2023 **BORED OF STUDIES TRIAL EXAMINATION**

4th October

Physics

General instructions

- Reading time – 5 minutes
- Working time – 3 hours
- Write using a black or blue pen
- Draw diagrams using pencil
- Calculators approved by NESA may be used
- A data sheet, formulae sheet, data sheet and Periodic Table are provided

Total marks: 100

Section I – 20 marks (pages 2–9)

- Attempt Questions 1–20
- Allow about 35 minutes for this section

Section II – 80 marks (pages 13–39)

- Attempt Questions 21–32
- Allow about 2 hour and 25 minutes for this section

Section I

20 marks
Attempt Questions 1–20
Allow about 35 minutes for this section

Use the multiple-choice answer sheet provided for Questions 1–20.

---

1 Which of the following types of particle accelerators are unable to accelerate particles with an initial kinetic energy of zero joules?

A. Linear Accelerators

B. Cyclotrons

C. Synchrotrons

D. Phototrons

2 Which of the following laws accurately describe the spectral density of a blackbody's radiance as a function of temperature and wavelength?

A. Planck's Law

B. Wien's Law

C. Stefan-Boltzmann Law

D. Rayleigh-Jeans Law

3 Which of these statements relating to the Standard Model of Matter is FALSE?

A. All fermions are hadrons.

B. All baryons are fermions.

C. All mesons are bosons.

D. All baryons are hadrons.

4 A satellite moved from geostationary orbit to a higher orbit. Which of the following statements is true about the orbit change?

A. The gravitational potential energy will decrease.

B. The kinetic energy will increase.

C. The work done is the absolute difference between the gravitational potential energy of the higher orbit and that of the geostationary orbit.

D. The work done is the absolute difference between the kinetic energy of the higher orbit and that of the geostationary orbit.

5 Monochromatic light is incident on two identical slits to produce an interference pattern on a screen. One slit is then covered so that no light emerges from it. What is the change to the pattern observed on the screen?

A. Fewer maxima will be observed.

B. The intensity of the central maximum will increase.

C. The outer maxima will become narrower.

D. The width of the central maximum will decrease.

6 Two particles with charges q_1 and q_2 are separated by a distance r. Which of the following represents the magnitude of the electric field halfway between them?

A. $\frac{1}{4\pi\epsilon_0} \cdot \frac{|q_1|+|q_2|}{\left(\frac{r}{2}\right)^2}$

B. $\frac{1}{4\pi\epsilon_0} \cdot \frac{|q_1|-|q_2|}{\left(\frac{r}{2}\right)^2}$

C. $\frac{1}{4\pi\epsilon_0} \cdot \frac{|q_1||q_2|}{\left(\frac{r}{2}\right)^2}$

D. $\frac{1}{4\pi\epsilon_0} \cdot \frac{|q_1-q_2|}{\left(\frac{r}{2}\right)^2}$

7 The relativistic energy of an object with rest mass *m* and velocity *v* is determined by

$$K = (\gamma - 1)\, mc^2$$

where $\gamma = \frac{1}{\sqrt{1-\frac{v^2}{c^2}}}$.

The total relativistic energy is $E_{\text{total}} = E_{\text{rest}} + K$, where E_{rest} is the energy at rest.

Which of the following represents E_{total} ?

A. $mc^2 \sqrt{1-\frac{v^2}{c^2}}$

B. $\frac{mc^2}{\sqrt{1-\frac{v^2}{c^2}}}$

C. mv^2

D. $\frac{1}{2}mv^2$

8 Which properties of a star CANNOT be determined from only its absorption spectra, as measured on Earth?

A. Core temperature

B. Chemical composition

C. Atmospheric pressure

D. Rotational velocity

9 Monochromatic electromagnetic radiation ejects photoelectrons from a metal surface. The minimum frequency for which this is possible is *f* . When radiation of frequency 2*f* is incident on the surface, the maximum velocity of photoelectrons is *v*.

What is the maximum velocity of the photoelectrons when the radiation's frequency is 4*f*?

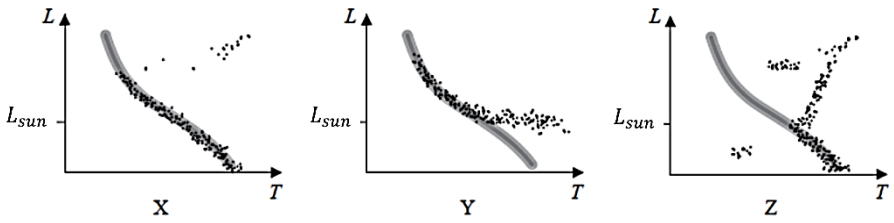
A. $\sqrt{2}v$

B. $\sqrt{3}v$

C. $2v$

D. $3v$

10 The Hertzsprung-Russell diagrams of three star clusters X, Y and Z are shown below.



Which of the following correctly lists the star clusters in order of increasing age (youngest to oldest)?

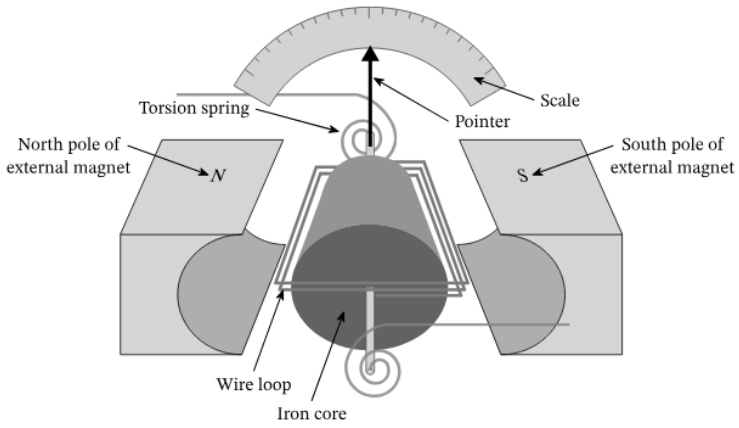
A. X, Z, Y

B. Y, X, Z

C. Y, Z, X

D. Z, X, Y

11 A galvanometer contains a 3.0 cm × 3.0 cm square coil of wire with 100 turns in a radial magnetic field of 0.54 T. The coil is attached to a torsion spring, which resists twisting motion according to a modified Hooke's Law $\tau = -k\theta$ where $k = 0.034$ Nm and θ is in radians.



