JAMES RUSE AGRICULTURAL HIGH SCHOOL

2021

TRIAL HIGHER SCHOOL CERTIFICATE EXAMINATION

Physics

General Instructions

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

Total marks: 100

Section I – 20 marks (pages 2–17)

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

Section II – 80 marks (pages 20–44)

- Attempt Questions 21–34
- Allow about 2 hours and 25 minutes for this section

Please Turn over

Section I

20 marks
Attempt Questions 1–20
Allow about 35 minutes for this section
Use the multiple-choice answer sheet for Questions 1–20.

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1 Figure 1 and Figure 2 illustrate two pieces of experimental evidence.

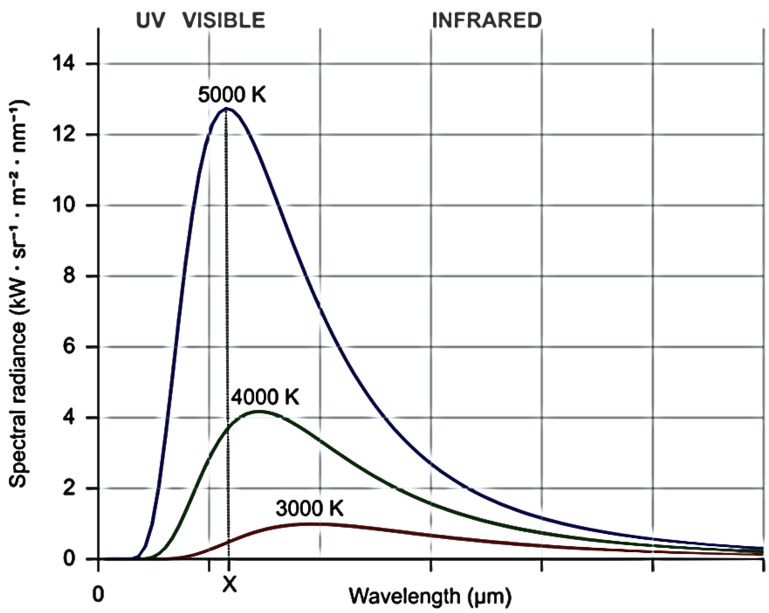


Figure 1

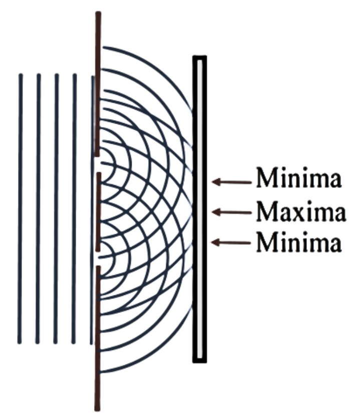
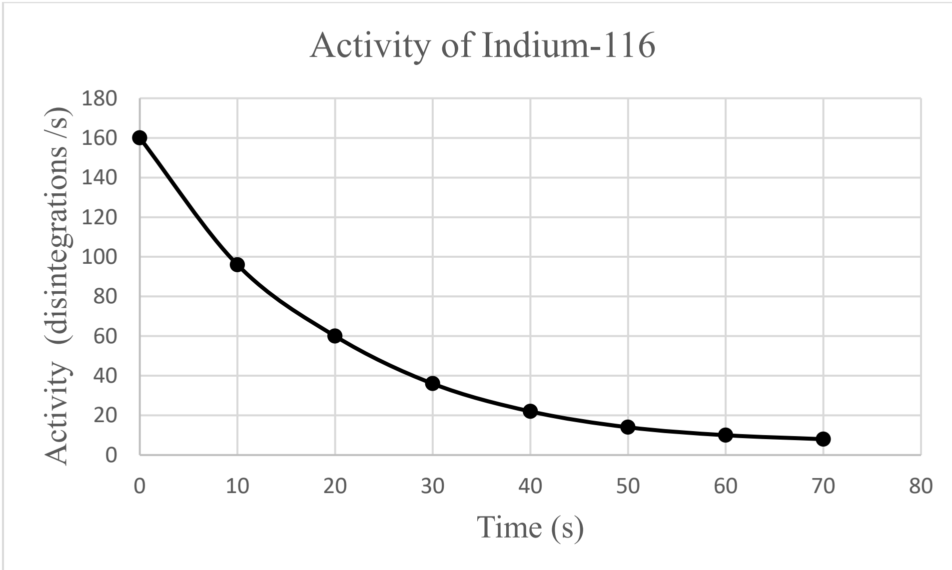


Figure 2

Which model of light does the evidence in each figure support?

	Figure 1	*Figure 2*
A.	wave	particle
B.	wave	wave
C.	particle	particle
D.	particle	wave

2 The graph shows the activity of Indium-116 as a function of time.



What is the half-life and decay constant of this isotope?

	Half-life (s)	*Decay constant (s^{-1})*
A.	13	18.76
B.	35	50.49
C.	13	0.053
D.	35	0.020

3 Unpolarised light with intensity I_0 passes through two crossed polarising filters and the intensity is then measured to be $\frac{I_0}{4}$.

What is the angle between the axes of the two polarising filters?

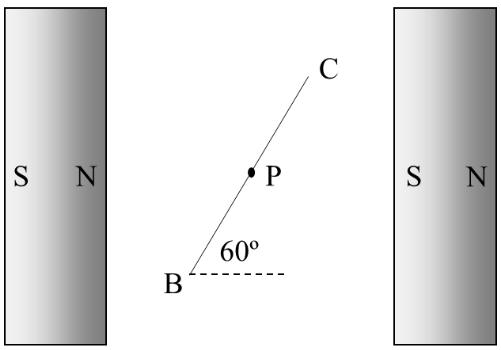
A. 30°

B. 45°

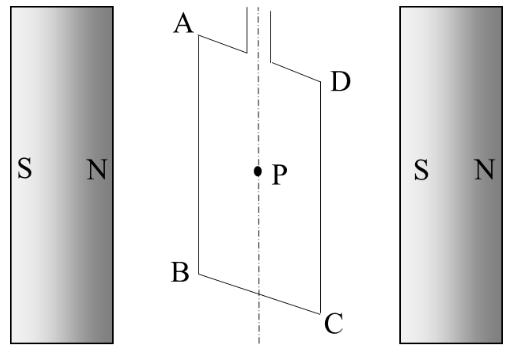
C. 60°

D. 90°

4 A square coil carrying a current of 1 A with sides of 10 cm and 50 turns is free to pivot about point P in a magnetic field of 1.2 T.



End on view



Top view

When the coil is at the angle shown, what is the torque on the coil?

A. 0.3 Nm

B. 0.5 Nm

C. 30 Nm

D. 50 Nm

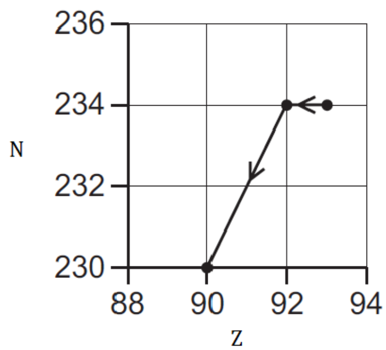
5 An alpha particle is fired at a thin piece of gold foil and passes close to a gold nucleus. As it approaches the gold nucleus, which one of the following is true about the electric potential energy of the system and the magnitude of the momentum of the alpha particle?

	Potential Energy	*Magnitude of momentum*
A.	decreases	unchanged
B.	increases	decreases
C.	decreases	decreases
D.	increases	unchanged

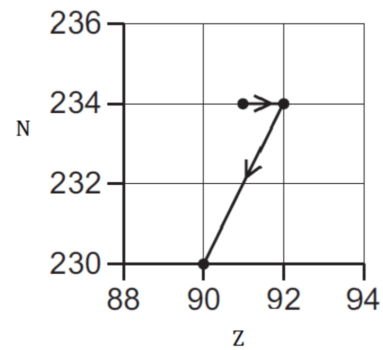
6 A radioactive nucleus is formed by β^-decay. The nucleus then decays by α $-$decay.

Which graph of nucleon number N plotted against proton number Z shows the β^-decay followed by α $-$decay?

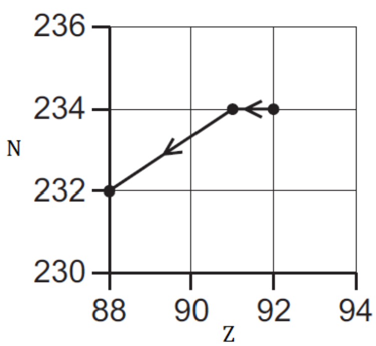
A.



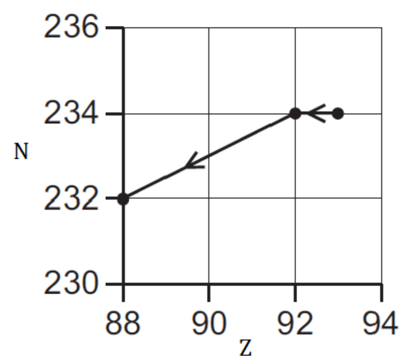
B.



C.



D.



7 A student is investigating the force between two parallel current carrying wires of equal length. With a particular experimental setup, the student measures a force of F Newtons.

Which of the following changes to the experiment would produce the force described?

	Change to experimental design	*Force produced*
A.	reverse the direction of one of the currents	$\frac{F}{2}$
B.	double the length of one wire	F
C.	double each current	$2F$
D.	halve the distance between the wires	$4F$

8 Which of the following is a contribution that Schrodinger made to the current model of the atom?

A. Postulated that electrons exist as standing waves with quantized angular momentum which explains their unusual stability.

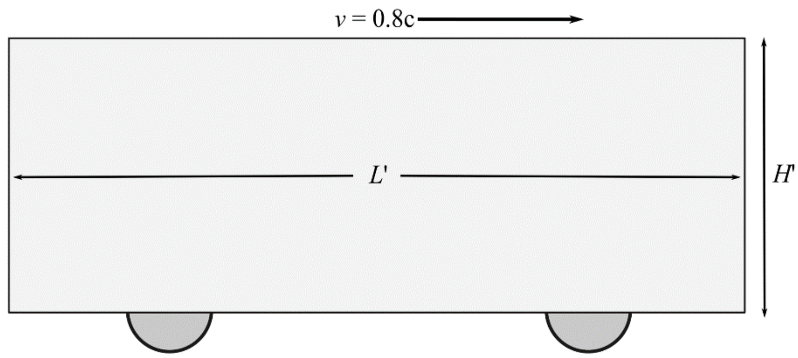
B. Developed a mathematical model called matrix mechanics to simultaneously determine the position and momentum of a particle.

C. Developed a mathematical model called wave mechanics which can be used to describe the likelihood of finding an electron in a certain position.

D. Proposed that no two electrons in the same quantum system can simultaneously have the same set of four quantum numbers.

9 The length and height of a train carriage are measured to be $L = 5\ m$ and $H = 2.5\ m$ respectively by an observer at rest with respect to the carriage.

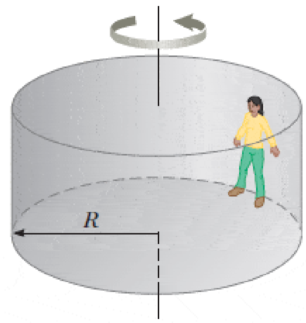
Another observer measures the length L' and height H' of the same carriage as it moves past him at a speed of $v = 0.8c$ as shown in the diagram.



Which of the following correctly describes this observer's measurements?

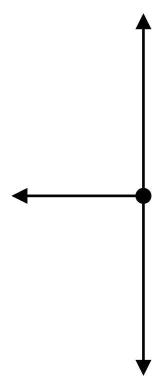
	length L' (m)	*height H' (m)*
A.	5	1.5
B.	5	2.5
C.	3	2.5
D.	3	1.5

10 A rider in the "rotor" in an Amusement Park finds herself stuck with her back to the wall as the floor gradually falls down while the rotor reaches its optimum safe speed.

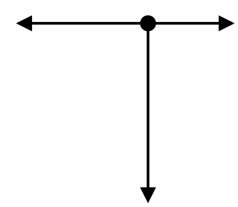


Which diagram correctly shows the forces acting on her?

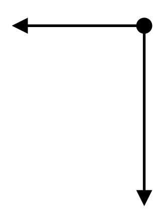
A.



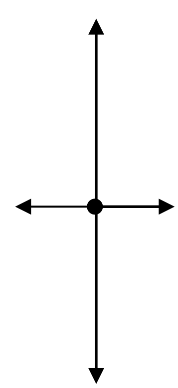
B.



C.



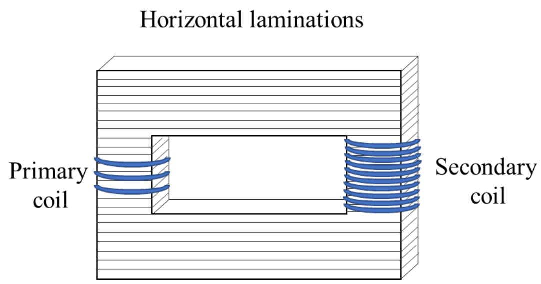
D.



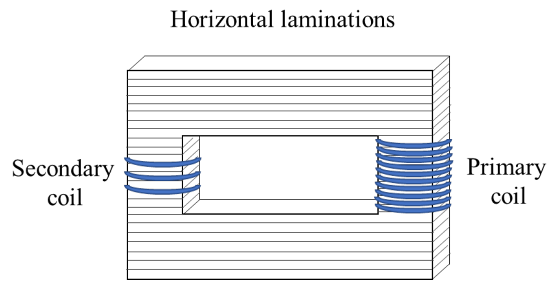
11 The electrical substation at Carlingford contains a number of transformers as part of the electricity supply to local households, schools and businesses.

