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.

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

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

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

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

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 $2f$ 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 $4f$?

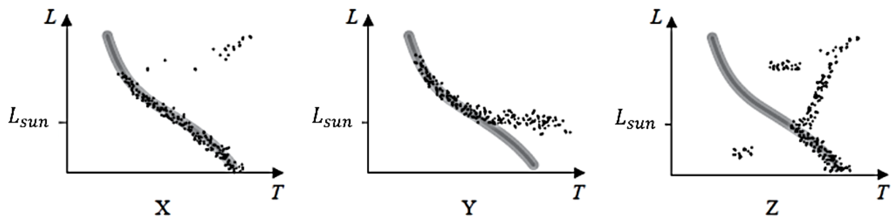
A. $\sqrt{2}v$

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)?

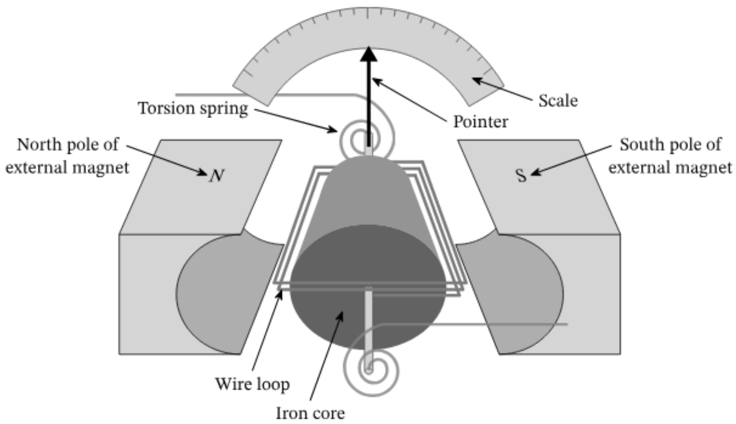
A. X, Z, Y

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. 95 m

B. 96 m

C. 97 m

D. 98 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?

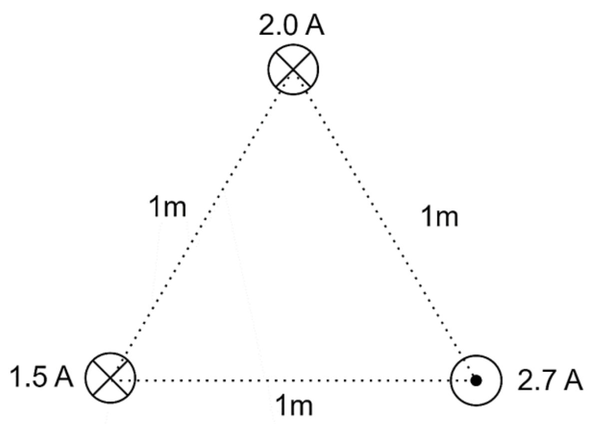
A. Spaceship Y is correct since they are the one observing the light's frequency.

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?

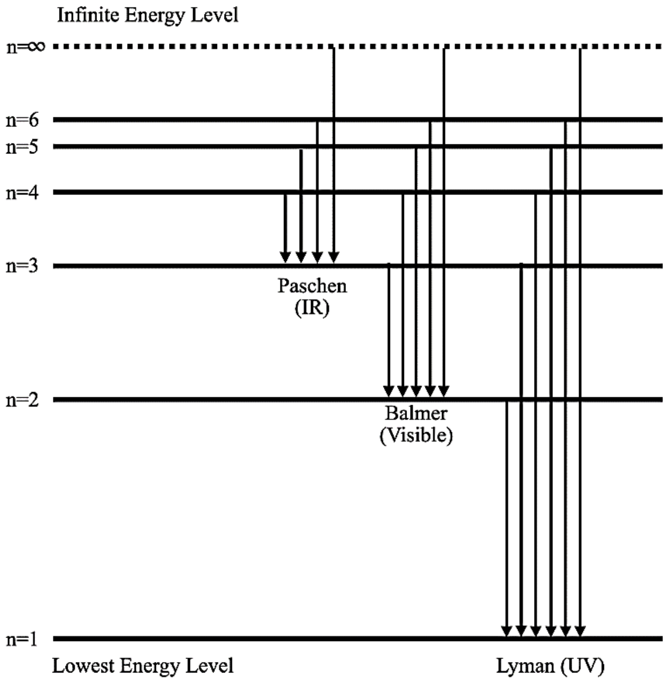
A. 7.05×10^{-7} Nm^{-1}

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

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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)

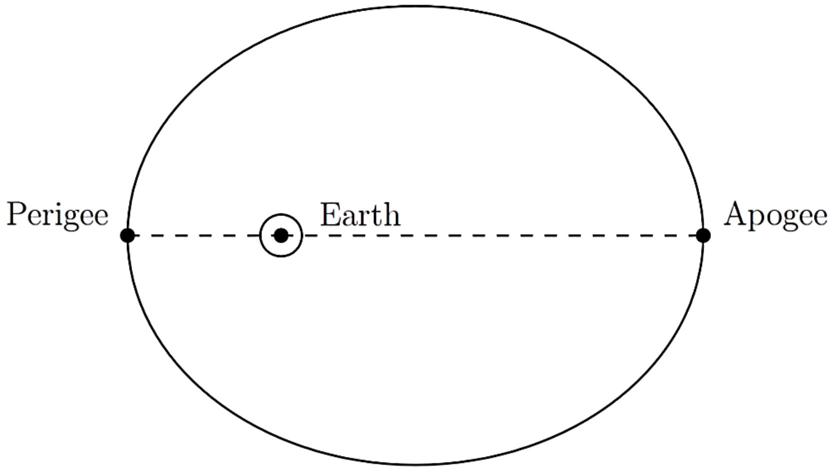
Instructions

- 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**

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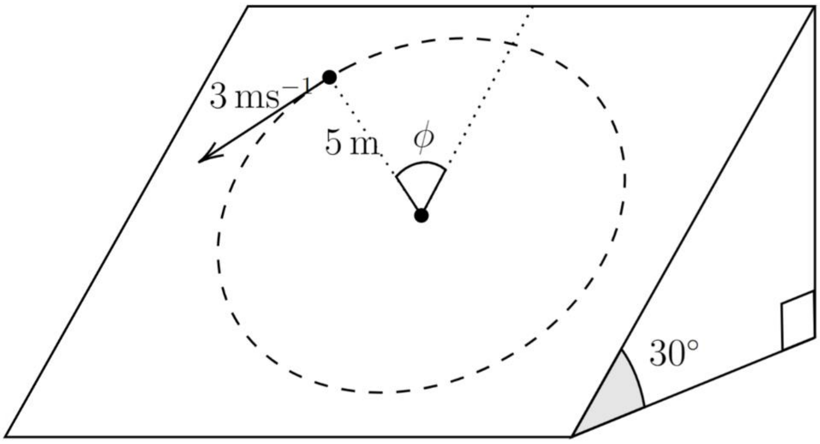
Question 22 (6 marks)

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**

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Question 22 continues on page 16

Question 22 (continued)

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

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

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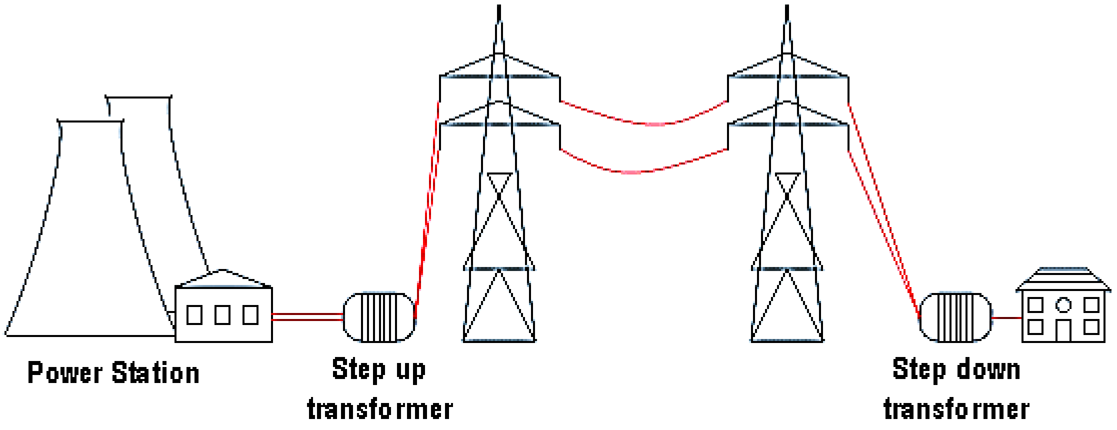
End of Question 22

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.

