on the following page)



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

- (ii) State and explain, with reference to you answer in (a)(i), what needs to be done to produce a clear image of the leg artery using X-rays. [4]

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- (b) In nuclear magnetic resonance (NMR) protons inside a patient are made to emit a radio frequency electromagnetic radiation. Outline the mechanism by which this radiation is emitted by the protons. [3]

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**End of Option C**



**Option D — Astrophysics**

**15.** 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 15 continued)**

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

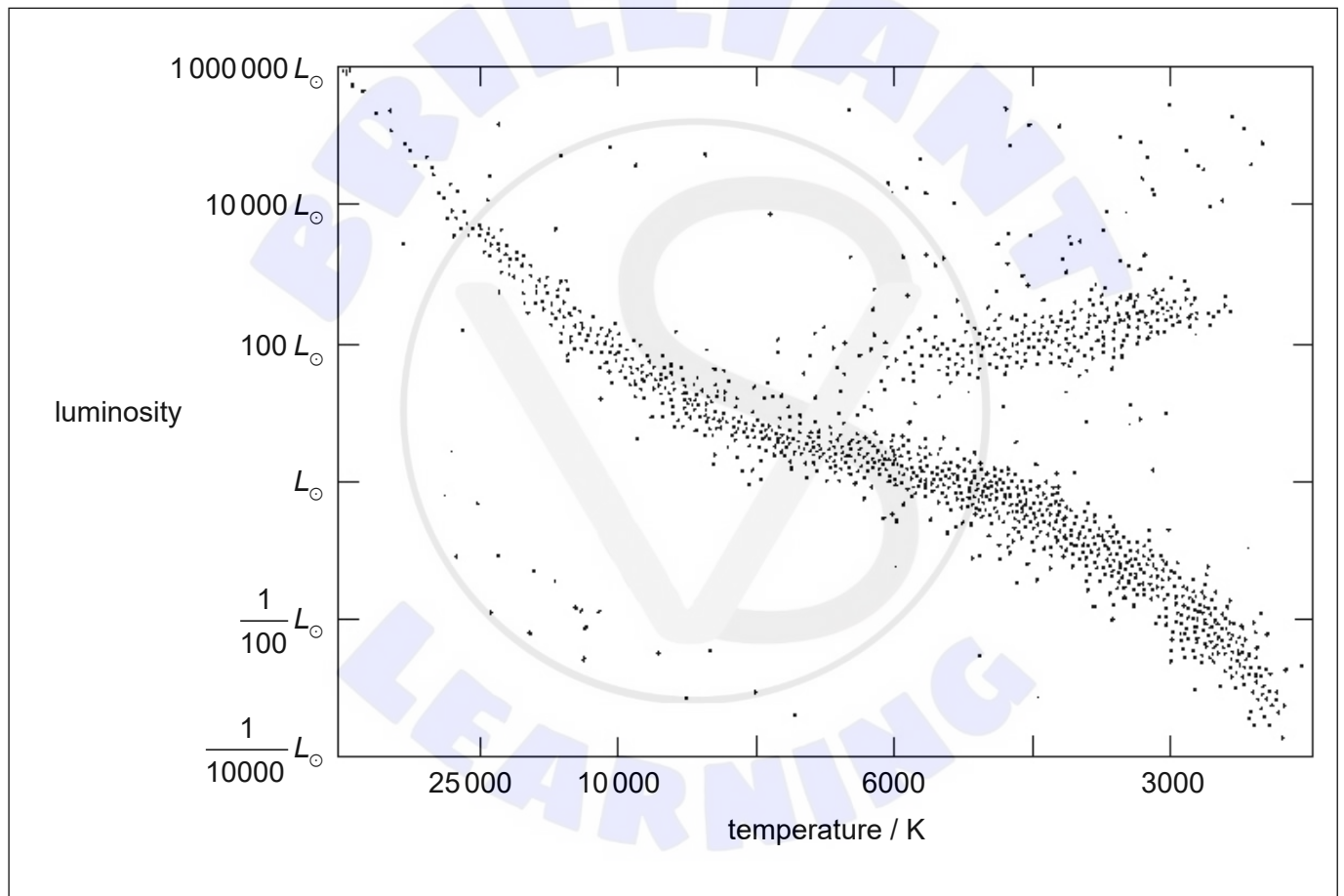
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- (c) A Hertzsprung–Russell (HR) diagram is shown.



- (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 15 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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16. (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 16 continued)**

(b) Evidence from the Planck space observatory suggests that the density of matter in the universe is about 32 % of the critical density of the universe.

(i) State what is meant by the critical density. [1]

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(ii) Calculate the density of matter in the universe, using the Hubble constant  $70 \text{ km s}^{-1} \text{ Mpc}^{-1}$ . [3]

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(iii) It is estimated that less than 20 % of the matter in the universe is observable. Discuss how scientists use galactic rotation curves to explain this. [2]

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



**(Option D continued)**

17. (a) Proxima Centauri is a main sequence star with a mass of 0.12 solar masses.

Estimate  $\frac{\text{lifetime on main sequence of Proxima Centauri}}{\text{lifetime on main sequence of Sun}}$ . [2]

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(b) Describe why iron is the heaviest element that can be produced by nuclear fusion processes inside stars. [2]

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(c) Discuss **one** process by which elements heavier than iron are formed in stars. [3]

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**End of Option D**