Which of the following diagrams provides a model for these transformers?

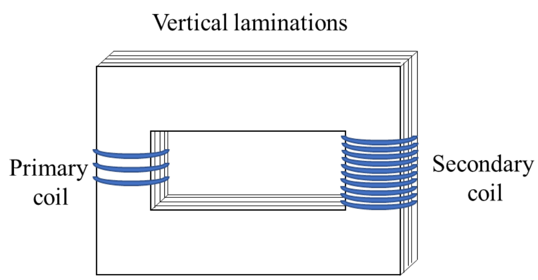
A.



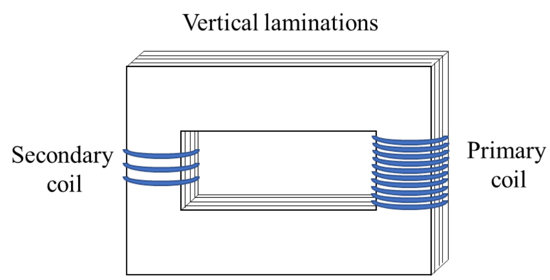
B.



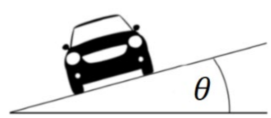
C.



D.



12 To safely negotiate curved section of roads at some critical speed, the roads are usually banked, as shown below.



Which of the following statements is correct?

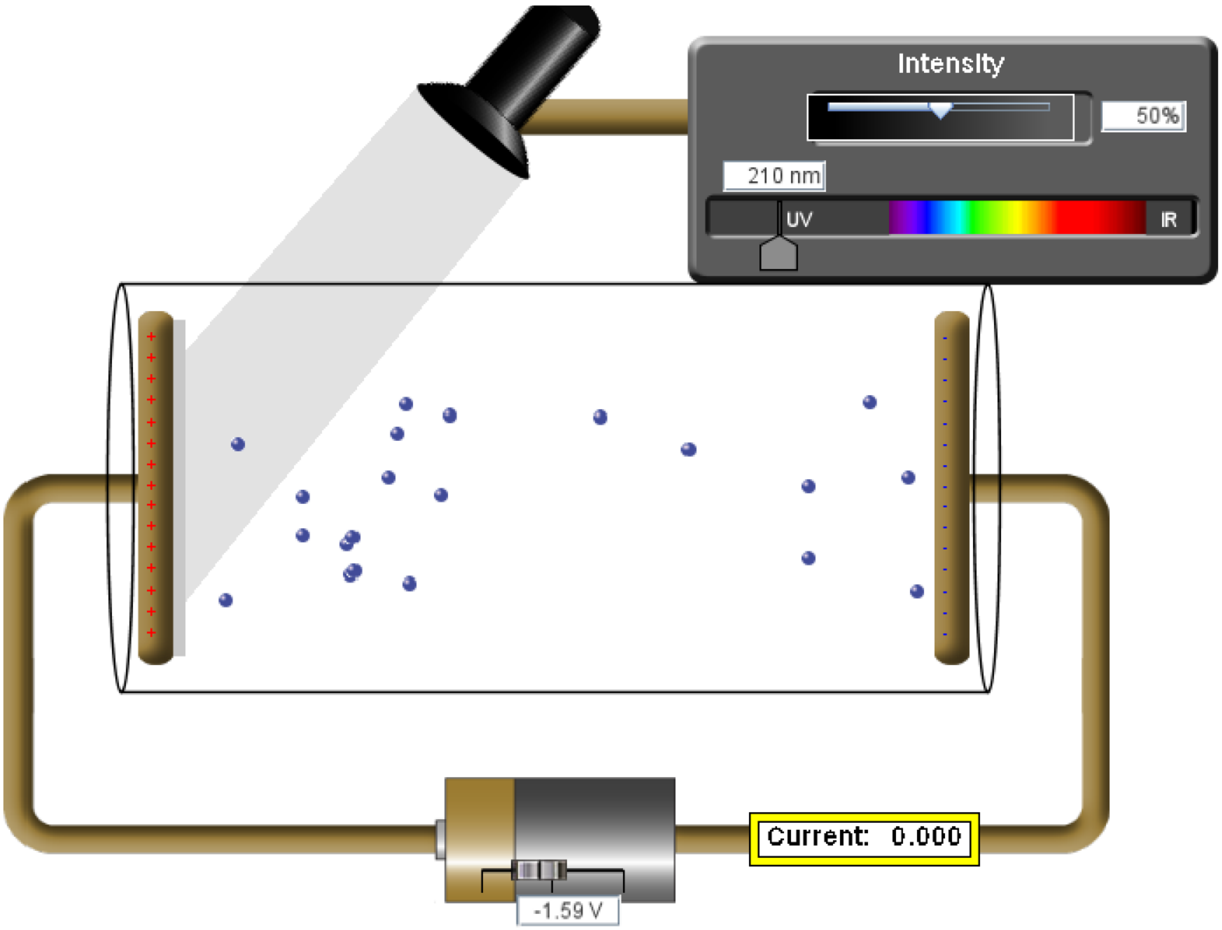
A. A component of the normal reaction force provides the frictional force, parallel to the inclined plane of the road.

B. At speeds lower than the critical speed, the car will tend to slide up the inclined plane of the road, while the frictional force acts down the plane.

C. A component of the normal reaction force provides the centripetal force, directed towards the centre of the curved section of the road.

D. At speeds greater than the critical speed, the car will tend to slide down the inclined plane of the road, while the frictional force acts up the plane.

13 The diagram shows a screenshot from a simulation of the Photoelectric effect. The voltage has been adjusted to the value with the smallest magnitude so that there is no current between the cathode and anode.



Using the information provided in the diagram, the work-function of the metal is:

A. 1.59 eV

B. 4.32 eV

C. 5.91 eV

D. 7.50 eV

14 Figure 1 shows satellite A in an elliptical orbit around Earth. The velocity of satellite A at two locations, X and Y, is shown using vectors.

Figure 2 shows satellite B in a circular orbit around Earth. The velocity of satellite B at two locations P and Q is also shown using vectors.

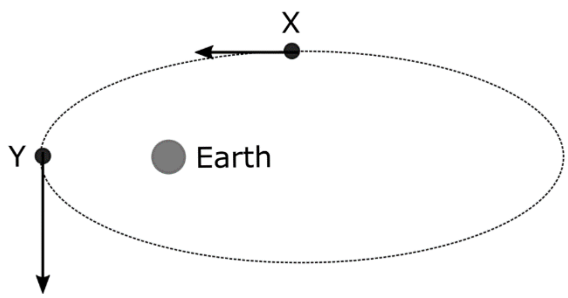


Figure 1: Satellite A

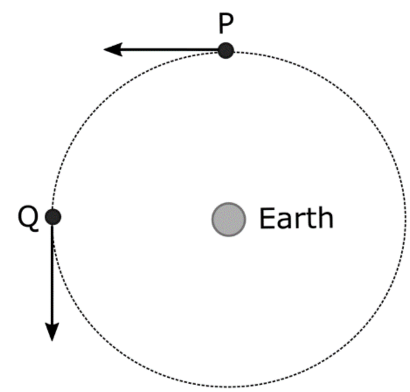
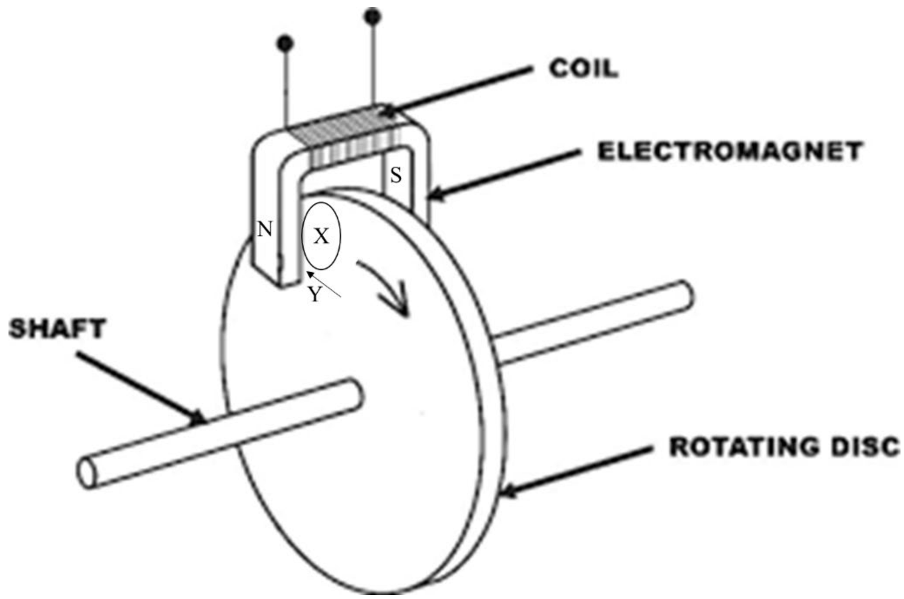


Figure 2: Satellite B

Which of the following correctly describes the work done by the force of gravity on satellite A as it moves between positions X and Y, and the work done on satellite B as it moves between positions P and Q?

	Work done on satellite A from X to Y	*Work done on satellite B from P to Q*
A.	non-zero	zero
B.	non-zero	non-zero
C.	zero	zero
D.	zero	non-zero

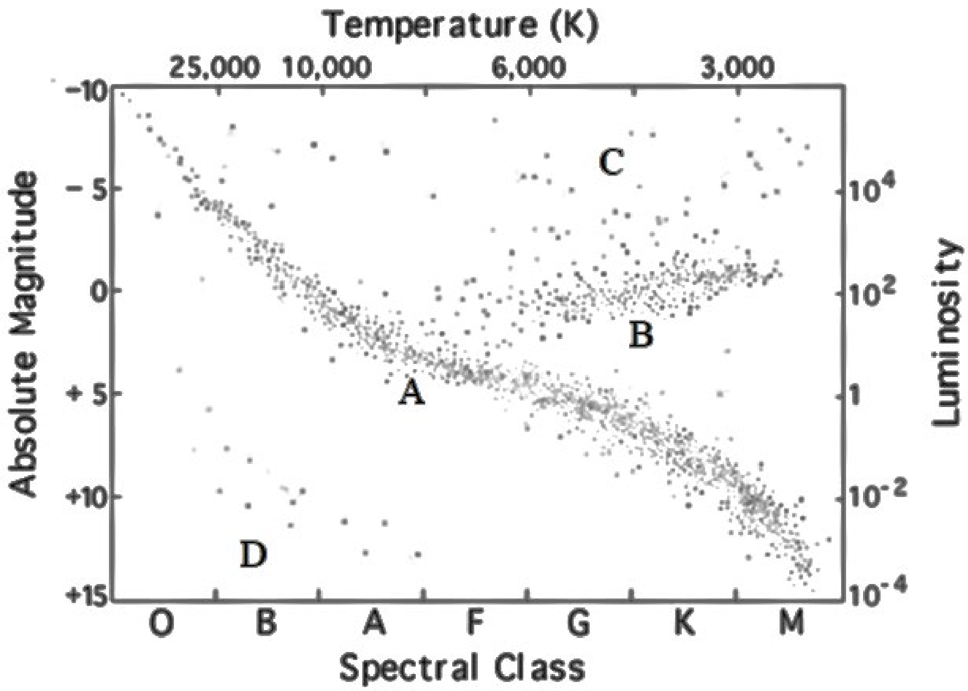
15 An electromagnetic brake is shown below, with the disc rotating in a clockwise direction.



Which of the following correctly describes the eddy current at X and the vector quantity Y, as shown on the diagram?

	Direction of eddy current at X	*Vector quantity Y*
A.	Clockwise	Force
B.	Clockwise	Torque
C.	Anticlockwise	Force
D.	Anticlockwise	Torque

16 Consider the HR diagram with 4 star groups labelled A, B, C and D.



Identify the star groups where the following predominately occur:

(i) <u>p-p Chain reaction</u>:

$$4\,{}^{1}_{1}\mathrm{H} \rightarrow {}^{4}_{2}\mathrm{He} + 2\,{}^{0}_{+1}e + 2\nu + 2\gamma$$

(ii) <u>Triple – Alpha reaction</u>:

$${}^{4}_{2}\mathrm{He} + {}^{4}_{2}\mathrm{He} \rightarrow {}^{8}_{4}\mathrm{Be} + \gamma$$

$${}^{4}_{2}\mathrm{He} + {}^{8}_{4}\mathrm{Be} \rightarrow {}^{12}_{6}\mathrm{C} + \gamma$$

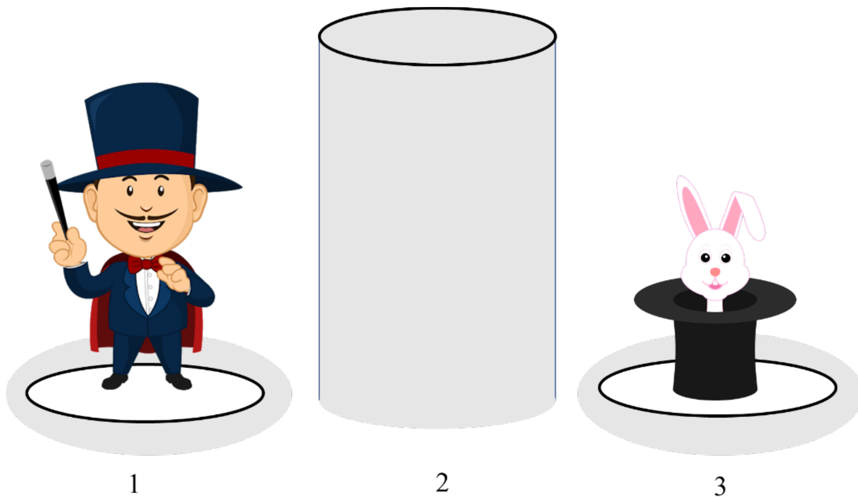
	p-p Chain reaction	*Triple – Alpha reaction*
A.	A	A and C
B.	D	B and C
C.	A	B and C
D.	D	A and C

17 Two satellites, A and B, of equal mass m, orbit the Earth at an altitude of R and $3R$ respectively, where R is the radius of the Earth in km.