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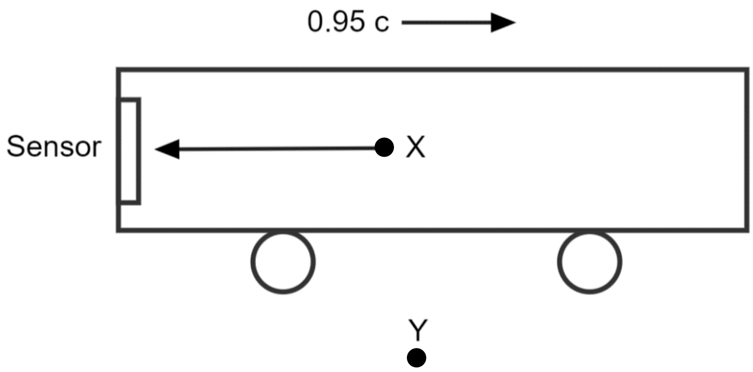
Question 24 (5 marks)

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.*"

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(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**

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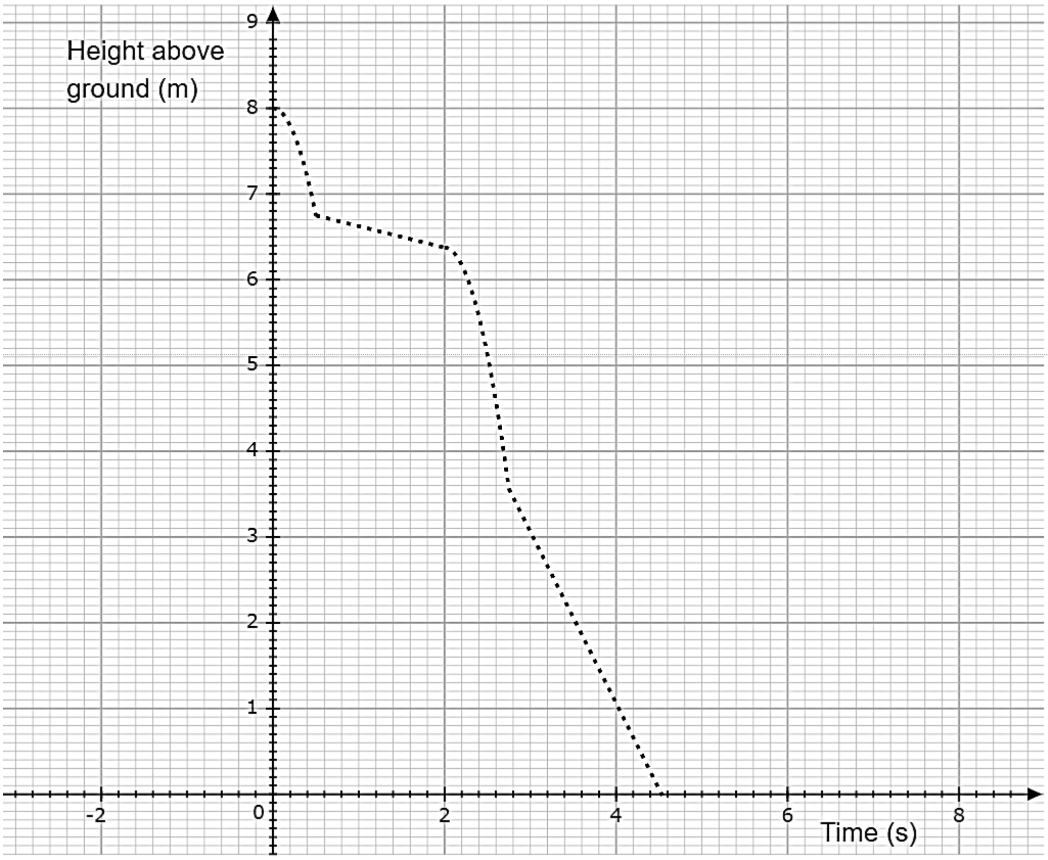
Question 25 (6 marks)

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.

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Question 25 continues on page 20

Question 25 (continued)

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

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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.

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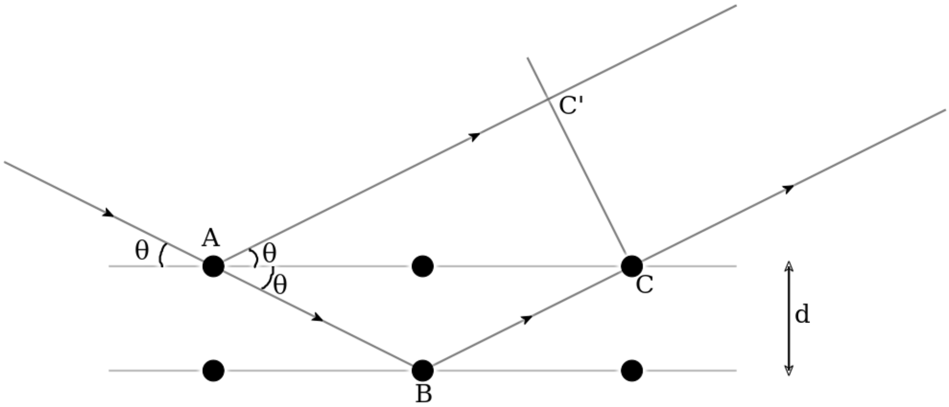
Question 27 (11 marks)

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**

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(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**

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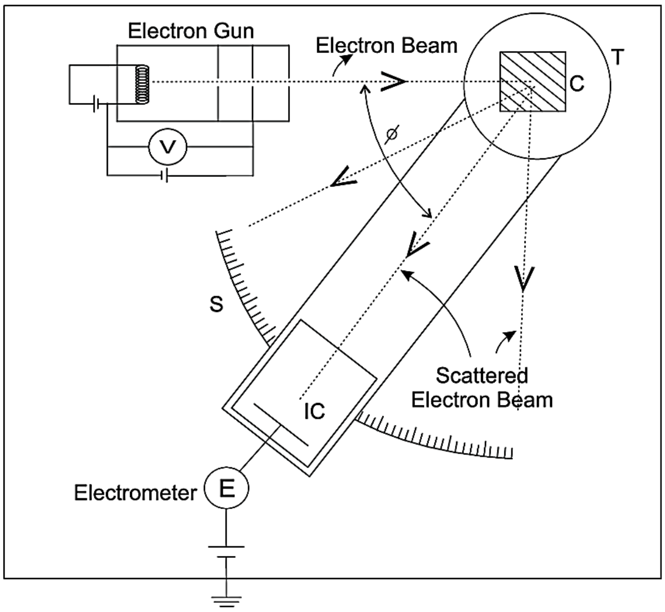
Question 27 continues on page 23

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°, what voltage was used to accelerate the electron?

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Question 27 continues on page 24

Question 27 (continued)

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

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End of Question 27

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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 is powered by the fission of Uranium-235 into Krypton-92 and Barium-141. It is launched at 0.5*c* to escape a neutron star with mass 4.1×10^{30} kg and radius 11 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**

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(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**

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Question 28 continues on page 27

(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**

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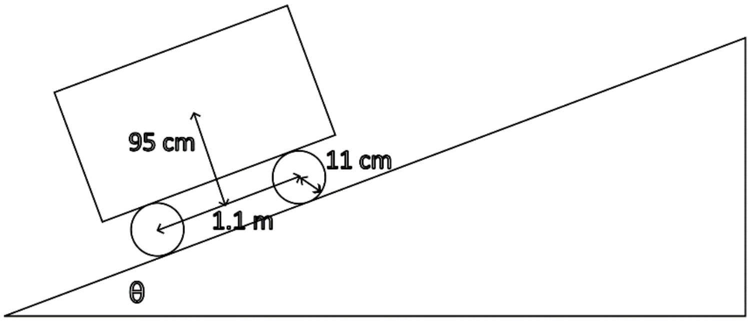
End of Question 28

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.

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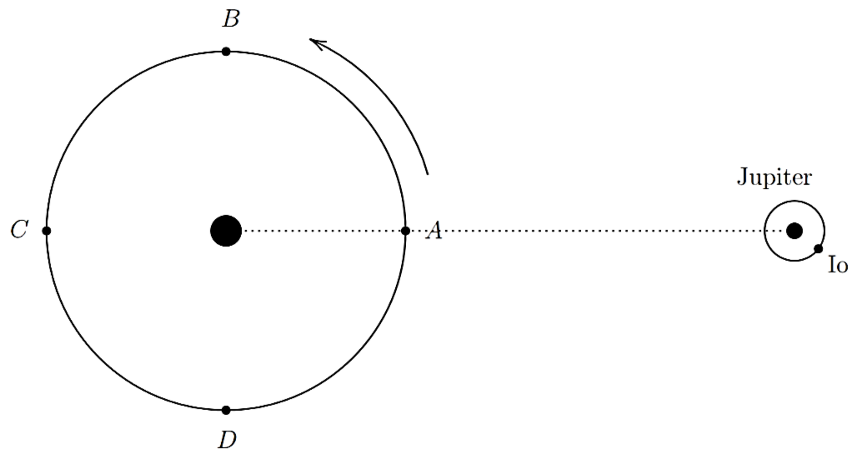
Question 30 (9 marks)

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**

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(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**

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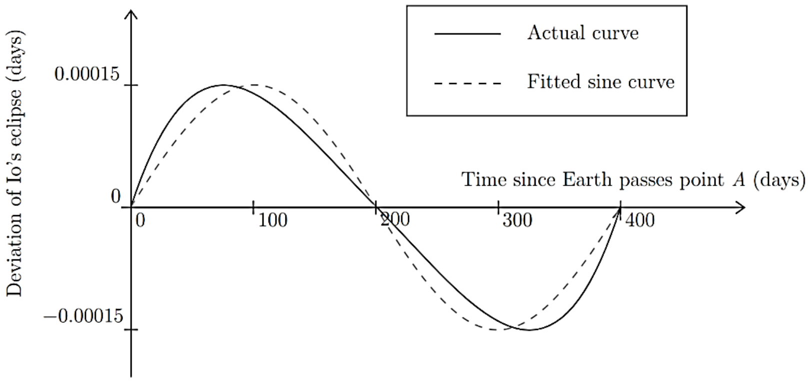
Question 30 continues on page 31

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.

