P Σ Λ K
PHYSICS & CHEMISTRY

2021

HIGHER SCHOOL CERTIFICATE
TRIAL EXAMINATION

Name: .....

Class: .....

Section I	/20
Section II	/80
Total	/100

Physics

General Instructions
- Reading time – 5 minutes
- Working time – 3 hours
- Write using blue or black pen
  Black pen is preferred
- Draw diagrams using pencil
- Board-approved calculators may be used
- A data sheet and a Periodic Table are provided at the back of this paper
- Write your name and class at the top of this page

Total marks – 100

Section I Pages 2 – 11

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

Section II Pages 12 – 28

80 marks
- Attempt Questions 21 – 36
- Allow about 2 hours and 25 minutes for this section

Section I: Multiple Choice Questions (20 marks)
Attempt Questions 1 – 20
Allow about 35 minutes for this section

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

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)

1. What is the angular velocity of Earth around the Sun assuming a circular orbit?
   (A) 7.3×10^{-5} rad s^{-1}
   (B) 1.7×10^{-3} rad s^{-1}
   (C) 2.0×10^{-7} rad s^{-1}
   (D) 1.2×10^{-5} rad s^{-1}

2. Which of the following is not a limitation of the ideal transformer model?
   (A) Thermostatic homeostasis
   (B) Incomplete flux linkage
   (C) Hysteresis loss
   (D) Resistive heating

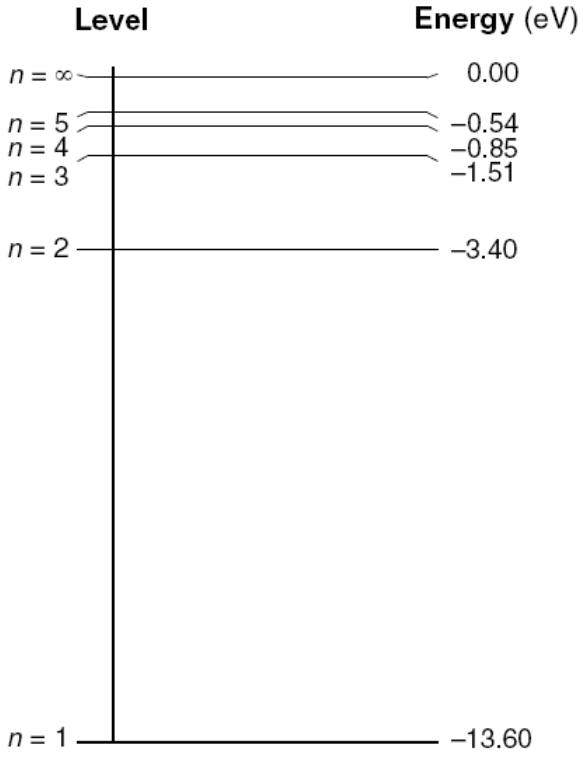
3. What is the frequency of the shortest wavelength of light in the Balmer series?
   (A) 4.57×10^{14} Hz
   (B) 6.17×10^{14} Hz
   (C) 7.31×10^{14} Hz
   (D) 6.91×10^{14} Hz

4. Sam rides his bicycle on a banked surface with an inclined angle of θ and radius r at the minimum possible speed required such that the bicycle does not slide up or down the banked track.

   If the coefficient of static friction between his bike tyres and the surface is μ_s, which of the following equations best represents the minimum speed (v) of his bike?
   (A) $v = \sqrt{mg(\dfrac{\tan\theta - \mu_s}{1 + \mu_s \tan\theta})}$
   (B) $v = \sqrt{gr(\dfrac{\tan\theta - \mu_s}{1 + \mu_s \tan\theta})}$
   (C) $v = \sqrt{mg(\dfrac{\tan\theta + \mu_s}{1 - \mu_s \tan\theta})}$
   (D) $v = \sqrt{gr(\dfrac{\tan\theta + \mu_s}{1 - \mu_s \tan\theta})}$

5. Who proposed that there was a relationship between the peak intensity wavelength and the temperature of a black body?
   (A) Planck
   (B) Maxwell
   (C) Wien
   (D) Young

6. Some energy levels of the hydrogen atom are shown below.



An electron of hydrogen is excited to the −0.54 eV energy level.