Which row of the table is a correct comparison of the satellites' gravitational potential energy U and orbital velocity v?

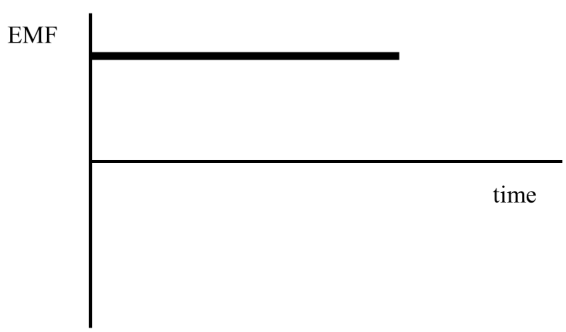
	Gravitational Potential Energy U	*Orbital Velocity* v
A.	$U_A = 3U_B$	$v_A = \sqrt{3}v_B$
B.	$U_A = 2U_B$	$v_A = \sqrt{3}v_B$
C.	$U_A = 3U_B$	$v_A = \sqrt{2}v_B$
D.	$U_A = 2U_B$	$v_A = \sqrt{2}v_B$

18. In a famous magic trick, a magician stands inside a metal ring attached to a lightweight curtain. The magician throws the ring into the air (1), and is momentarily hidden by the curtain (2). When the curtain falls down again, the magician has been replaced by a rabbit (3).

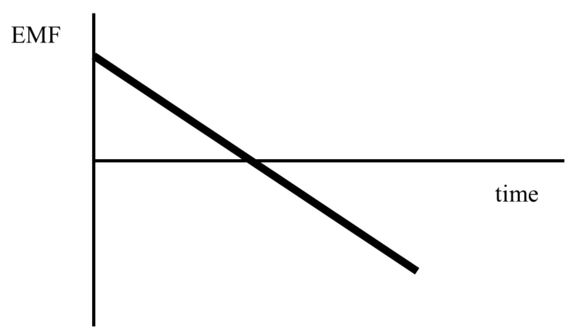


Which of the following graphs is consistent with the predicted emf induced by the movement of the ring in the Earth's magnetic field?

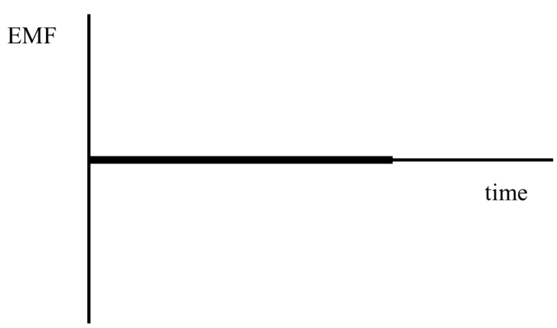
A.



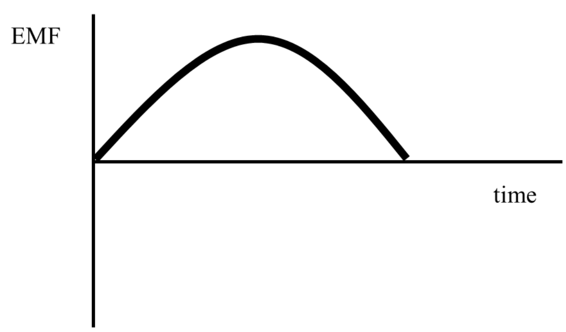
B.



C.



D.



19 Figures 1 and 2 show two designs for a rollercoaster. Both designs are frictionless and have an identical shape everywhere except between positions x_1 and x_2. Between these positions, rollercoaster A has a hill of height H, whereas on rollercoaster B, the cart leaves the track, flying through the air before landing safely on the other side.
In both designs, the cart starts from rest at the position shown.

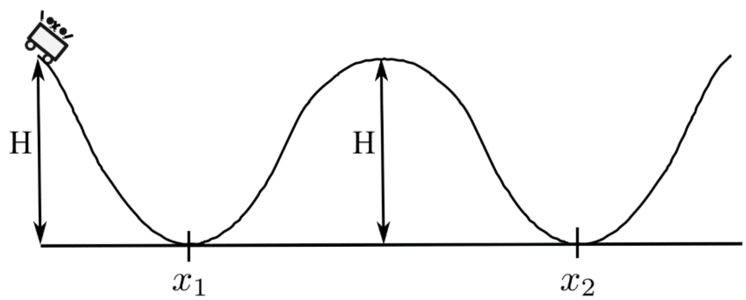


Figure 1: Rollercoaster A

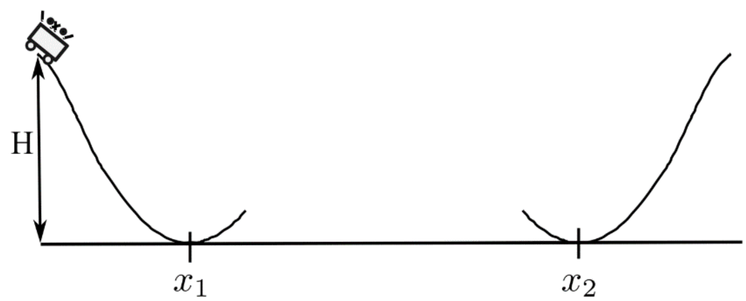


Figure 2: Rollercoaster B

Which of the following correctly describes the maximum height that the carts in rollercoaster A and B reach between positions x_1 and x_2?

	Maximum height for A	*Maximum height for B*
A.	equal to H	equal to H
B.	equal to H	less than H
C.	less than H	equal to H
D.	less than H	less than H

20 A probe is launched vertically upwards from the surface of a planet, of radius R, with speed equal to three quarters the escape speed for that planet.

In terms of R, what is the maximum height, from the surface of the planet, reached by the probe? Ignore air resistance.

A. $\left(\frac{16}{7}\right)R$

B. $\left(\frac{9}{16}\right)R$

C. $\left(\frac{9}{7}\right)R$

D. $\left(\frac{23}{9}\right)R$

Student Number

TRIAL HSC EXAMINATION 2021

Physics

Multiple Choice Answer Sheet

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 ◯

Student Number

Physics

Mark

Section II Answer Booklet

80 marks

Attempt Questions 21 – 34

Allow about 2 hours and 25 minutes for this part

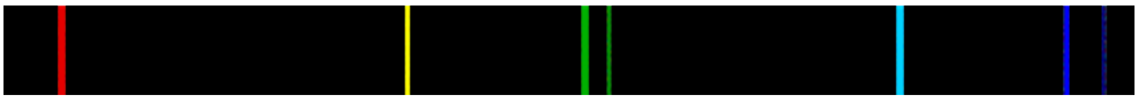
Instructions

- Write your Student Number at the top 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
- Extra writing space is provided at the back of this booklet. If you use this space, clearly indicate which questions you are answering.

Question 21 (5 marks)

A

B



a) Name the two types of spectra shown above. **2**

A: ……………………………..

B: ……………………………..

b) Describe how the two spectra shown can be produced and observed in a science classroom. **3**

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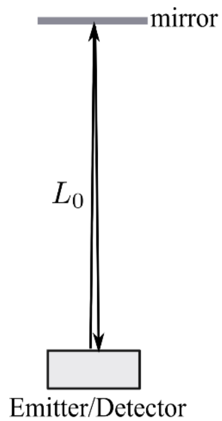
Question 22 (7 marks)

The diagram shows a "light clock", in which light travels from an emitter to a mirror a distance L_0 and back along the same path to a detector.



a) Write down an expression for the time, t_0, taken by light to travel from the emitter to the mirror and back as measured by an observer in the same reference frame as the clock. **1**

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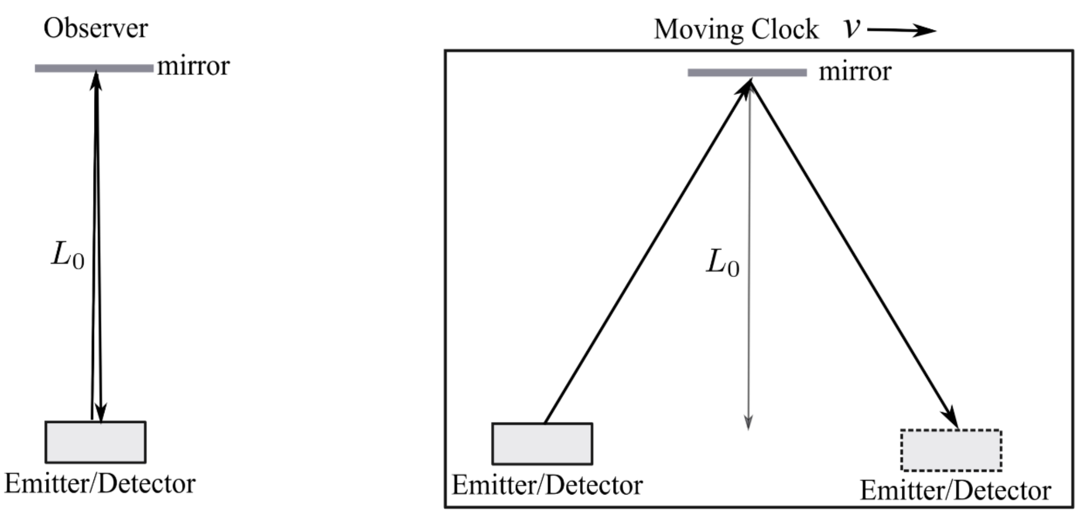
In a thought experiment, an observer with a light clock observes a second light clock moving at speed v to the right.



Question 22 continues on page 23

b) Explain why the observer will see light take longer to travel from the emitter to the mirror and back on the moving clock than the time it took light to travel this path in part (a). **3**

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(c) Name the effect predicted by the thought experiment **1**

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(d) Describe ONE way in which this effect has been validated experimentally **2**

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End of Question 22

Question 23 (5 Marks)

(a) Outline the key features of the Rutherford model of the atom. **2**

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(b) Explain how the Bohr model of the atom overcomes an identified limitation of the Rutherford model of the atom. **3**

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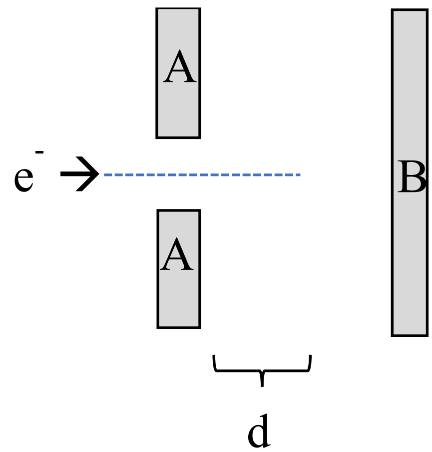
Question 24 (10 Marks)

Electrons of different velocities are passed through a hole in plate A. A potential difference V, is generated between plates A and B, resulting in an electric field $\vec{E}$. After the electrons enter the gap between the plates, they slow down and stop.



The stopping distance, d, is recorded as shown below for different velocities of the electron.

Electron velocity, v *(m s^{-1})*	*Stopping distance, d* *(μm)*	*Square of electron velocity, v^2* *(m^2 s^{-2})*
1000	1.9	
2000	8	
3000	17	
4000	31	
5000	46	

(a) Complete the table. **1**

Question 24 continues on page 26

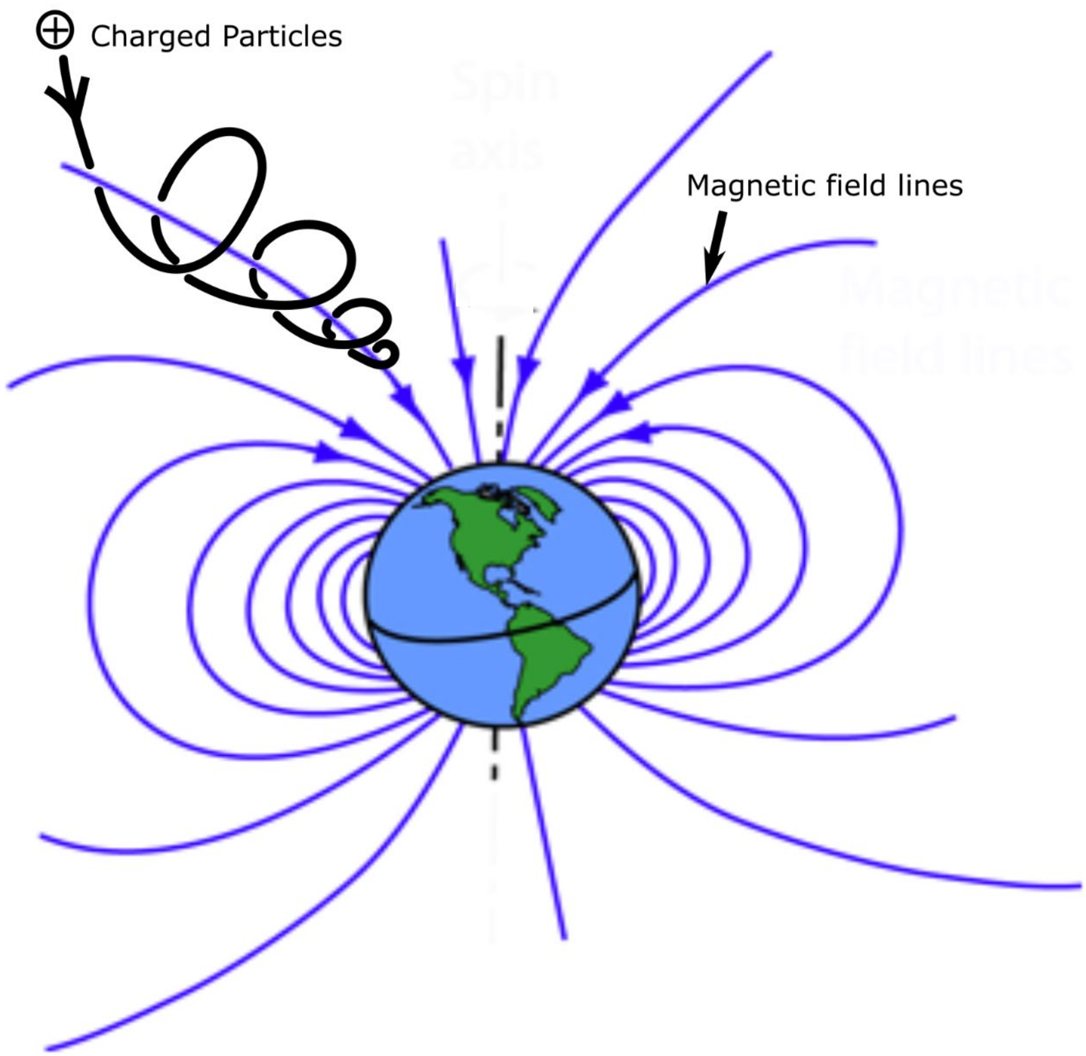
(b) Plot a graph of the square of the electron velocity and the stopping distance and draw the line of best fit. **4**