What is the current through the wire when the needle is deflected by 18°?

A. 0.17 A

B. 0.22 A

C. 0.55 A

D. 1.26 A

12 A projectile is launched from Earth's surface at an angle of 30° above the horizontal with initial speed 50 ms^{-1}. Midway to the peak of its trajectory, an external upward vertical force acts on the projectile such that its net vertical force is halved until the end of its trajectory. What is the maximum height of the projectile?

A. 46 m

B. 47 m

C. 48 m

D. 49 m

13 A ball is stationary on a smooth, flat table in a train carriage, 2.1 m away from the right edge. The train begins to move, accelerating to the left at a constant 3.0 ms^{-2} and the ball rolls off the table. If the table is 1.0 m above the floor, how far does the ball land from the bottom of the table?

A. 0.3 m

B. 1.4 m

C. 1.9 m

D. 2.1 m

14 Heisenberg's Uncertainty Principle states that the calculation of the position and momentum of an object can never be simultaneously definitive. Mathematically, it is represented by

$$\Delta x \Delta p \geq \frac{h}{4\pi}$$

where Δx and Δp refer to the uncertainty of the position and momentum of the object respectively.

For an electron confined to move within an atom of diameter 1×10^{-10} m, what is minimum uncertainty in the velocity of the electron?

A. 1×10^{6} ms^{-1}

B. 1×10^{5} ms^{-1}

C. 1×10^{4} ms^{-1}

D. 1×10^{3} ms^{-1}

15 A nucleus of Uranium-238 undergoes alpha decay to form Thorium-234. Use the following information to calculate the binding energy per nucleon of Uranium-238.

Measure	Energy (MeV)
Energy released in decay	4.27
Binding energy per nucleon for helium	7.07
Binding energy per nucleon for thorium	7.60

A. 1.20×10^{-12} J

B. 1.21×10^{-12} J

C. 1.22×10^{-12} J

D. 1.23×10^{-12} J

16 One common nucleosynthesis reaction is the proton-proton chain, which fuses hydrogen into helium. What is the overall nuclear equation for this reaction?

A. $4\,{}^{1}_{1}\mathrm{H} \rightarrow {}^{4}_{2}\mathrm{He} + 2\mathrm{e}^{+} + 2\gamma + 2\nu$

B. $4\,{}^{1}_{1}\mathrm{H} \rightarrow {}^{4}_{2}\mathrm{He} + 2\mathrm{e}^{+} + 2\gamma$

C. $4\,{}^{1}_{1}\mathrm{H} + 2\mathrm{e}^{-} \rightarrow {}^{4}_{2}\mathrm{He} + 2\gamma + 2\nu$

D. $4\,{}^{1}_{1}\mathrm{H} + 2\mathrm{e}^{-} \rightarrow {}^{4}_{2}\mathrm{He} + 2\gamma$

17 Two spaceships X and Y are travelling directly towards each other at constant relativistic velocities. Their relative speed is *v*. Spaceship X shines monochromatic light of frequency f towards spaceship Y.

According to spaceship X, the observer Y is moving towards a stationary source X and sees a Doppler shifted frequency $f' = \left(\frac{c+v}{c}\right) f$.

According to spaceship Y, the light source from spaceship X is moving towards the stationary observer Y, which sees $f' = \left(\frac{c}{c-v}\right) f$.

How is this apparent paradox resolved?

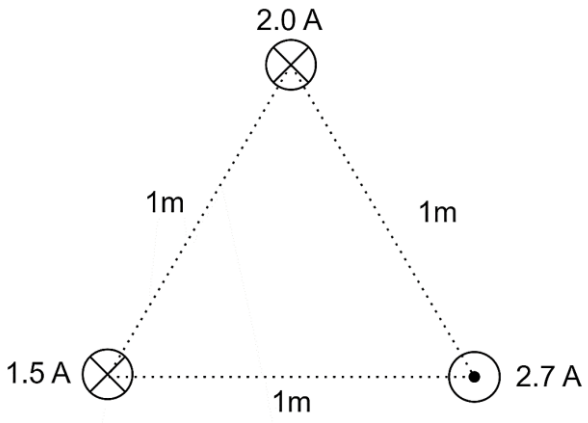
A. Spaceship Y is correct since they are the one observing the light's frequency.

B. Spaceship X is correct since they were the source of the light.

C. Both X and Y are correct. According to Einstein's Special Theory of Relativity, every inertial reference frame is equally correct.

D. Neither X nor Y is correct. This Doppler effect equation is not valid for light.

18 Three long parallel current carrying wires are positioned as shown in the diagram below.



What is the magnitude of the force per unit length on the bottom left wire with 1.5 A of current?

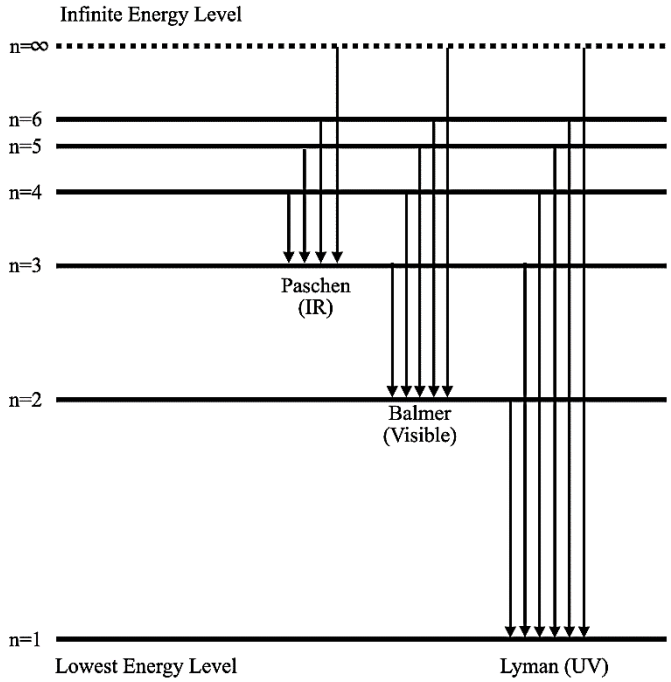
A. 7.05×10^{-7} Nm^{-1}

B. 1.23×10^{-6} Nm^{-1}

C. 3.64×10^{-7} Nm^{-1}

D. 7.28×10^{-7} Nm^{-1}

19 The electron energy levels of the hydrogen atom are shown in the diagram below.



Which of these photon frequencies is NOT part of the emission spectrum of hydrogen?