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

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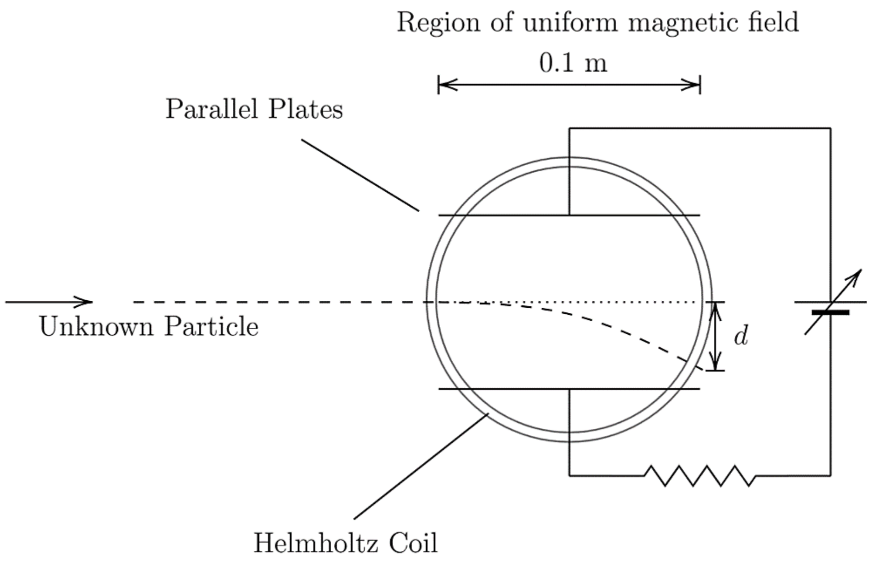
End of Question 30

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**

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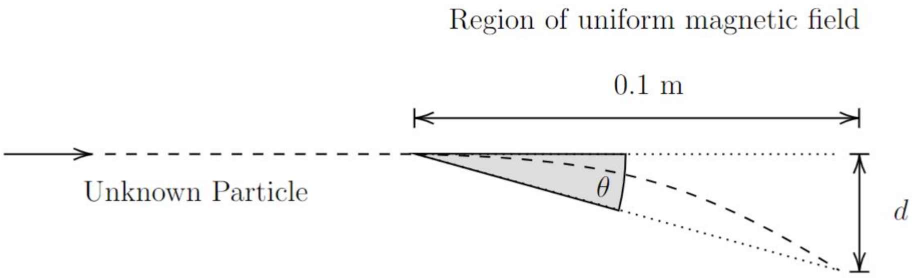
Question 31 continues on page 33

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**



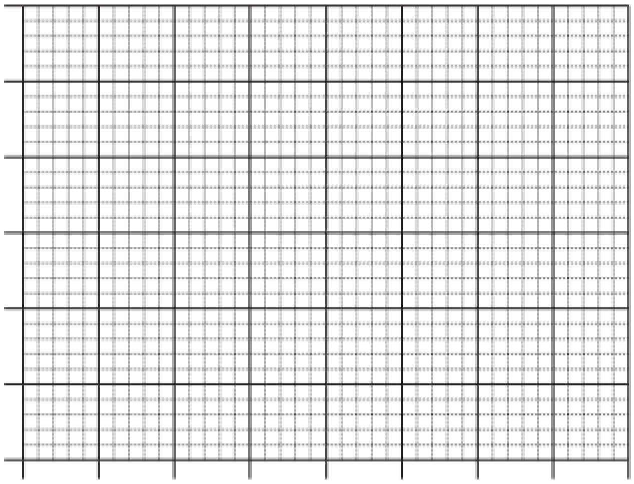
The strength of the magnetic field is set to various known values. For each value of B, the amount of vertical deflection d is measured and tabulated. Assume that in this specific apparatus, v has been determined to be 10^5 ms^{-1}.
Complete the last column of the following table.

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)

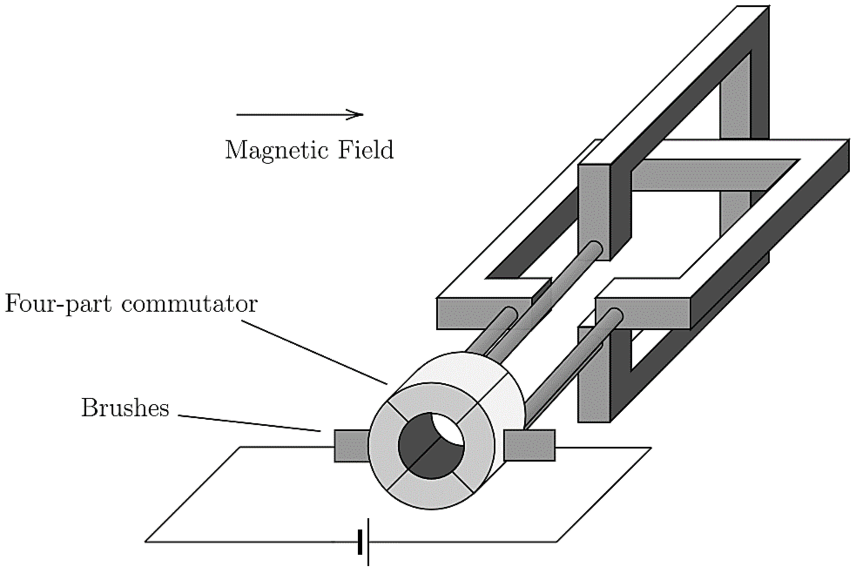
(c) By drawing and considering the gradient of an appropriate line graph, find the mass to charge ratio of the unknown particle. **4**



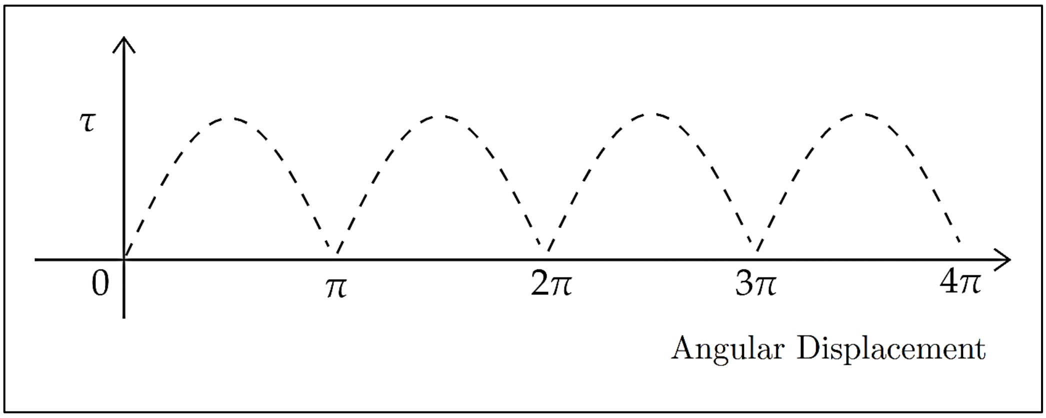
End of Question 31

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 $\mathcal{E}_\mathrm{b} = \mu\omega$, 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 $\frac{V_s}{\mu}$.