(c) Derive an expression for the relationship between electron velocity and stopping distance in terms of the mass and charge on the electron and the electric field strength. **2**

(d) Use the graph and diagram to determine the electric field $\vec{E}$, between plates A and B. **3**

Question 25 (6 marks)

Auroras can be viewed as coloured lights in the sky at the North and South Poles. They are caused by charged particles ejected from the Sun as part of the solar wind. When the charged particles come close to the Earth, they can spiral inwards around the Earth's magnetic field lines and then interact with gases in the atmosphere to produce coloured lights.



Question 25 continues on page 28

(a) With references to the force(s) on a hydrogen nucleus shown above, explain the motion of the charged particle when it is close to the Earth but before it reaches the atmosphere. **4**

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(b) Outline qualitatively how the motion of an electron from the solar wind would differ from the motion of a hydrogen nucleus once it reaches the Earth's magnetic field. **2**

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End of Question 25

Question 26 (4 marks)

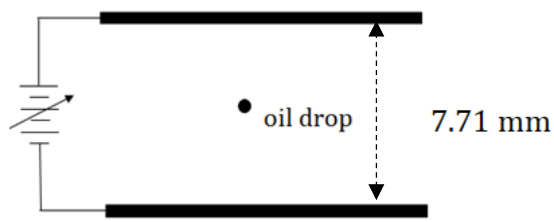
A toy car with a DC motor is connected to a 9 V battery. A child switches on the car while it is held in the air and the motor starts to spin freely. The car is then placed on some grass and the car starts to move. As the grass gets caught in the axle of the wheels, the motor stops spinning. The child picks up the car and switches off the motor. **4**

Describe the changes to back EMF that occur to the motor during this time.

Car's motion	*Description of back EMF*
Car is switched off	…………………………………………………………………………… …………………………………………………………………………… ……………………………………………………………………………
Car is switched on an held in the air	…………………………………………………………………………… …………………………………………………………………………… ……………………………………………………………………………
Car is moving on grass	…………………………………………………………………………… …………………………………………………………………………… ……………………………………………………………………………
Car is stationary on grass	…………………………………………………………………………… …………………………………………………………………………… ……………………………………………………………………………
Car is switched off	…………………………………………………………………………… …………………………………………………………………………… ……………………………………………………………………………

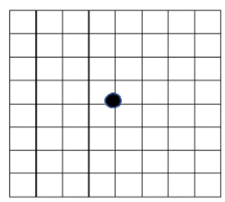
Question 27 (6 marks)

In an experiment to measure the charge of an electron, a student allows many tiny oil drops to enter the space between two horizontal plates connected to a variable voltage supply.



Initially there is no potential difference between the plates and the student chooses an oil drop and, using a microscope, watches as it slowly falls, measuring its speed. The student determines that the speed is constant at 0.0313 mm s^{-1}.

(a) On the grid below, draw a free body diagram showing all the forces acting on the oil drop as it falls. **1**



Using the speed of the oil drop and other known quantities the student calculates the mass of the oil drop as 2.93×10^{-15} kg. The oil drop is exposed briefly to radiation and it captures one or more electrons and hence becomes negatively charged.

The student then adjusts the potential difference between the plates until the oil drop is stationary. The voltage at which this occurs is 346 V.

(b) Name the two forces now acting on the oil drop. **2**

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(c) Calculate the electric charge of the oil drop. **2**

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Question 27 continues on page 31

(d) The student continues to carry out Millikan's oil drop experiment and obtains the following results for the charges on the oil drops that were investigated. **1**

9.6×10^{-19} C $\quad$ 12.8×10^{-19} C $\quad$ 3.2×10^{-19} C

State how the student's results supported Millikan's conclusion.

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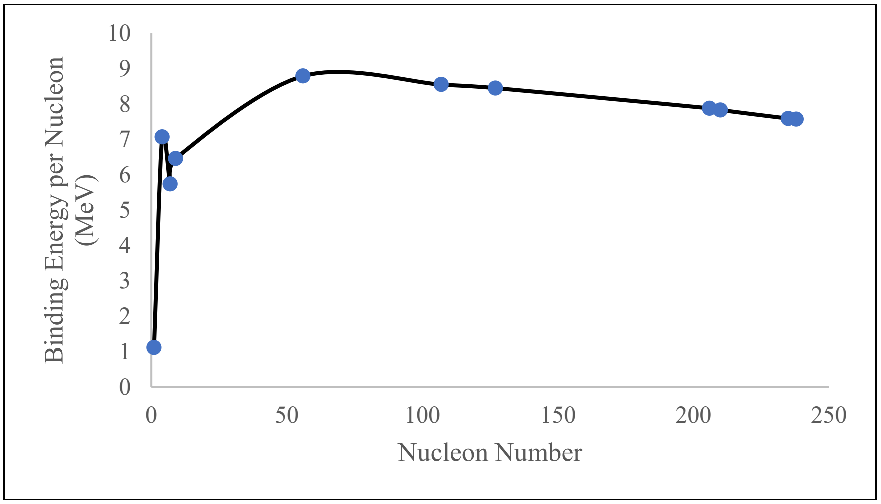
End of Question 27

Question 28 (5 marks)

(a) The graph shows the binding energy per nucleon as a function of nucleon number. **3**



Using this diagram, account for the release of energy in fission and fusion reactions.

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(a) Consider one of the reactions in the proton-proton chain reaction and the data below:

$$^{2}_{1}\mathrm{H} + ^{1}_{1}\mathrm{H} \rightarrow ^{3}_{2}\mathrm{He} + \gamma$$

Binding energy per nucleon for deuterium ($^{2}_{1}\mathrm{H}$) is 1.1 MeV .
Binding energy per nucleon for helium-3 ($^{3}_{2}\mathrm{He}$) is 2.6 MeV.

Calculate the energy released in the above reaction. **2**

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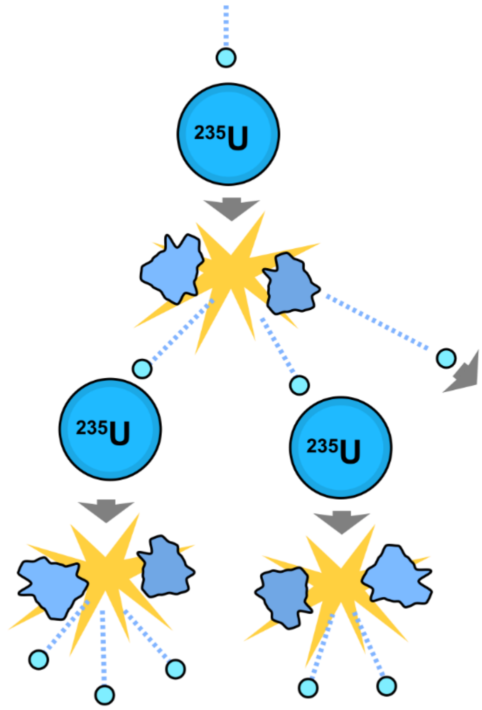
Question 29 (4 marks)

The diagram shows a model of nuclear fission. **4**



Relate this model to the concepts of controlled and uncontrolled chain reactions.

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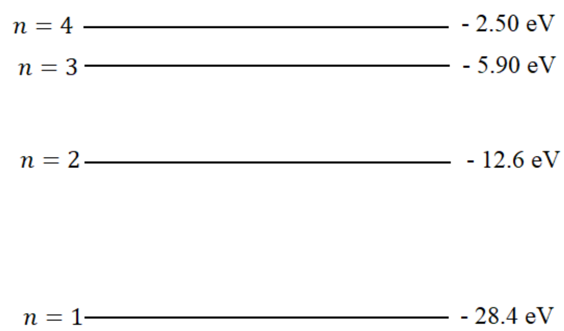
Question 30 (6 marks)

When gaseous mercury atoms are excited, they emit photons of varying wavelengths. Some of the energy levels in a mercury atom are shown in the diagram below.



(a) On the diagram above, show all the possible downward electron transitions that can occur in a mercury atom after a successful collision with an incoming 22.5 eV photon. Justify your reasoning. **2**

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The mercury lamp is then used to produce light which is first fed through a filter that eliminates all wavelengths except those produced from the $n = 2$ to $n = 1$ transition. The resultant light is then shone onto a potassium metal plate whose work function is 2.00 eV.

(b) Calculate the wavelength of the photon that strikes the potassium metal plate. **2**

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(c) Calculate the maximum velocity of any electrons liberated from the potassium metal plate. Ignore relativistic effects. **2**

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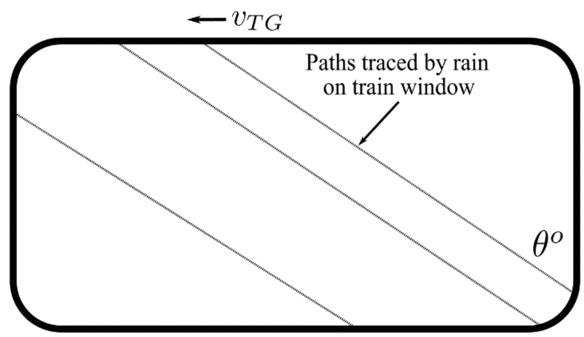
Question 31 (3 Marks)

A student standing in the rain on a windless day measures the velocity of raindrops to be v_{RG} directly downwards. Another student travelling on a train moving with a velocity of v_{TG} to the left relative to the ground observes that the apparent direction that the rain is arriving from is θ° to the vertical.



a) Construct an equation which relates v_{TG}, v_{RG} and the angle θ°. **1**

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A similar effect is observed when light arriving from stars is observed from the Earth. The apparent direction of the starlight (that is, the apparent position of the star) changes as the direction of the Earth's motion around the sun changes over a year (Figure 1). The largest shift in position, of $0^o 0' 20.5"$, occurs for stars near the poles (Figure 2).

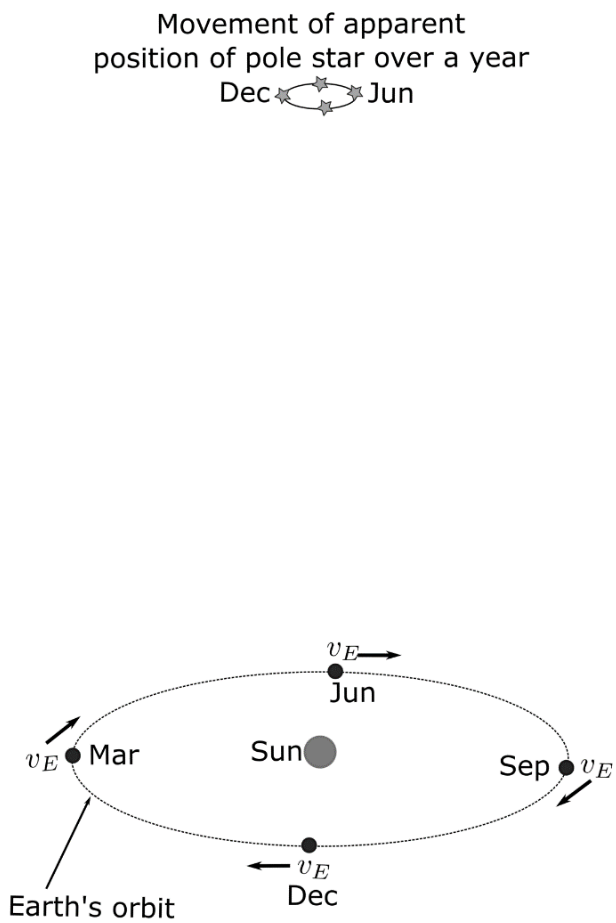

Figure 1

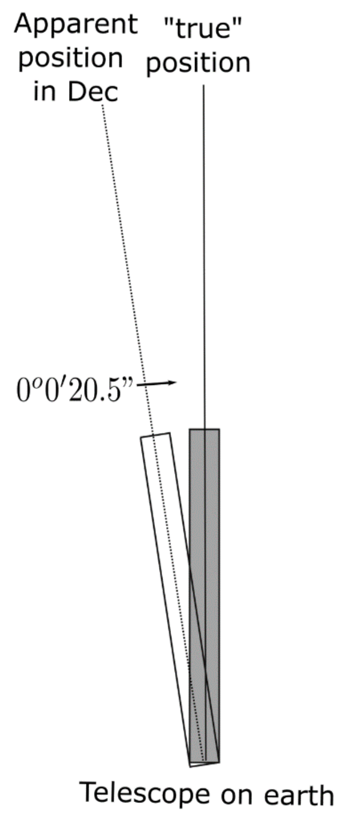

Figure 2

Question 31 continues on page 36

(b) Showing all working, determine the speed of light from the information above if the distance from the Earth to the Sun is known to be $r_E = 1.5 \times 10^{11}$m, and its orbital period around the sun is $T = 365.25$ days. **2**

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End of question 31

Question 32 (7 Marks)

In the future, the human race decides to construct an artificial "ringworld" around a newly discovered star (Neos). The ring world will consist of a thin cylinder with a radius R that completely encircles Neos (Figure 1). While the Sun is a "G-class" star, the new star Neos is an "A-class" star (Figure 2).
Human inhabitants will colonise the inner face of the cylinder that faces Neos. Artificial gravity will be produced by rotating the ring at a speed v and the radius of the ring will be chosen to ensure that the intensity of light on the inner surface is the same as that on Earth.

