James Ruse Agricultural High School

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2024

HIGHER SCHOOL CERTIFICATE TRIAL EXAMINATION

Physics

General Instructions

- Reading time – 5 minutes
- Working time – 3 hours
- Write using black pen
- Draw diagrams using pencil
- NESA approved calculators and equipment may be used
- A formula sheet and data sheet and Periodic Table are provided.
- For questions in Section II, **show all relevant working** in questions involving calculations.

Total marks 100

Section I -20 marks (pages 2-13)
- Attempt Questions 1– 20
- Allow about 35 minutes for this part

Section II -80 marks (pages 16-36)
- Attempt Questions 21–35
- Allow about 2 hours and 25 minutes for this part

This paper MUST NOT be removed from the examination room.

Section I

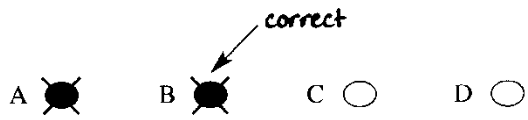
20 marks
Attempt Questions 1-20
Allow about 35 minutes for this section.
Mark your answers on the ANSWER grid in the Answer booklet on page 15.

Select the alternative A, B, C or D that best answers the question. Fill in the response oval completely.

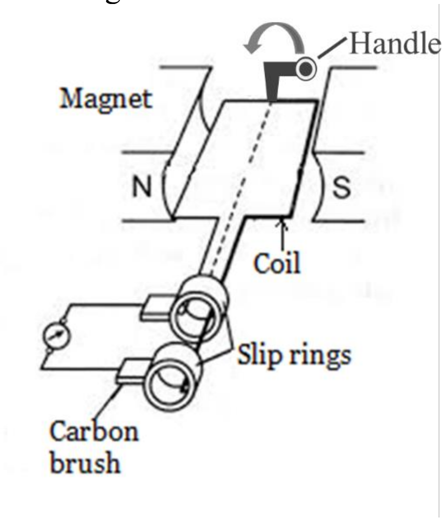
Sample: $2 + 4 =$ (A) 2 (B) 6 (C) 8 (D) 9

If you think you have made a mistake, put a cross through the incorrect answer and fill in the new answer.

If you change your mind and have crossed out what you consider to be the correct answer, then indicate the correct answer by writing the word *correct* and drawing an arrow as follows.



1. What is the name of the following device?



A. DC motor

B. DC generator

C. AC generator

D. AC induction motor

2. An object is moving in a horizontal circle on a string with a constant angular velocity ω. The tension in the string, which is approximately horizontal, is F. If ω is doubled while all the other quantities are kept constant, what will the tension in the string become?

A. 4F

B. 2F

C. F/2

D. F/4

3. If an astronaut orbiting the Earth near its surface were to stand on a set of bathroom scales, why would there be a reading of zero?

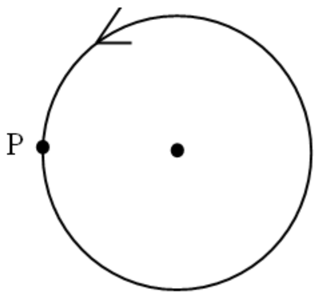
A. The astronaut’s mass becomes zero.

B. The strength of the gravitational field is zero.

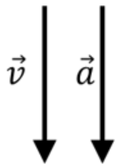
C. The pull of the Earth is balanced by the pull of the Moon.

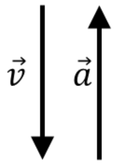
D. The astronaut falls towards the Earth at the same rate as the space capsule.

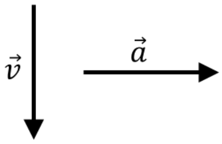
4. An object is executing uniform circular motion, as shown in the figure below.

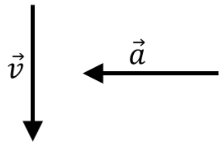


At position P, which of the following shows the directions of instantaneous velocity and acceleration?

A. 

B. 

C. 

D. 

5. Iodine–131 is a radioisotope used in nuclear medicine. It has a half-life of 8 hours and eventually becomes a stable isotope Xenon-131 according to the following equation:

$$^{131}_{53}\mathrm{I} \rightarrow {}^{131}_{54}\mathrm{Xe} + \gamma$$

24.0 mg of Iodine–131 is injected in the body of a patient.

How many milligrams of Xenon-131, produced as a result of this reaction, is present in the body after 16 hours?

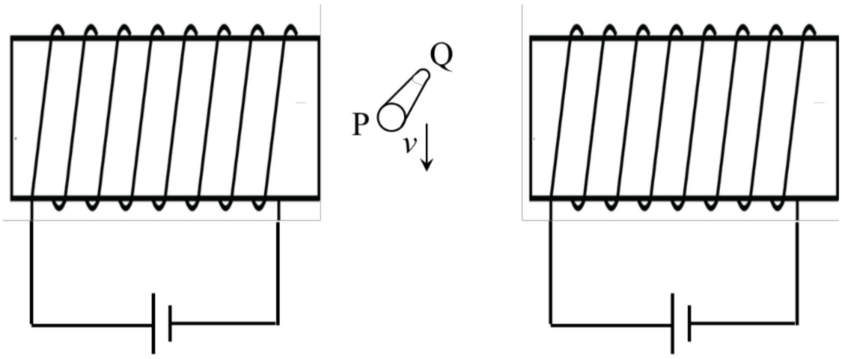
A. 6.0

B. 12.0

C. 18.0

D. 24.0

6. A horizontal metal cylinder PQ, perpendicular to the page, moves down between two solenoids, as shown below:



Which of the following correctly show the direction of the magnetic field between the solenoids and the charge at P?

	Direction of magnetic field	*Charge at P*
A.	left	positive
B.	left	negative
C.	right	positive
D.	right	negative

7. A radioactive isotope decays by alpha and beta particle emission. Over a number of decays, the nucleon number decreases by 4 while the proton number is unchanged.

How many alpha and beta particles have been emitted?

A. 2 alpha particles and 1 beta particle

B. 1 alpha particle and 2 beta particles

C. 1 alpha particle and 1 beta particle

D. 2 alpha particles and 2 beta particles

8. Two students are discussing the advantages of magnetic brakes.

Student A says that because the magnetic force is proportional to velocity they provide a smoother braking action.

Student B says that because magnetic fields do no work, the brakes produce no heat.

Which of the students, if any, is/are correct?

A. Student A only

B. Student B only

C. Both student A and student B

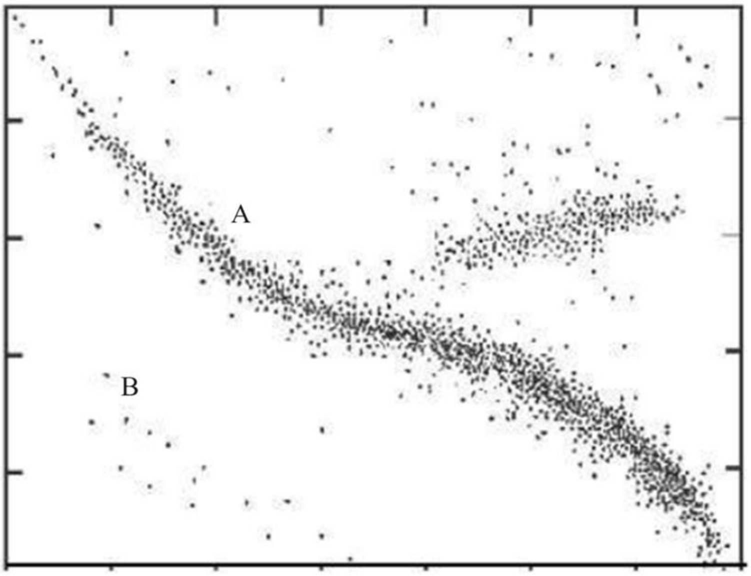
D. Neither student A nor student B

9. Control rods and moderators play a key role in controlling the rate of fission in nuclear reactors.

Which row of the table correctly shows how this is achieved?

	Control Rod	*Moderator*
A.	By absorbing neutrons.	By slowing down fast neutrons to thermal speeds.
B.	By absorbing neutrons.	By speeding up slow neutrons so that a chain reaction is sustainable
C.	By increasing the capture cross-section of neutrons.	By speeding up slow neutrons so that a chain reaction is sustainable
D.	By increasing the capture cross-section of neutrons.	By slowing down fast neutrons to thermal speeds.

10. This is a Hertzsprung-Russell (H-R) diagram showing many star plots. The axes are not labelled.



Which of the following statements is true of the luminosity and temperature of stars A and B?

A. The luminosity of star A is lower while the temperature of star B is higher.

B. The luminosity of star A is lower while the temperature of star B is lower.

C. The luminosity of star A is higher while the temperature of star B is higher.

D. The luminosity of star A is higher while the temperature of star B is lower.

11. At what angle, θ should two polaroid sheets be placed to reduce the intensity by ninety percent?

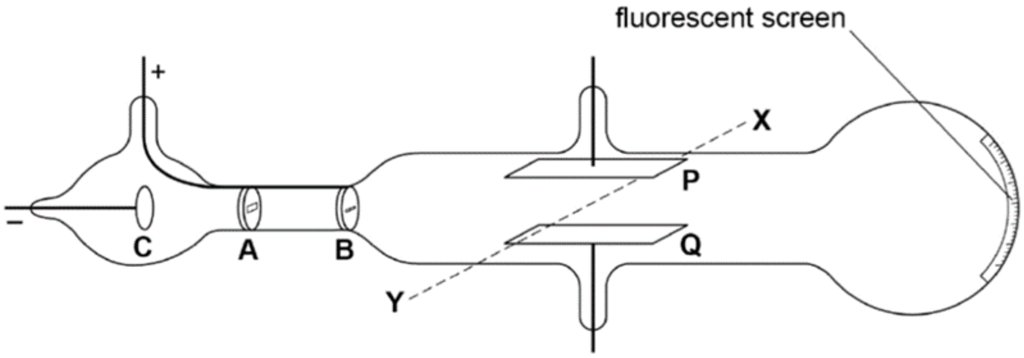
A. $\theta = \cos^{-1}\sqrt{0.8}$

B. $\theta = \cos^{-1}\sqrt{0.2}$

C. $\theta = \cos^{-1}\sqrt{0.9}$

D. $\theta = \cos^{-1}\sqrt{0.1}$

12. The diagram shows a discharge tube used by Thomson to investigate cathode rays. When the connections are made to a high voltage power supply, cathode rays are produced at C and accelerated across AB and through parallel plates P and Q, connected to a second power supply, with P positively charged. The rays then hit the centre of the fluorescent screen, when a magnetic field is positioned (in the XY direction) between the plates P and Q.



Which row of the table shows the aim of this experiment and the correct direction of the applied magnetic field?

	Aim of the experiment	*Direction of magnetic field*
A.	To determine the charge of the electron	From X to Y
B.	To determine the charge of the electron	From Y to X
C.	To determine the charge to mass ratio of the electron	From X to Y
D.	To determine the charge to mass ratio of the electron	From Y to X

13. Two satellites orbit a planet. One of the satellites has an orbital radius of 2.3×10^6 m and a period of 7.6×10^4 s. The other satellite has an orbital period of 1.3×10^5 s. What is the orbital radius of this second satellite?

A. 1.3×10^6 m

B. 3.3×10^6 m

C. 3.9×10^6 m

D. 5.1×10^6 m

14. A 500 kg satellite is initially in a circular orbit with a radius of 10 000 km around the Earth. The satellite is then moved to a new circular orbit with a radius of 20 000 km.

What is the change in the gravitational potential energy of the satellite?

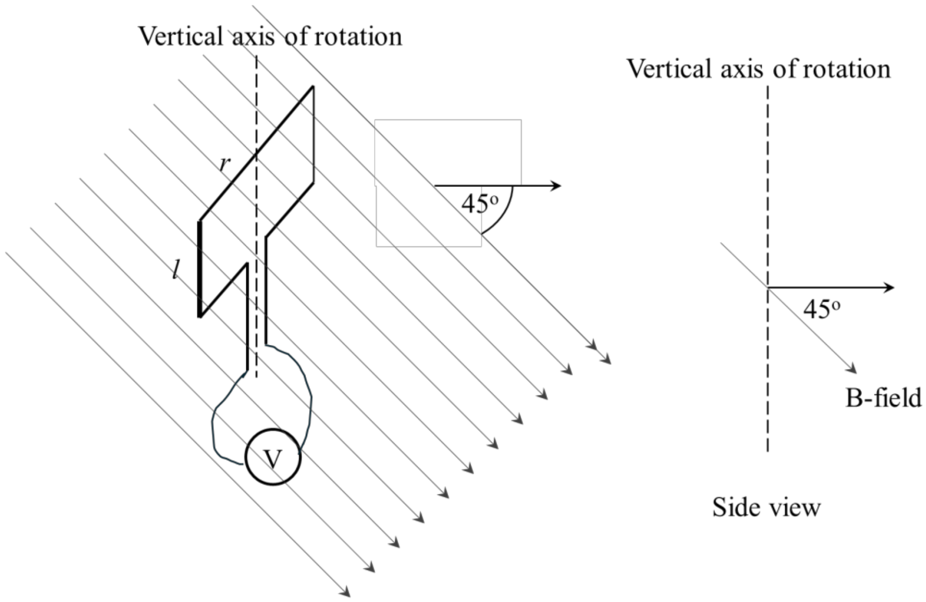
A. 1.5×10^3 J

B. 1.5×10^9 J

C. 1.0×10^{10} J

D. 1.0×10^{13} J

15. A coil of wire is rotating about a vertical axis in a magnetic field that is directed 45° below the horizontal:



Which set of changes will result in the largest reading on the voltmeter?

A. Double *r* and halve *l*.

B. Increase both *l* and *r* by 50 %.

C. Rotate the magnetic field to vertical and double *r*.

D. Rotate the magnetic field to horizontal and double *l*.

16. Two stars, A and B, are equally bright as seen from the Earth. Stars A and B are 10 and 15 parsecs away from Earth respectively. One parsec = 3.26 light years.

Which of the following statements about the luminosities of stars A and B (L_A and L_B) are correct?

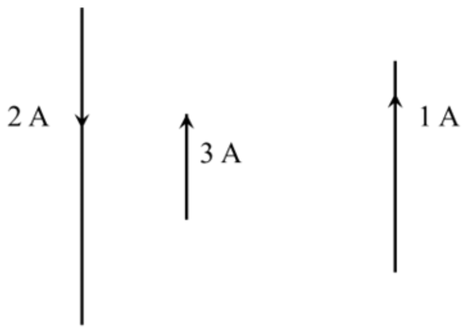
A. $L_A = \frac{3}{2} L_B$

B. $L_A = \frac{2}{3} L_B$

C. $L_A = \frac{4}{9} L_B$

D. $L_A = \frac{9}{4} L_B$

17. Three wires carry currents, as shown in the following scale diagram.



How many of the wires experience a net force to the left?

A. 0

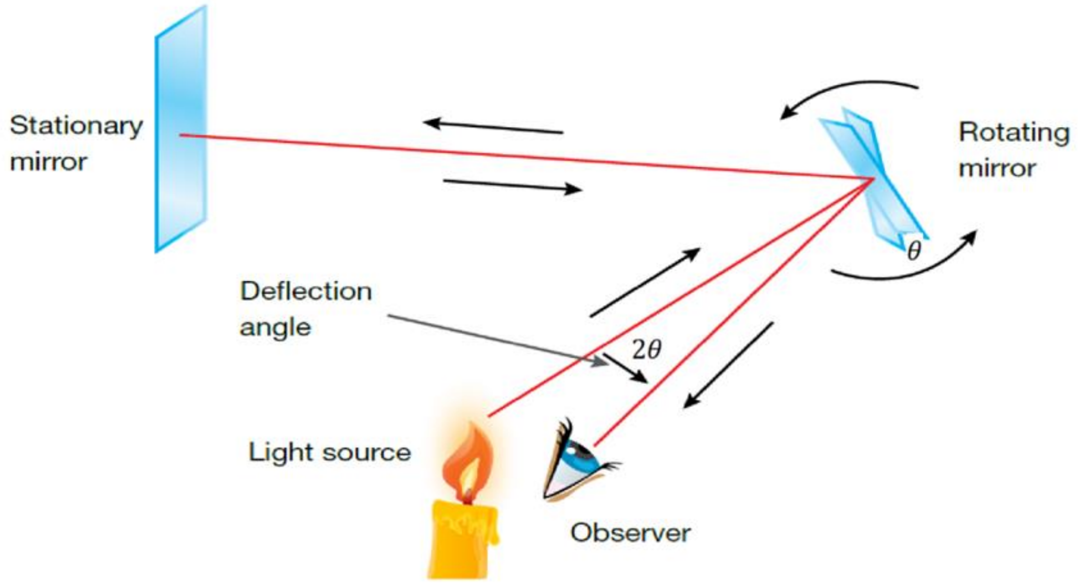
B. 1

C. 2

D. 3

18. Foucault measured the speed of light by focusing light onto a rotating mirror, which reflected it onto a stationary mirror, which in turn reflected it back to a fixed observer.