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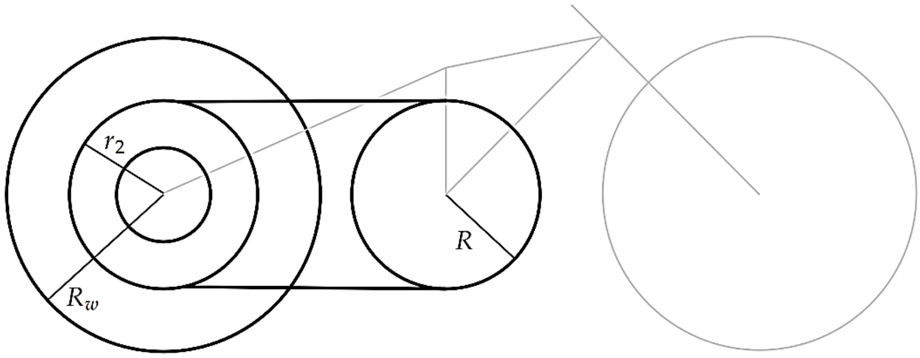
Question 32 continues on page 37

(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 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)

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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**

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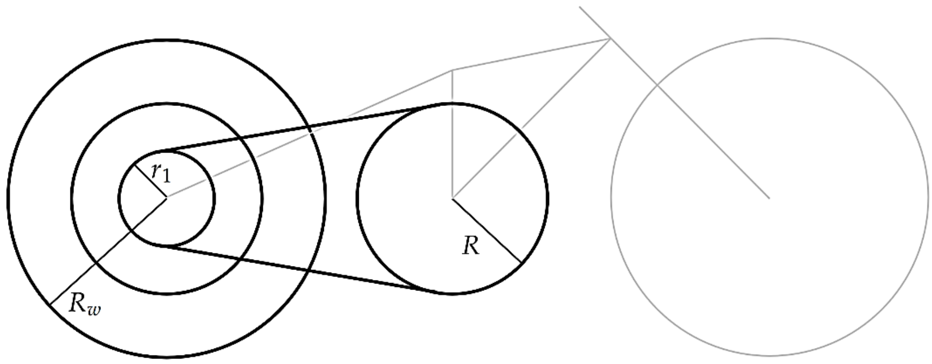
(e) The cyclist is travelling forwards on the bicycle at terminal velocity along a highway. At time t_1, the cyclist switches gear. **4**

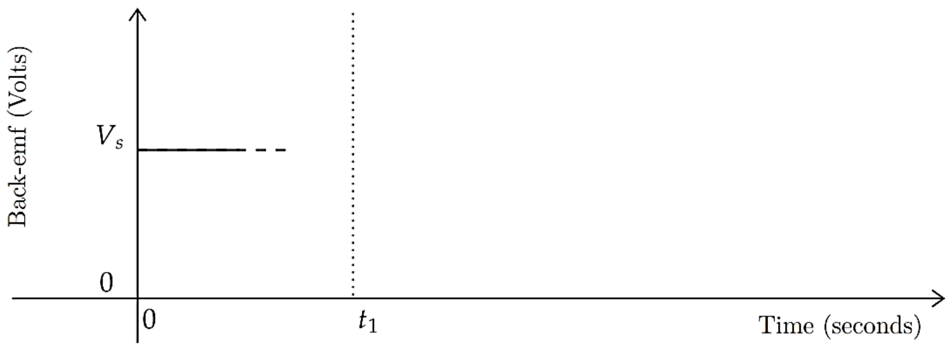


The chain is moved such that is is now wrapped around the gear of radius r_1, which is fixed onto the centre of the rear wheel.

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)



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End of paper

Section II extra writing space

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

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2023 BORED OF STUDIES TRIAL EXAMINATION

Physics

Marking Guidelines

Section I

Multiple-choice answer key

1	2	3	4	5	6	7	8	9	10
D	A	A	D	A	D	B	A	B	B
11	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
B	C	C	B	B	A	D	B	C	D

Multiple-choice explanations

Question	Ans	Explanation
1	D	Phototrons do not exist.
2	A	Planck's Law gives the spectral radiance of a blackbody as a function of temperature and wavelength. $$B = \frac{2hc^2}{\lambda^5} \cdot \frac{1}{e^{\frac{hc}{\lambda k_B T}} - 1}$$
3	A	Hadrons are particles made from quarks. Fermions are particles with half-integer spin. Baryons are particles made from three quarks (protons and neutrons) so all baryons are hadrons. Quarks have half-integer spin, so all baryons are also fermions. Bosons are particles with integer spin. Mesons are particles made from two quarks (half-integer spin), so all mesons have integer spin and are bosons. Leptons have half-integer spin, but are not made of quarks, so not all fermions are hadrons.
4	D	When the satellite is moved to a higher orbit, the radius increases. The gravitational potential energy is $$U = -\frac{GMm}{R}$$ The orbital velocity $v = \sqrt{\frac{GM}{R}}$ gives a kinetic energy of $$K = \frac{1}{2}\frac{GMm}{R} = -\frac{1}{2}U$$ Hence the total energy is given by $E = K + U = \frac{1}{2}U = -K$ The work done is the magnitude of the change in total energy which is the

		same as the absolute change in kinetic energy, giving option D.
5	A	The finite width double slit pattern is the convolution of a double slit interference pattern bounded by a single slit diffraction envelope. Removing the second slit produces just the diffraction envelope, hence decreasing the number of maxima seen.
6	D	The electric field halfway between the charges is the vector sum of the contributions from each. The magnitude of the contribution from a charge q and a distance $\frac{r}{2}$ is $$\lvert E_i \rvert = \frac{1}{4\pi\epsilon_0} . \frac{q_i}{\left(\frac{r}{2}\right)^2}$$ If the charges are the same sign, then the electric field acts in opposite directions and have the same magnitude so they cancel out. If the charges are opposite in sign, then the electric field strength is doubled. Hence $$\lvert E \rvert = \frac{1}{4\pi\epsilon_0} . \frac{\lvert q_1 - q_2 \rvert}{\left(\frac{r}{2}\right)^2}$$
7	B	$$E_{\text{total}} = mc^2 + (\gamma - 1)mc^2$$ $$E_{\text{total}} = \gamma mc^2 = \frac{mc^2}{\sqrt{1 - \frac{v^2}{c^2}}}$$
8	A	Only the surface temperature of a star can be determined from the absorption spectra, not the core temperature.
9	B	At the threshold frequency f $$K = 0 = hf - \phi$$ So, the work function is $\phi = hf$ At frequency $2f$ $$K_{2f} = 2hf - hf = hf$$ At frequency $4f$ $$K_{4f} = 4hf - hf = 3hf = 3K_{2f}$$ The kinetic energy of photoelectrons is three times greater and $K \propto v^2$ then $$v_{4f} = \sqrt{3} v_{2f}$$
10	B	In cluster Y, the more massive stars have reached the main sequence, while the lower mass stars are still in the pre-main sequence (T Tauri) stage. In cluster X, the more massive stars have either gone to supernova or expanded into red giants or super giants, leaving the lower mass stars in the main sequence.

		In cluster Z, even the medium mass stars have started forming red giants. There is also the formation of white dwarfs beginning.
11	B	The torque on the coil should be balanced at equilibrium. Since the magnetic field is radial, the torque is not dependent on the angle. $$nIAB - k\theta = 0$$ Solving this gives $$I = \frac{k\theta}{nAB} = \frac{0.034 \times 18 \times \frac{\pi}{180}}{100 \times 0.03^2 \times 0.54} = 0.22 \text{ A}$$
12	C	First, find the maximum height s_1 of the projectile if the acceleration does not change, which occurs when $$v_y^2 = 0 = u_y^2 - 2gs_1$$ So $$s_1 = \frac{u_y^2}{2g} = \frac{(50 \sin 30°)^2}{2 \times 9.8} = 31.89 \text{ m}$$ At half this height, the acceleration changes to $\frac{g}{2}$. At this point, we let $v_{\frac{1}{2},y}$ be the upward velocity of the projectile at this time. Then $$v_{\frac{1}{2},y} = \sqrt{u_y^2 - \frac{2gs_1}{2}} = \sqrt{(50 \sin 30°)^2 - \frac{2 \times 9.8 \times 31.89}{2}} = 17.68 \text{ ms}^{-1}$$ Now to find the new maximum height above $\frac{s_1}{2}$, set $$v_y^2 = 0 = v_{\frac{1}{2},y}^2 - \frac{2g}{2}s_2$$ $$s_2 = \frac{v_{\frac{1}{2},y}^2}{g} = \frac{17.68^2}{9.8} = 31.89 \text{ m}$$ And finally, the maximum height above the ground is $$h = \frac{s_1}{2} + s_2 = \frac{31.89}{2} + 31.89 = 48 \text{ m}$$ Hence, the answer is C.
13	C	First consider the ball as it rolls along the table. Relative to the table, the ball accelerates at 3.0 ms^{-2} to the right. The horizontal velocity as it reaches the edge is $$v^2 = 2as$$

		$$v = \sqrt{2 \times 3 \times 2.1} = 3.54965\ldots\ \mathrm{ms^{-1}}$$ Now consider the time taken for the ball to fall 1 m vertically. $$h = \frac{1}{2}gt^2$$ $$t = \sqrt{\frac{2h}{g}} = \sqrt{\frac{2 \times 1}{9.8}} = 0.45175\ldots\ \mathrm{s}$$ Then the distance travelled by the ball horizontally during this time is $$x = vt + \frac{1}{2}at^2 = 3.54965 \times 0.45175 + \frac{1}{2} \times 3 \times 0.45175^2 = 1.9\ \mathrm{m}$$
14	B	At the minimum uncertainty, $$\Delta x \Delta p = \frac{h}{4\pi}$$ Since the electron is bound to the atom $\Delta x = 1 \times 10^{-10}$ m then $$\Delta x m \Delta v = \frac{h}{4\pi}$$ and the uncertainty in the velocity is $$\Delta v = \frac{h}{4\pi m \Delta x} = \frac{6.626 \times 10^{-34}}{4\pi \times 9.109 \times 10^{-31} \times 1 \times 10^{-10}} = 5.8 \times 10^5\ \mathrm{ms^{-1}}$$ To 1 significant figure, this gives the answer B.
15	B	The energy released in the reaction is the binding energy of the products less the binding energy of the reactants. Hence, $$\Delta E = 234 \times 7.6 + 4 \times 7.07 - 238 \times E_{\text{per nucleon U}} = 4.27\ \mathrm{MeV}$$ $$E_{\text{per nucleon U}} = \frac{234 \times 7.6 + 4 \times 7.07 - 4.27}{238} = 7.573\ldots\ \mathrm{MeV}$$ Converting to Joules, $$E_{\text{per nucleon U}} = 7.573\ldots \times 1.602 \times 10^{-19} \times 10^6 = 1.21 \times 10^{-12}\ \mathrm{J}$$
16	A	A single helium nucleus produced by the proton-proton cycle involves the fusion of two pairs of hydrogen into deuterium. $${}^1_1\mathrm{H} + {}^1_1\mathrm{H} \rightarrow {}^2_1\mathrm{H} + {}^0_1\mathrm{e}^+ + \nu$$ To balance the above equation, the fusion must be accompanied by the emission of a positron, which always required the emission of a neutrino.