Use the following information to answer this question:

Earth's distance from the Sun, r_E ………………… 1.5×10^{11} m

Mass of Neos …………………………………….. 4.0×10^{30} kg

Surface area of a sphere ………………………….. $4\pi r^2$

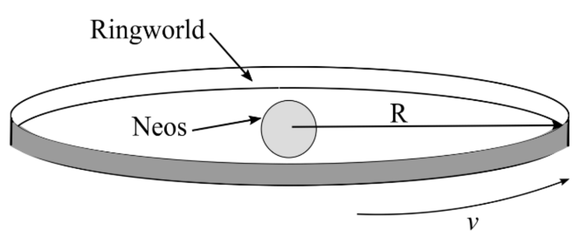

Figure 1: The "ringworld" around the star Neos

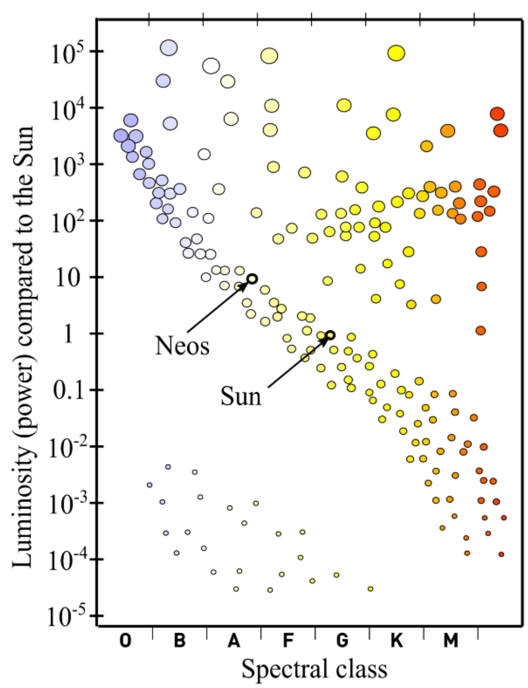

Figure 2: Hertzspring-Russell diagram

Question 32 continues on page 38

(a) Show, with working, that the intensity of light on the surface of the ringworld will be the same as the intensity on Earth if the radius of the ringworld is $R = 4.7 \times 10^{11}$ m. **1**

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(b) Identify how the electromagnetic radiation experienced by the inhabitants of the ringworld will be different from that they would experience on Earth. **1**

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(c) Calculate the escape velocity for an object at a distance R from Neos. **2**

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Question 32 continues on page 39

(d) Explain how rotating the ring can provide the sensation of weight for the inhabitants and determine the speed, v, at which the ring should spin to produce artificial gravity that will mimic that experienced on the surface of Earth. **3**

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Question 32 continues on page 40

(e) Draw the trajectory (path) taken by an inhabitant who accidentally stepped off the side of the ring at position X. Explain why the trajectory you have drawn is correct. **2**

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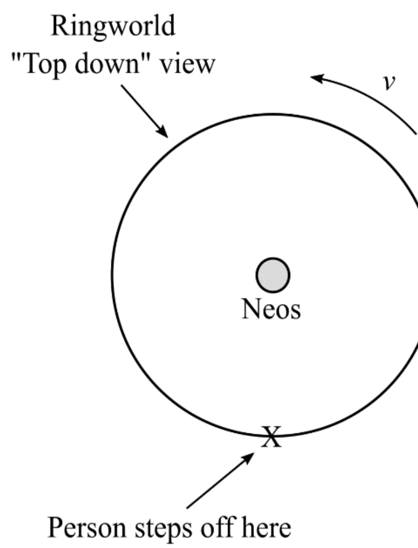
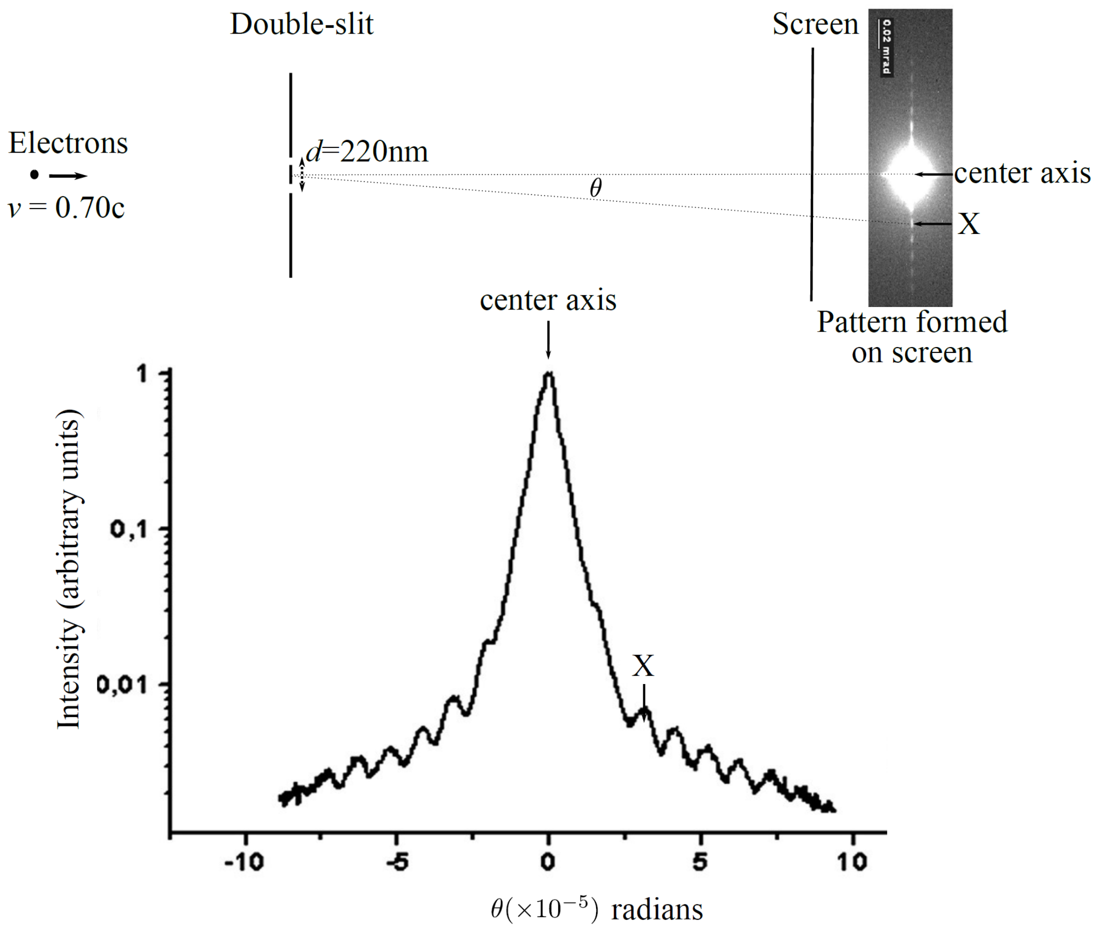


End of question 32

Question 33 (5 marks)

In an experiment, electrons with a velocity of $0.70c$ pass through a double slit so that they arrive at a screen to form the interference pattern shown. The intensity of the pattern is graphed as a function of the angle θ from the centre axis of the experiment.
The maxima marked with an 'X' is the third order maxima of the pattern (the 0^{th}, 1^{st} and 2^{nd} order maxima have been obscured by some direct transmission of the electron beam straight through the double slit material).



https://aapt.scitation.org/doi/10.1119/1.2757621

a) Show that the momentum of the electrons is $p = 2.7 \times 10^{-22}$ kg ms^{-1}. **1**

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Question 33 continues on page 42

De Broglie proposed that matter exhibits wave-like properties according to $\lambda = \frac{h}{p}$.

b) Describe how the data from this experiment provides qualitative evidence to support this proposal. **1**

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c) Explain how the data from this experiment provides quantitative evidence to support this proposal. **3**

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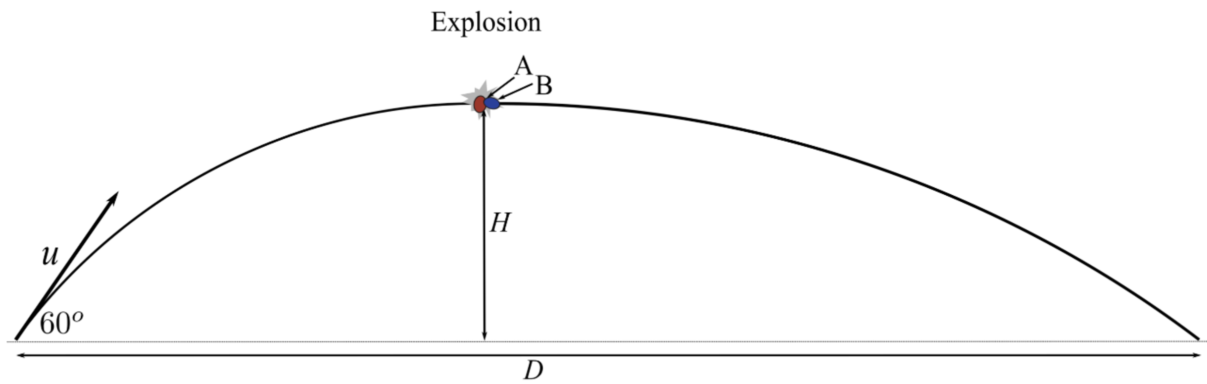
End of Question 33

Question 34 (7 Marks)

A 1 kg explosive device is fired at an angle of 60 degrees with a speed of $u = 30\ ms^{-1}$ into the air. When it reaches its maximum height, H, it explodes into two pieces (A and B), each of mass 0.5 kg. Piece A has zero velocity immediately after the explosion. Assume air resistance is negligible.



a) Determine the maximum height H reached by the device. **2**

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Question 34 continues on page 44

b) Apply conservation of momentum and conservation of energy to calculate the mass defect due to the conversion of chemical energy to other forms of energy during the explosion. **4**

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c) Is the momentum of piece B conserved after the explosion? Explain why or why not. **1**

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END OF PAPER

Section II extra writing space

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

Trial marking schemes

Multiple Choice Answer Sheet

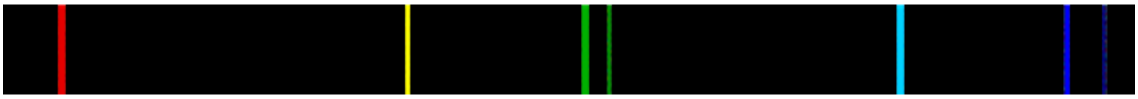
1.	A ○	B ○	C ○	D ●
2.	A ○	B ○	C ●	D ○
3.	A ○	B ●	C ○	D ○
4.	A ●	B ○	C ○	D ○
5.	A ○	B ●	C ○	D ○
6.	A ○	B ●	C ○	D ○
7.	A ○	B ●	C ○	D ○
8.	A ○	B ○	C ●	D ○
9.	A ○	B ○	C ●	D ○
10.	A ●	B ○	C ○	D ○
11.	A ○	B ○	C ○	D ●
12.	A ○	B ○	C ●	D ○
13.	A ○	B ●	C ○	D ○
14.	A ●	B ○	C ○	D ○
15	A ●	B ○	C ○	D ○
16.	A ○	B ○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

Extended response

Question 21 (5 marks)

A

B



a) Name the two types of spectra shown above (2 marks)

A:________________________

B:________________________

b) Describe how the two spectra shown can be produced and observed in a science classroom (3 marks)

Answer:

A: Continuous (black body) spectrum

B: Emission spectrum

Criteria	Marks
Correctly identifies both types of spectra	2
Correctly identifies one of the spectra	1

Mark distribution:

Marks	0	1	2		
% students	0	16	84		

Range: 1-2; Average: 1.8

Visible light spectrum, full spectrum or complete spectrum was not accepted.

b)

To produce a continuous spectra, a voltage was applied to an incandescent filament so that it heated up and visibly glowed (alternatively, reflected sunlight from a white surface was viewed).

To produce an emission spectra, a high voltage was applied to a spectral tube containing gas.

To observe the spectra a diffraction grating is used (to allow different colours to interfere constructively at different angles).

Criteria	Marks
Identifies how to produce: - Emission spectra - Continuous spectra Identifies how these may be observed (diffraction grating/spectroscope)	3
Identifies two of the above	2
Provides relevant information	1

Mark distribution:

Marks	0	1	2	3	
% students	5	5	23	67	

Range: 0-3; Average: 2.5

Need to identify a tool used to make observations of spectra.