A. 2.3×10^{14} Hz

B. 6.2×10^{14} Hz

C. 1.1×10^{15} Hz

D. 3.1×10^{15} Hz

20 A small sample of a radioactive substance X initially contains 90 nuclei at time $t = 0$. Let the half-life of X be $t_{\frac{1}{2}}$. How many nuclei remain at $t = 1.3t_{\frac{1}{2}}$?

A. 35

B. 36

C. 37

D. Cannot be predicted

BLANK PAGE

BLANK PAGE

BLANK PAGE

Student Number: ……...…

Username: …….

Name: ……

Physics
Section II Answer Booklet 1

80 marks
Attempt Questions 21–32
Allow about 2 hours and 25 minutes for this section

Booklet 1 – Attempt Questions 21–27 (40 marks)
Booklet 2 – Attempt Questions 28–32 (40 marks)

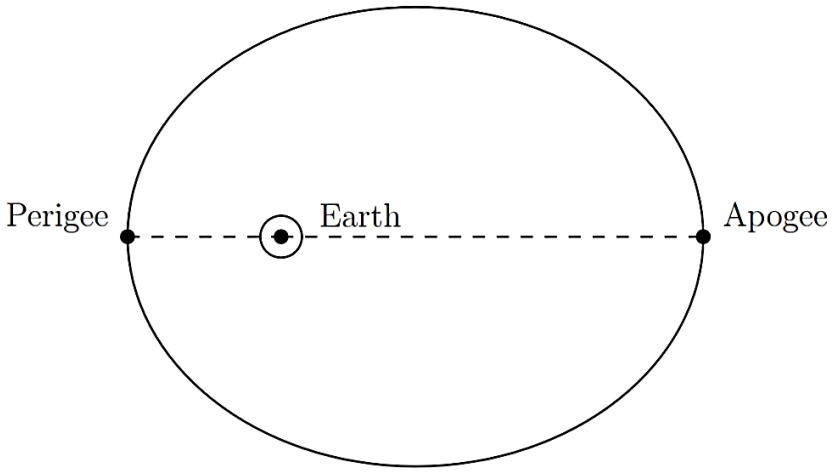
Instructions

- Write your student number, username and name on the top right of this page.
- Answer the questions in the spaces provided. These spaces provide guidance for the expected length of response.
- Show all relevant working in questions involving calculations.
- If you require extra writing space, please ask for a writing booklet. If you use a writing booklet, clearly indicate which questions you are answering.

Please turn over

Question 21 (2 marks)

The moon orbits the Earth in an elliptical path as shown in the diagram below. At the apogee, the moon is furthest away from the Earth, and at the perigee, the moon is closest to Earth.



The Moon's Orbit around Earth

Explain why the time taken for the moon to travel from the perigee to the apogee is equal to the time taken for the moon to travel from the apogee to the perigee. **2**

……

……

……

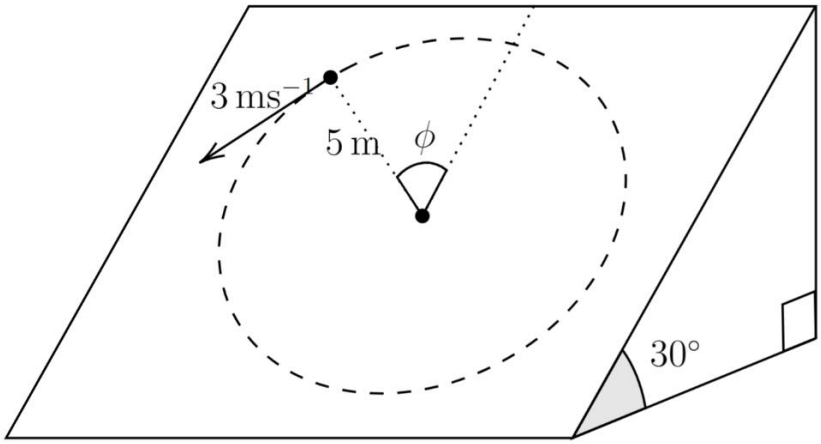
……

……

……

Question 22 (6 marks)

A 1000 kg car is driving at 3 ms^{-1} in uniform circular motion on a ramp inclined at 30° to the horizontal. The radius of the car's path is 5 m. At any given time, the angle that the line between the centre of motion and the car makes with the line that travels the steepest path up the ramp is ϕ.



(a) Calculate the component of weight force acting parallel to the ramp. **1**

……..

……..

……..

……..

Question 22 continues on page 16

Question 22 (continued)

(b) Hence, calculate the magnitude of the friction force when $\phi = 45°$. **3**

……..

……..

……..

……..

……..

……..

……..

……..

……..

……..

(c) Calculate the work done by friction on the car as it moves around the ramp from $\phi = 45°$ to $\phi = 180°$. **2**

……..

……..

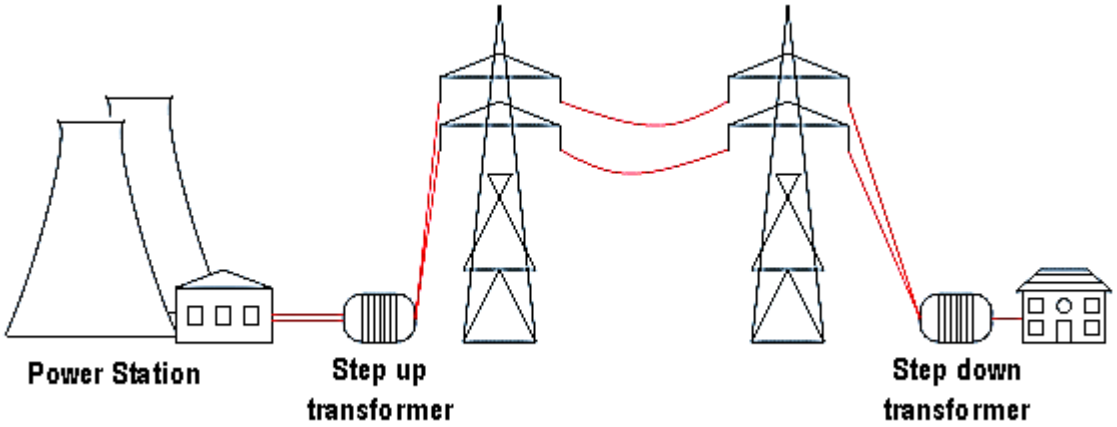
……..