Whilst the light travelled to the fixed mirror and back, the rotating mirror rotated through an angle, θ. By measuring the angle, θ and with a known angular velocity, ω of the mirror, Foucault was able to calculate a value for the speed of light.



What would be the easiest adjustment to make to the experimental design to reduce the uncertainty in the measured value of the speed of light?

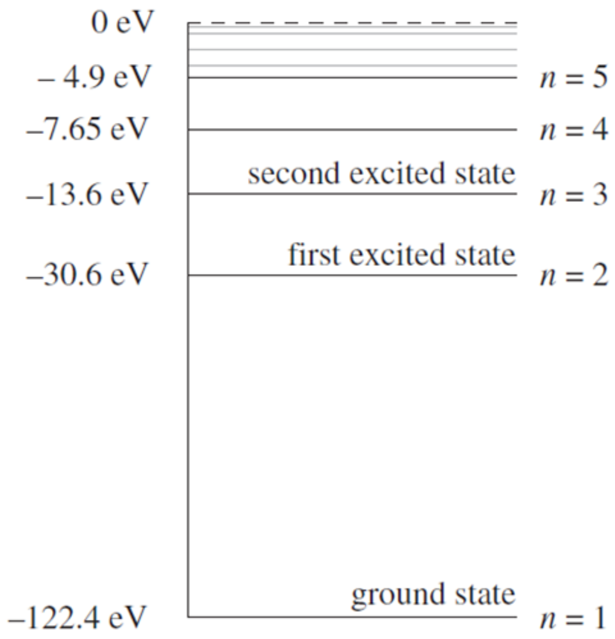
A. Increase the distance between the mirrors.

B. Decrease the distance between the mirrors.

C. Increase the rotational velocity of the rotating mirror.

D. Decrease the rotational velocity of the rotating mirror.

19. The energy level diagram for a particular element is shown below.



Which of the following is inconsistent with the wavelength of a photon emitted from an atom of the element during an electron transition?

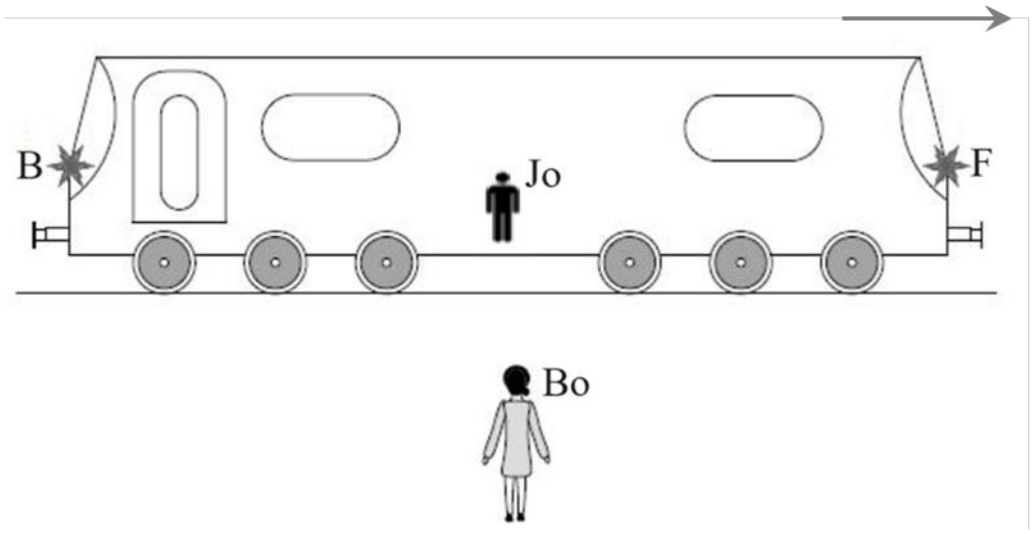
A. 48.3 nm

B. 66.4 nm

C. 72.6 nm

D. 169.0 nm

20. Jo is in the centre of a train carriage travelling close to the speed of light to the right. Lamps F and B located at the front and back of the train respectively are switched on simultaneously as Jo passes an observer Bo who is on the platform equidistant from the lamps when the light is emitted.



According to Bo, which of the following statements is correct in terms of the perceived arrival times of the flashes of light?

A. The lights turn on simultaneously for Jo.

B. The lights turn on simultaneously for Bo.

C. The light at the back turns on before the light at the front for Jo.

D. The light at the front turns on before the light at the back for Bo.

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James Ruse Agricultural High School

Please write your student number NEATLY in the boxes.

Mark

JRAHS Physics Trial 2024

Section I Multiple Choice Answers

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

Section II

80 marks
Attempt Questions 21-35
Allow about 2 hours and 25 minutes for this section.

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.

Extra writing space is provided at the back of this booklet. If you use this space, clearly indicate which question you are answering.

Question 21 (4 marks)

Artificial satellites monitor weather conditions on Earth and are used for surveillance and communications. Such satellites may be placed in a geostationary orbit.

(a) Identify TWO features of a geostationary orbit. **2**

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(b) Explain what happens to the speed of a satellite when it moves to a lower orbit. **2**

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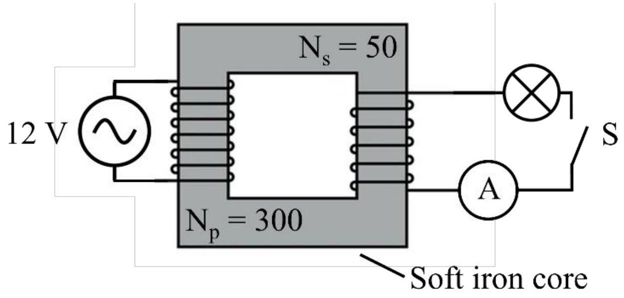
Question 22 (5 marks)

Consider the model of an ideal transformer shown below:



(a) When the switch S is closed, the ammeter reads 0.23 A. **3**

Calculate the power dissipated in the light bulb.

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(b) Explain ONE way in which the model could be improved to more closely approximate an ideal transformer. **2**

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Question 23 (7 marks)

A stationary nucleus of uranium-232 decays into thorium-228 by means of alpha decay. The nuclear masses of each are given below:

Isotope	*Mass (u)*
uranium-232	232.0317
thorium-228	228.0287
helium-4	4.0026

(a) Calculate the energy released in this decay in MeV. **2**

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(b) Calculate the ratio of kinetic energy of the alpha particle to the kinetic energy of the thorium nucleus. **3**

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(c) Explain why the uranium-232 nucleus decays by emitting an alpha particle instead of 2 individual neutrons and 2 individual protons. **2**

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Question 24 (3 marks)

Explain why the period of a satellite in orbit around the Earth cannot be less than 85 minutes. **3**
Include a calculation to support your response.

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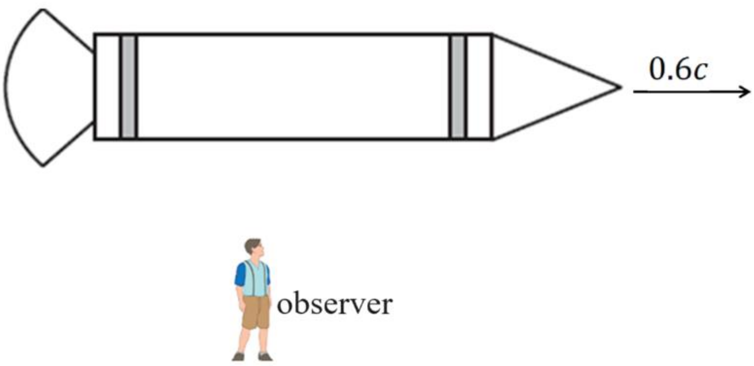
Question 25 (2 marks)

A spacecraft travels at a uniform speed of $0.6c$ within the Earth's gravitational field.
An observer on the ground measures the length of the spacecraft to be 80 m.



Calculate the length of the spacecraft as measured by the astronaut on board. **2**

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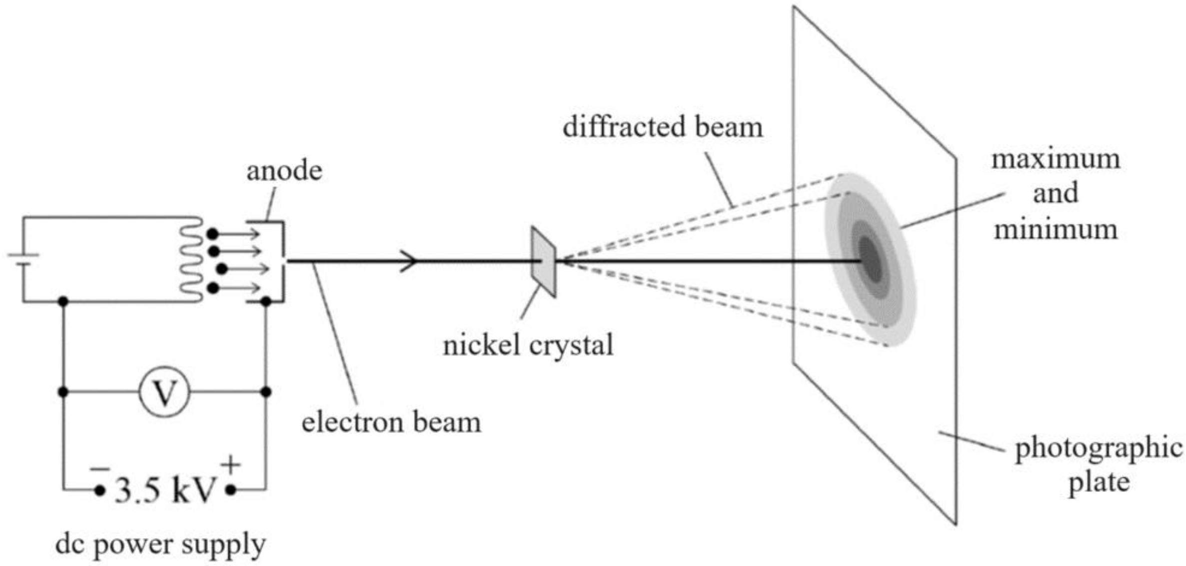
Question 26 (6 marks)

The figure shows part of the apparatus used to investigate de Broglie's matter waves.

Electrons were accelerated through a potential difference to form a beam which was then incident on a thin nickel crystal.

Regions of maximum and minimum intensity were formed on a photographic film behind the crystal.



(a) Show that the de Broglie wavelength of the electrons are given by **3**

$$\lambda = \frac{h}{\sqrt{2mqV}}$$

where V is the voltage of the power supply, m and q the mass and charge of the electron respectively.

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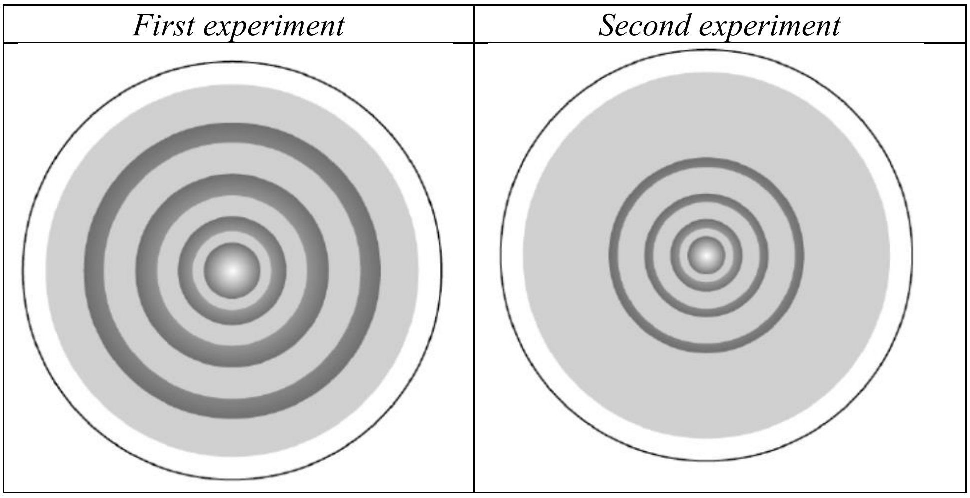
Question 26 continues on page 21

Question 26 (continued)

(b) Determine whether the voltmeter reading of 3.5 kV is consistent with a de Broglie wavelength of about 0.02 nm for the electrons in the beam. **1**

(c) The experiment is repeated using a similar arrangement to that shown above. The diagram below compares the result of the two experiments. **2**

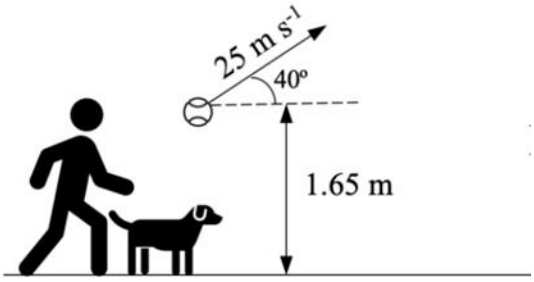


State and explain one independent change that could be made to the arrangement of the first experiment to produce the results shown for the second experiment.

End of Question 26

Question 27 (6 marks)

A person launches a ball upward at a 40º angle with an initial velocity of 25 ms^{-1} from a height of 1.65 meters above the ground.



(a) Calculate the time it takes for the ball to return to the initial height from which it was launched. **2**

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(b) Simultaneously, a dog, initially at rest beside the person, starts running in the same direction as the ball's path with a constant acceleration. **4**

Determine the dog's acceleration if the dog pounces on the ball precisely when it lands on the ground.

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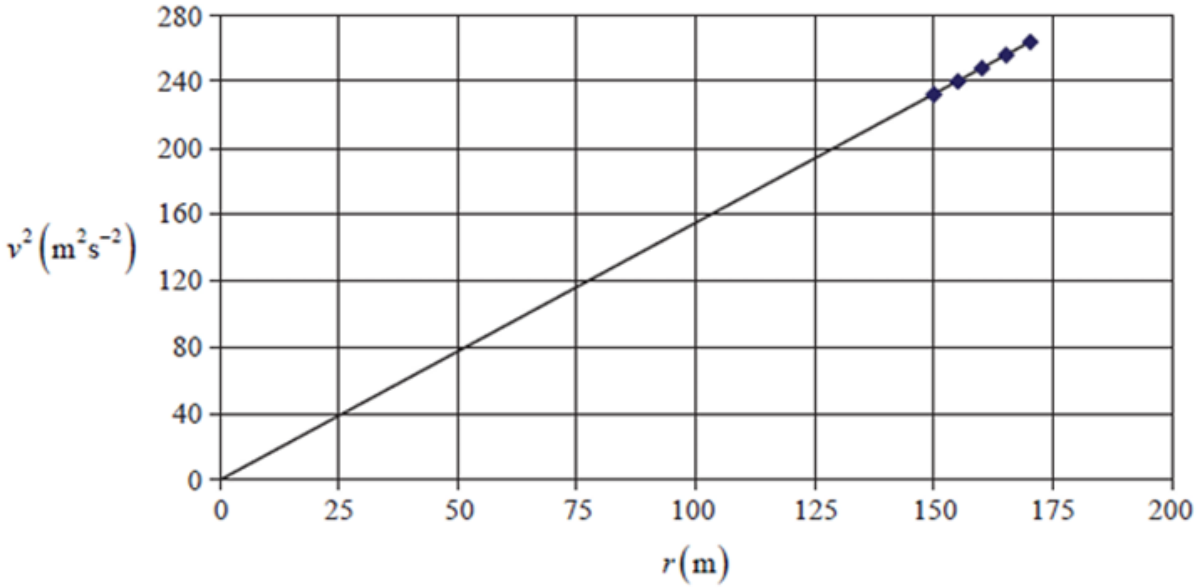
Question 28 (3 marks)

A motor-racing track has banked quarter-circle turns. Racing cars travel around the turns at different radii and speeds. Data are collected when the centripetal acceleration is not caused by the frictional force on the tyres. The graph below shows the data collected.