17	D	By Einstein's Special Theory of Relativity, every inertial reference frame must be correct, so the apparent frequency of must be the same for both. Note that answer C does not resolve the paradox. Hence, the equation for the classical doppler effect (which uses the velocity of the wave relative to some medium) cannot be valid for light since there is no medium. This can also be confirmed by noting that the derivation of the classical doppler effect does not consider relativistic effects.
18	B	First note that the triangle is equilateral, so the internal angles are all 60°. The magnitude of the force per unit length due to the top wire on the bottom left wire is $$\frac{F}{l}=\frac{\mu_0 I_{left} I_{top}}{2\pi r}=\frac{4\pi\times10^{-7}\times1.5\times2.0}{2\pi\times1}=6.0\times10^{-7}\text{ Nm}^{-1}$$ This is attractive, so this is directed at 60° above the positive *x*-axis. The magnitude of the force per unit length due to the bottom right wire on the bottom left wire is $$\frac{F}{l}=\frac{\mu_0 I_{left} I_{top}}{2\pi r}=\frac{4\pi\times10^{-7}\times1.5\times2.7}{2\pi\times1}=8.1\times10^{-7}\text{ Nm}^{-1}$$ This is repulsive, so this is directed in the negative *x* direction. Adding these forces as vectors gives a magnitude of $$\frac{\Sigma F}{l}=\sqrt{6^2+8.1^2-2\times6\times8.1\cos120°}\times10^{-7}=1.23\times10^{-6}\text{ Nm}^{-1}$$
19	C	By trial and error, using the Rydberg formula $$\frac{1}{\lambda}=R\left(\frac{1}{n_f^2}-\frac{1}{n_i^2}\right)$$ Gives $$f=cR\left(\frac{1}{n_f^2}-\frac{1}{n_i^2}\right)$$ 2.3×10^{14} Hz corresponds to the transition $n=5\rightarrow4$ 6.2×10^{14} Hz corresponds to the transition $n=4\rightarrow2$ 3.1×10^{15} Hz corresponds to the transition $n=4\rightarrow1$ No transition corresponds to 1.1×10^{15} Hz
20	D	The half-life model of radioactivity is inherently probabilistic. For such a small sample size it is impossible to predict exactly how many nuclei remain at any time.

Section II

Question 21

Criteria	Marks
• Applies Kepler's Second law to provide a valid explanation	2
• Provides some relevant information	1

Sample answer:
Kepler's Second Law states that satellites will sweep equal areas in equal times. Since ellipses are symmetrical about their major axis, the area swept by the moon as it travels from the apogee to the perigee is equal to the area swept by the moon as it travels from the perigee to the apogee. Thus, by Kepler's Second Law, the times taken are equal.

Question 22 (a)

Criteria	Marks
• Correctly calculates the component of weight force parallel to the surface	1

Sample answer:
$mg\sin\theta = 1000 \times 9.8 \times \sin 30° = 4900\text{ N}$

Question 22 (b)

Criteria	Marks
• Correctly calculates magnitude of frictional force	3
• Shows steps or substantial working in calculating the frictional force	2
• Provides a step in calculating the frictional force	1

Sample answer:
Let the *x*-axis go *across* the ramp to the right and let the *y*-axis go *up* the ramp. The magnitude of the net force acting on the car is

$$\frac{mv^2}{r} = \frac{1000 \times 3^2}{5} = 1800\text{ N}$$

The direction of the net force is towards the centre of the circle, thus

Net force in the *x*-direction is given by $\Sigma F_x = F_{g,x} + F_{fr,x}$ so

$$F_{fr,x} = \Sigma F_x - F_{g,x} = 1800\cos 45° - 0 = 1273\text{ N}$$

Net force in the *y*-direction is given by $\Sigma F_y = F_{g,y} + F_{fr,y}$ so

$$F_{fr,y} = \Sigma F_y - F_{g,y} = -1800\sin 45° - (-4900) = 3627\text{ N}$$

Hence, the magnitude of the friction is $F_{fr} = \sqrt{F_{fr,x}^2 + F_{fr,y}^2} = \sqrt{1273^2 + 3627^2} = 3844\text{ N}$

Question 22 (c)

Criteria	Marks
• Provides correct calculation • Uses the work energy theorem	2
• Provides some relevant information	1

Sample answer:

Since the kinetic energy of the car does not change, applying the Work-Energy theorem gives the following result

$$\Delta K = W_{gravity} + W_{friction} = 0$$

Hence,

$$W_{friction} = -W_{gravity} = -4900 \times 10 = -49000 \text{ J}$$

Question 23

Criteria	Marks
• Provides a comprehensive explanation of how step-up transformers reduce energy loss • Provides a comprehensive explanation of at least TWO methods of improving the efficiency of transformers • Provides and integrates at least TWO appropriate equations	5
• Provides an explanation of how step-up transformers reduce energy loss • Provides an explanation of at least ONE method of improving the efficiency of transformers • Provides at least ONE appropriate equation	3-4
• Provides some relevant information	1-2

Sample answer:

To reduce energy loss, a step-up transformer is used to increase the voltage before long-distance transmission. In an ideal transformer, the power generated is constant. So, $P = IV$ means that increasing the voltage V decreases the current I. The power dissipated as heat in a wire with resistance R is $P = I^2R$, so decreasing the current reduces the power lost during transmission.

To reduce energy loss due to the transformer, a soft iron core is used to direct the magnetic flux from the primary to the secondary coil. This prevents flux leakage, where some magnetic flux does not contribute to the induced current in the secondary coil, hence dissipating the magnetic energy.

By Faraday's Law, the changing magnetic flux due to the AC voltage, will induce eddy currents in the iron core. The eddy currents heat up the iron core, converting the energy of the magnetic field into heat. By laminating the sheets perpendicular to the magnetic field with an insulating material, the size of these eddy currents is reduced and hence the amount of energy lost.

Question 24 (a)

Criteria	Marks
• Assesses the claim as false since the length is contracted • Justifies why time dilation cannot be used to analyse this situation	2
• Assesses the claim as false since the length is contracted OR • Justifies why time dilation cannot be used to analyse this situation	1

Sample answer:

The claim is false because neither X or Y experience proper time since the events occur at different positions in both reference frames. Instead, the distance from X to the sensor is length contracted in Y's reference frame, so Y sees the light pulse take a shorter time.

Question 24 (b)

Criteria	Marks
• Provides correct calculation for X's frame • Provides correct calculation for Y's frame	3
• Provides correct calculation for X's frame • Applies length contraction for Y's frame	2
• Provides correct calculation for X's frame	1

Sample answer:

In X's frame, light travels a distance $\frac{L}{2}$ at the speed of light c. The time according to X is

$$t_X = \frac{L}{2c} = \frac{35}{2 \times 3 \times 10^8} = 58 \text{ ns}$$

In Y's frame, the distance between the back of the train and the light pulse is length contracted and reduces at speed $c + v$. The contracted length of the whole train is

$$L' = L\sqrt{1 - \left(\frac{v}{c}\right)^2}$$

The time according to Y is

$$t_Y = \frac{L\sqrt{1 - \left(\frac{v}{c}\right)^2}}{2(c + v)} = \frac{35 \times \sqrt{1 - 0.95^2}}{2(3 \times 10^8 + 0.95 \times 3 \times 10^8)} = 9.3 \text{ ns}$$

This supports the answer to part (a) since $t_Y < t_X$.

Question 25 (a)

Criteria	Marks
• Provides the correct lengths for all THREE sections	2
• Provides the correct length of at least ONE section	1

Sample answer:
The first section of the graph is freefall above the tube and can be ignored. The linear sections occur inside the metal sections. Copper is more conductive than aluminium and hence the gradient is shallower so the second section is copper. The third section is non-linear and must be wood. The final section is linear with a steeper gradient and is aluminium.

From the displacement on the graph, the lengths are:
- Cu 0.38 m
- Wood: 2.8 m
- Al: 3.6 m

Remark: A length of 4.2 m also accepted for the wood if students assumed the freefall above the tube was in wood.