……..

End of Question 22

Question 23 (5 marks)

The diagram below shows a model of the long-distance transmission of electricity. **5**



Using appropriate equations, explain how power loss is reduced in the distribution of electricity from power stations to homes.

……

……

……

……

……

……

……

……

……

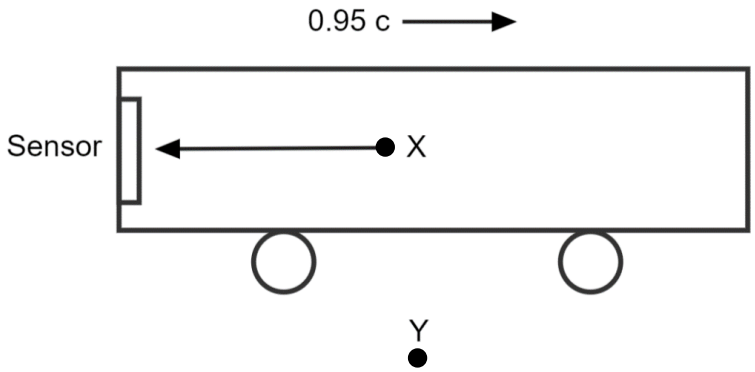
……

……

……

Question 24 (5 marks)

Person X is sitting at the centre of a train carriage of rest length 35 m, travelling at 0.95*c* relative to Person Y who is outside the train. There is a sensor at the rear end of the train which is triggered when a light pulse strikes it. Person X sends a light pulse directly towards the rear end and measures the time for light to reach the sensor.



(a) Assess the following claim. **2**

"*Person Y will see the light pulse take a longer time to reach the sensor than Person X because of time dilation.*"

……..

……..

……..

……..

(b) Find the time taken for the light pulse to reach the sensor in Person X's reference frame and the time taken for the light pulse to reach the sensor in Person Y's reference frame to support your answer to part (a). **3**

……..

……..

……..

……..

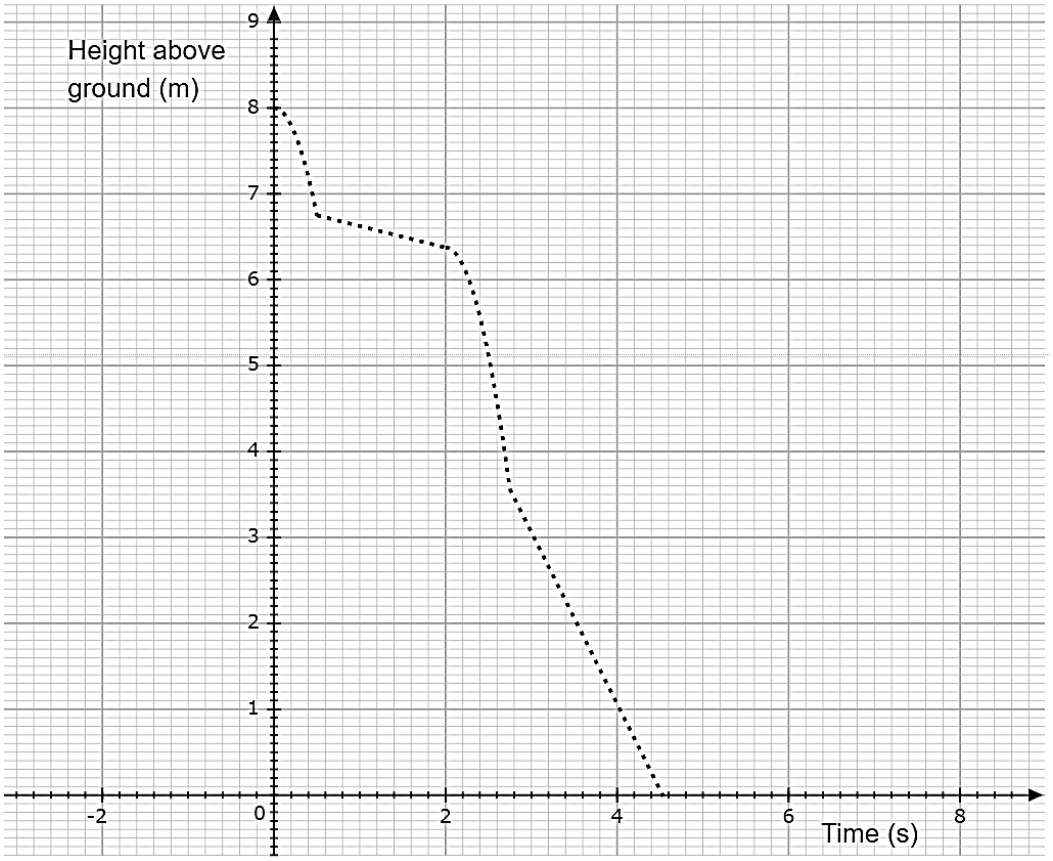
……..

……..

Question 25 (6 marks)

A 500 g bar magnet is dropped from rest vertically above a hollow cylindrical pipe made from three distinct sections: copper, aluminium and wood, not necessarily in that order.

The graph below shows the height of the bar magnet above the ground over time.



(a) Find the lengths of each section in the cylindrical pipe. **2**

You may assume that the magnetic field does not contribute to the centripetal force as a result of its orientation.

……..

……..

……..

……..

Question 25 continues on page 20

Question 25 (continued)

(b) Explain and compare the motion of the magnet in each of the three sections with respect to the law of conservation of energy. **4**

……..

……..

……..

……..

……..

……..

……..

……..

……..

……..

……..

……..

End of Question 25

Question 26 (5 marks)

"Unpolarised light is a mix of x and y polarisations." **5**

Assess the validity of this statement, with reference to an experiment that supports your claim.