Based on the above model, how many different wavelengths of light can be emitted when the electron becomes de-excited?

(A) 10

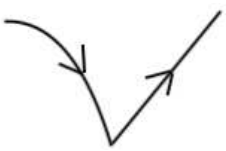
(B) 8

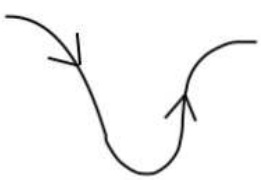
(C) 6

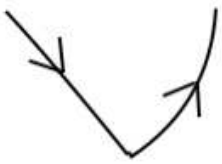
(D) 4

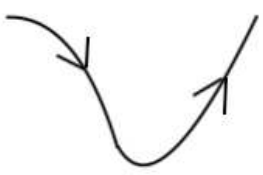
7. A boy is on a plane flying at a constant horizontal velocity, far enough above the Earth's surface that air resistance is negligible. He drops his toy helicopter off the plane. Luckily, he is able to activate the thrusters on his toy which applies a force directly upwards and is greater than the force of gravity.

Which of the following correctly shows the trajectory of the toy helicopter?

(A) 

(C) 

(B) 

(D) 

8. A particle of charge q and mass m is placed in a uniform electric field of voltage V and is released from rest. The velocity of the particle is denoted as v.

Which of the following expressions is correct?

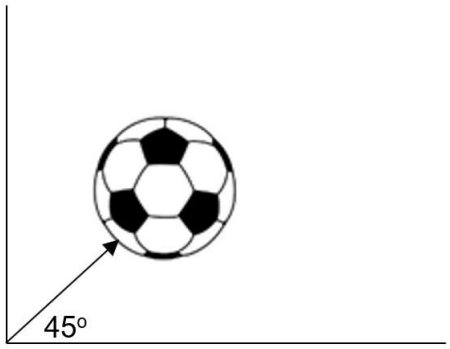
(A) $v = \sqrt{\dfrac{2q}{Vm}}$

(B) $q = \dfrac{Vm}{v^2}$

(C) $m = \dfrac{2qV}{v^2}$

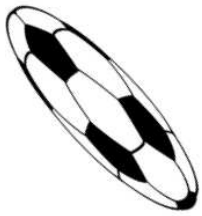
(D) $V = \dfrac{mv}{2q}$

9. Ronaldo kicks a soccer ball in the trajectory shown below at relativistic speeds.



What would the ball look like to the fans at the stadium?

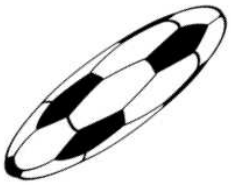
(A)



(B)

(C)

(D)



10. A spaceship is sent to colonise another planet. It is capable of moving at $0.95c$ and maintains this speed for the duration of the journey to the planet, which is 3 light years away.

    How long will this journey take according to the personnel remotely controlling the spaceship from Earth?