Using the graph, calculate the banking angle of the turns. **3**

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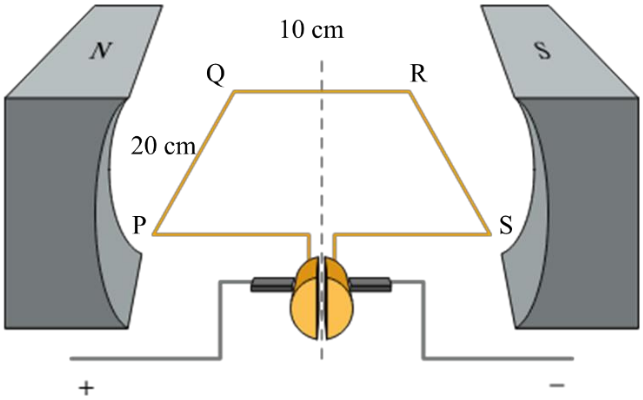
Question 29 (8 marks)

A student was investigating a DC motor with 50 turns of wire in the 20 cm × 10 cm horizontal rectangular coil PQRS by applying a vertical force to one of the sides of the coil to stop the motor from turning.



(a) Annotate the diagram to indicate where this force could be applied. **1**

The student varied the current and measured the force required to keep the coil stationary, as shown below:

Current (A)	Force (N)
0.5	0.011
1.0	0.026
2.0	0.047
3.0	0.068
4.0	0.097

(b) Graph the data on the axes on page 25. **4**

Question 29 continues on page 25

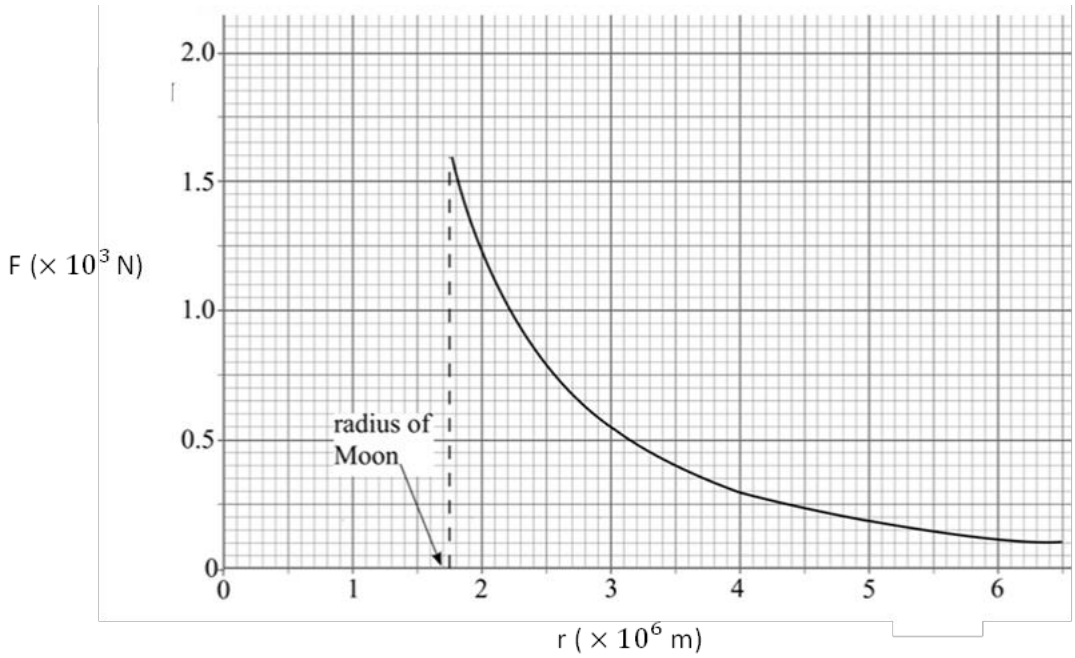
Question 29 (continued)

(c) Use the graph to calculate the strength of the magnetic field. **3**

End of Question 29

Question 30 (4 marks)

The graph shows how the gravitational force F between a 1000 kg mass and the Moon varies with the distance r from the Moon's centre for points above its surface.



(a) Use data from the graph to determine the mass of the Moon. **2**

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(b) Calculate the speed at which the 1000 kg mass should be thrown vertically upwards from the surface of the Moon if it is to escape from the Moon's gravitational field. **2**

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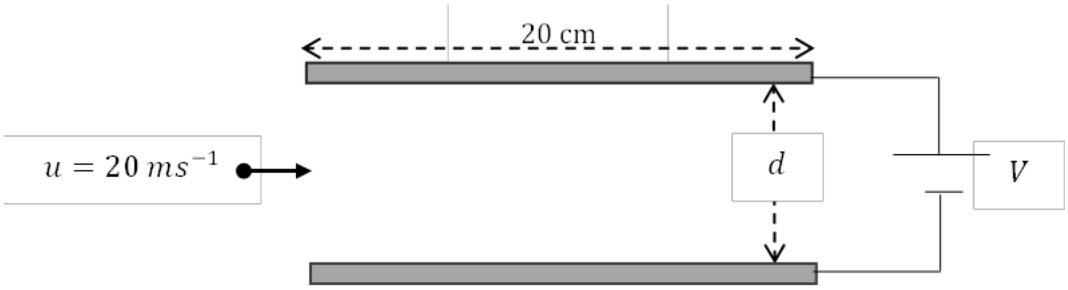
Question 31 (5 marks)

An inkjet printer operates by accelerating charged droplets of ink onto the printer paper. The ink drops are deflected by two plates across which a voltage is applied.



An ink drop of mass $m = 2.0 \times 10^{-10}$ kg and charge $q = 1.0 \times 10^{-13}$ C passes through two plates with an initial horizontal velocity, $u = 20$ m s^{-1}. The plates, a distance $d = 5$ mm apart, are connected to a DC voltage source, $V = 10\ 000$ V.

Ignore the effects of gravity.

(a) Show that the vertical acceleration of the ink drop is given by $a = \frac{Vq}{md}$. **2**

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(b) Find the vertical deflection of the ink drop. **3**

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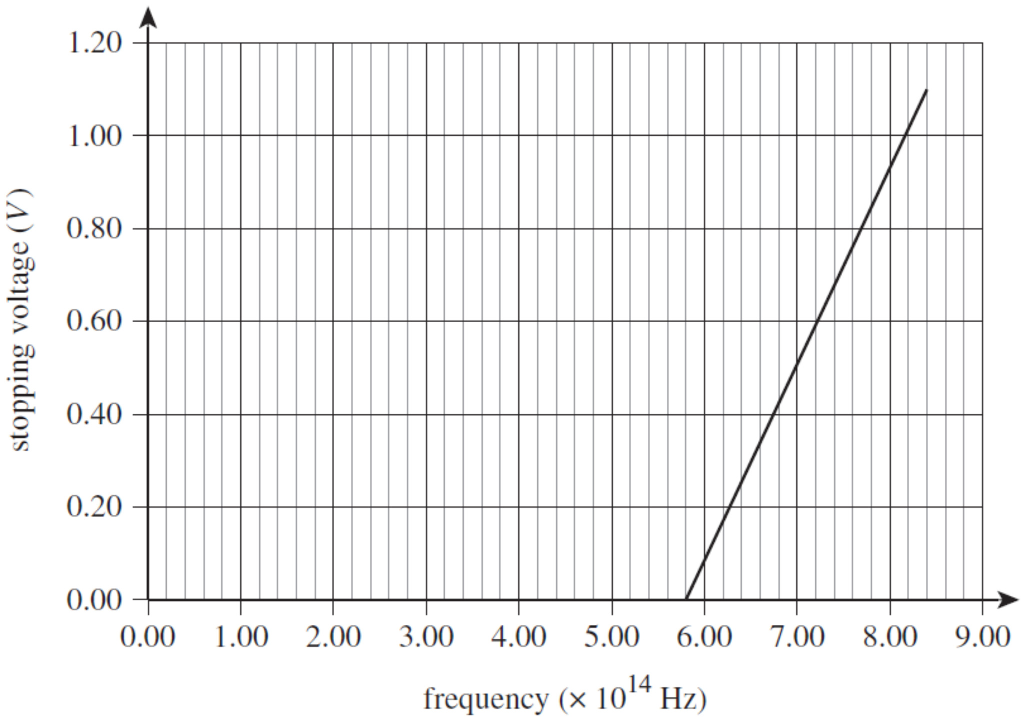
Question 32 (6 marks)

In an experiment involving the photoelectric effect, the results for the stopping voltage versus the light frequency for a particular metal is shown below.



(a) Determine the stopping voltage needed if light of frequency 1.20×10^{15} Hz is used. **3**

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Question 32 continues on page 29

Question 32 (continued)

(b) On the axes provided on page 28, sketch the graph of the results if a metal whose work function of 1.95 eV is used instead. **3**

Any relevant calculations used to assist in sketching should be shown below.

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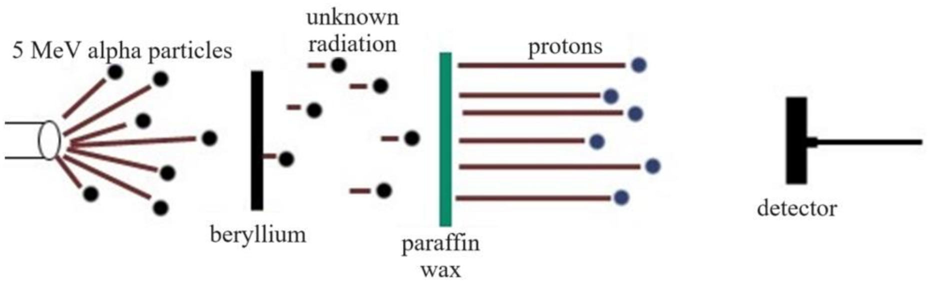
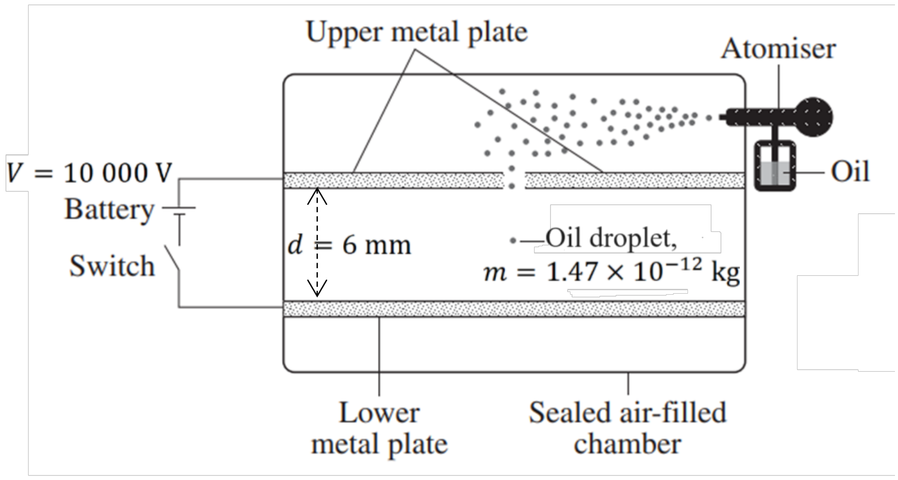
End of Question 32

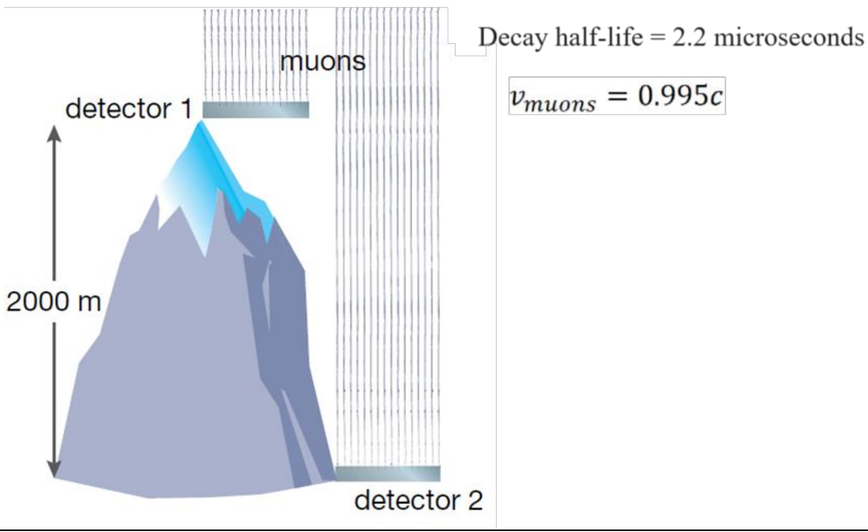
Question 33 (9 marks)

Experiments conducted by Millikan and Chadwick as well as cosmic-origin muons played a pivotal role in our understanding of the structure of matter and the laws of physics.

<table>
<tr><th>Experimental setup</th><th>Data</th></tr>
<tr><td>
</td><td>Energy of alpha particles = 5 MeV</td></tr>
<tr><td>
</td><td>$V = 10\ 000$ V

$m = 1.47 \times 10^{-12}$ kg

Distance between plates, $d = 6$ mm

Oil droplet balanced between the plates</td></tr>
<tr><td>
</td><td>$t_{\frac{1}{2}} = 2.2\ \mu s$

$v_\mu = 0.995c$</td></tr>
</table>

Question 33 continues on page 31

Question 33 (continued)

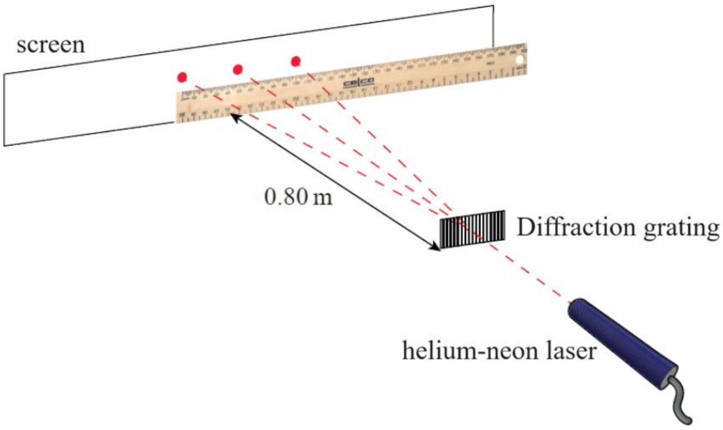
Using the three stimuli provided, show how these three particles improved our understanding of the structure of matter and the laws of physics. **9**

Include a significant calculation for at least two of the three stimuli provided.

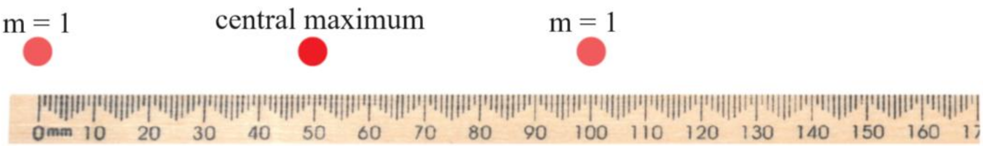
End of Question 33

Question 34 (5 marks)

A student undertook an experiment to investigate diffraction using a helium-neon laser and a diffraction grating containing 100 lines per mm, positioned 0.80 m from a screen.



The image below shows the distances between the central maximum and the first orders of the diffraction pattern that was observed on the screen.



drawn to scale

(a) Calculate the wavelength of the helium-neon laser. **3**

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(b) Given that the range of the visible spectrum is 400 nm to 700 nm, predict how the distances between the central maximum and subsequent maxima will be affected if blue laser light is used in the above investigation. **2**

Justify your answer.

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Question 35 (7 marks)

A particle P, of mass $2m$ and charge $+q$, is injected into an evacuated glass chamber with an initial velocity of v. The particle experiences a uniform magnetic field perpendicular to the direction of motion and a uniform gravitational field directed downwards. Particle P travels through the tube in a straight horizontal path until it reaches X, as shown in Figure 1.

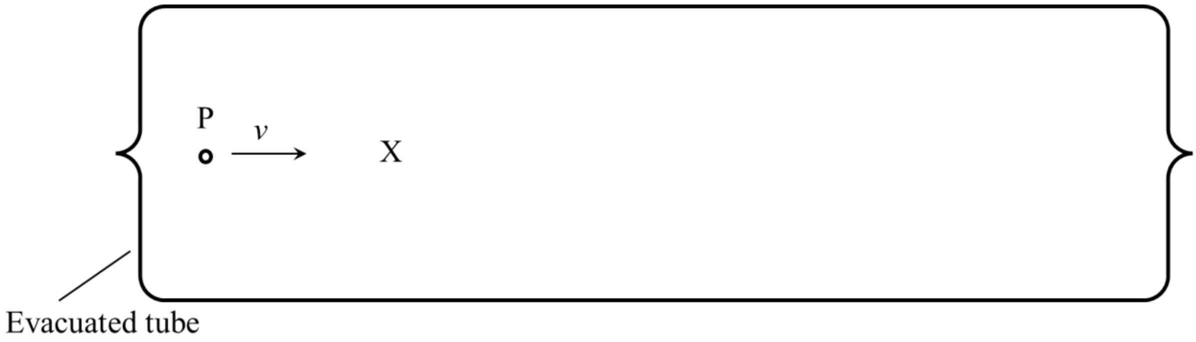

Figure 1

Particle P has a fine crack in it and when it reaches X, it breaks into two fragments Q and R, as shown in Figure 2. The upper fragment, Q has mass m, and charge $+q$, and the lower fragment R, also has mass m but is uncharged. The breaking process is elastic and momentum is conserved during the breaking process.