……

……

……

……

……

……

……

……

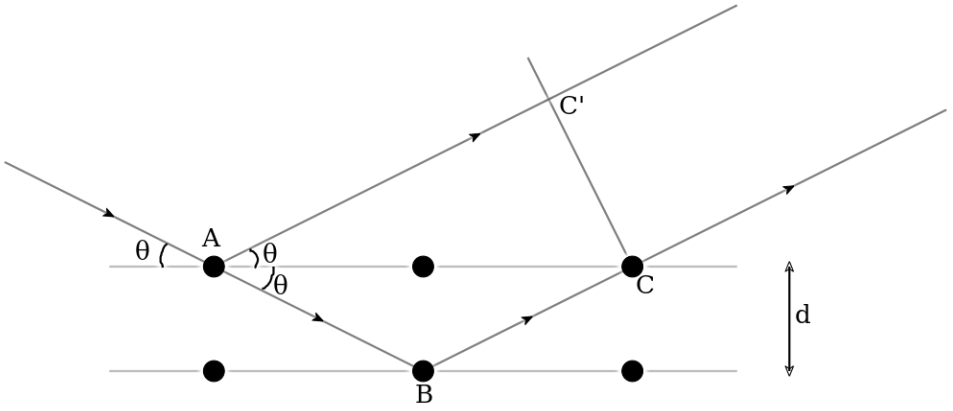
……

……

……

Question 27 (11 marks)

Bragg diffraction occurs when radiation is reflected off a crystal at angle θ to the horizontal with lattice planes separated by a constant distance d as shown in the diagram below.



(a) Using the diagram above or otherwise, derive the condition for the maximum reflectivity of radiation of wavelength λ, in terms of d and θ. **1**

……..

……..

……..

……..

(b) When X-rays of wavelength 3.2 nm are scattered off a crystal surface, two consecutive peaks of maximum intensity are found at $\theta = 27°$ and $\theta = 43°$. Find the lattice spacing d of this unknown crystal. **2**

……..

……..

……..

……..

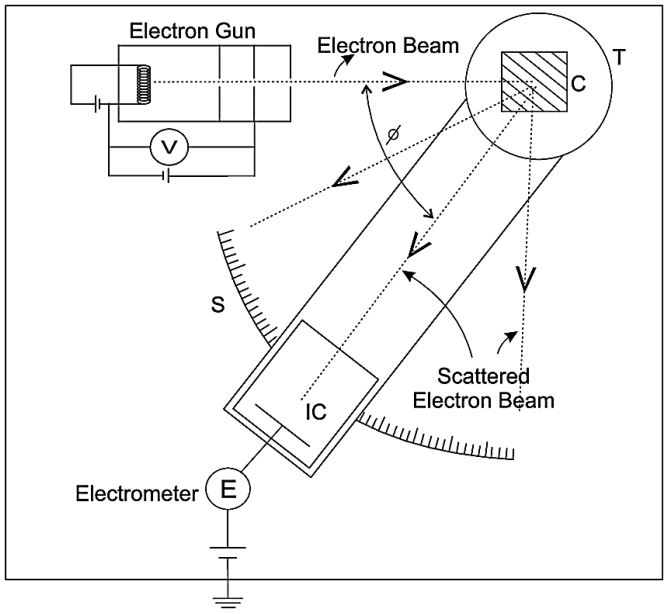
……..

……..

Question 27 continues on page 23

Question 27 (continued)

(c) In the Davisson-Germer experiment, electrons are used instead of X-rays to image a nickel surface with lattice spacing 0.091 nm. An electron gun accelerates electrons across a large voltage towards the nickel surface which scatters the electron beam as shown in the diagram below. **3**



The intensity of the scattered electron beam is measured by the electrometer as a function of the scattering angle ϕ.

If the first-order diffraction peak occurs at ϕ = 50°, find the voltage used to accelerate the electron.

……..

……..

……..

……..

……..

……..

……..

……..

Question 27 continues on page 24

Question 27 (continued)

(d) Explain how the Davisson-Germer experiment contributed to improvements on the Bohr model of the atom. **5**

……..

……..

……..

……..

……..

……..

……..

……..

……..

……..

……..

……..

End of Question 27

Student Number: ……...…

Username: …….

Name: ……

Physics
Section II Answer Booklet 2

Booklet 2 – Attempt Questions 28–32 (40 marks)

Instructions

- Write your student number, username and name on the top right of this page.
- Answer the questions in the spaces provided. These spaces provide guidance for the expected length of response.
- Show all relevant working in questions involving calculations.
- If you require extra writing space, please ask for a writing booklet. If you use a writing booklet, clearly indicate which questions you are answering.

Please turn over

Question 28 (7 marks)

A rocket powered by the fission of Uranium-235 into Krypton-92 and Barium-141 is launched at 0.743*c* to escape a neutron star with mass 4.10×10^{30} kg and radius 11.0 km.

The atomic masses are provided for the following particles:

Particle	**Atomic Mass** (amu)
Neutron	1.008665
Krypton-92	91.926156
Barium-141	140.914411
Uranium-235	235.043925

(a) Calculate the escape velocity of the rocket from this neutron star. You may ignore relativistic effects. **1**

……..

……..

……..

(b) Write the equation for this nuclear reaction and determine the energy (in joules) produced by the fission reaction per kilogram of Uranium-235. **2**

……..

……..

……..

……..

……..

……..

Question 28 continues on page 27

Question 28 (continued)

(c) If the rocket just managed to escape the star, what percentage of the initial total mass of the rocket was the Uranium-235 fuel? **4**

……..

……..

……..

……..

……..

……..

……..

……..

……..

……..

……..

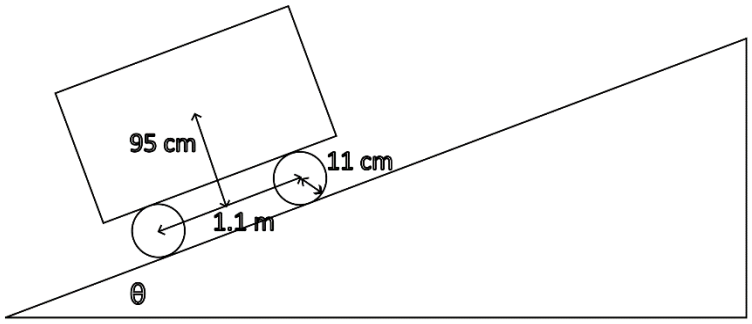
……..