Can't be vague regarding what light source is being analysed, where did the light come from?

Question 22

a) $t_0 = \frac{2L_0}{c}$

Mark distribution:

Marks	0	1			
% students	17	83			

Range: 0-1; Average: 0.8

b)

- Light travels the same speed in the reference frame of the observer and the moving light clock.
- The observer sees light take a longer path in the moving clock than in the stationary clock.
- v = d/t so the observer sees light taking a longer time to move between the emitter and detector in the moving clock than it takes for his own clock.

Criteria	Marks
- Light travels the same speed (c) in both reference frames - The observer sees light travel a greater distance in the moving clock - Application of v = d/t to argue that time between ticks is longer in moving clock	3
TWO of the above	2
ONE of the above	1

Mark distribution:

Marks	0	1	2	3	
% students	5	8	37	50	

Range: 0-3; Average: 2.3

Most responses were well-rounded and clear. Missing details such as stating that c is constant in both reference frames, and the application of v = d/t, by assuming that these details were given, will not support the conclusion of time dilation.

c) The effect is time dilation.

Criteria	Marks
Identifies the effect as time dilation	1

Mark distribution:

Marks	0	1			
% students	12	88			

Range: 0-1; Average: 0.9

Need to be specific to the experiment mentioned in the question.

d) Muons are unstable particles that can be created as a result of the interaction of cosmic rays with the upper atmosphere. When at rest their lifetime is 2.2μs. In 1941 Rossi and Hall measured the flux of muons travelling at 0.994c at the top of Mount Evans in Colorado and compared it to the flux of muons at a lower altitude in Denver. Many more muons were detected than would be expected from their short lifetime before they decay. The result could only be explained by assuming that in the earth's frame of reference the muon lifetime was increased due to time dilation. (References: Video made by Rossi and Hall: Time Dilation -- An experiment with μ-mesons (1962): https://www.youtube.com/watch?v=O4v_h1dTNsY and original paper: http://spiff.rit.edu/classes/phys314/lectures/muon/rossi.pdf)
OR
In 1971 Hafele and Keating flew four atomic clocks around the world on commercial flights both eastwards and westwards. They compared the time that passed on these clocks compared to identical atomic clocks left behind on the ground at the US Naval observatory. It was found that the moving clocks exhibited time dilation to an extent consistent with the predictions of special relativity. (See abstract of original papers: http://www.personal.psu.edu/rq9/HOW/Atomic_Clocks_Predictions.pdf and http://personal.psu.edu/rq9/HOW/Atomic_Clocks_Experiment.pdf)

Criteria	Marks
Describes a relevant experiment in detail, explaining clearly and succinctly how it demonstrates time-dilation.	2

Outlines a relevant experiment.	1

Mark distribution:

Marks	0	1	2		
% students	3	21	76		

Range: 0-2; Average: 1.7

All responses could have been more detailed!

Question 23

Sample Answer

(a) A small, dense, centrally situated, positively charged nucleus, with electrons orbiting around it at a distance. The atom is mostly empty space.

Criteria	Mark
Outlines key features of the model	2
States a feature of the model	1

Mark distribution:

Marks	0	1	2		
% students	5	46	49		

Range: 0-2; Average: 1.4

Most responses did not clearly state that the atom was mostly empty space (can not be implied!).

Some missing critical details are the charge of the nucleus and the presence of electrons.

There are NO neutrons in Rutherford's model!!

(b) Rutherford's model could not explain the hydrogen emission lines.

Bohr's model placed electrons into quantised energy shells. When electrons moved from a higher to a lower shell, they released energy. This energy corresponded to the frequencies in the emission spectra.

Rutherford's model could not explain why electrons orbiting in circular orbits do not radiate energy (while accelerating) and hence spiral into the nucleus. Bohr postulated that electrons orbit the nucleus in fixed, stationary, stable, quantized orbits (without radiating energy while in orbit).

Criteria	Mark
Identifies one limitation of Rutherford's model and explains the relevant Bohr's postulate to account for the limitation	3
Identifies one limitation of Rutherford's model or identifies a relevant Bohr's postulate to account for a limitation	2
Identifies a feature of Bohr's model (or a feature of Rutherford's model)	1

Mark distribution:

Marks	0	1	2	3	
% students	2	14	59	25	

Range: 0-3; Average: 2.1

Responses needed to identify the limitation of the use of Rutherford's model and how this limitation can not be accounted for in the components of his model.

Identify components of Bohr's model which enabled his model to be used to explain what Rutherford's model could not, this could be done by stating Bohr's postulates.

Question 24

(a)

Criteria	Marks
Correctly completes table	1

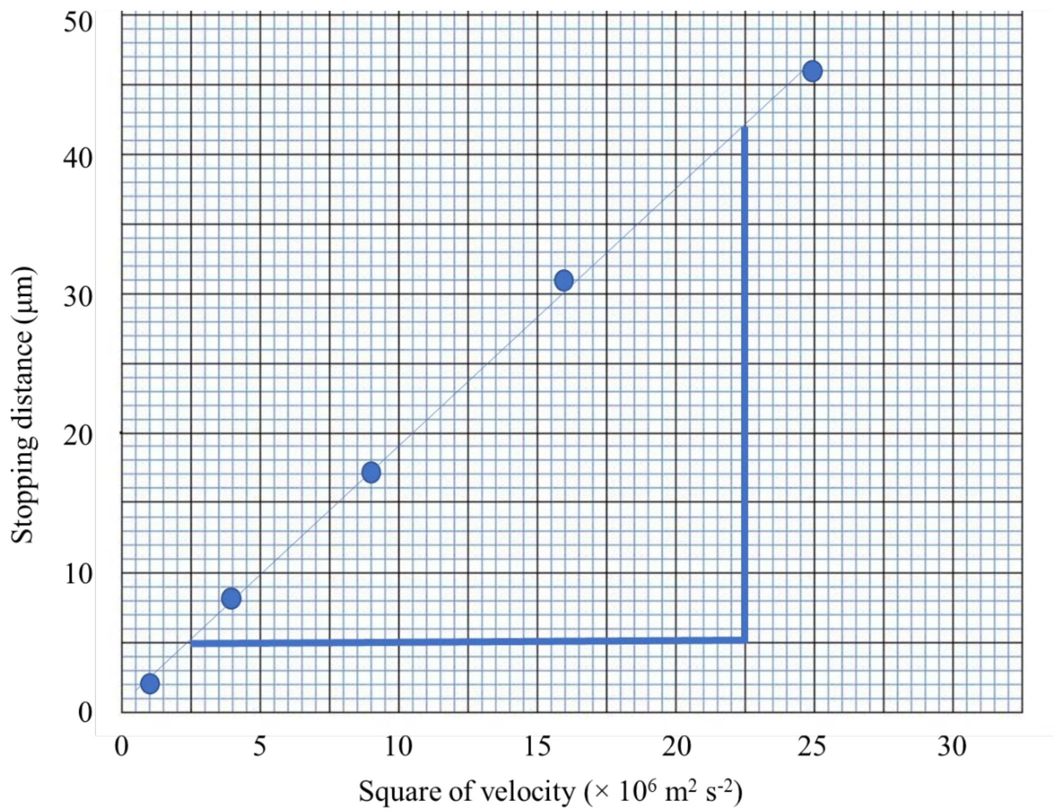
Electron velocity, v *($m\ s^{-1}$)*	*Stopping distance, d* *(μm)*	*Square of electron velocity, v^2 ($m^2\ s^{-2}$)*
1000	1.9	1×10^6
2000	8	4×10^6
3000	17	9×10^6
4000	31	1.6×10^7
5000	46	2.5×10^7

Range: 1-1; average: 1

Comments: Do not alter the headings in a supplied table. Scientific notation would be good here.

(b)

Criteria	Marks
Labelled axes with units Graph of suitable linear scale Points correctly plotted Line of best fit drawn	4
3 of the above	3
2 of the above	2
1 of the above	1



Range: 3-4; average: 3.9

When including multiples in the labels, they belong inside the brackets as shown in the sample answer. If you have them outside, then it means that you have multiplied the number by that factor to get the number you are plotting. It is best to choose a scale that is based on the number of divisions in the graph, in this case 5. Don't go beyond the edge of the graph paper.

(c)

Criteria	Marks
Correctly derives expression	2
Calculates work done or change in KE	1

Work done = F.s = qEd

Work done = Δ KE = ½ mv^2

½ mv^2 = qEd

v^2 = 2qEd/m or d = mv^2/2qE

Range: 0-2; average: 1.7

Comments: most students were able to derive an equation showing the relationship between the variables v (velocity) and d (stopping distance). It is best to put the two variables on different sides of the equation (e.g. make one variable the subject of the equation)

(d)

Criteria	Mark
Uses graph to correctly calculate gradient Correctly calculates magnitude of E (1.4-1.6 NC^{-1}) Gives correct direction of E	3
Two of the above	2
One of the above	1

Gradient = m/2qE (d vs v^2) or 2qE/m (v^2 vs d)

Gradient from graph = rise/run = $(42-5)*1x10^{-6}/(22.5-2.5)*1x10^{6} = 37/20 * 10^{-12}\ m^{-1}\ s^2$

$= 1.85 \times 10^{-12}\ m^{-1}\ s^2$

$m/2qE = 1.85 \times 10^{-12}$ E=m/(2q*gradient)

E $= 9.1 \times 10^{-31}/(2 \times 1.6 \times 10^{-19} \times 1.85 \times 10^{-12})$

$= 1.54\ N\ C^{-1}$ or $V\ m^{-1}$ to the right

Range: 0-3; average: 1.6

Comments: if the quantity has units and direction, please include them. This question was marked for direction, not units, but you should still have them there (and correct!). Try to use a large portion of your line of best fit (never a data point provided) to reduce the size of the error. Some students mixed up velocity (v) and voltage (V) when doing this question.

Question 25

(a)

Criteria	Marks
Explains the effect on the component of the velocity parallel to the B field Explains the effect on the component of the velocity perpendicular to the B field Explains the direction of helical motion Explains the effect of increasing strength of B field Explains at least one other effect of a force acting on the particle	4
3-4 of the above	3
Outlines 2 of the above	2

Identifies 1 relevant force contributing to motion OR Identifies the property of one field that affects the motion	1

The hydrogen nucleus experiences a force as a charged particle moving through a magnetic field ($F = qvB \sin \theta$). The component of the velocity which is parallel to the magnetic field is not changed by the magnetic field. The component of the velocity which is perpendicular to the magnetic field results in a force perpendicular to the velocity according to the right hand rule, in this case for a positive charge it is in an anticlockwise motion when looking towards the Earth. Together, this results in the helical motion shown. As the Earth's magnetic field gets stronger, the radius of the motion decreases $qvB = mv^2/r$ or $qB=mv/r$ (B is inversely proportional to r), so the helical movement spirals inwards.

As the particle moves towards the Earth, it is accelerating due to gravitational attraction (however, as the proton is travelling at relativistic velocity, it will be observed as an increase in mass). As the particle has not encountered the atmosphere, there is negligible friction opposing the motion. As the charge is accelerating, it is radiating EMR, reducing its kinetic energy (again, at relativistic velocity this will have negligible impact on reducing the radius of motion). As the particle is entering a region of stronger magnetic field, there is a force opposing the motion which reduces the pitch of the helix (magnetic mirror).

Range: 0-3; average 2.1

Comments: many capable students did not make full use of the stimulus and so were unable to gain full marks. Most students were able to identify that a charged particle moving perpendicular to field lines (doesn't have to be constant B field) experiences a force which will result in circular motion. There were also a number of misconceptions that students demonstrated in their written explanations. A number of students confused the effect of force on velocity and acceleration. In particular, they relied on a force towards the Earth (e.g. gravity) to explain why the circular motion became a helical motion. Others seemed to think that acceleration due to gravity would result in a change to the radius (it affects the velocity towards the Earth, in a similar way to projectile motion). Some students also confused some of the properties of electric and magnetic fields. The magnetic field shows the direction a North pole experiences a force, but that doesn't mean that it moves along the field line, as it may already have motion in another direction. But in this question, there was a positive charge, not a test North pole.

(b)

Criteria	Marks
Identifies different direction of helix Outlines factors which could result in different radius	2

One of the above	1

The electron has the opposite chare to the proton, so will rotate in the opposite direction as it approaches the Earth. It has a much higher charge-to -mass ratio, so will have a much tighter radius for the same velocity (which we are not given)

Range: 0-2; average: 1.1

Comments: Many students identified that electrons had a different charge or mass to a proton, but not both. A few students confused a hydrogen nucleus (generally a proton) with a helium nucleus (generally 2 protons and 2 neutrons). Since this was a qualitative question, they weren't penalised, but some revision here would be useful. Again, there were students confusing electric and magnetic fields, with a number of students stating that the electron would either be attracted to the South pole, spiral along the field lines to the South pole, be repelled from the North pole etc. Some students stated that the motion would be opposite, which is ambiguous (does it mean clockwise/anticlockwise and inwards/outwards). Some students thought that the electron would spiral outwards. Some students thought that because the gravitational attraction of an electron to the Earth was lower than that of a proton (it is), it would accelerate more slowly (it won't, because the mass is less).

Question 26

Criteria	Marks
Describes back EMF when motor is off Describes back EMF when motor is switched on Describes back EMF when load is applied Describes back EMF when motor is on but not spinning	4
Outlines 3 of the above	3
Identifies 2 of the above	2
Some relevant information	1

Before the motor is switched on, EMF and back EMF are zero.