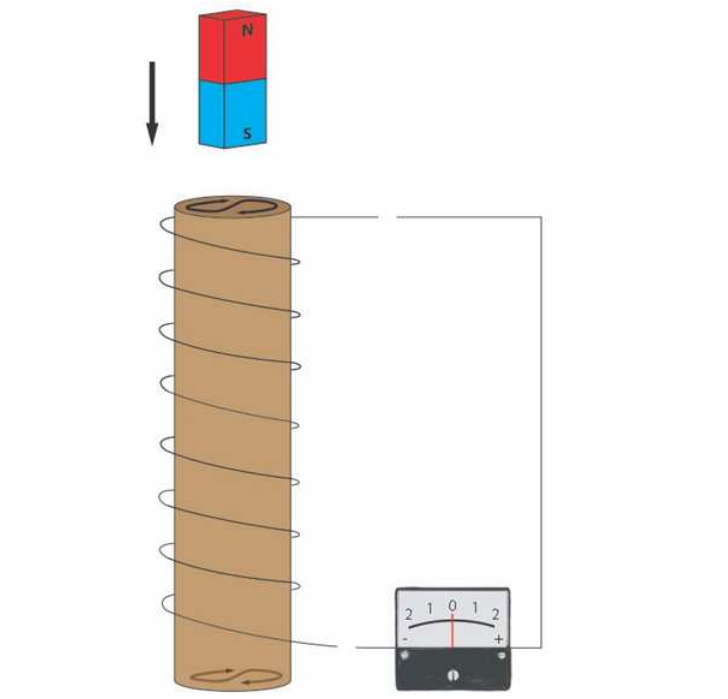
    (A) 1153 days

    (B) 3691 days

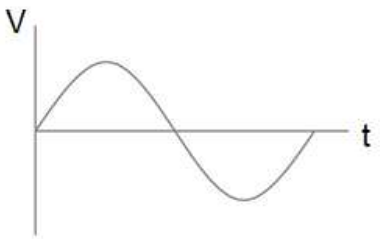
    (C) 360 days

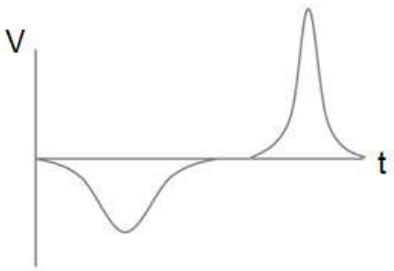
    (D) 894 days

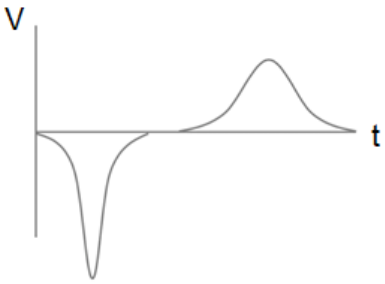
11. A student conducts an experiment where they drop a magnet through a coil and then records a voltage versus time graph using a galvanometer.

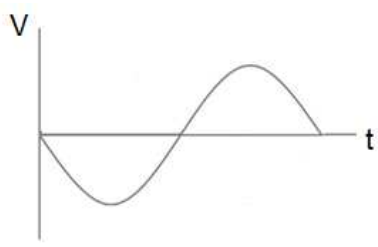


    Which of the following would be the most accurate graph produced in this experiment?

(A)


(B)


(C)


(D)


12. A student is working with 6.0×10^{-18} kg of radioactive technetium-99m which has a half-life of 6 hours. He comes back after 4 hours and to his dismay, realises that much of it is gone.

How much technetium-99m has decayed during the 4 hours?

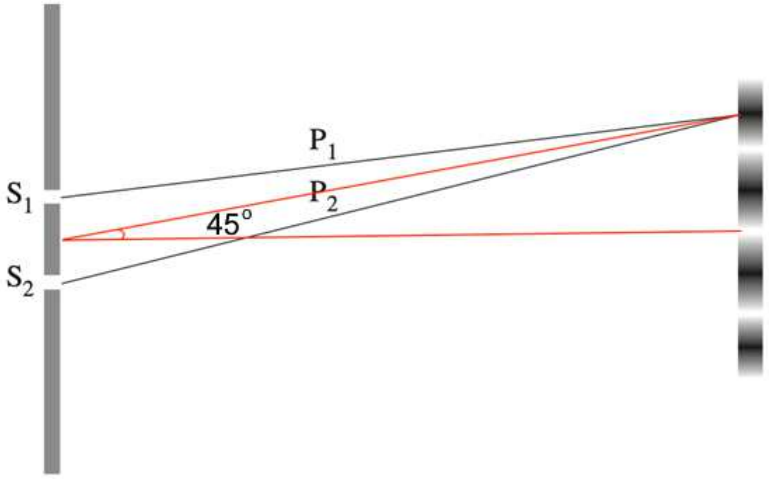
(A) 3.9×10^{-18} kg

(B) 3.0×10^{-18} kg

(C) 2.2×10^{-18} kg

(D) 1.7×10^{-18} kg

13. Monochromatic light of wavelength λ strikes a double slit as shown in the diagram below.



What is the distance between the two slits?