Question 25 (b)

Criteria	Marks
• Provides a comprehensive explanation of the motion of the magnet in the metal with explicit reference to conservation of energy via Faraday and Lenz's Law • Provides a comprehensive comparison of the motion of the magnet between the three sections	4
• Applies conservation of energy • Provides some explanation of the motion of the magnet in the metal • Provides some comparison of the motion of the magnet between the three sections	2-3
• Provides some relevant information	1

Sample answer:

As the magnet falls, there is a change in flux through the pipe, inducing an EMF by Faraday's Law. In the wood section, current cannot flow, so the only force acting is gravity, which does work to convert the magnet's gravitational potential energy into kinetic energy.

Since Cu and Al are conductive metals, this EMF causes current to flow in the direction that produces a magnetic field opposing the original change in flux by Lenz's Law. This applies a resistive magnetic force with magnitude that increases with the rate of change of magnetic flux i.e., speed of the magnet, so it reaches a constant 'terminal' velocity quickly in the metals, producing the linear sections of the graph. The strength of the magnetic field is proportional to the induced current and hence conductivity of the metal. Since Cu is more conductive than Al, the terminal speed in Cu is lower and hence the gradient is shallower.

In the metals, the magnetic force does work to oppose gravity, converting kinetic energy into electrical energy and heat. By the Law of Conservation of Energy, energy cannot be created or destroyed, only transformed. Mathematically, this can be written

$$E_i = E_f$$
$$K_i + U_i = K_f + U_f + W$$

where W represents the work done by the magnetic force or the energy lost to heat. Since

$$U_f = K_i = 0$$
$$U_i = mgh$$
$$K_f = \frac{1}{2}mv^2$$
$$W = mgh - \frac{1}{2}mv^2$$

From the gradient of the final section of the graph, the speed at the bottom is $v = 2.0\ \mathrm{ms^{-1}}$. From the graph, $h = 8.0$ m which yields an energy lost to heat of

$$W = 0.5 \times 9.8 \times 8.0 - \frac{1}{2} \times 0.5 \times 2.0^2 = 38.2\ \mathrm{J}$$

Question 26

Criteria	Marks
• Provides the correct description of unpolarised light • Provides a comprehensive explanation of an experiment to support claim • Provides the correct judgement of the statement	5
• Provides a description of unpolarised light • Provides a description of an experiment to support claim • Provides a consistent judgement of the statement	3-4
• Provides some relevant information	1-2

Sample answer:

While unpolarised light is comprised of *x* and *y* polarisations, the ratio of these two components is rapidly and randomly varying such that no overall polarisation can be observed. A constant mix of *x* and *y* polarisations would simply have a linear polarisation of the vectors sum of the two components.

To differentiate between a constant mix of *x* and *y* polarisations and unpolarised light, we propose an experiment.

1. Shine unpolarised light of a controlled intensity through a polariser with plane perpendicular to the direction of light.
2. Measure the intensity of light that passes through the polariser as the polariser rotates about an axis parallel to the direction of light with a photometer.

If the unpolarised light was comprised of a constant mix of *x* and *y* polarisations, the intensity is expected to vary with the angle that the polarisation axis makes with the vector sum of the *x* and *y* polarisations, by Malus's Law. However, in this experiment a constant intensity that is half of the original intensity is observed. This is because the variations are so rapid, that only the time-averaged intensity can be observed, which is always half of the original intensity. Hence, it can be concluded that the statement is partially valid.

Question 27 (a)

Criteria	Marks
• Provides the correct formula OR • Equivalent merit with some correct working	1

Sample answer:
The path length difference is $(AB + BC) - AC'$. Since

$$\sin\theta = \frac{d}{AB}$$

$$\tan\theta = \frac{d}{0.5AC} = \frac{2d}{AC}$$

Also, since $\Delta AC'C$ is a right-angle triangle then

$$AC' = AC\cos\theta = \frac{2d}{\tan\theta}.\cos\theta = \frac{2d}{\sin\theta}(\cos^2\theta)$$

Combining the equations, noting that $AB = BC$

$$(AB + BC) - AC' = \frac{2d}{\sin\theta}(1 - \cos^2\theta) = \frac{2d}{\sin\theta}.\sin^2\theta = 2d\sin\theta$$

For constructive interference, this path length is an integer multiple of the wavelength. Also note that the reflections are the same so the phase change can be ignored.

$2d\sin\theta = m\lambda$ for some positive integer m.

Remark: Any mathematically equivalent formula was accepted.

Question 27 (b)

Criteria	Marks
• Provides the correct lattice spacing	2
• Provides some relevant information	1

Sample answer:

Suppose the *n* and (*n* + 1)th order peaks are at 27° and 43°. Then

$$d = \frac{\lambda}{2} . \frac{n}{\sin 27°} = \frac{\lambda}{2} . \frac{n+1}{\sin 43°}$$

Solving for *n*

$$n = \frac{\frac{1}{\sin 27°}}{\frac{1}{\sin 27°} - \frac{1}{\sin 43°}} = 2$$

Then substitute back in for *d*

$$d = \frac{n\lambda}{2 \sin 27°} = \frac{2 \times 3.2 \times 10^{-9}}{2 \sin 27°} = 7.0 \text{ nm}$$

Question 27 (c)

Criteria	Marks
• Provides the correct wavelength • Provides the correct expression for kinetic energy • Provides the correct voltage	3
• Provides the correct wavelength • Provides the correct expression for kinetic energy	2
• Provides some relevant working	1

Sample answer:

First, find the corresponding value of θ for ϕ.

$$\theta = 90 - \frac{\phi}{2}$$

Then since this is the first order maximum, $n = 1$ and so the wavelength of the electrons is

$$\lambda = 2d \sin\left(90° - \frac{\phi}{2}\right) = 2 \times 0.091 \times 10^{-9} \sin\left(90° - \frac{50°}{2}\right) = 1.6495 \times 10^{-10} \text{ m}$$

The kinetic energy of the electrons is provided by the work done due to the accelerating voltage and can be related to the electron momentum

$$K = eV = \frac{p^2}{2m}$$

By De Broglie's matter-wave equivalence electron wavelength and momentum can be related by

$$p = \frac{h}{\lambda}$$

Substituting and solving for the voltage

$$V = \frac{h^2}{2me\lambda^2} = \frac{(6.626 \times 10^{-34})^2}{2 \times 9.109 \times 10^{-31} \times 1.602 \times 10^{-19} \times (1.6495 \times 10^{-10})^2} = 55 \text{ V}$$

Question 27 (d)

Criteria	Marks
• Comprehensively explains how the Davisson-Germer experiment contributed to an improvement on the Bohr model of the atom	5
• Explains how the Davisson-Germer experiment contributed to an improvement on the Bohr model of the atom	4
• Explains some aspects of how the Davisson-Germer experiment contributed to an improvement on the Bohr model of the atom	3
• Provides details of how the Davisson-Germer experiment contributed to an improvement on the Bohr model of the atom	2
• Provides some relevant information	1

Sample answer:
In the Bohr model, the atom contains a small dense positive nucleus orbited by electrons held by electrostatic attraction. The orbits of these electrons are governed by three postulates.

1. Electrons orbit the nucleus in a circle in certain discrete energy levels and radii.
2. A transition between energy levels is accompanied by the emission or absorption of a photon with frequency corresponding to the energy difference between the levels.
3. The angular momentum of electrons is quantised.

The Bohr model successfully explained the discrete lines in the emission spectra of hydrogen and single-electron systems – each line corresponds to a specific transition between energy levels. However, the Bohr model could not explain how electrons could orbit without radiating energy, since they must continuously be accelerating. It also could not explain why angular momentum would be quantised.

In the Davisson-Germer experiment, electrons were shown to undergo diffraction, which is a property of waves. This supports De Broglie's matter wave theory, where particles display wave properties and vice-versa. This provides an improvement to the Bohr model by explaining how and why these discrete energy levels exist. Electrons form standing waves around the nucleus, which requires an integer number of wavelengths to fill the circumference of the orbit. Hence, the nth energy level corresponds to n wavelengths inside the circumference, from which the third postulate can be derived. The energy of a standing waves is constant, so the existence of these states can be explained.

Question 28 (a)

Criteria	Marks
• Provides the correct escape velocity	1

Sample answer:
Using the formula for escape velocity

$$v_{esc} = \sqrt{\frac{2GM}{R}} = \sqrt{\frac{2 \times 6.67 \times 10^{-11} \times 4.10 \times 10^{30}}{11.0 \times 10^{3}}} = 2.23 \times 10^{8} \text{ ms}^{-1}$$

Remark: Note that taking relativity into account actually returns the classical expression, but this is beyond the scope of the course.