As the motor is switched on (there is a short-lived large back EMF) and starts to spin freely, EMF is large (~9V) and back EMF increases to a constant value (a little less than 9V). It varies periodically with the angular rotation of the motor.

When the car is put on the ground (load is placed) the back EMF reduces significantly as does the angular rotation of the motor. The motor speed decreases as the car slows down due to grass in its axle, back EMF is reduced.

When the car stops moving (due to more grass wrapped around the axle) the motor stops spinning, at which point the back EMF is zero.

When the motor is switched off, the back EMF is zero.

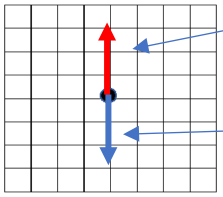
Range: 1-3; average: 2.6

Comments: Most students had a good understanding of back EMF, but did not fully engage with the stimulus, or had a few minor issues that need correcting. In this question, a real (non-ideal) motor is used. There would be some internal resistance and some friction in the axle, so even with no applied load, the back EMF would not reach the supply voltage (in this case 9V). Although back EMF varies periodically, it isn't sinusoidal unless you have an AC motor with a uniform B field. A DC motor with a uniform B field with be a rectified sinusoid, and the functional form would be different if the B field were not uniform. You weren't required to discuss the functional form, but there it is. Describe means to provide features and characteristics, not explain. Maximum speed of the car on the ground doesn't mean maximum speed of the motor (that would be when the car was in the air with no load). When a load is applied, the rotation of the motor slows, hence back EMF reduces, net EMF increases and the current goes up and more power is delivered. Some students identified that back EMF reduces in order to increase the current rather than an increase in the current being a consequence of lowered back EMF.

Question 27 (Average : 4.6 range 0 - 6)

1 (a) Red arrow – drag force (upwards)

Blue arrow – weight force (downwards)



Criteria	Marks
For 2 correctly labelled forces , including equal magnitudes (equal length) and direction	1

Comment:

About one third of the cohort got the full mark in part (a).

Common errors were:

(i) no labels provided, or if indicated then symbols like F_g *or* F_r *or* w were not accepted

(ii) only the weight force was shown

(iii) unequal lengths for the vectors drawn (recall constant velocity implies no acceleration and hence the forces are balanced). Note the grid was provided for a reason.

(b) Upward force due to the electric field (just Electric field only – not accepted)

Downward force of gravity

Criteria	Marks
For identifying two correct forces	2
For identifying 1 force correctly	1

Comments:

Average mark: 1.8 ; range (0 – 2)

Common errors

(i) Not specific enough to identify the upward force – just electric field was not accepted.

(ii) Just electric was used by many students, which was just accepted.

(c) $q = \frac{mgd}{V} = \frac{2.93\times10^{-15}\times9.8\times7.71\times10^{-3}}{346} = 6.4 \times 10^{-19}\ C$

Criteria	Marks
For correct substitution into correct formula, and correct charge, including units	2
Provides some relevant information ($Eq = mg$, not accepted as relevant information)	1

Comments:

Average mark: 1.6 ; range (0 – 2)

Common errors:

(i) lack of full substitution

(ii) not realising that the strength of the electric field is given by $\frac{V}{d}$

(iii) units omitted, or expressed as eV.

(d) The charge on the oil drop is an integral multiple of the charge on the electron, i.e. $q_{oil\ drop} \approx n\ q_{electron}$ which supports Millikan's conclusion.

Just stating that the charge on the electron is quantised was not accepted.

Criteria	Marks
For correct comparison	1

Comments:

Average mark: 0.93 ; range (0 – 1)

Overall well done

Question 28 (Average : 2.7 range 0 – 5)

(a)

The binding energy of a nucleon is a measure of the strength of the bond between a nuclear force and the nucleus. For a typical nucleus the binding energy is equivalent to the mass defect by the formula $E = \Delta mc^2$. (1 MARK)

For elements below Fe-56 the joining together of atoms produces nuclei with higher binding energy per nucleon producing energy. This is called nuclear fusion. (1 MARK)

For elements larger than Fe-56, which are split into two new smaller nuclei, the binding energy per nucleon is greater than the average binding energy, again releasing energy. This is called nuclear fission. (1 MARK)

Marking Criteria	Mark
Accounts for the release of energy in fission and fusion reactions, with reference to the diagram	3
Provides a reason for the release of energy in fission or fusion, with reference t diagram OR shows some understanding of binding energy and/or mass defect and/or fusion and/or fission	2
Shows a basic understanding of the energy associated with nuclear reactions OR provides some relevant information	1

Comments:

Average mark: 1.46; range (0 – 3)

A large majority of the students were often interchanging binding energy with binding energy per nucleon. The features of the graph were often not utilised to its optimum. In both fusion and fission, the binding energy per nucleon (vertical axis) increases, from left to right (fusion) before Fe-56 and from right to left(fission), before Fe-56. The mass of the fission products is less than the mass of the reactants and in the process the more stable nuclides have higher binding energy per nucleon.

In fusion, the larger nucleus that is formed has a greater binding energy and less mass per nucleon than the two that combined. Thus mass is “destroyed” in the fusion reaction, and energy is released

Most students did not expand on the idea about the equivalence of mass and energy, and in particular the mass defect being the energy equivalent of the binding energy.

(b)

Energy released = 2.6 x 3 – 1.1 x 2 – 0 = 5.6 MeV

Marking Criteria	Marks
Correct energy released	2
Provides some relevant information (i.e. implies that energy released is BE (products) minus BE (reactants) or uses correct BE for any nuclide) No marks were awarded if BEN (products) – BEN (reactants)	1

Comments

Average: 1.26 ; range (0 – 2)

Very few students explicitly stated that the BEN for H-1 is zero.

Students who did get the right answer may have figured out that since it is not given it was not expected to be used.

Once again, a poor understanding of binding energy per nucleon resuled in students not being able to calculate the binding energy.

Question 29 (average: 3.1 ; range 1 - 4)

Sample answer:

The model shows:

- A neutron colliding with a Uranium 235 atom and causing fission
- More than one neutron is emitted (neutron multiplication). In this model three neutrons are emitted in the first fission reaction. One is “lost” (not used in further fissions) while the other two each collide with an atom to produce two more fission reactions which each release either two or three neutrons.

In both controlled and uncontrolled nuclear chain reactions, a neutron is used to initiate fission as shown in the model.

In an uncontrolled nuclear reaction, each fission reaction goes on to produce more than one reaction, on average. The “multiplication factor” (the ratio of neutrons in each generation of fission reactions) $k > 1$ (supercritical), so rate of energy release increases over time. This situation is shown in the model as more than one neutron from the first reaction goes on to produce a new fission reaction.

In a controlled reaction, exactly one new fission reaction is produced, on average, by each fission event. The multiplication factor, $k = 1$ (critical). The model could be adapted to represent a controlled reaction if two of the neutrons released “escaped” (absorbed) and only one went on to produce a new fission reaction.

Marking scheme (essentially mirrored from the HSC question):

Criteria	Marks
● Relates features of the model to both controlled and uncontrolled nuclear chain reactions (a) Neutron to initiate fission (b) Uncontrolled : $k > 1$, neutrons go on to initiate more fissions (supercritical) (c) Controlled : $k = 1$, only 1 of the resulting neutrons go on to produce 1 fission event, others absorbed ; OR there is a critical mass of the fissile substance present (d) Relates all this to the diagram (shows connection)	4
● Relates the model to either controlled or uncontrolled nuclear chain reactions **AND** ● Identifies another feature of controlled or uncontrolled nuclear chain reactions **OR** ● Identifies another feature of the model	3
● Identifies feature(s) of the model AND/OR ● Identifies feature(s) of controlled or uncontrolled chain reactions	2
● Provides some relevant information	1

Comments:

It is important to use the model and outline exactly what is being represented. Those who were able to do this were often successful in gaining full marks. The question says “Relate”, so one needs to show a connection between what is being modelled and the concepts of controlled and uncontrolled chain reactions.

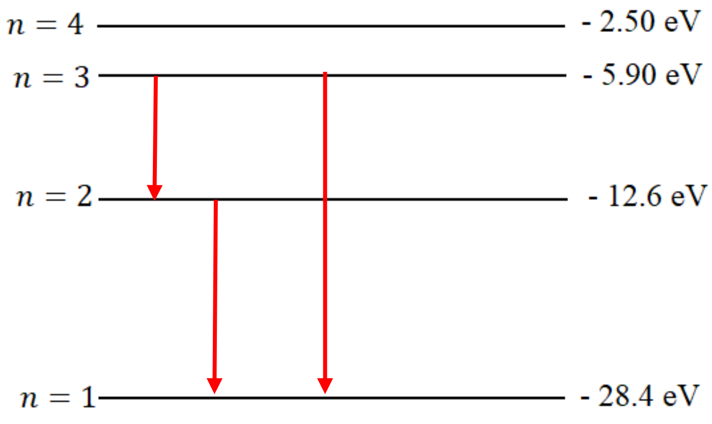
The fair number of students were unable to specifically mention what happens to the lone neutron on the diagram does not “instigate” further fissions.

Some students who attempted to describe what happens to the lone neutron, incorrectly linked the use of moderators to the absorption of neutrons. Moderators serve to thermalise the fast neutrons to lower speeds to increase the probability of being captured by a nuclide.

Using vague words like many/multiple neutrons are produced in a fission reaction, as opposed to 2 to 3 on average, and “the neutrons are limited” were less likely to gain maximum marks.

Question 30 **(average: 3.5 ; range: (0 – 6)**

(a)



3 to 1: $\Delta E = 22.5\ eV = 28.4 - 5.9$ which is the maximum the electron absorbed during the excitation stage to the $n = 3\ level$.

Hence downward transitions (de-excitations) could occur from level 3 to 2, or from level 2 to 1 or from level 3 to 1

Criteria	Marks
For correctly predicting all 3 transitions with justification	2
For correctly predicting all 3 transitions with limited justification Or Provides some relevant information	1

Comments

Average: 0.76; range 0 – 2

The most common way that students did not get maximum for this question was due to their poor justification. Merely stating that 22.5 eV was sufficient to enable the electron to transition between levels 3 and 1 was not sufficient. The actual subtraction, which good students had shown, was a more convincing argument to present.

There was also some degree of confusion between absorption of energy resulting in excitation to a higher level and subsequent downward transition due to instability. Some students had their arrow pointing upwards.

There were 3 transitions and it would be better to separate the transitions for ease of viewing.

Showing just one downward transition from level 3 to 1 was just sufficient to earn 1 mark if the justification was poor.

(c) Using the n = 2 to n = 1 transition ($\Delta E = 28.4\ eV - 12.6\ eV = 15.8\ eV$)

$$\lambda = \frac{hc}{E} = \frac{6.626\times10^{-34}\times3\times10^{8}}{15.8\times1.602\times10^{-19}} = 78.5\ nm$$

Criteria	Marks
For correct computation of wavelength (correct substitution into correct formula)	2
Provides some relevant information	1

Comments:

Average: 1.2 ; range (0 – 2)

Many students failed to read the question carefully. It clearly states the transition considered is from n = 2 to 1for the Hg lamp to then emit this light onto a potassium metal.

To calculate the wavelength of this emitted light, a large number of students used the Rydberg formula ($\lambda = R_H\left(\frac{1}{n_f^2} - \frac{1}{n_i^2}\right)$ which in this form applies to the Hydrogen atom only. This cannot be used for mercury unless Rydberg's constant is changed. The syllabus is very clear on the use of this formula for hydrogen atom only.

Also, many students were guilty of not showing any substitution in $\lambda = \frac{hc}{\Delta E}$. Be aware you could potentially lose all marks if you do not get the right numerical value.

(c) $K_{max} = hf - \phi$

$$v_{max} = \sqrt{\frac{2\times(15.8-2)\times1.602\times10^{-19}}{9.109\times10^{-31}}} = 2.2\times10^{6}\ m\ s^{-1}$$

Criteria	Marks
Correct substitution into correct formula, and correct speed obtained	2
Provides some relevant information	1

Comments:

Average: 1.5 ; range (0 – 2)

Those students who were able to solve part (b) were all successful in part (c), which is encouraging.

Those students who used the incorrect wavelength from part (b) in part (c) were given gratis marks if their correctly went ahead and solved for the maximum velocity, although technically speaking this is absolutely incorrect.

As a good exam technique, students need to read the question carefully and if possible should underline key words to remind them what needs to be done/calculated. A fair number of students (almost 5) simply calculated the maximum kinetic energy only.

Students should also look at the reasonableness of their answers. If a speed greater than the speed of light is obtained, then go back and troubleshoot.

Question 31

Answer:

a) $v_{TG} = v_{RG}\, tan(\theta)$

Criteria	Marks
$v_{TG} = v_{RG}\, tan(\theta)$ (or equivalent equation)	1

Most students were able to do this question

Mark distribution:

Marks	0	1			
% students	5	95			

b) The orbital velocity of the earth is given by $v_E = \frac{2\pi r_E}{T} = \frac{2\pi \times 1.5 \times 10^{11}}{365.25 \times 24 \times 3600} = 3.0 \times 10^4 ms^{-1}$

The speed of light is $c = \frac{v_E}{tan(\theta)} = \frac{3 \times 10^4}{tan(0°0'20.5)} = 3.0 \times 10^8 ms^{-1}$

Criteria	Marks
Correctly calculates the orbital velocity of the earth Identifies the equation relating the speed of light, $\theta°$ and r_E, and substitutes correctly to calculate the speed of light.	2
Correctly calculates the orbital velocity of the earth OR Identifies the relationship between the speed of light, $\theta°$ and r_E	1

This question required students to:

- Recognise the analogy between the change in apparent direction of the rain for the moving observer in part a) and the change in the apparent direction of light from a star
- To convert the period from days to seconds
- To use v = 2πr/T to calculate the earth's orbital velocity
- To substitute these into an adapted version of their formula from part a)

Mark distribution:

Marks	0	1	2		
% students	17.7	12.5	71		

Question 32 Answer:

a) Intensity obeys an inverse square law, and the luminosity of Neos is 10 times greater than the sun so $\frac{10L_{sun}}{4\pi R^2} = \frac{L_{sun}}{4\pi \times r_E^2}$ so $R = \sqrt{10} \times 1.5 \times 10^{11} = 4.7 \ \times 10^{11} m.$

Criteria	Marks
• Correct working	1

This question required students to:

- Obtain relevant information provided on the Hertzsprung-Russell diagram to determine that Neos was 10x more Luminous than the Sun.
- Apply an understanding of the inverse square law for light from module 3

Mark distribution:

Marks	0	1			
% students	14.6	85.4			

b) Using Wein's law, the peak wavelength will be shorter (they will experience more UV radiation).