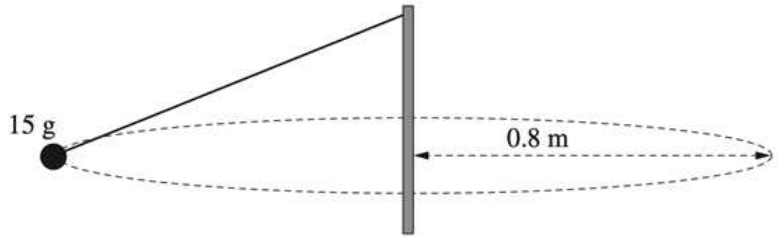
(A) 4λ

(B) 3λ

(C) 2λ

(D) λ

14. A 15 g ball is swung in a circular path around a pole in a horizontal plane as shown below.



If the angular velocity of the ball is 4 rad s^{-1}, what is the horizontal component of the tension in the string that is required to maintain the motion of the ball?

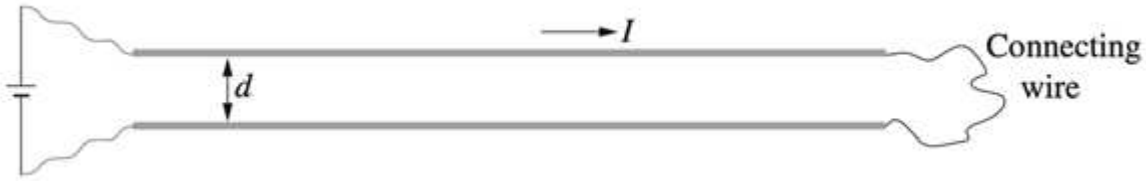
(A) 1.2 N

(B) 1.9 N

(C) 2.4 N

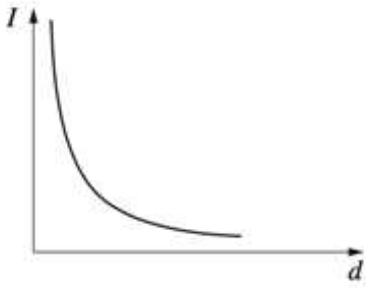
(D) 3.8 N

15. Two parallel conducting rods are connected by a wire and carry a current I. They are separated by a distance d and repel each other with a force F.

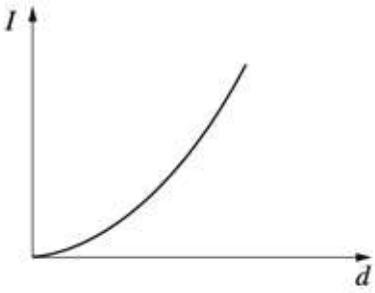


Which graph shows the relationship between current and distance if the repulsive force between the two rods is kept constant?

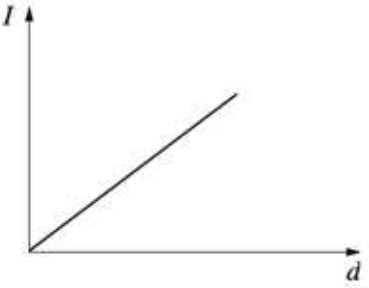
(A)



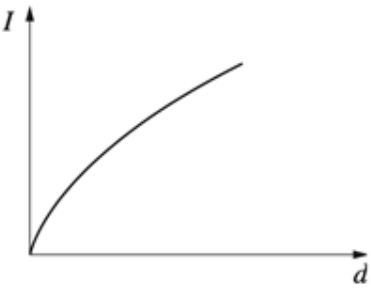
(C)



(B)



(D)



16. A scientist playing with his synchrotron decides to accelerate a proton to a speed of $0.85c$.

If the orbital radius of the proton is 100 m, what is the magnitude of the magnetic field required to keep the proton in orbit?