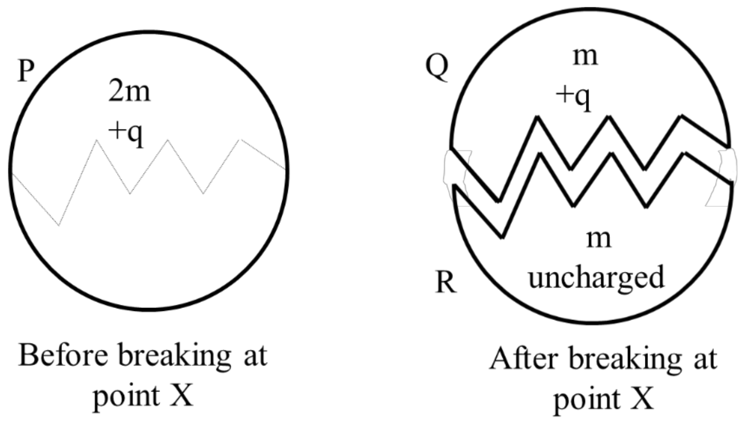

Figure 2

Question 35 continues on page 35

Question 35 (continued)

Account for the trajectories of the initial particle P and its fragment R and discuss factors that affect the trajectory of fragment Q. **7**

Support your answer with mathematical models, relevant laws of physics and diagrams.

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End of Exam

Part B extra writing space
If you use this space, clearly indicate which question you are answering here AND on your paper.

James Ruse Agricultural High School

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2024

HIGHER SCHOOL CERTIFICATE TRIAL EXAMINATION

Physics

General Instructions	• Reading time – 5 minutes • Working time – 3 hours • Write using black pen • Draw diagrams using pencil • NESA approved calculators and equipment may be used • A formula sheet and data sheet and Periodic Table are provided. • For questions in Section II, **show all relevant working** in questions involving calculations.
Total marks 100	**Section I -20 marks** (pages 2-13) • Attempt Questions 1– 20 • Allow about 35 minutes for this part **Section II -80 marks** (pages 16-36) • Attempt Questions 21–35 • Allow about 2 hours and 25 minutes for this part

This paper MUST NOT be removed from the examination room.

Section I

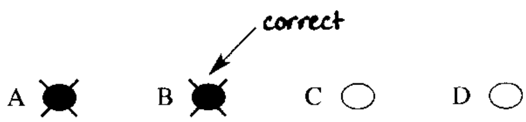
20 marks
Attempt Questions 1-20
Allow about 35 minutes for this section.
Mark your answers on the ANSWER grid in the Answer booklet on page 15.

Select the alternative A, B, C or D that best answers the question. Fill in the response oval completely.

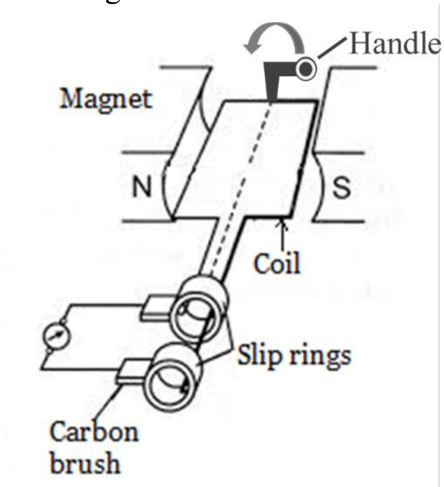
Sample: 2 + 4 = (A) 2 (B) 6 (C) 8 (D) 9

If you think you have made a mistake, put a cross through the incorrect answer and fill in the new answer.

If you change your mind and have crossed out what you consider to be the correct answer, then indicate the correct answer by writing the word *correct* and drawing an arrow as follows.



1. What is the name of the following device?



A. DC motor

B. DC generator

C. AC generator

D. AC induction motor

2. An object is moving in a horizontal circle on a string with a constant angular velocity ω. The tension in the string, which is approximately horizontal, is F. If ω is doubled while all the other quantities are kept constant, what will the tension in the string become?

A. 4F

B. 2F

C. F/2

D. F/4

3. If an astronaut orbiting the Earth near its surface were to stand on a set of bathroom scales, why would there be a reading of zero?

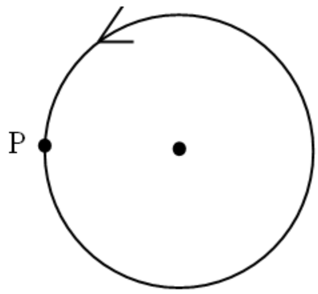
A. The astronaut's mass becomes zero.

B. The strength of the gravitational field is zero.

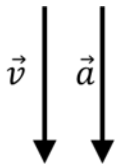
C. The pull of the Earth is balanced by the pull of the Moon.

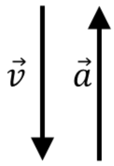
D. The astronaut falls towards the Earth at the same rate as the space capsule.

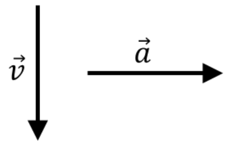
4. An object is executing uniform circular motion, as shown in the figure below.

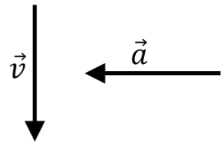


At position P, which of the following shows the directions of instantaneous velocity and acceleration?

A. 

B. 

C. 

D. 

5. Iodine–131 is a radioisotope used in nuclear medicine. It has a half-life of 8 hours and eventually becomes a stable isotope Xenon-131 according to the following equation:

$$^{131}_{53}\mathrm{I} \rightarrow {}^{131}_{54}\mathrm{Xe} + \gamma$$

24.0 mg of Iodine–131 is injected in the body of a patient.

How many milligrams of Xenon-131, produced as a result of this reaction, is present in the body after 16 hours?

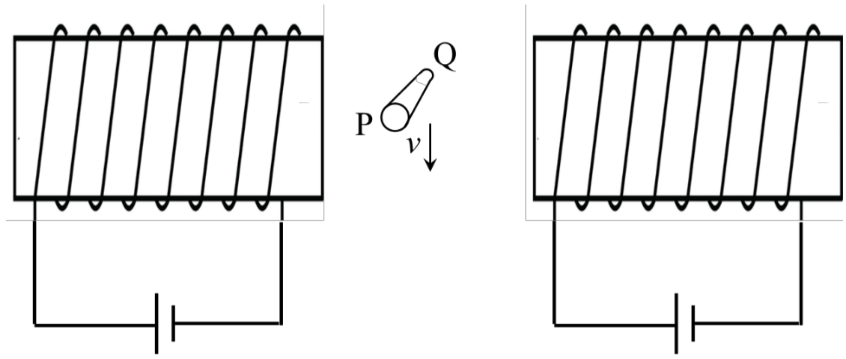
A. 6.0

B. 12.0

C. 18.0

D. 24.0

6. A horizontal metal cylinder PQ, perpendicular to the page, moves down between two solenoids, as shown below:



Which of the following correctly show the direction of the magnetic field between the solenoids and the charge at P?

	Direction of magnetic field	*Charge at P*
A.	left	positive
B.	left	negative
C.	right	positive
D.	right	negative

7. A radioactive isotope decays by alpha and beta particle emission. Over a number of decays, the nucleon number decreases by 4 while the proton number is unchanged.

How many alpha and beta particles have been emitted?

A. 2 alpha particles and 1 beta particle

B. 1 alpha particle and 2 beta particles

C. 1 alpha particle and 1 beta particle

D. 2 alpha particles and 2 beta particles

8. Two students are discussing the advantages of magnetic brakes.

Student A says that because the magnetic force is proportional to velocity they provide a smoother braking action.

Student B says that because magnetic fields do no work, the brakes produce no heat.

Which of the students, if any, is/are correct?

A. Student A only

B. Student B only

C. Both student A and student B

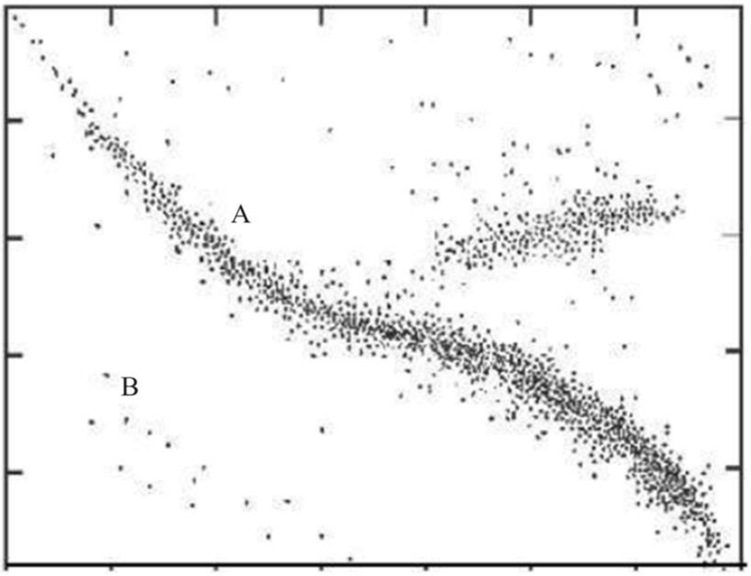
D. Neither student A nor student B

9. Control rods and moderators play a key role in controlling the rate of fission in nuclear reactors.

Which row of the table correctly shows how this is achieved?

	Control Rod	*Moderator*
A.	By absorbing neutrons.	By slowing down fast neutrons to thermal speeds.
B.	By absorbing neutrons.	By speeding up slow neutrons so that a chain reaction is sustainable
C.	By increasing the capture cross-section of neutrons.	By speeding up slow neutrons so that a chain reaction is sustainable
D.	By increasing the capture cross-section of neutrons.	By slowing down fast neutrons to thermal speeds.

10. This is a Hertzsprung-Russell (H-R) diagram showing many star plots. The axes are not labelled.



Which of the following statements is true of the luminosity and temperature of stars A and B?

A. The luminosity of star A is lower while the temperature of star B is higher.

B. The luminosity of star A is lower while the temperature of star B is lower.

C. The luminosity of star A is higher while the temperature of star B is higher.

D. The luminosity of star A is higher while the temperature of star B is lower.

11. At what angle, θ should two polaroid sheets be placed to reduce the intensity by ninety percent?

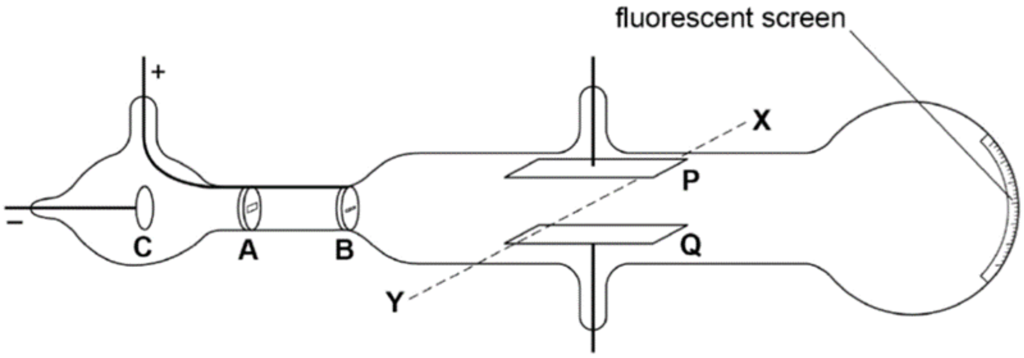
A. $\theta = \cos^{-1}\sqrt{0.8}$

B. $\theta = \cos^{-1}\sqrt{0.2}$

C. $\theta = \cos^{-1}\sqrt{0.9}$

D. $\theta = \cos^{-1}\sqrt{0.1}$

12. The diagram shows a discharge tube used by Thomson to investigate cathode rays. When the connections are made to a high voltage power supply, cathode rays are produced at C and accelerated across AB and through parallel plates P and Q, connected to a second power supply, with P positively charged. The rays then hit the centre of the fluorescent screen, when a magnetic field is positioned (in the XY direction) between the plates P and Q.



Which row of the table shows the aim of this experiment and the correct direction of the applied magnetic field?

	Aim of the experiment	*Direction of magnetic field*
A.	To determine the charge of the electron	From X to Y
B.	To determine the charge of the electron	From Y to X
C.	To determine the charge to mass ratio of the electron	From X to Y
D.	To determine the charge to mass ratio of the electron	From Y to X

13. Two satellites orbit a planet. One of the satellites has an orbital radius of 2.3×10^6 m and a period of 7.6×10^4 s. The other satellite has an orbital period of 1.3×10^5 s. What is the orbital radius of this second satellite?

A. 1.3×10^6 m

B. 3.3×10^6 m

C. 3.9×10^6 m

D. 5.1×10^6 m

14. A 500 kg satellite is initially in a circular orbit with a radius of 10 000 km around the Earth. The satellite is then moved to a new circular orbit with a radius of 20 000 km.

What is the change in the gravitational potential energy of the satellite?

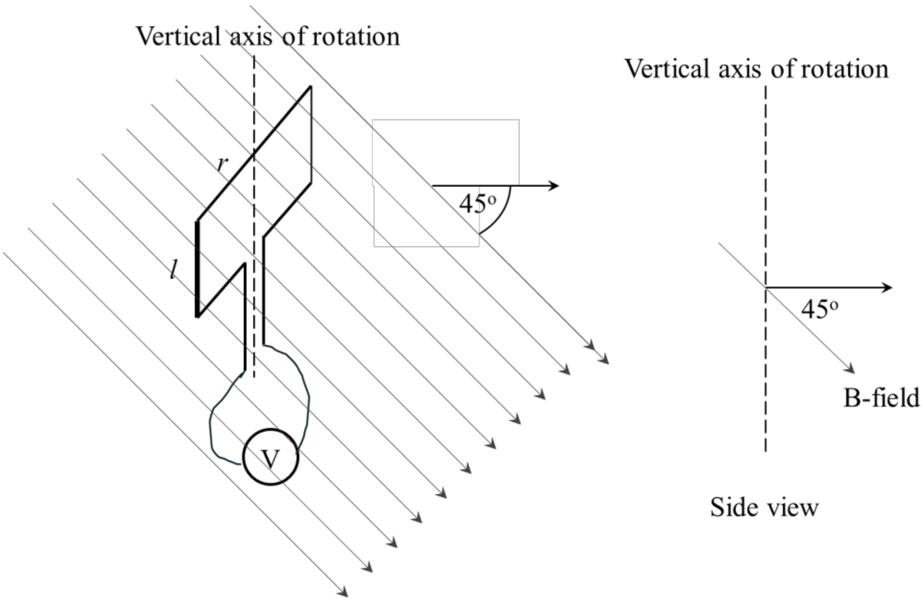
A. 1.5×10^3 J

B. 1.5×10^9 J

C. 1.0×10^{10} J

D. 1.0×10^{13} J

15. A coil of wire is rotating about a vertical axis in a magnetic field that is directed 45° below the horizontal:



Which set of changes will result in the largest reading on the voltmeter?

A. Double *r* and halve *l*.

B. Increase both *l* and *r* by 50 %.

C. Rotate the magnetic field to vertical and double *r*.

D. Rotate the magnetic field to horizontal and double *l*.

16. Two stars, A and B, are equally bright as seen from the Earth. Stars A and B are 10 and 15 parsecs away from Earth respectively. One parsec = 3.26 light years.

Which of the following statements about the luminosities of stars A and B (L_A and L_B) are correct?

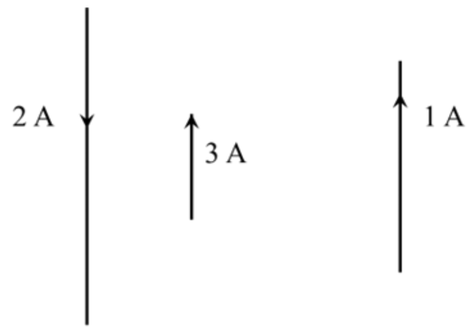
A. $L_A = \frac{3}{2} L_B$

B. $L_A = \frac{2}{3} L_B$

C. $L_A = \frac{4}{9} L_B$

D. $L_A = \frac{9}{4} L_B$

17. Three wires carry currents, as shown in the following scale diagram.



How many of the wires experience a net force to the left?