End of Question 28

Question 29 (7 marks)

The rear wheels of a 3.8 kg cart are powered by a 20V DC motor which is climbing a hill inclined at some angle θ. The motor has internal resistance of 0.13 Ω and contains a coil of wire with 500 turns and a circular cross-sectional area of 12 cm^2 in a radial magnetic field of 0.023 T. **7**

The centre of mass of the cart is 95 cm above the wheel axles and equidistant from the centre of the wheels. The wheels are separated by 1.1 m, and have the same radius of 11 cm. The coefficients of kinetic and static friction between the wheel and the surface of the hill are $\mu_k = 0.58$ and $\mu_s = 0.62$, respectively.



Analyse, both qualitatively and quantitatively, the factors that limit the steepness of the hill that the cart can climb. Your answer should include a calculation of the maximum steepness.

……

……

……

……

……

……

……

……

……

……

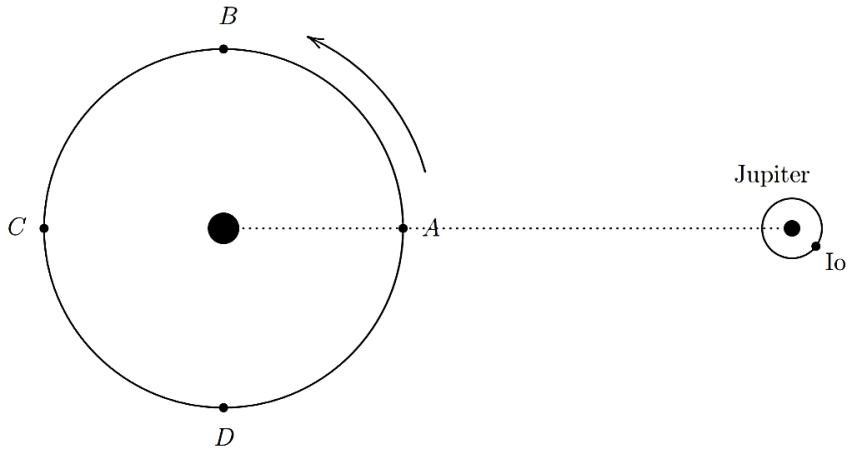
……

……

Question 30 (9 marks)

Io, one of Jupiter's moons, can be seen from Earth. An eclipse occurs when Io passes behind Jupiter such that it is blocked from Earth's view. When Io disappears from Earth's view, this is called an "immersion". When it reappears into Earth's view, this is called "emergence". The duration of the eclipse is the time between immersion and emergence.

Consider the frame of reference where both the Sun and Jupiter are stationary (this is a rotating frame of reference). The time taken for Earth to complete an orbit around the Sun in this frame of reference is 400 days (one synodic year). If Earth is at point A as per the diagram below (the closest point of the orbit to Jupiter), then Earth will return to point A after one synodic year.



The period of Io's orbit around Jupiter is approximately 42 hours. There are approximately 230 eclipses of Io over the course of a synodic year and the duration of each eclipse is approximately 2 hours.

Question 30 continues on page 30

Question 30 (continued)

(a) Using the fact that a synodic year is 400 days, calculate the ratio between the orbital radius of Earth and the orbital radius of Jupiter. **2**

……..

……..

……..

……..

……..

(b) In 1676, Rømer determined the speed of light by timing the apparent durations of Io's eclipses, which appeared to oscillate over time. Explain and describe the variation of the apparent duration of Io's eclipse over the course of a synodic year. **2**

……..

……..

……..

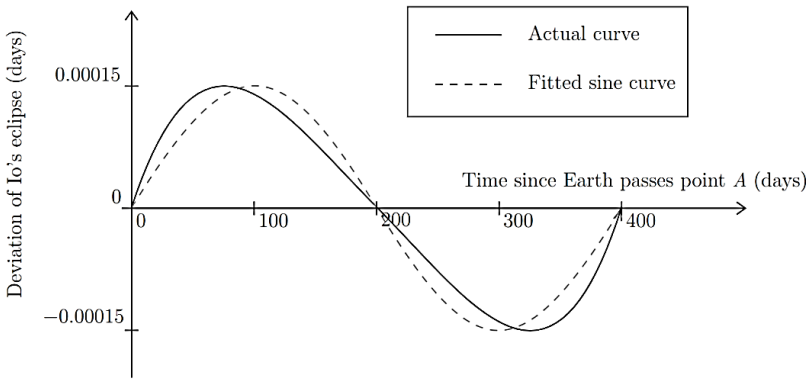
……..

……..

Question 30 continues on page 31

Question 30 (continued)

(c) The deviation of an eclipse of Io is equal to (*duration of eclipse – average duration of eclipse*). Plotting the deviation of the numerous eclipses that occur throughout a year gives a curve similar to the solid black line below, which is "slanted" compared to the fitted sine curve (dotted). Note that the slanting effect is exaggerated in the graph below. **3**



Explain how this slanting effect occurs.

……..

……..

……..

……..

……..

……..

(d) How many days after Earth is at point A does the maximum deviation of Io's eclipse occur? **2**

……..

……..

……..

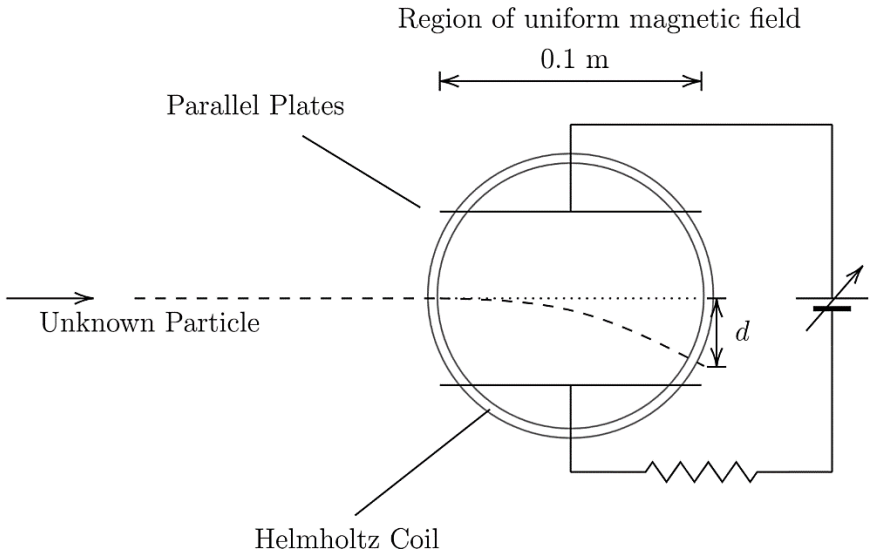
……..