Criteria	Marks
• Identifies that the peak wavelength will be shorter (or equivalent statement)	1

The phrasing of this question could have been better. It was intended that students use Wein's law, but some students observed that there would be no night and day on the ringworld and this was accepted as a valid difference. Answers related to the atmosphere or lack of atmosphere were not accepted as there was no information about this provided in the question.

However, it is wise approach question with an assumption that you are being asked to respond using syllabus content!

Mark distribution:

Marks	0	1			
% students	53	47			

c) The escape velocity at a distance R from Neos is $v_{esc} = \sqrt{\frac{2GM}{R}} = 3.4 \times 10^4 ms^{-1}$.

Criteria	Marks
• Correctly calculates escape velocity	2
• Attempts to correct formula for escape velocity	1

Students had to substitute into the formula for escape velocity and evaluate this. Many students left their answer as an expression containing R. Note the word "calculate" in the question stem.

Mark distribution:

Marks	0	1	2		
% students	5.2	27.0	68.8		

d) The normal force acting upwards on the inhabitants through their feet provides the sensation of weight. This normal force acts to provide the centripetal force on the inhabitants due to the rotation of ring.
To achieve the same sensation of weight that the inhabitants would experience on earth, the normal force must be equal to mg, so the centripetal acceleration must be $9.8ms^{-2}$.
$\Sigma F = ma$, so $mg = m\frac{v^2}{R}$, and $v = \sqrt{Rg} = \sqrt{4.7 \times 10^{11} \times 9.8} = 2.1 \times 10^6 ms^{-1}$
(Note : acceleration due to gravity from Neos = GM/R^2 = 0.0012 m/s/s is negligible here.)

Criteria	Marks
• Identifies that the normal force acting on the inhabitants provides sensation of weight • Identifies that the normal force must be equal to mg (where g=9.8m/s/s) • Correct calculation of speed	3
• Two of the above	2
• Provides relevant information	1

The explanation of the origin of apparent weight was very challenging for many students.

Most students were able to identify that the ring would apply a centripetal force on the inhabitants.

However, it was common for students to then argue that there was an "equal and opposite" force acting on inhabitants due to Newton's 3rd law, which provided the sensation of weight. It is very important to note that if the ring exerts a normal force on the inhabitants to provide the centripetal force to accelerate them inwards, then the equal and opposite force is a force that acts *on the ring due to the inhabitants*. This force acts on the ring, it does NOT act on the inhabitants.

Some students attempted to discuss centrifugal force (often incorrectly identifying this as the "equal and opposite force" by Newton's 3rd law) but very few were able to do this clearly and precisely.

To discuss centrifugal force (which I would not recommend…) it would be necessary to carefully identify this as a *pseudoforce* that appears to act within the inhabitants non-inertial (rotating) reference frame). An inertial observer would only observe a centripetal force acting on the inhabitants. It is not the case that there are centrifugal and centripetal forces acting on the inhabitants in opposite directions – if there were really two forces in opposite directions that balanced, the inhabitants would move off through space with constant velocity.

Mark distribution:

Marks	0	1	2	3	
% students	8.3	12.5	42.7	37.5	

e) As the inhabitant has a velocity much greater than escape velocity, they would leave tangent to the ring and never return….. (Safety barriers would be important on the ringworld!)

Criteria	Marks
• Draws a path that is a straight line that is a tangent to the ring with a velocity in the direction that an inhabitant would be moving just prior to stepping off • Explains this trajectory as resulting from the velocity being much larger than escape velocity	2
• Draws a possible trajectory for an object subject to an inverse square law force that has constant mechanical energy (i.e. an ellipse or hyperbola) OR • Provides a correct explanation relating velocity to escape velocity, but draws an incorrect trajectory.	1

Most students appeared not to realise that they should apply their understanding of orbital motion from 5.3 here, with many responses involving sprials and orbits that crashed into Neos – such orbits are not possible for an object with constant total mechanical energy subject to a central inverse square law force.

If the person's velocity was:

- less than orbital velocity then they would enter an elliptical orbit where the point they left the ringworld would be the apoapsis
- orbital velocity then trajectory is a cirlce
- more than orbital velocity but less than escape velocity, the person would enter an elliptical orbit where the point they left the ringworld would be the periapsis
- exactly escape velocity they would follow a parabolic trajectory
- more than escape velocity (which is the case for this question) then they would follow a hyperbolic trajectory

Source:
https://history.nasa.gov/conghand/traject.htm

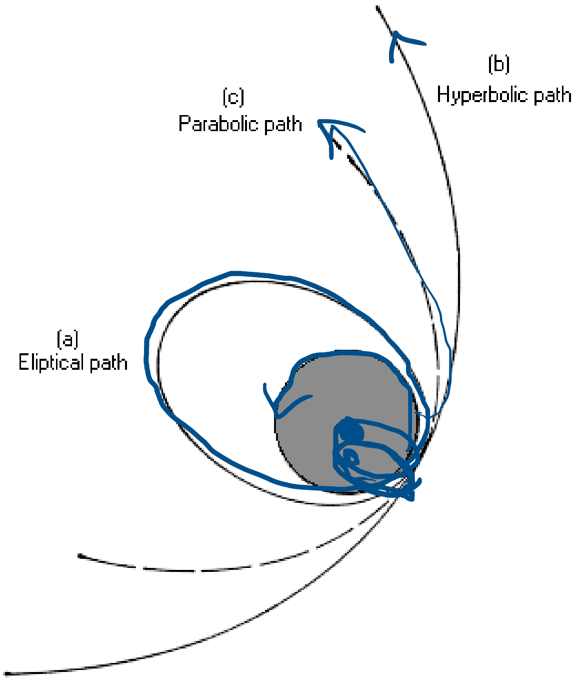


Fig-1: Types of paths

Mark distribution:

Marks	0	1	2		
% students	32.3	52.0	16.7		

Question 33 Sample answer:

a) $p = \frac{m_0 v}{\sqrt{1-\frac{v^2}{c^2}}} = \frac{9.109\times10^{-31}\times0.7\times3\times10^{8}}{\sqrt{1-0.695^2}} = 2.7\times10^{-22} kgms^{-1}$

Criteria	Marks
Uses the equation for relativistic momentum to show that the momentum is equal to the given value.	1

Mark distribution:

Marks	0	1			
% students	17.7	82.3			

b) The data qualitatively supports de Broglie's proposal as it shows that electrons are diffracted as they pass through the double slit, which is wave-like behavior.

Criteria	Marks
Identifies that the electrons are diffracted (or uses the term "interference" and that this is a wave property.	1

This was generally well done.

Mark distribution:

Marks	0	1			
% students	18.8	81.2			

c)

The data also supports his proposal quantitatively.

Using de Broglie's equation, the wavelength of the electrons can be calculated to be

$$\lambda = \frac{h}{p} = \frac{6.626\times10^{-34}}{2.64\times10^{-22}} = 2.5\times10^{-12} m$$

If the electrons are diffracted by a double slit, the angular spacing of maxima will be described by the formula:

$$d \sin\theta = n\,\lambda$$

From the information provided on the diagram and graph, $\mathrm{d} = 220\times10^{-9}$ m and for n=3, $\theta \approx 3.3\times10^{-5}$ radians. Using the small angle approximation and rearranging, we obtain $\lambda = \frac{d\theta}{n} = \frac{220\times10^{-9}\times3.3\times10^{-5}}{3} = 2.4\times10^{-12} m$

Which is within 5% of the value predicted by de Broglie's equation, providing experimental support for de Broglie's proposal.

1 mark:

Criteria	Marks
- Calculates the wavelength of the electrons using De Broglie's equation - Uses the diagram to obtain a value for $\theta \approx 3.3\times10^{-5} rad$ and d=220nm	3

- Correctly substitutes into $d \sin \theta = n \lambda$ (or equivalent equation for minima) to show that the data provides support for de Broglie's proposal (and explains how the data supports de Broglie)	
As above, but: - makes an error of substitution/calculation, or error in reading information from the graph OR - does not make an adequate explain how their calculations provide support for de Broglie's hypothesis	2
ONE of the above or relevant information	1

There was a range of approaches taken, usually determining the wavelength predicted by DeBroglie's equation then comparing this to the wavelength obtained from the experimental data.

Mark distribution:

Marks	0	1	2	3	
% students	10.4	8.3	14.6	67.7	

Question 34

Answer:

a) Determine the initial vertical and horizontal velocities:

$u_x = 15ms^{-1}$

$u_y = 30 \sin 60 = 26ms^{-1}$

<u>Calculating H (2 marks)</u>

To find max height H, $v^2 = u^2 + 2a\mathrm{H}$ and v=0 at top of flight, so

$$H = \frac{-u_y^2}{2a} = \frac{-26^2}{-9.8\times 2} = 34.4m = 34m(2s.f.)$$

Criteria	Marks
• Calculates H correctly	2
• Attempts to apply , $v^2 = u^2 + 2a\mathrm{H}$ or another valid approach	1

Most students knew how to approach this question. Numerical errors were common however.

Mark distribution:

Marks	0	1	2		
% students	4.1	22.9	74.0		

b) **Applying conservation of momentum to the explosion at the top of the flight:**

The momentum of the system of two pieces before the explosion equals the momentum after the explosion as the external forces acting for the duration of the collision (gravity and drag) are negligible compared to the internal forces acting over that time, so $\Sigma F \Delta t = \Delta p \approx 0$.

Vertical direction: Momentum in the vertical direction is zero before the explosion, and piece A has no vertical momentum after the explosion, so the vertical momentum of piece B is also zero.

Horizontal direction: Let the initial velocity of the explosive just prior to the collision be u_x and the velocity of piece B after the collision be u_B. The final velocity of piece A is $u_A = 0$.

$m_0 u_x = m_A u_A + m_B u_B$, so $u_B = \frac{m_0 u_x}{m_B} = \frac{15\times1}{0.5} = 30ms^{-1}$

Applying conservation of energy to the explosion to calculate mass defect.

As the external force acting during the explosion can be neglected (in comparison to the internal forces during the explosion) there is no external work done on the explosion (and no other transfers of energy such as heat or particle transfer) so the total energy of the explosive (the sum of its kinetic energy and mass-energy) is conserved.

The kinetic energy of the explosive before the explosion is

$$KE_i = \frac{1}{2} m_0 u_x^2 = 112.5J$$

The sum of the kinetic energies of both pieces just after the explosion is

$$KE_f = \frac{1}{2} m_A u_A^2 + \frac{1}{2} m_B u_B^2 = \frac{1}{2} 0.5 \times 30^2 + 0 = 225J$$

The difference between these two is the energy equivalent, E, of the mass defect due to conversion of energy from a stored chemical form to kinetic energy.

This difference in mass is equal to $m_D = \frac{E}{c^2} = \frac{112.5}{(3\times10^8)^2} = 1.25 \times 10^{-15} kg$

Criteria	Marks
• Correctly applies conservation of momentum to calculate the final velocity of piece B • Correctly calculates the mass defect by calculating the change in kinetic energy and applying E = mc^2	4
• Correctly applies conservation of momentum to calculate the final velocity of piece B • Uses a correct approach to calculate mass defect by calculating the change in kinetic energy and applying E = mc^2 but makes a numerical error OR • Uses a correct approach to apply conservation of momentum to calculate the final velocity of piece B but makes a numerical error • Correctly calculates the mass defect by calculating the change in kinetic energy and applying E = mc^2	3

• Uses a correct approach to apply conservation of momentum to calculate the final velocity of piece B but makes a numerical error • Uses a correct approach to calculate mass defect by calculating the change in kinetic energy and applying E = mc^2 but makes a numerical error OR • Uses an incorrect approach for one aspect of the question, but correctly calculates (potentially with a carry on error) the other aspect.	2
• Provides relevant information	1

- Most student were at least able to start this question.
- Some students made errors in applying conservation of momentum to calculate the velocity of piece B after the collision.
- Most students were able to calculate the initial and final kinetic energies (many students included potential energy, which wasn't necessary here are both pieces are at the same height before and after the explosion).
- A substantial number of students did not realise that the initial and final kinetic energies were not in fact equal
- Those students who did recognize that the initial and final kinetic energies were not equal were then able to go on to successfully apply E = mc^2 to determine the mass defect.

Mark distribution:

Marks	0	1	2	3	4
% students	20.8	15.6	16.7	15.6	31.3

c) The momentum of piece B changes as it falls as there is an external force (gravity) acting during this time ($\Sigma F \Delta t = \Delta p$)

Criteria	Marks
Identifies that the momentum of piece B changes as it falls as there is an external force (gravity) acting during this time	1

Even though many students could (and did!) identify that momentum is conserved in a closed system, they were not able to apply this to this situation.

After the explosion, piece B experiences an external net force due to gravity so its momentum changes.

Mark distribution:

Marks	0	1			
% students	79	21			