A. 0

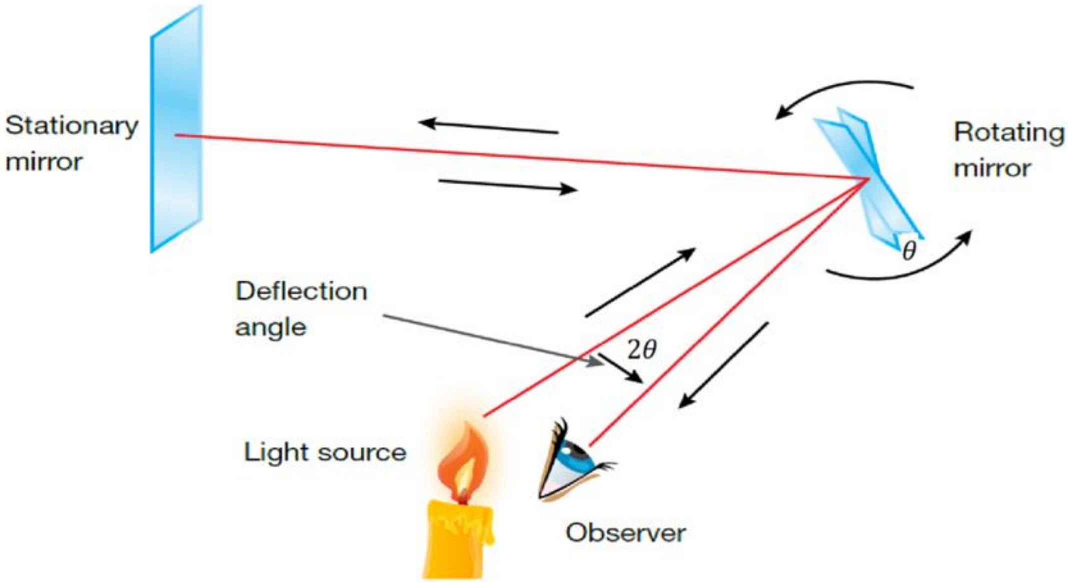
B. 1

C. 2

D. 3

18. Foucault measured the speed of light by focusing light onto a rotating mirror, which reflected it onto a stationary mirror, which in turn reflected it back to a fixed observer.

Whilst the light travelled to the fixed mirror and back, the rotating mirror rotated through an angle, θ. By measuring the angle, θ and with a known angular velocity, ω of the mirror, Foucault was able to calculate a value for the speed of light.



What would be the easiest adjustment to make to the experimental design to reduce the uncertainty in the measured value of the speed of light?

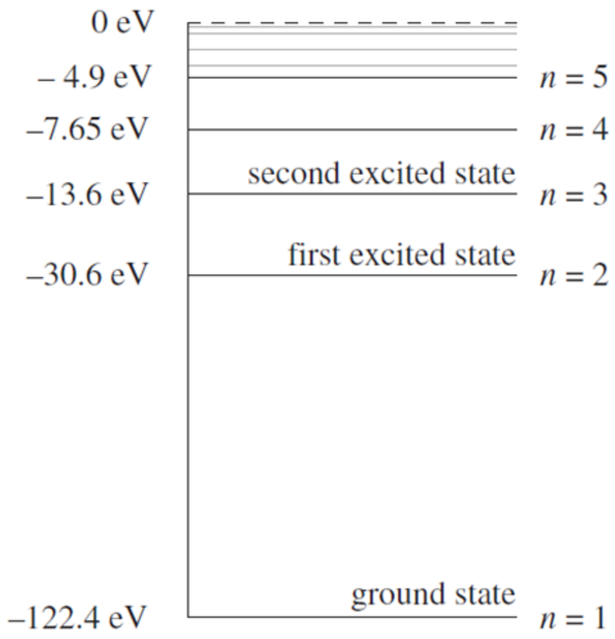
A. Increase the distance between the mirrors.

B. Decrease the distance between the mirrors.

C. Increase the rotational velocity of the rotating mirror.

D. Decrease the rotational velocity of the rotating mirror.

19. The energy level diagram for a particular element is shown below.



Which of the following is inconsistent with the wavelength of a photon emitted from an atom of the element during an electron transition?

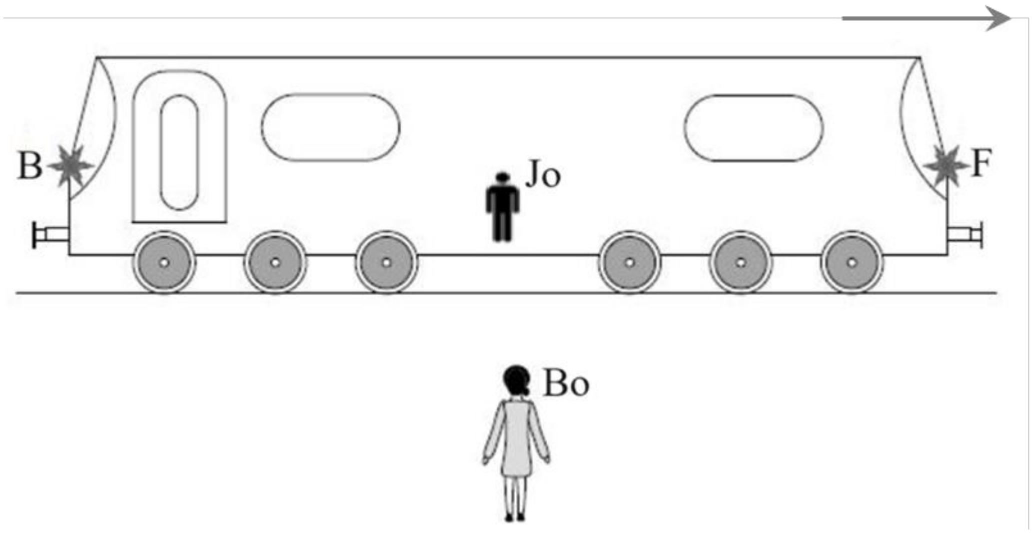
A. 48.3 nm

B. 66.4 nm

C. 72.6 nm

D. 169.0 nm

20. Jo is in the centre of a train carriage travelling close to the speed of light to the right. Lamps F and B located at the front and back of the train respectively are switched on simultaneously as Jo passes an observer Bo who is on the platform equidistant from the lamps when the light is emitted.



According to Bo, which of the following statements is correct in terms of the perceived arrival times of the flashes of light?

A. The lights turn on simultaneously for Jo.

B. The lights turn on simultaneously for Bo.

C. The light at the back turns on before the light at the front for Jo.

D. The light at the front turns on before the light at the back for Bo.

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Please write your student number NEATLY in the boxes.

Mark

JRAHS Physics Trial 2024

Section I Multiple Choice Answers

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

Section II

80 marks
Attempt Questions 21-35
Allow about 2 hours and 25 minutes for this section.

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.

Extra writing space is provided at the back of this booklet. If you use this space, clearly indicate which question you are answering.

Question 21 (4 marks)

Artificial satellites monitor weather conditions on Earth and are used for surveillance and communications. Such satellites may be placed in a geostationary orbit.

(a) Identify TWO features of a geostationary orbit. **2**

- Orbits westwards over the equator and maintain a fixed position relative to the surface of Earth.
- Period is 24 hours.

Criteria	Marks
Any two relevant properties of the geostationary orbit	2
One property of the geostationary orbit	1

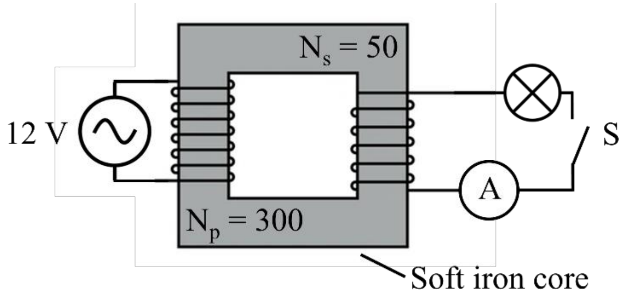
(b) Explain what happens to the speed of a satellite when it moves to a lower orbit. **2**

The satellite must travel faster to stop it from falling inwards when gravitational force increases.

Criteria	Marks
Correct explanation with cause-effect relationship	2
Any relevant information	1

Question 22 (5 marks)

Consider the model of an ideal transformer shown below:



(a) When the switch S is closed, the ammeter reads 0.23 A. **3**

Calculate the power dissipated in the light bulb.

Marking criteria	*Marks*
Correctly calculates voltage in secondary circuit Correctly calculates power dissipated Gives appropriate units for power	3
Two of the above	2
Some relevant information	1

$N_s/N_p = V_s/V_p$
$50/300 = V_s/12$
$V_s = 2$ V
$P=VI = 2 * 0.23 = 0.46$ W

Marking comments: this question was generally well done.

(b) Explain ONE way in which the model could be improved to more closely approximate an ideal transformer. **2**

Marking criteria	*Marks*
Provides detailed improvement to transformer Uses cause and effect statement linking change to ideal transformer	2
One of the above	1

Sample answer: The transformer could have its soft iron core laminated, with sheets of insulating material alternating with sheets of soft iron in the plane of the page shown. This will reduce the size of eddy currents induced by the changing B field, and so reduce energy losses through heating, bringing it closer to $P_{in} = P_{out}$.

Answer could also include thicker wires, toroidal core.

Marking comments: some students proposed changes that were vague, such as "laminate the transformer", without indicating which part would be laminated.

Question 23 (7 marks)

A stationary nucleus of uranium-232 decays into thorium-228 by means of alpha decay. The nuclear masses of each are given below:

Isotope	*Mass (u)*
uranium-232	232.0317
thorium-228	228.0287
helium-4	4.0026

(a) Calculate the energy released in this decay in MeV. **2**

Marking Criteria	Mark
Calculates the energy released	2
Provides some relevant information	1

Sample answer:

$$E = \Delta mc^2$$

$$= (232.0317 - 228.0287 - 4.0026) \times \frac{931.5\ MeV}{c^2} \times c^2$$

$$= 0.3726\ MeV$$

Comment:

Once again, many students were not aware that when masses are given in atomic mass units (u), then simply multiplying the mass defect by 931.5, the energy released comes out in MeV.

(b) Calculate the ratio of kinetic energy of the alpha particle to the kinetic energy of the thorium nucleus. **3**

Marking Criteria	Mark
Calculates the ratio of the kinetic energies	3
Provides substantial working to calculate the ratio of the kinetic energies	2
Provides one correct step in calculation	1

Sample answer:

Method 1:
Since momentum is conserved in this decay process,

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

$$K \propto \frac{1}{m}$$

Thus

$$\frac{K_\alpha}{K_{Th}} = \frac{m_{Th}}{m_\alpha}$$

$$\sim \frac{228}{4}$$

$$= 57:1$$

Method 2:

Conservation of momentum: $m_{Th}v_{Th} = m_\alpha v_\alpha$

$$\frac{v_{Th}}{v_\alpha} = \frac{m_\alpha}{m_{Th}}$$

$$\frac{K_\alpha}{K_{Th}} = \frac{\frac{1}{2}m_\alpha v_\alpha^2}{\frac{1}{2}m_{TH}v_{Th}^2}$$

$$= \frac{m_\alpha}{m_{Th}}\left(\frac{v_\alpha}{v_{Th}}\right)^2$$

$$= \frac{m_\alpha}{m_{Th}}\left(\frac{m_{Th}}{m_\alpha}\right)^2$$

$$= \frac{m_{Th}}{m_\alpha}$$

$$= \frac{228.0287}{4.0027}$$

$$\sim 57:1$$

Comment:

A large majority of the candidature assumed the speeds of the Helium nucleus and the Thorium nuclide are the same (maximum mark if this was the case was 1). Many students did not realise that the lighter nucleus goes off with a larger speed due its smaller mass, and hence goes off with a larger kinetic energy.

(c) Explain why the uranium-232 nucleus decays by emitting an alpha particle instead of 2 individual neutrons and 2 individual protons. **2**

Marking Criteria	Mark
Explains why the uranium nucleus emits an alpha particle	2
Provides some relevant information	1

Sample Answer:

Alpha decay occurs in unstable nuclei (having large neutron to proton ratios), producing daughter nuclei that are energetically more stable than the parent nucleus. The strong nuclear force between nucleons in the helium nucleus is responsible for its stability. The large electrostatic force between the protons in the parent nucleus is reduced by the emission of an alpha particle.

Comment:
The binding energy per nucleon is also another measure of stability. As can be seen on the BE/N curve, helium has a high BE/N while that of the neutron and proton are zero.

Question 24 (3 marks)

Explain why the period of a satellite in orbit around the Earth cannot be less than 85 minutes. Include a calculation to support your response. **3**

$$Let\ h = 0\ (limiting\ case)$$

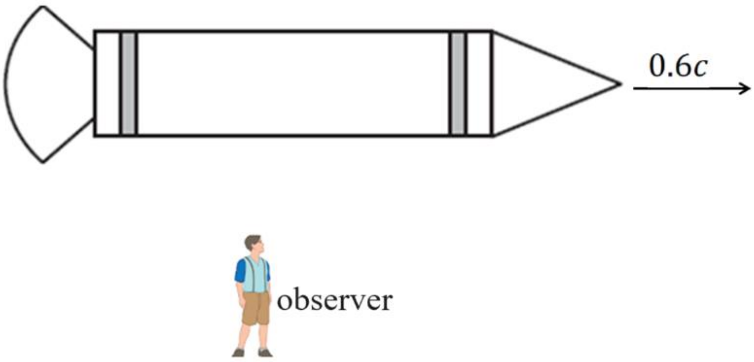
$$T^2 = \frac{4\pi^2 R^3}{GM} = 50905 = 85\ mins$$

Criteria	**Marks**

Correct explanation supported by one calculation.	3
Calculations or explanation	2
Any relevant information	1

Question 25 (2 marks)

A spacecraft travels at a uniform speed of $0.6c$ within the Earth's gravitational field. An observer on the ground measures the length of the spacecraft to be 80 m.



Calculate the length of the spacecraft as measured by the astronaut on board. **2**

Marking Criteria	Mark
Calculates the length of the spacecraft	2
Provides some relevant information	1

$$l = l_0\sqrt{1 - \frac{v^2}{c^2}}$$

$$80 = l_0\sqrt{1 - 0.6^2}$$

$$\therefore l_0 = 100\ m$$

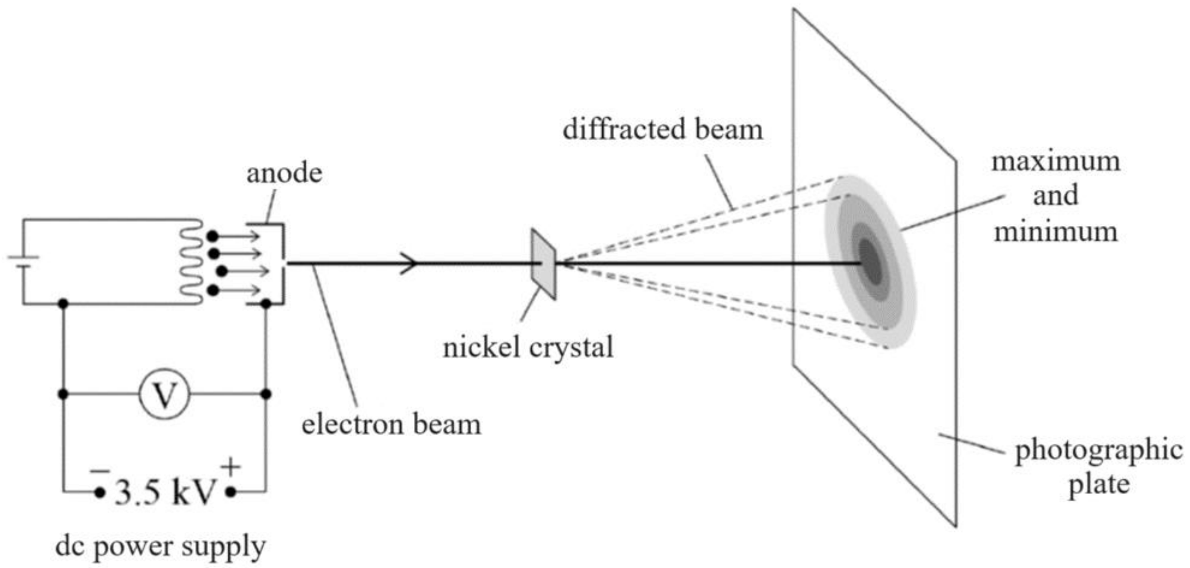
Comment:
Many students had difficulty with identifying the proper length of the spaceship. Five students scored zero, while almost 10 students scored 1, which was really disappointing considering the low level of the question.