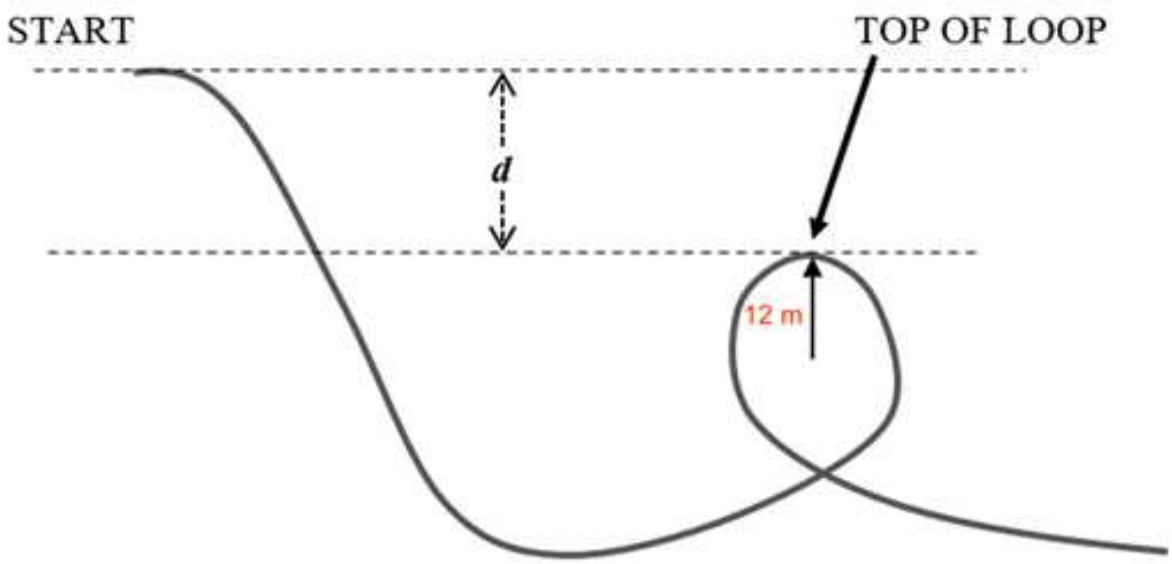
(A) 0.051 T

(B) 0.027 T

(C) 0.014 T

(D) 0.039 T

17. The diagram below shows a roller coaster ride that is being designed.



At the top of the loop, the designer wants the passengers to be upside down and undergo an acceleration equal to g while in their seats, making them feel weightless. The radius of the loop is 12 m. The ride begins with negligible speed and friction can be ignored.

What does the distance between the starting position and the top of the loop, d, need to be such that this is possible?

(A) 4.7 m

(B) 12.0 m

(C) 8.5 m

(D) 6.0 m

18. A scientist observes the annihilation of an electron and positron. Both particles were stationary when they were annihilated.

What is the minimum energy of a gamma ray produced by this event?