End of Question 30

Question 31 (7 marks)

A beam of unknown particles with unknown mass and charge, all with the same unknown velocity *v* is directed along the horizontal to the right, towards an apparatus. The apparatus consists of a voltage source which is used to produce a uniform electric field between two parallel conductive plates of width *w*.

The magnitude of the voltage of this voltage source can be controlled and set to known values. Electromagnets are set up to produce a uniform magnetic field of strength *B* into the page. This magnetic field only exists within the circled region, which has a width of 0.1 m. The strength of this magnetic field can also be controlled and set to known values. After travelling a horizontal distance of *w*, the beam was measured to have a vertical deflection *d* from the horizontal.



(a) Explain how this apparatus can be used to determine the speed *v* of the particles. **1**

……..

……..

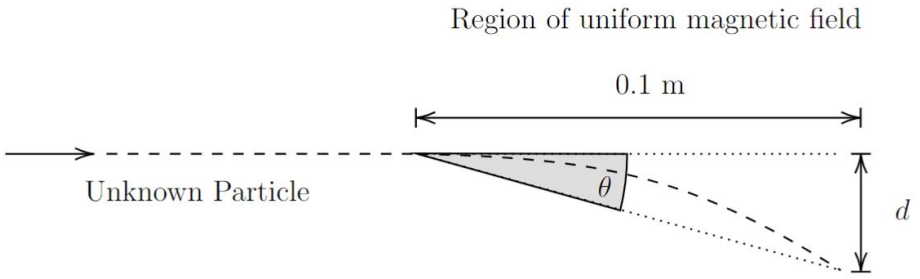
……..

……..

Question 31 continues on page 33

Question 31 (continued)

(b) For a given vertical deflection d, the radius of curvature is known to be $\frac{d}{1-\cos 2\theta}$. **2**



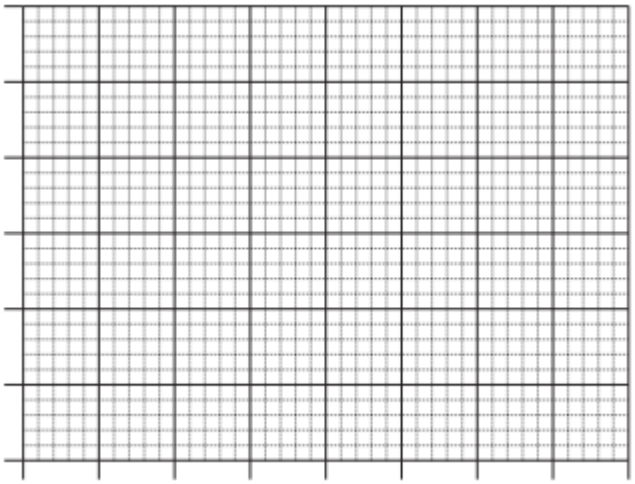
The strength of the magnetic field is set to various known values. For each value of B, the amount of vertical deflection d is measured and tabulated. Assume that in this specific apparatus, v has been determined to be 10^5 ms^{-1}.
Complete the last column of the following table.

Field Strength B (μT)	**Vertical deflection d (m)**	$\frac{1}{r}$ **(m^{-1})**
1.0	1.667×10^{-3}	
1.5	2.502×10^{-3}	
3.0	5.013×10^{-3}	
5.0	8.392×10^{-3}	

Question 31 continues on page 34

Question 31 (continued)

(c) By drawing and considering the gradient of an appropriate line graph, find the mass to charge ratio of the unknown particle. **4**



……..

……..

……..

……..

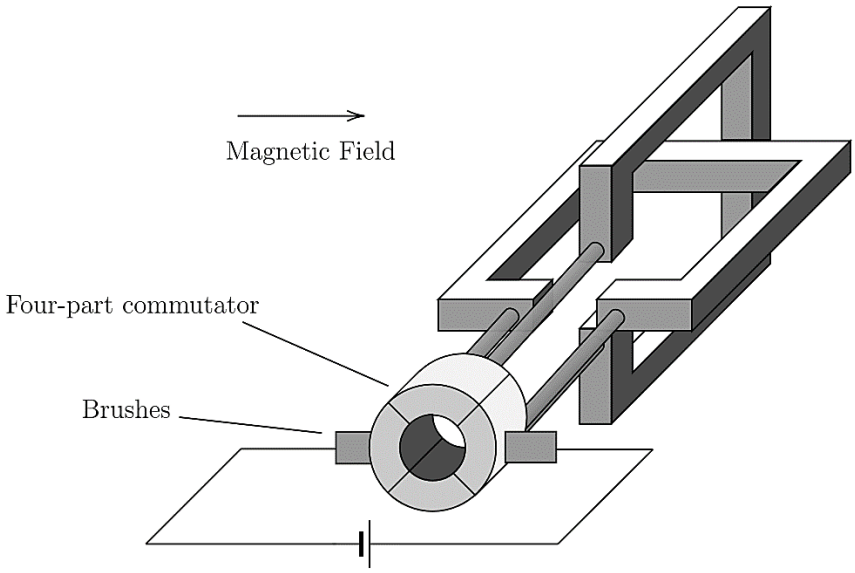
……..

……..

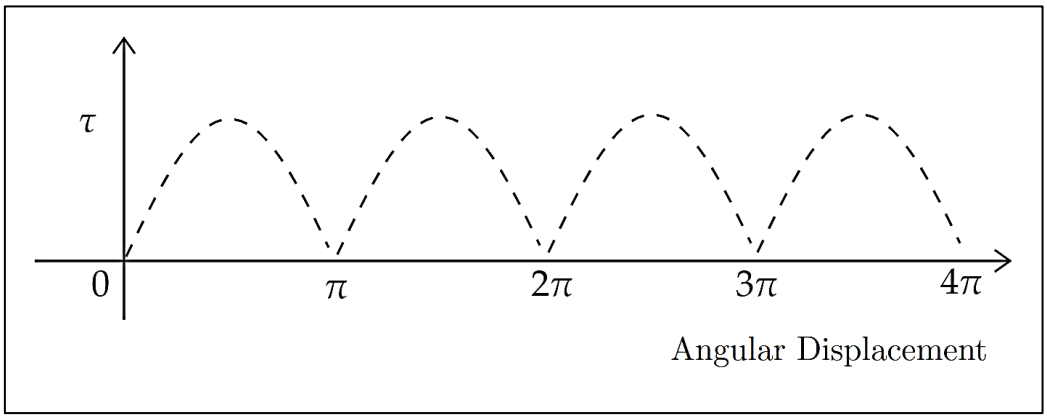
End of Question 31

Question 32 (10 marks)

In a DC motor, the torque (τ) vs angular displacement (θ) curve can be flattened by using a four-part commutator instead of a regular split ring commutator. The curve will be flatter the more divided the commutator is.