Question 26 (6 marks)

The figure shows part of the apparatus used to investigate de Broglie's matter waves.

Electrons were accelerated through a potential difference to form a beam which was then incident on a thin nickel crystal.

Regions of maximum and minimum intensity were formed on a photographic film behind the crystal.



(a) Show that the de Broglie wavelength of the electrons are given by **3**

$$\lambda = \frac{h}{\sqrt{2mqV}}$$

where V is the voltage of the power supply, m and q the mass and charge of the electron respectively.

Marking Criteria	Mark
Correctly derives the required equation	3
Shows substantial working towards the derivation	2
Provides some relevant information	1

Sample answer:

$$W = qV = \Delta K$$

$$eV = \frac{1}{2}mv^2 - \frac{1}{2}mu^2$$

$$v = \sqrt{\frac{2eV}{m}}$$

But $$\lambda = \frac{h}{mv}$$

$$= \frac{h}{m\sqrt{\frac{2eV}{m}}}$$

$$= \frac{h}{\sqrt{2meV}}$$

Comment:

Students need to be reminded about the work energy theorem. The work done is not equal to kinetic energy, but rather the change in kinetic energy. Understandably, the question was vague in this regard, not mentioning explicitly that the electrons are accelerated from rest. Overall, the vast majority scored full marks here.

Question 26

(b) Determine whether the voltmeter reading of 3.5 kV is consistent with a de Broglie wavelength of about 0.02 nm for the electrons in the beam. **1**

Marking Criteria	Mark
Correctly determines the wavelength to be consistent	1

$$\lambda = \frac{h}{\sqrt{2meV}}$$

$$= \frac{6.626 \times 10^{-34}}{\sqrt{2 \times 9.109 \times 10^{-31} \times 1.602 \times 10^{-19} \times 3.5 \times 10^{3}}}$$

$$= 2.07 \times 10^{-11}$$

$$\sim 0.02\ nm$$

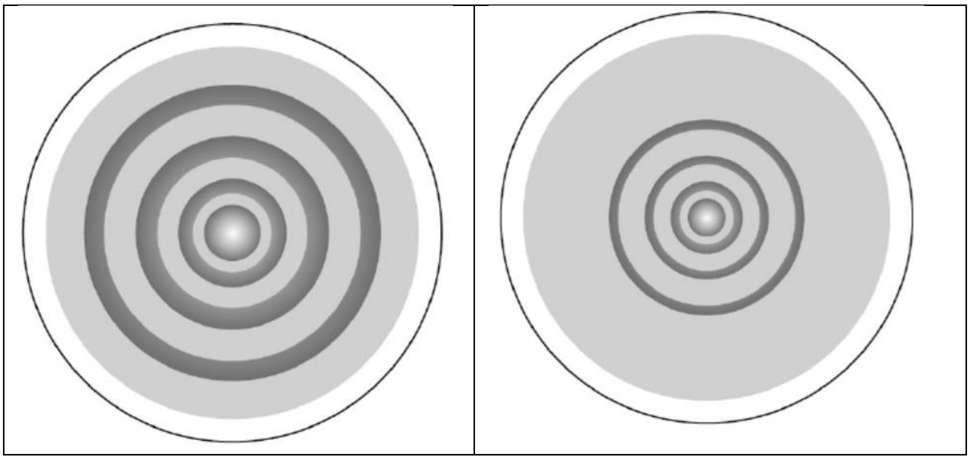
Hence 3.5 kV was sufficient to produce wavelength of about 0.02 nm.

Comment:

Some students used 0.02 nm and arrived at 3.76 kV, giving an uncertainty of about 7.4%, which was fine, while the uncertainty in the wavelength was about 3.5 %.

(c) The experiment is repeated using a similar arrangement to that shown above. The diagram below compares the result of the two experiments. **2**

First experiment	*Second experiment*



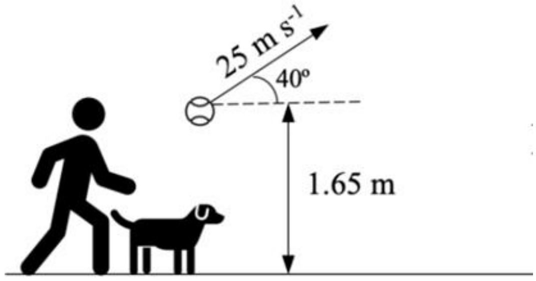
State and explain one independent change that could be made to the arrangement of the first experiment to produce the results shown for the second experiment.

Marking Criteria	Mark
Correctly provides and explains an independent change	2
Correctly provides an independent change or provides some relevant information	1

- Replace nickel target with target having greater spacing between atoms and from $d \sin\theta = m\lambda \rightarrow y = \frac{m\lambda L}{d}$ =fringe separation, is proportional to $\frac{1}{d}$. Hence smaller fringe separation is obtained.
- Increase voltage V, the wavelength will decrease, and thus the fringe separation will decrease using $\lambda = \frac{h}{\sqrt{2mqV}}$.
- Decrease distance between the nickel target and the photographic film since fringe separation is proportional to L.

Question 27 (6 marks)

A person launches a ball upward at a 40º angle with an initial velocity of 25 ms^{-1} from a height of 1.65 meters above the ground.



(a) Calculate the time it takes for the ball to return to the initial height from which it was launched. **2**

u_y=$u$sinθ

u_y=25sin40°=16.1 ms^{-1}

The vertical displacement s will be zero when the ball returns to its initial height.

$s_y = u_y t + \frac{1}{2} a_y t^2$

0=(16.1) t+12(−9.8) t^2

t=0 or $\frac{16.1}{4.9}$

t=3.28 seconds

Criteria	Marks
Using the correct formula. Determining the correct time.	2
Any relevant calculations.	1

(b) Simultaneously, a dog, initially at rest beside the person, starts running in the same direction as the ball's path with a constant acceleration. **4**

Determine the dog's acceleration if the dog pounces on the ball precisely when it lands on the ground.

The time taken by the dog to catch the ball is equivalent to the time the ball takes to reach the ground, which has a vertical displacement of—1.65 m.

$$v_y{}^2 = u_y{}^2 + 2as$$

$$v_y{}^2 = (16.1)2+2(-9.8)(-1.65)$$

$$v_y vy = \pm 17.0 \text{ m}s^{-1}$$

$vy = -17.0 \text{ m}s^{-1}$ (since the ball is travelling in a downward direction)

Calculating the time taken to reach this vertical displacement:

$v=u+at$

$-17.0=16.1+(-9.8)t$

t=3.38 seconds

Now, using this time and the ball's horizontal velocity to calculate horizontal displacement:

$\Delta x=u_x t$

Δx=(25cos40°)(3.38)

Δx=64.7 m from where it was thrown.

Finally, using time and horizontal displacement together to calculate the dog's acceleration:

$s=ut+12at^2$

64.7=(0)(3.38)+12a(3.38)2

a=2×64.7(3.38)2

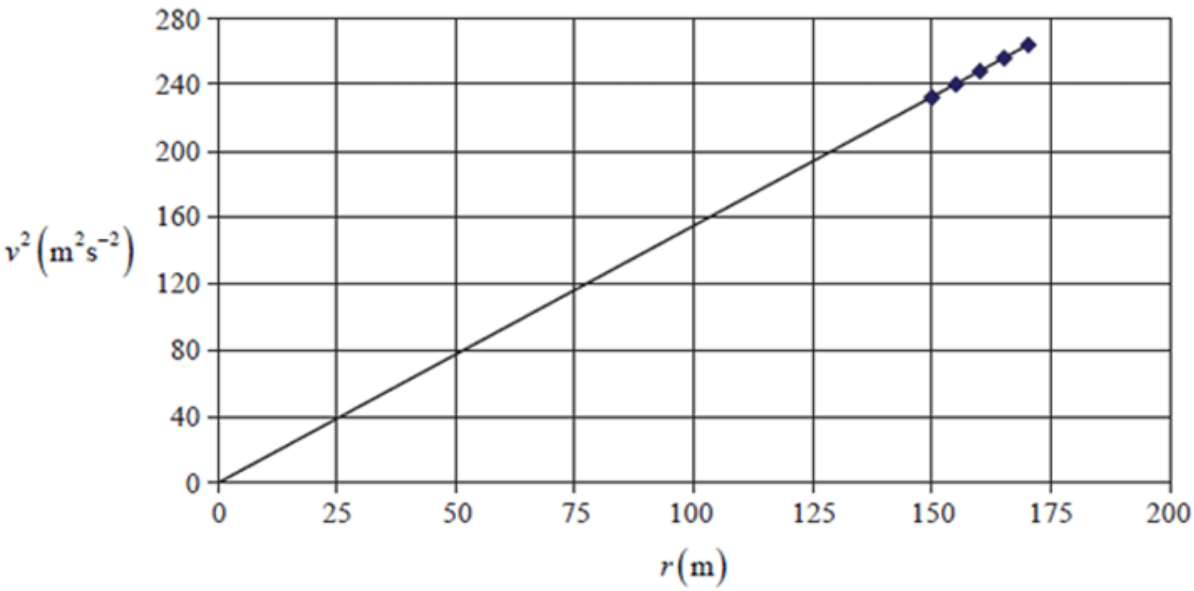
$a=11.3 \text{ m } s^{-2}$

Marking Criteria	**Marks**
Correct calculation of the time the ball takes to reach the ground. Correct calculation of the horizontal displacement of the ball when it lands on the ground. Correct calculation of the acceleration of the dog	4
Any relevant calculation for the time the ball takes to reach the ground.	3

Correct calculation of the horizontal displacement of the ball when it lands on the ground. Correct calculation of the acceleration of the dog	
Any relevant calculation for the time the ball takes to reach the ground. Any relevant calculation of the horizontal displacement of the ball when it lands on the ground. Correct calculation of the acceleration of the dog	2
Any relevant calculations	1

Question 28 (3 marks)

A motor-racing track has banked quarter-circle turns. Racing cars travel around the turns at different radii and speeds. Data are collected when the centripetal acceleration is not caused by the frictional force on the tyres. The graph below shows the data collected.



Using the graph, calculate the banking angle of the turns. **3**

$$v^2 = 1.55r$$

$$tan\theta = \frac{v^2}{rg}$$

$$v^2 = rgtan\theta$$

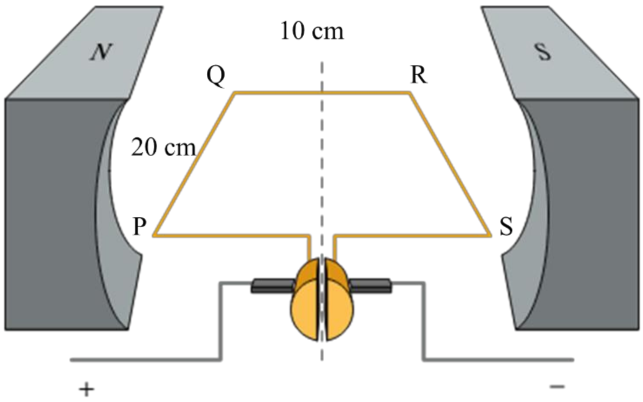
$$1.55 = gtan\theta$$

$$\theta = 8.990$$

Criteria	Marks
Acceptable value of the gradient from the graph Correctly identifies the relationship to be used. Correct substitution with an acceptable answer.	3
Correctly identifies the relationship to be used. Correct substitution with an acceptable answer.	2
Any relevant information	1

Question 29 (8 marks)

A student was investigating a DC motor with 50 turns of wire in the 20 cm × 10 cm horizontal rectangular coil PQRS by applying a vertical force to one of the sides of the coil to stop the motor from turning.



(a) Annotate the diagram to indicate where this force could be applied. **1**

Marking criteria	*Marks*
Arrow pointing up on the left hand side or down on the right hand side	1

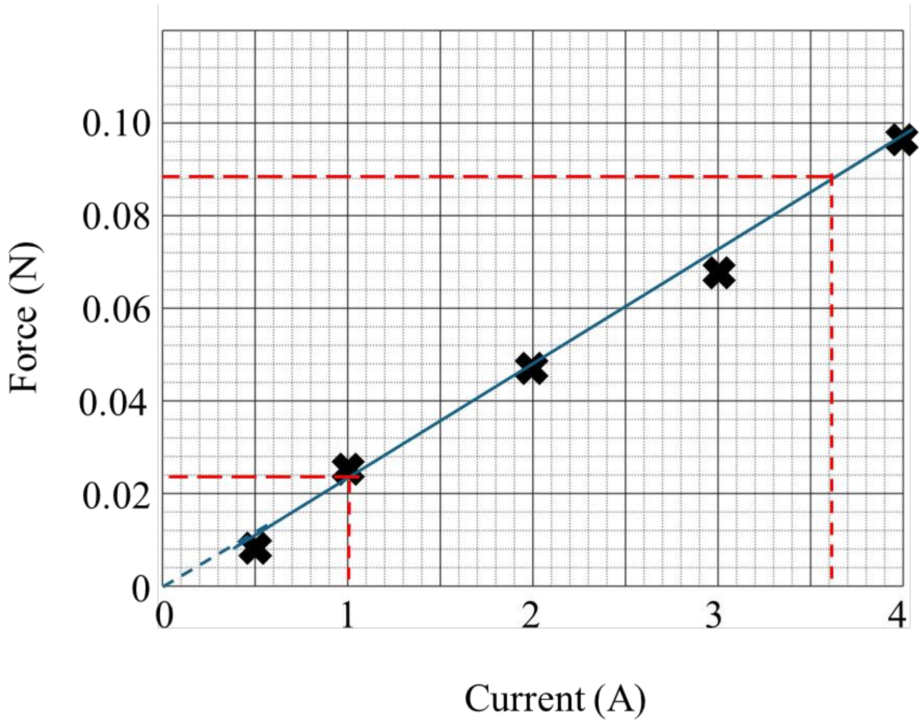
Comments: mostly done well. Some students gave two answers, this was not penalised if they were both correct, but avoid doing this.

The student varied the current and measured the force required to keep the coil stationary, as shown below:

Current (A)	Force (N)
0.5	0.011
1.0	0.026
2.0	0.047
3.0	0.068
4.0	0.097

(b) Graph the data on the axes on page 25. **4**

Marking criteria	*Marks*
Linear graph with suitable scale Labelled axes Points correctly plotted Line of best fit drawn	4
3 of the above	
Two of the above	3
Some relevant information	1



(c) Use the graph to calculate the strength of the magnetic field. **3**

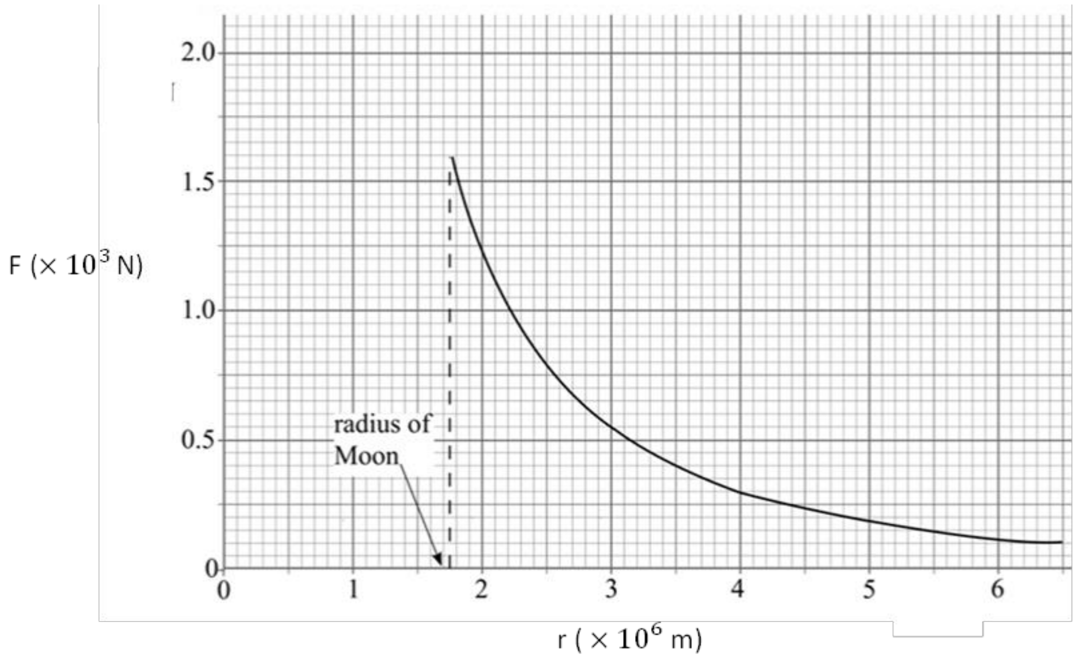
Marking criteria	*Marks*
Used the graph to calculate gradient Balanced motor torque with torque due to applied force Correctly substituted values of 0.05 cm and 50 turns with gradient to calculate B field	3
Two of the above	2
Some relevant information	1

Gradient = (0.088-0.024)/(3.6/1.0) = 0.0246 = F/I
Fr = nBIA
F/I = nBl(2r)/r = 2nBl
2nBl = 0.0246; n = 50, l = 0.2
B = 0.0246/(2*50*0.2) = 1.2 x 10^{-3} T

Marking comments: it was pleasing to see that almost all students calculated the gradient for further use in the question. Many students did not realise that the torques needed to be balanced. There were a significant number of students who tried to use the motor effect force as the applied force.