Question 28 (b)

Criteria	Marks
• Provides the correct nuclear equation • Provides the correct energy per kg	2
• Provides some relevant working	1

Sample answer:
The fission of uranium is given by

$${}^{235}_{92}\text{U} + {}^{1}_{0}\text{n} \rightarrow {}^{92}_{36}\text{Kr} + {}^{141}_{56}\text{Ba} + 3{}^{1}_{0}\text{n}$$

Alternatively, the net equation is

$${}^{235}_{92}\text{U} \rightarrow {}^{92}_{36}\text{Kr} + {}^{141}_{56}\text{Ba} + 2{}^{1}_{0}\text{n}$$

The fission of one uranium nuclei results is a mass difference of

$$\Delta m = 235.043925 - 140.914411 - 91.926156 - 2 \times 1.008665$$

$$\Delta m = 0.186028 \text{ amu}$$

This releases energy $E = 0.186028 \times 1.661 \times 10^{-27} \times (3 \times 10^{8})^{2} = 2.781 \times 10^{-11}$ J per nuclei of Uranium-235.

The mass of one nuclei of Uranium-235 is

$$m_{\text{nuclei}} = 235.043925 \times 1.661 \times 10^{-27} = 3.9041 \times 10^{-25} \text{ kg}$$

Then the energy released per kg of uranium is

$$E_{per\ kg} = \frac{E}{m_{\text{nuclei}}} = \frac{2.781 \times 10^{-11}}{3.9041 \times 10^{-25}} = 7.12 \times 10^{13} \text{ Jkg}^{-1}$$

Question 28 (c)

Criteria	Marks
• Correctly calculates percentage of the initial total mass of the rocket was the Uranium-235 fuel	4
• Provides substantial working to calculate percentage of the initial total mass of the rocket was the Uranium-235 fuel	3
• Calculates one relevant quantity	2
• Provides one correct step in calculation	1

Sample answer:
If the initial mass is m, including Δm of fuel, then by conservation of energy, the increase in mechanical energy must have come from the fuel.

$$E_i - E_f = E_{fuel}$$

$$\left(\frac{1}{2}mv^2 - \frac{GMm}{R}\right) - 0 = \Delta mc^2$$

Solving this gives the initial percentage by mass of fuel in the rocket.

$$\frac{\Delta m}{m} = \frac{1}{c^2}\left(\frac{GM}{R} - \frac{1}{2}v^2\right)$$

$$\frac{\Delta m}{m} = \frac{1}{(3\times10^8)^2}\left(\frac{6.67\times10^{-11}\times4.10\times10^{30}}{11.0\times10^3} - \frac{1}{2}(0.743\times3\times10^8)^2\right) = 2.078\times10^{-4}$$

But the mass difference per kg of Uranium-235 is $\frac{0.186028}{235.043925} = 7.9146\times10^{-4}$ kg

Hence, the percentage of Uranium-235 is

$$\%\text{Uranium} = \frac{2.078\times10^{-4}}{7.9146\times10^{-4}} = 26.3\%$$

Question 29

Criteria	Marks
• Provides a comprehensive analysis of at least THREE relevant factors BOTH qualitatively and quantitatively • Provides the correct final steepness	7
• Provides a thorough analysis of at least THREE relevant factors BOTH qualitatively and quantitatively	5-6
• Provides a sound analysis of at least TWO relevant factors BOTH qualitatively and quantitatively OR • Provides a sound analysis of at least THREE relevant factors either qualitatively OR quantitatively only	3-4
• Provides some relevant information	1-2

Sample answer:

1. Friction

The static friction between the wheels and the surface provides the upwards force, so must be greater than the component of the weight force down the hill.

$$F_{g,\,\text{parallel}} < F_{\text{static friction}}$$
$$mg\sin\theta < \mu_s mg\cos\theta$$
$$\tan\theta < \mu_s$$
$$\theta < \tan^{-1}(0.62) = 31.8°$$

2. Max torque

The force produced by the motor must be greater than the component of the weight force down the hill.

$$mg\sin\theta < F_{\text{motor}} = \frac{\tau_{\text{motor}}}{r}$$
$$mg\sin\theta < \frac{nIAB}{r}$$
$$\sin\theta < \frac{nVAB}{rmgR}$$
$$\theta < \sin^{-1}\left(\frac{500 \times 20 \times 12 \times 10^{-4} \times 0.023}{0.11 \times 3.8 \times 9.8 \times 0.13}\right) = 31.2°$$

3. Centre of mass

The centre of mass cannot be directly above the back wheel, else the net torque around the back wheel will tip the cart over.

$$\theta + \tan^{-1}\frac{2h}{d} < 90°$$
$$\theta < 90° - \tan^{-1}\left(\frac{2 \times 0.95}{1.1}\right) = 30.1°$$

Overall, steepness is limited to $\theta < 30.1°$.

Question 30 (a)

Criteria	Marks
• Provides correct calculations of the ratio between the orbital radii	2
• Provides some relevant information	1

Sample answer:
Since Earth takes about 365 days to orbit around the Sun, Earth's angular velocity ω_e is given by

$$\frac{2\pi}{\omega_{\mathrm{e}}} = 365$$

$$\omega_{\mathrm{e}} = \frac{2\pi}{365} = 1.72 \times 10^{-2}\ \mathrm{d}^{-1}$$

The angular velocity of the Earth relative to Jupiter is ω_e - ω_{j}. Since Earth takes 400 days to orbit the Sun relative to Jupiter, this gives

$$\frac{2\pi}{\omega_{\mathrm{e}} - \omega_j} = 400$$

As a result

$$\omega_{\mathrm{e}} - \omega_j = \frac{2\pi}{400}$$

$$\frac{2\pi}{365} - \omega_j = \frac{2\pi}{400}$$

$$\omega_j = \frac{2\pi}{365} - \frac{2\pi}{400} = 1.51 \times 10^{-3}\ \mathrm{d}^{-1}$$

Applying Kepler's third law

$$\left(\frac{r_j}{r_e}\right)^3 = \left(\frac{T_j}{T_e}\right)^2$$

$$\frac{r_j}{r_e} = \left(\frac{T_j}{T_e}\right)^{\frac{2}{3}} = \left(\frac{\omega_e}{\omega_j}\right)^{\frac{2}{3}} = \left(\frac{1.72 \times 10^{-2}}{1.51 \times 10^{-3}}\right)^{\frac{2}{3}} = 5.07$$

Question 30 (b)

Criteria	Marks
• Identifies and explains how the speed of light is the main factor • Uses the Doppler Effect or otherwise to explain the variation • Correctly describes the variation of the duration of Io's eclipses	2
• Mentions the speed of light	1

Sample answer:

The apparent immersion and emergence of Io can be thought of as signals which travel at the speed of light. The immersion signal and emergence signal can be thought of as two successive wavefronts. The Doppler effect can be applied to this scenario.

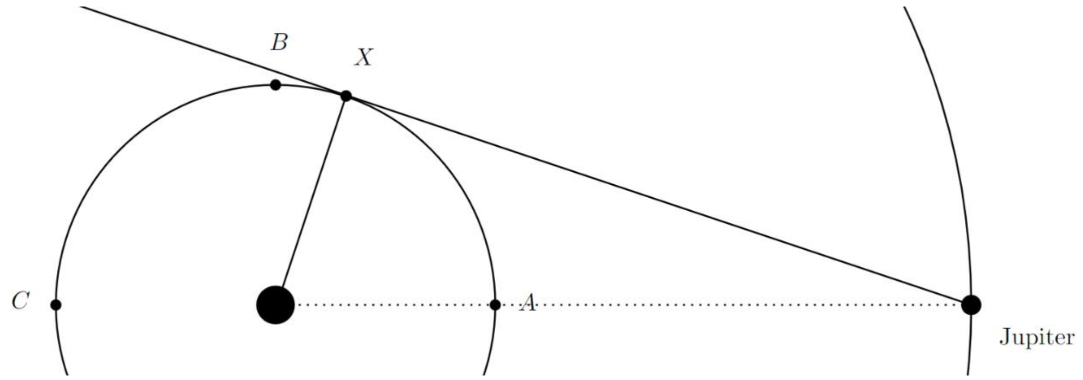
Starting from Point A, as the distance from Earth to Io increases, the Doppler effect causes the period between the immersion and emergence signals to increase. The maximum duration occurs near point B (travelling away from Io the fastest), and the minimum duration occurs near point D (travelling towards Io the fastest)

Question 30 (c)

Criteria	Marks
• Relates the deviation of the duration of Io's eclipse to Earth's recessional velocity relative to Jupiter AND • Explains how the graph of Earth's recessional velocity over time deviates from a perfect sine curve	3
• Relates the deviation of the duration of Io's eclipse to Earth's recessional velocity relative to Jupiter OR • Explains how the graph of Earth's recessional velocity over time deviates from a perfect sine curve	2
• Provides some relevant information	1

Sample answer:

Using reasoning from part (b), the faster Earth is receding from Io, the longer the duration and vice versa. The point of maximum deviation thus should be when Earth is receding from Io the fastest. However, this doesn't occur precisely at point B, instead this occurs at X.