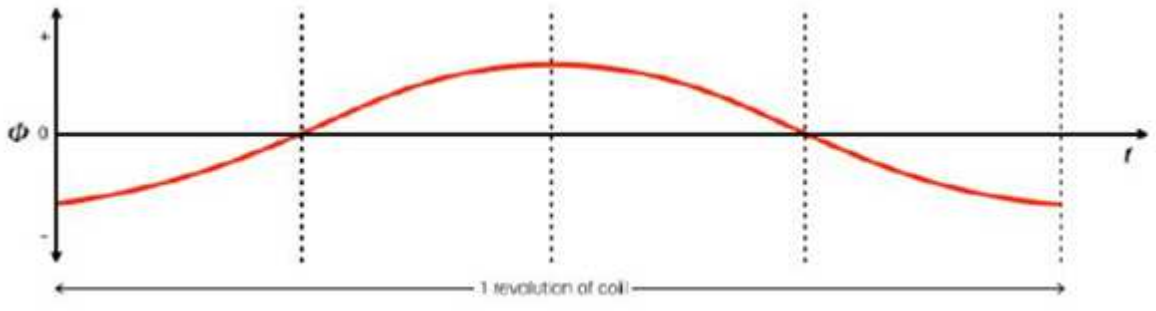
(A) 5.12×10^{5} eV

(B) 1.64×10^{-13} J

(C) 8.20×10^{-14} eV

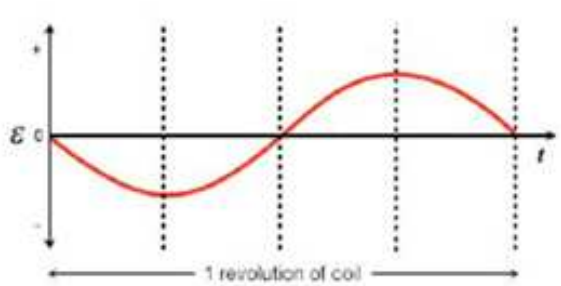
(D) 2.01 MeV

19. The graph below shows the variation of flux of a generator coil as it completes a single revolution.

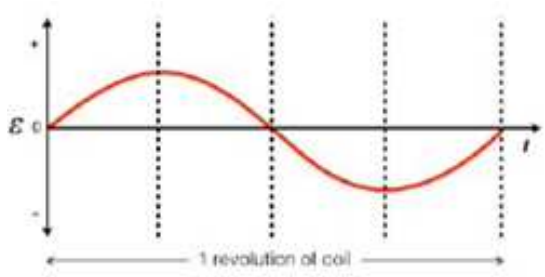


Which of the following graphs shows the corresponding EMF in the generator?

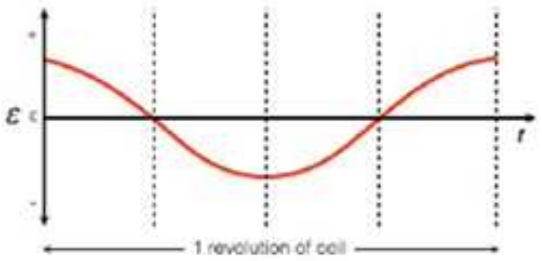
(A)



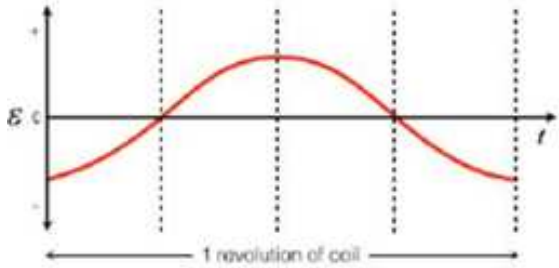
(C)



(B)



(D)



20. Consider the following nuclear reaction:

$$W + X \rightarrow Y + Z$$

Information about W, X and Y are given in the table below.

Species	**Mass defect (u)**	**Total binding energy (MeV)**	**Binding energy per nucleon (MeV)**
W	0.00238817	2.224566	1.112283
X	0.00910558	8.481798	2.827266
Y	0.03037664	28.29566	7.073915

Based on the above information, which of the following statements is correct?