Question 30 (4 marks)

The graph shows how the gravitational force F between a 1000 kg mass and the Moon varies with the distance r from the Moon's centre for points above its surface.



(a) Use data from the graph to determine the mass of the Moon. **2**

$$M = \frac{Fr^2}{Gm}$$

$$= \frac{1600 \times (1.75 \times 10^6)^2}{6.67 \times 10^{-11} \times 1000}$$

$$= 7.3 \times 10^{22}\ kg$$

Criteria	Mark
Correctly obtaining measurements from the graph. Correct substitution with an acceptable answer. ($7.0 \times 10^{22}\ kg\ to\ 8.5 \times 10^{22}\ kg$)	2

Any relevant information	1

(b) Calculate the speed at which the 1000 kg mass should be thrown vertically upwards from the surface of the Moon if it is to escape from the Moon's gravitational field. **2**

$$Potential\ energy\ lost = gain\ in\ \text{K. E}$$

$$\frac{1}{2}mv^2 = \frac{GMm}{r}$$

$$v = \sqrt{\frac{2GM}{r}}$$

$$= \sqrt{\frac{2 \times 6.67 \times 10^{-11} \times 7.35 \times 10^{22}}{1.75 \times 10^6}}$$

$$escape\ speed = 2370ms^{-1}$$

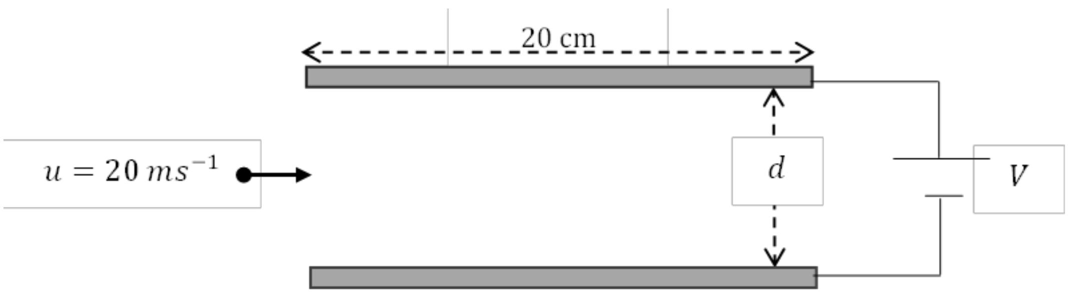
$$\frac{1}{2}mv^2 = 2.8 \times 10^9$$

$$v = 2370ms^{-1}$$

Criteria	Mark
Correctly identifies the relationship between Correct substitution with an acceptable answer.	2
Any relevant information	1

Question 31 (5 marks)

An inkjet printer operates by accelerating charged droplets of ink onto the printer paper. The ink drops are deflected by two plates across which a voltage is applied.



An ink drop of mass $m = 2.0 \times 10^{-10}$ kg and charge $q = 1.0 \times 10^{-13}$ C passes through two plates with an initial horizontal velocity, $u = 20 \text{ m s}^{-1}$. The plates, a distance $d = 5$ mm apart, are connected to a DC voltage source, $V = 10\,000$ V.

Ignore the effects of gravity.

(a) Show that the vertical acceleration of the ink drop is given by $a = \frac{Vq}{md}$. **2**

Marking Criteria	Mark
Correctly derives the relationship (Equates net force to electrostatic force and expresses the electric field as the ratio of the voltage to the separation)	2
Makes significant progress towards the derivation or provides some relevant information.	1

Sample Answer:

$$F_{net} = Eq$$

But the electric field between the plates is given $E = \frac{V}{d}$ and by Newton II, $F_{net} = ma$

Hence

$$ma = \frac{V}{d} \times q$$

$$a = \frac{Vq}{md}$$

Comment:

Generally well done, although some students were guilty of making assumptions.

(b) Find the vertical deflection of the ink drop. **3**

Marking Criteria	Mark
Calculates the vertical deflection (1 for time 1 for acceleration, 1 for final distance)	3
Provides some correct steps in the calculation	2
Provides some relevant information	1

Sample answer:

$$s_x = u_x t$$

$$t = \frac{0.20}{20} = 0.01\ s$$

Sub into $$s_y = u_y t + \tfrac{1}{2} a_y t^2$$

$$= \tfrac{1}{2} a_y t^2$$

$$= \frac{1}{2}\left(\frac{Vq}{md}\right) 0.01^2$$

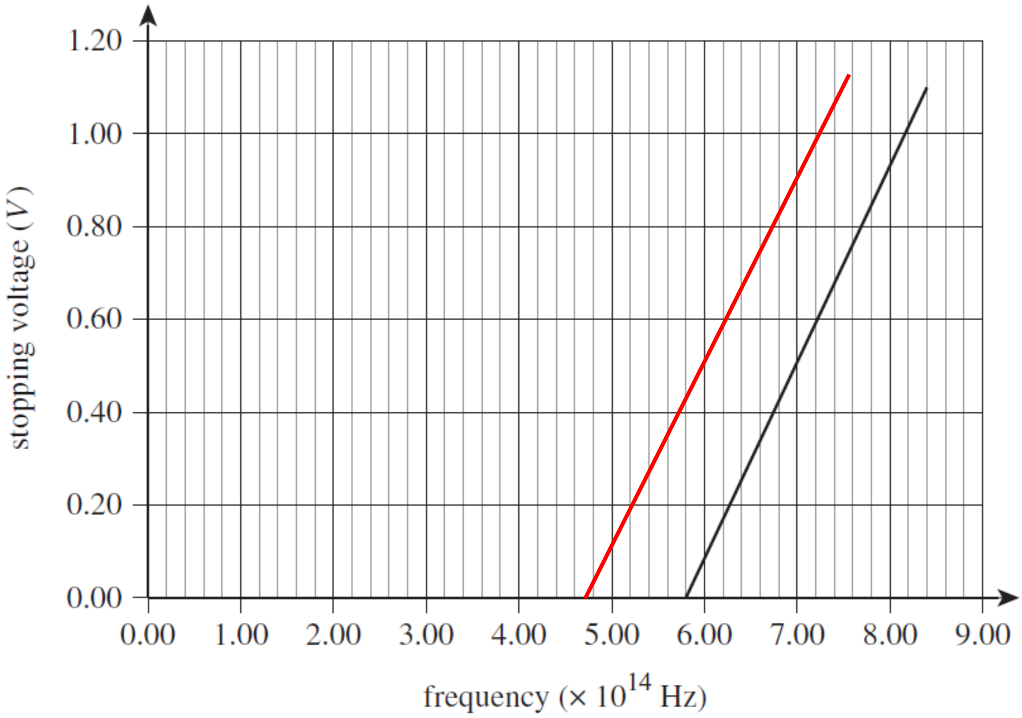
$$= \frac{1}{2}\left(\frac{10\ 000 \times 1.0 \times 10^{-13}}{2 \times 10^{-10} \times 0.005}\right)(0.01)^2$$

$$= 0.05\ m$$

Comment:
Generally, it was pleasing to note that many students were able to obtain the correct vertical deflection (displacement in the y-direction). However, a good number of students were not familiar with the term vertical deflection and thus were unable to solve this problem. Some alert and technically minded students were able to realise that this deflection was far bigger than the plate separation (5 cm compared to 5 mm). When the droplet leaves the plate it would travel in a straight line and so it would be meaningless to talk about the vertical deflection, unless it just misses the edge of the plate. Furthermore, the question did not specify exactly where droplets entered the region between the plates. The intent of the question was to determine the vertical deflection as it misses the edge of the bottom plate (assuming the oil droplet was positively charged). If $V = 500\ V$, then the deflection would be about 2.5 mm.
No student was disadvantaged for this question.

Question 32 (6 marks)

In an experiment involving the photoelectric effect, the results for the stopping voltage versus the light frequency for a particular metal is shown below.



(a) Determine the stopping voltage needed if light of frequency 1.20×10^{15} Hz is used. **3**

Marking Criteria	Mark
Correctly calculates the stopping voltage	3
Provides some correct steps in the calculation	2
Provides some relevant information	1

$$K_{max} = hf - \phi$$

$$eV_s = hf - hf_0$$

$$V_s = \frac{h}{e}(f - f_0)$$

$$= \frac{6.626 \times 10^{-34}(12 - 5.8) \times 10^{14}}{1.602 \times 10^{-19}} = 2.56\ V$$

Comment:
Generally, well done. Some students attempted to first principles to find the equation of the line using $y - y_1 = m(x - x_1)$, by finding the gradient and using another point on the line, which was fine, but be aware of the propagation errors. The gradient was 4.29×10^{-15} which was worth 1 mark.

(b) On the axes provided on page 28, sketch the graph of the results if a metal whose work function of 1.95 eV is used instead. **3**

Any relevant calculations used to assist in sketching should be shown below.

Marking Criteria	Mark
Correctly determining the cut-off frequency and draws line parallel to existing line with correct intercept	3
Any two of the above	2
Any one of the above OR provides some relevant information	1

Sample answer:

$$E = hf_0$$

$$f_0 = \frac{1.95 \times 1.602 \times 10^{-19}}{6.626 \times 10^{-34}} = 4.7 \times 10^{14}\ Hz$$

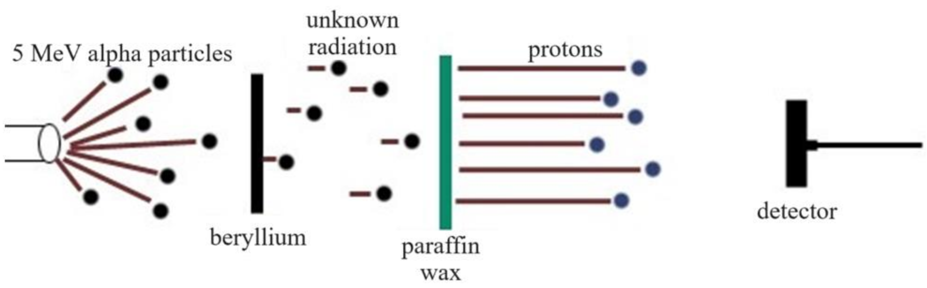
Comment:

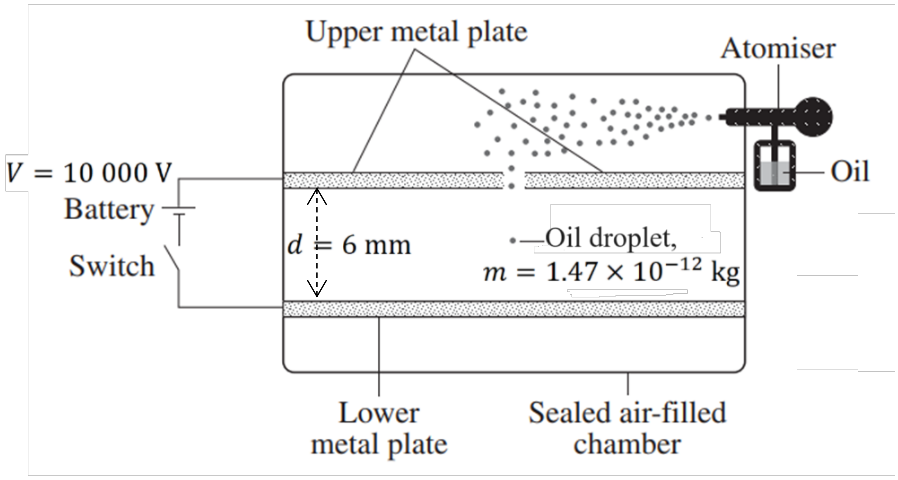
Generally, well done.

End of Question 32

Question 33 (9 marks)

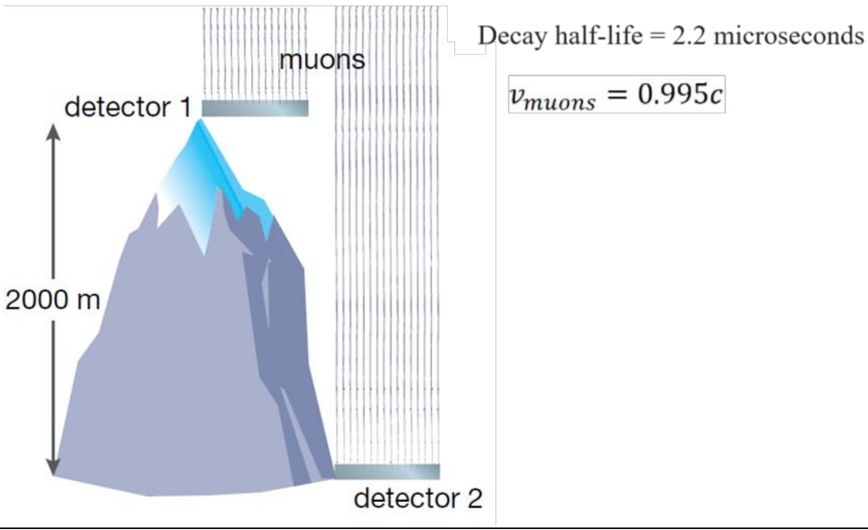
Experiments conducted by Millikan and Chadwick as well as cosmic-origin muons played a pivotal role in our understanding of the structure of matter and the laws of physics.

Experimental setup	*Data*
	Energy of alpha particles = 5 MeV

<table>
<tr><td>
</td><td>$V = 10\ 000$ V

m
$= 1.47 \times 10^{-12}$ kg

Distance between plates, $d = 6$ mm

Oil droplet balanced between the plates</td></tr>
<tr><td>
</td><td>$t_{\frac{1}{2}} = 2.2\ \mu s$

$v_\mu = 0.995c$</td></tr>
</table>

Question 33 continues on page 31

Using the three stimuli provided, show how these three particles improved our understanding of the structure of matter and the laws of physics. **9**

Include a significant calculation for at least two of the three stimuli provided.

Marking Criteria	Mark
• Provides a comprehensive analysis of the three stimuli, showing **HOW** features of the particles improved our understanding • Incorporates a significant calculation for two of the stimuli	9
• Provides a thorough analysis of the three stimuli, showing **HOW** features of the particles improved our understanding • Incorporates a significant calculation for two of the stimuli	8

• Relates features of the particles to the experimental evidence • Includes a relevant calculation for two of the stimuli	6-7
• Identifies some links between the particles and the experimental evidence and/or includes a calculation	4-5
• Provides details of the particles and/or the experimental evidence	2-3
• Provides some relevant information	1

Sample Answer:
Chadwick:
Experiments conducted by Chadwick revealed that the unknown radiation produced when alpha particles of 5 MeV struck a beryllium target, was indeed neutrons. This was confirmed when this unknown radiation was allowed to interact with paraffin wax, producing protons in the process, and by obeying the laws of conservation of momentum and energy, it was shown that the unknown radiation had a mass almost similar to the proton.

- The discovery of the neutron helped towards the improvement of the previous models of the atom viz. Rutherford.
- Furthermore, neutrons being neutral was able to penetrate matter without being affected by electric or magnetic fields which further enhanced our understanding of the structure of matter. Through scattering experiments or collisions, the structure of matter can thus be analysed.
- Their de Broglie wavelength is of the order of interatomic spacing and are thus useful for electron diffraction experiments.
- Further investigations revealed the quark content of neutrons (up, down quarks etc.).
- Neutrons decay to produce a proton, electron and an electron antineutrino.
- Neutrons with an ability to increase the N-P ratios in heavy nuclides, are useful in fission reactors to enable unstable heavy nuclei to split, releasing energy in the process.
- The discovery of neutrons also helped towards understanding the unusual stability of atoms in terms of providing the strong nuclear force (SNF) that binds the nucleons together. If neutrons were not present in atoms, then the repulsive force between protons would instantaneously split the nucleus apart.