(a) The graph below shows the τ vs θ curve of a regular split ring commutator (dotted). On the same graph, draw the curve for the same motor but with a four-part commutator. **1**



Question 32 continues on page 36

Question 32 (continued)

(b) In an ideal DC motor, the τ vs θ curve is perfectly flat. **1**

The magnitude of the torque of the motor at time t is given by $\tau = \lambda I$, where I is the current at time t and λ is a constant of proportionality which depends on the structure of the motor.

The back-emf at time t is given by $\mathscr{E}_b = \mu\omega$, where ω is the angular velocity of the motor at time t and μ is a constant of proportionality which depends on the structure of the motor.

The motor is powered by a voltage source with voltage V_s.

Explain why the motor's angular speed when switched on without a load is $\frac{V_S}{\mu}$.

……..

……..

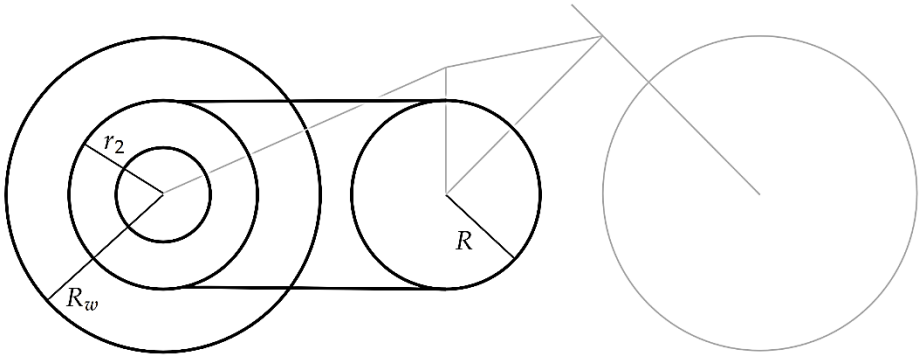
……..

……..

Question 32 continues on page 37

Question 32 (continued)

(c) The motor is used to power an electric bicycle. The motor turns a gear of radius R, which is linked by a chain to another gear of radius r_2. This gear is fixed in place to the rear wheel of the bicycle which has radius of R_w. **3**



The cyclist has a mass of m, while the rest of the bicycle has negligible mass. The bicycle starts at rest. Assume that the friction is sufficient to prevent slippage of the real wheel against the ground. P is the resistance of the circuit which contains the motor and the voltage source.

Find the initial acceleration of the bicycle when the motor is first switched on, in terms of m, r_2, R, R_w, V_s, P and λ.

(**Hint**: An object of negligible mass also has negligible net forces and net torques acting on that object, even if it is accelerating)

……..

……..

……..

……..

……..

……..

……..

……..

Question 32 continues on page 38

Question 32 (continued)

(d) The cyclist puts the bike in reverse by reversing the polarity of the voltage source. The tension in the bottom chain is initially T_1 when the motor is first switched on. Find the initial tension T_2 in the top chain in terms of T_1, V_s, P and λ. **1**

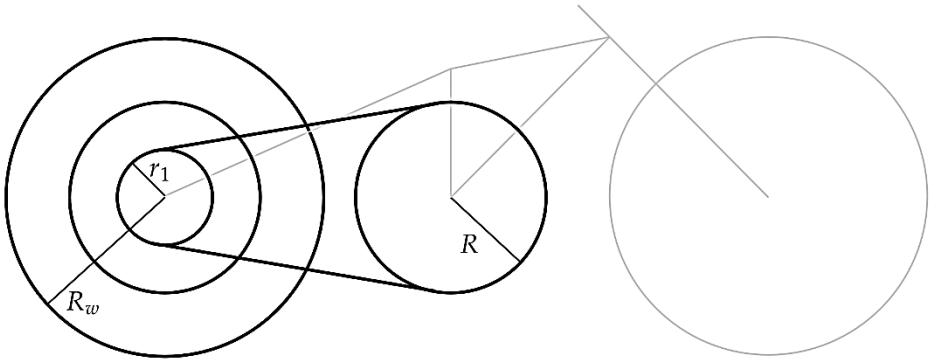
……..

……..

……..

……..

(e) The cyclist is travelling forwards on the bicycle at terminal velocity along a highway. At time t_1, the cyclist switches gear. **4**

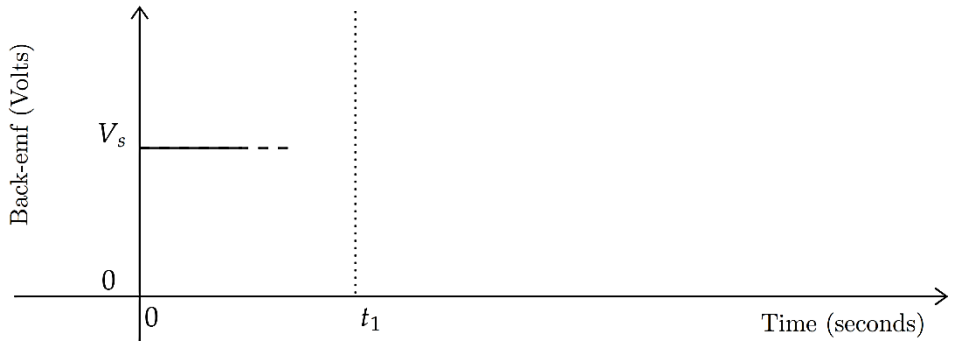


The chain is moved such that is is now wrapped around the gear of radius r_1, which is fixed onto the centre of the rear wheel.

On the graph on the next page, plot how the back-emf changes over time, labelling any critical points and asymptotes. Provide supporting qualitative reasoning on the dotted lines below the graph.

Question 32 continues on page 39

Question 32 (continued)



……

……

……

……

……

……

……

……

End of paper

Section II extra writing space

If you use this space, clearly indicate which question you are answering.