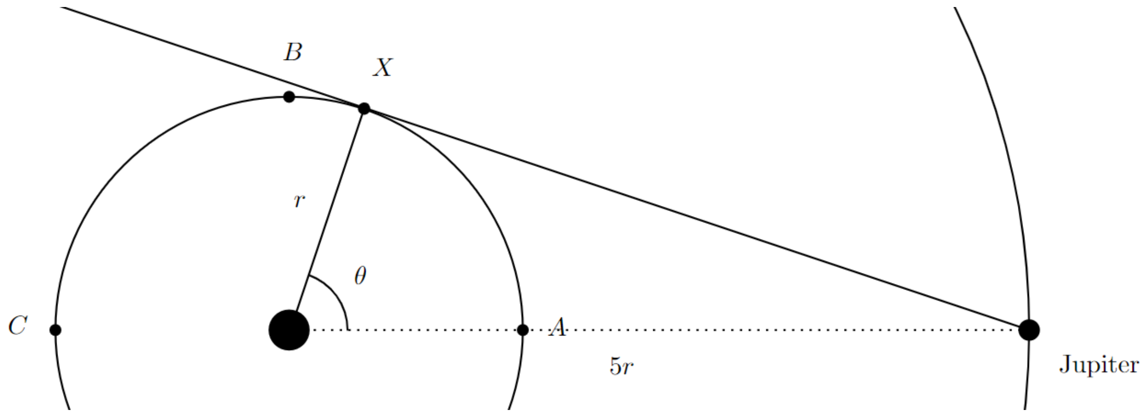
It occurs a little bit earlier, when Earth's tangential velocity vector is pointing parallel to the line between Jupiter and Earth. Similarly, the point of minimum deviation occurs when Earth is travelling towards Io the fastest. This will occur a little bit after point D.

This causes the deviation vs time graph to appear skewed, where the point of maximum deviation occurs slightly before a quarter of a synodic year, and the point of minimum deviation occurs slightly after three quarters of a synodic year.

Question 30 (d)

Criteria	Marks
• Calculates the correct time at which maximum deviation occurs	2
• Provides some relevant information	1

Sample answer:



The maximum deviation occurs when Earth is at point X as per the diagram above. Note, that the tangent line makes a right angle with the radius at X. Since

$$\cos\theta = \frac{1}{5}$$

$$t = \frac{\theta}{\omega} = \frac{\cos^{-1}\frac{1}{5}}{1.72 \times 10^{-2}} = 79.6 \text{ days}$$

Question 31 (a)

Criteria	Marks
• Explains how the speed can be determined by measuring the electric and magnetic fields when the beam is undeflected	1

Sample answer:

The magnetic field and electric field can be adjusted such that the beam passes through undeflected. The electric and magnetic force must be balanced, so the speed can be measured as the ratio of the electric and magnetic field strengths.

$$qvB = qE$$

$$v = \frac{E}{B}$$

Question 31 (b)

Criteria	Marks
• All entries in the table are correct	2
• At least one entry in the table is correct OR • All entries are correct except for a unit conversion error	1

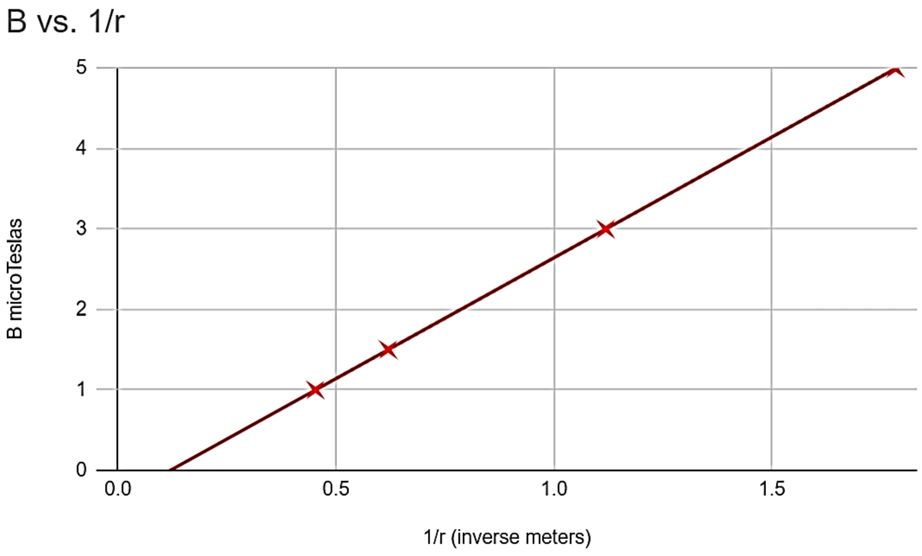
Sample answer:

Field Strength *B* (μT)	**Vertical deflection *d* (m)**	$\frac{1}{r}$ **(m^{-1})**
1.0	1.667×10^{-3}	0.4532
1.5	2.502×10^{-3}	0.6200
3.0	5.013×10^{-3}	1.110
5.0	8.392×10^{-3}	1.780

Question 31 (c)

Criteria	Marks
• Provides a graph with ALL required elements including an appropriate title, correct units and axes labels, accurately plotted points, and an appropriate line of best fit • Provides the correct mass to charge ratio from the gradient	4
• Provides a graph with SOME required elements • Provides a mass to charge ratio from the gradient	2-3
• Provides some relevant information	1

Sample answer:



This graph has gradient 3.01×10^{-6} Tm. The magnetic force provides the centripetal force, so

$$qvB = \frac{mv^2}{r}$$

$$B = \frac{mv}{q} \times \frac{1}{r}$$

$$\frac{mv}{q} = 3.01 \times 10^{-6}$$

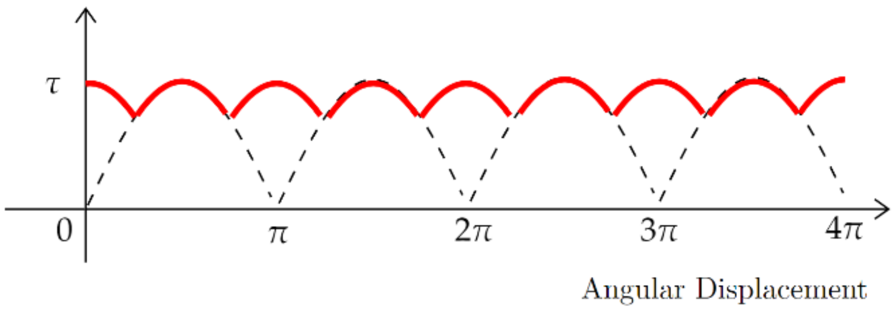
$$\frac{m \times 10^5}{q} = 3.01 \times 10^{-6}$$

$$\frac{m}{q} = 3.01 \times 10^{-11}\ \text{kgC}^{-1}$$

Question 32 (a)

Criteria	Marks
• Draws the correct curve	1

Sample answer:



Question 32 (b)

Criteria	Marks
• Explains the formula for the angular speed	1

Sample answer:
The terminal angular speed will occur when the net torque on the motor is 0. Since there is no load, the current must also be 0. Hence,

$$V_s - \epsilon_b = 0$$

$$V_s = \mu\omega$$

$$\mu = \frac{V_s}{\omega}$$

Question 32 (c)

Criteria	Marks
• Correctly calculates the initial acceleration of the bicycle	4
• Provides substantial working to calculate the initial acceleration of the bicycle	3
• Calculates one relevant quantity	2
• Provides one correct step in calculation	1

Sample answer:
Initially, there is no back EMF since the motor is not moving.

$$I = \frac{V_s}{P}$$

The net torque on the gear with radius R must be 0 since its mass is negligible.

$$R(T_2 - T_1) = \lambda I$$

The net torque on the wheel must also be 0.

$$F_{\text{fr}} R_w = r_2(T_2 - T_1) = \frac{r_2 \lambda I}{R}$$

The force that accelerates the bicycle is the friction force.

$$F_{\text{fr}} = ma$$

Hence the acceleration is

$$a = \frac{r_2 \lambda V_2}{R R_w m P}$$

Question 32 (d)

Criteria	Marks
• Provides the correct value of tension	1

Sample answer:
When the bicycle is put in reverse, the torque due to the top and bottom chains reverse direction, so

$$R(T_1 - T_2) = \lambda I$$

$$T_2 = T_1 - \frac{\lambda V_s}{PR}$$

Question 32 (e)

Criteria	Marks
• Provides the correct graph with ALL appropriate labels • Provides a comprehensive explanation for the dotted points	4
• Provides a graph with SOME appropriate labels • Provides a thorough explanation for the dotted points	3
• Provides a graph • Provides some description for the dotted points	2
• Provides some relevant information	1

Sample answer:

Since the cyclist moves at terminal velocity, the bike wheels maintain their angular velocities ω. At time t_1, the radius of the wheel gear decreases suddenly, so the speed of the chain decreases by $v = r\omega$. The velocity of the chain is equal to the speed of the outer edge of the wheel gear, which is also equal to the speed of the outer edge of the motor gear, so the angular velocity of the motor decreases.

The back EMF is proportional to the angular velocity of the motor, so the back-emf drops suddenly at time t_1. This causes the net voltage to become positive, so the motor starts providing torque. The bicycle wheels experience angular acceleration and rotate faster, causing the back EMF to increase again, approaching the supply voltage, where net torque returns to zero.