Millikan:
This experiment by Millikan enabled the charge on the electron to be found. With oil drops balanced between two charged parallel plates, the force of gravity and the force due to the electric field was equated to yield $q = \frac{mgd}{V} = \frac{1.47\times10^{-12}\times9.8\times6\times10^{-3}}{10\ 000} \cong 8.644 \times 10^{-19}\ C \approx 54 \times (Q)$. The charge on the oildrop was thus found to be an integer number of some basic charge, which turned out to be $1.602 \times 10^{-19}\ C$, a quantised, discrete value. The mass of the oil drop was found using the buoyant force, drag force.

With the charge of the electron known, the previous atomic models viz. Rutherford and Bohr's models provided further credibility and acceptance of their models. With the charge of the electron being known, the study of charges at rest (electrostatics) became well understood.

Knowing the charge of the electron, other models postulated by Shroedinger and De Broglie paved a way for a better understanding of the structure of matter.

Muons:

Muons are unstable elementary particles with a very short half-life which decay almost immediately when produced during cosmic bombardment of particles in the upper reaches of the atmosphere. With this short decay time, they are not known to reach the Earth, despite travelling at relativistic speeds. However, lab based detectors have been able to pick up these short-lived muons. The reason they are able to travel much longer distances during their short time span is due to their time of existence being dilated. This provided experimental evidence for time dilation, i.e. $t = \frac{t_0}{\sqrt{1-\frac{v^2}{c^2}}} = \frac{2.2}{\sqrt{1-0.995^2}} = 22\ \mu s$, which is about 10 times they decay half-life, enabling them to reach Earth-based detectors, covering a classical distance of $0.995 \times 3 \times 10^8 \times 22 \times 10^{-6} \approx 6600\ m$, far in excess of the 2000 m the two detectors are apart.

Furthermore, using the decay half life of 2.2 microseconds, the percentage of nuclei reaching detector 2 is $\frac{N}{N_0} = e^{-\lambda t} = e^{-\frac{0.693}{2.2\times10^{-6}}\times\frac{2000}{0.995\times3\times10^8}} = 0.12 \approx 12\%$, while, similarly, the proportion of nuclei reaching detector 2 with a dilated time of 22 microseconds is about 80%.

Thus the detection of muons on Earth provides striking evidence for Einstein's Special Theory of Relativity.

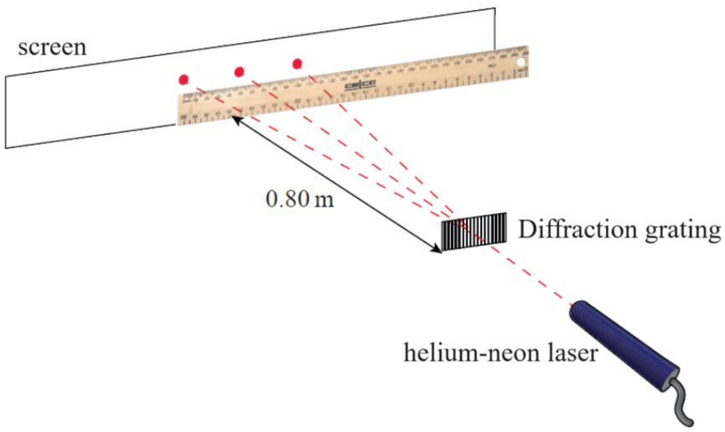
Comment:

This was generally well done with students scoring an average of 7. Those who were unable to score full credits were those guilty of not answering the questions which says "Show How…"

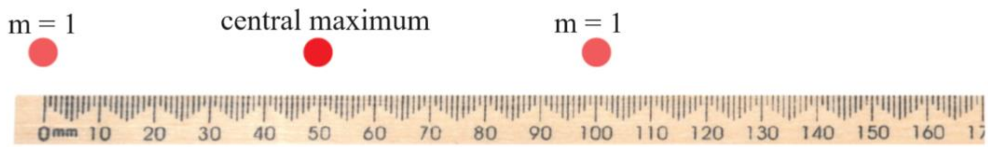
End of Question 33

Question 34 (5 marks)

A student undertook an experiment to investigate diffraction using a helium-neon laser and a diffraction grating containing 100 lines per mm, positioned 0.80 m from a screen.



The image below shows the distances between the central maximum and the first orders of the diffraction pattern that was observed on the screen.



drawn to scale

(a) Calculate the wavelength of the helium-neon laser. **3**

Marking Criteria	Mark
Calculates the wavelength (1 for $\theta = 3.6°$), 1 for $d = 1 \times 10^{-5}$, 1 for λ)	3
Provides substantial working to calculate the wavelength	2
Provides one correct step in calculation	1

Sample answer:

$$d \sin\theta = m\lambda$$

Using $\sin\theta \approx \tan\theta = \frac{y}{L}$, this becomes

$$d\left(\frac{y}{L}\right) = m\lambda$$

$$\lambda = \frac{dy}{mL} = \frac{\frac{1}{100} \times 10^{-3} \times 50 \times 10^{-3}}{1 \times 0.8} = 625\ nm$$

Comment:
Generally well done, except for those who messed up the distance between lines/slits.

(b) Given that the range of the visible spectrum is 400 nm to 700 nm, predict how the distances between the central maximum and subsequent maxima will be affected if blue laser light is used in the above investigation. **2**

Justify your answer.

Marking Criteria	Mark
Predicts correctly the impact of blue light and includes justification	2
Predicts correctly the impact of blue light or provides some relevant information	1

Sample answer:
λ_{blue} is closer to the 400 nm end than 700 nm, which implies that $\lambda_{blue} < 625\ nm$.
From $\lambda = \frac{dy}{mL}$, $\lambda \propto y$ (distance between central maximum and subsequent maxima)
Therefore, the distance between central maximum and subsequent maxima decreases.

Comment

Generally well done, apart from those who chose not to justify their choice by not making reference to an equation.

Question 35 (7 marks)

A particle P, of mass $2m$ and charge $+q$, is injected into an evacuated glass chamber with an initial velocity of v. The particle experiences a uniform magnetic field perpendicular to the direction of motion and a uniform gravitational field directed downwards. Particle P travels through the tube in a straight horizontal path until it reaches X, as shown in Figure 1.

Figure 1

Particle P has a fine crack in it and when it reaches X, it breaks into two fragments Q and R, as shown in Figure 2. The upper fragment, Q has mass m, and charge $+q$, and the lower fragment R, also has mass m but is uncharged. The breaking process is elastic and momentum is conserved during the breaking process.

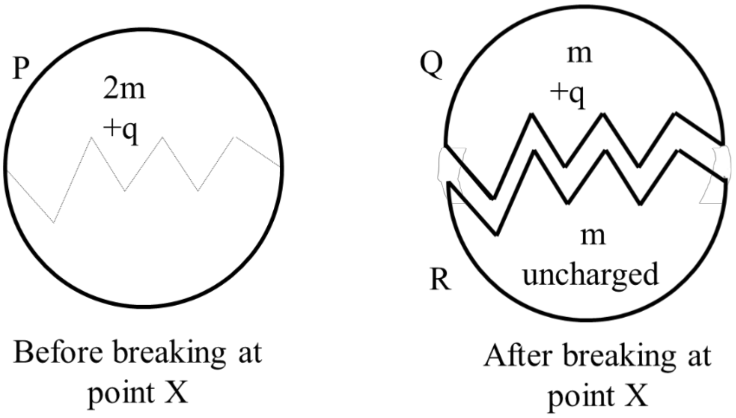


Figure 2

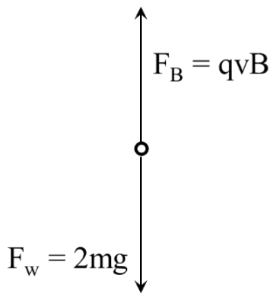
Account for the trajectories of the initial particle P and its fragment R and discuss factors that affect the trajectory of fragment Q. **7**

Support your answer with mathematical models, relevant laws of physics and diagrams.

Marking criteria	*Marks*
Demonstrates an extensive understanding of the magnetic and gravitational fields (2 from each code + QTL) Uses relevant mathematical models and diagrams	7
Demonstrates a thorough understanding of the magnetic and gravitational fields (2 of each code, 1 from each code + 1 QTL, 2 from 5 codes + QTL) Uses relevant mathematical models and/or diagrams	6
Demonstrates a good understanding of the magnetic and gravitational fields (1 of each code) Uses relevant mathematical models and/or diagrams	5
Four points from four categories	4
Three points from 3 categories	3
Two relevant points from 2 categories (may be qualitative)	2
Some relevant information	1

Sample answer:
Air resistance acts to oppose motion, but in a vacuum, there is no air resistance (PP).

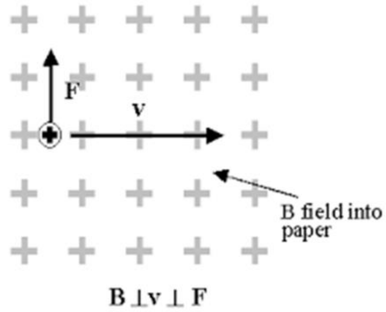
Trajectory of particle P
Particle P experiences weight vertically downwards $W = (2m)g$. (MM)
As the particle travels in a horizontal path, there must be an upwards force to balance this provided by the magnetic field. $F_M=qvB$ (MM)



(D)

$2mg = qvB$ so $v = 2mg/qB$ or $B = 2mg/qv$ (PT).

The B field is perpendicular to the velocity, so it must not have any component right or left. As the particle travels in a straight line, there is no force into/out of the page, so by the right hand rule, the B field must be into the page. (PT)



(D)

As there is no net force on P (either up/down, into/out page, or left/right), it will travel at a constant velocity (PT) in a straight line, demonstrating Newton's first law. (PP)

The magnitude of the B field must remain constant in order to keep F_M constant (PT).

Fragmentation

Momentum is conserved (given)

$\Sigma p_i = \Sigma p_f$ (MM)

$p = mv$ (MM) so $p_i = 2mv = p_f = mv_Q + mv_R$ as both Q and R have the same mass, m.

$2v = v_Q + v_R$ eq(1)

As the breaking is elastic, kinetic energy is conserved (PP)

As $KE = ½ mv^2$, $½ (2m)v^2 = ½ mv_Q^2 + ½ mv_R^2$ (MM)

$2v^2 = v_Q^2 + v_R^2$ eq (2)

Assuming no vertical impulse to Q and R (i.e. their motion is horizontal), take 2×eq(2) – eq(1)^2

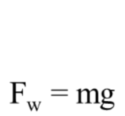
$0 = v_Q^2 - 2v_Qv_R + v_R^2$

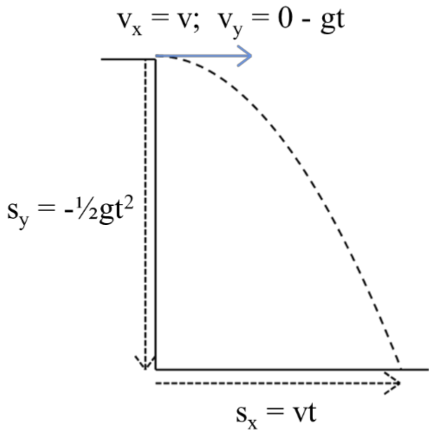
$v_Q = v_R$ and hence by eq(1) both are equal to v.

If there is some vertical impulse to Q and R, their change in vertical momentum must cancel. In order to conserve kinetic energy, the horizontal component of their velocity must be lower than v, and then the horizontal momentum would not be conserved. So both Q and R have initial velocities of v, directed to the right (QT or RT, but not both).

Trajectory of R

Particle R experiences only weight, W =mg (RT), as it is uncharged.
It will undergo parabolic (projectile) motion (RT) until it hits the side of the tube, with horizontal velocity equal to v and vertical velocity equal to -gt (RT) as the initial vertical velocity is zero. During this motion, R gains kinetic energy while losing gravitational potential energy, in line with the conservation of energy. (PP) The velocity of R is given by the vector sum of the horizontal and vertical components: magnitude of $(v^2 + g^2t^2)^{1/2}$, direction of $\tan^{-1}(gt/v)$ below the horizontal where t is the time after fragmentation. (RT)

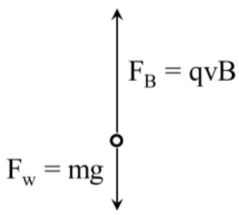


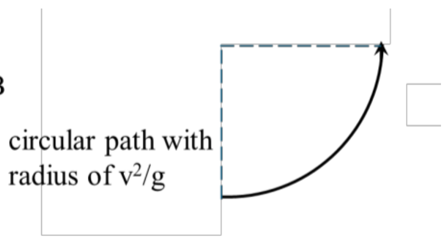


(D) (D)

Factors affecting the trajectory of Q

Initially, particle Q experiences weight (mg) vertically downwards and qvB upwards, with a net force equal in magnitude to mg (QT) upwards (as 2mg is equal in magnitude to qvB), perpendicular to its velocity.

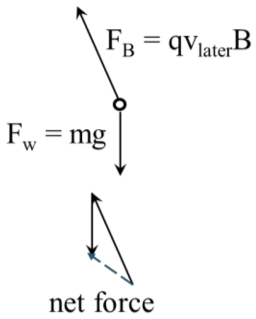




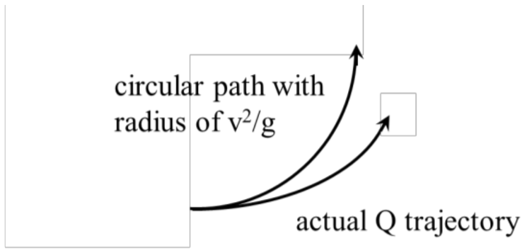
(D) (D)

This causes Q to turn upwards in circular motion (QT), with a radius of $mv^2/r = mg$, or $r = v^2/g$. (QT).

However as soon it does so, the direction of the magnetic force rotates anticlockwise, and the net force also rotates anticlockwise. (QTL) This causes the horizontal velocity to decrease as there is a component acting in the *-x* direction. The particle cannot maintain circular motion, with the trajectory being below that of a circle. (QTL)



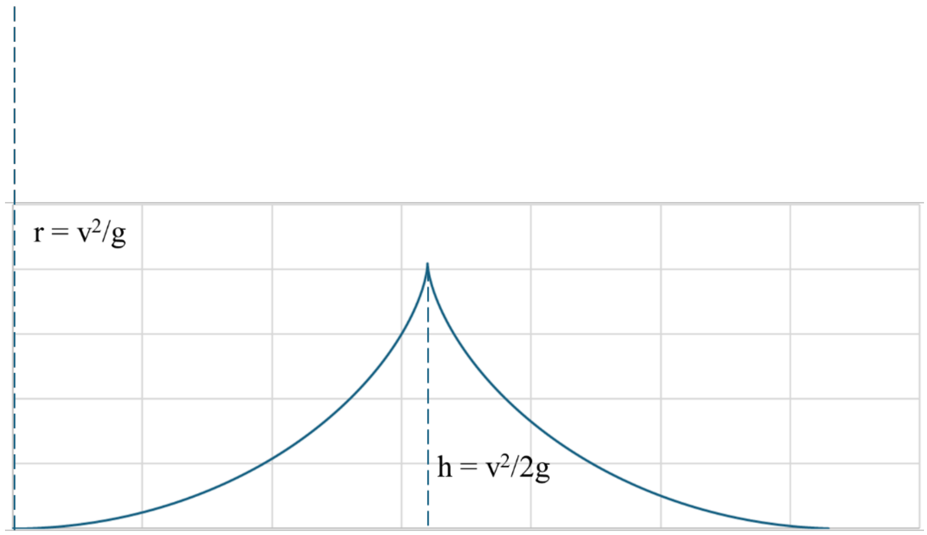
(D)



(D)

The kinetic energy decreases as the gravitational potential energy increases, conserving energy (the magnetic force, perpendicular to the velocity, does no work (PP)). As Q slows down, the size of the magnetic force decreases. As the size of the magnetic force decreases, the weight overcomes the vertical component of the magnetic force and Q accelerates downwards. The particle can not go higher than $v^2/2g$ above its starting position (QTL) (when all its initial KE ½ mv^2 would be converted to GPE mgh).

If the top of the evacuated tube is higher than this, the particle will start to move downwards, converting gravitational into kinetic energy. The particle oscillates up and down (just reaching the initial straight line) while travelling to the right.
Trajectory (a cycloid):
$x(t) = v^2/4g\ (2g/v\ t + \sin(2g/v\ t))$
$y(t) = v^2/4g\ (1 - \cos(2g/v\ t))$



As a charged particle undergoing acceleration, however, it will radiate energy (PP), so depending on the value of B (and hence v), will not quite follow this trajectory before striking the end of the tube.

End of Exam