(A) The properties of Z must be known before any conclusions can be made about whether the reaction releases or requires energy

(B) Since the mass defect of Y is greater than both W and X, we can conclude that this is an exothermic nuclear fission reaction

(C) At least one product is more stable than the reactants and hence the reaction releases energy

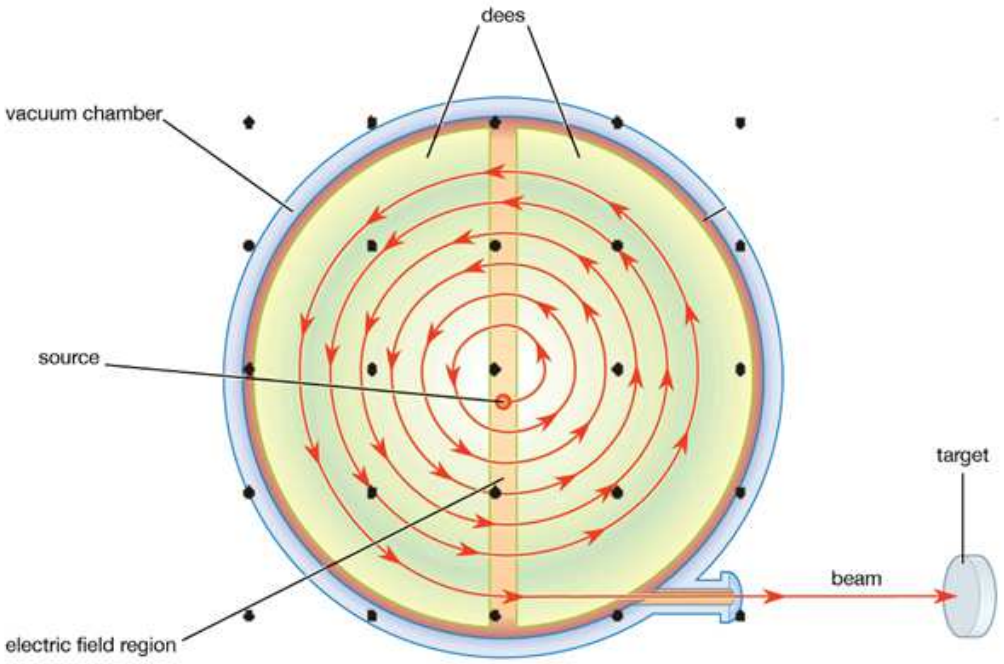
(D) The difference in total binding energy leads to the conclusion that product Y is smaller than W and X, making this an endothermic reaction where the reactants undergo decay to preserve nuclear stability

Section II: Short Answer Questions (80 marks)
Attempt Questions 21 – 36
Allow about 2 hours and 25 minutes for this part

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.

Question 21 (6 marks)
A charged particle is accelerated inside a cyclotron as shown below.



When the orbital radius is 20 m, the velocity of the particle is $0.8c$ and the magnitude of the magnetic field is 113.7 μT. It is known that the particle is a first generation fundamental particle.

(a) Calculate the mass to charge ratio of this particle. **3**

.....

.....

.....

.....

.....

.....

.....

.....

(b) Identify the particle and justify your conclusion. **3**

.....

.....

.....

.....

.....

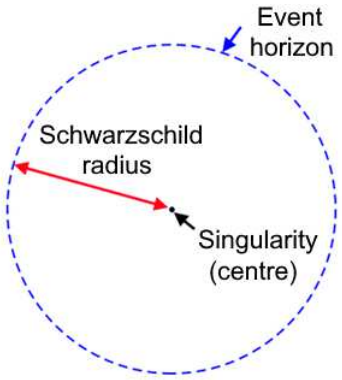
.....

.....

Question 22 (3 marks)

A student is is studying black holes for their depth study. They come across the concept of the Schwarzschild radius which is defined below: **3**

"The Schwarzschild radius is the radius of the event horizon surrounding a non-rotating black hole. The event horizon of a black hole is a boundary where gravity is powerful enough such that the velocity required for an object to escape exceeds the speed of light."



Derive an expression for the Schwarzschild radius (r) of a non-rotating black hole in terms of the mass of the black hole (M) and physical constants. Assume a point source of gravity at the centre of the black hole.

.....

.....

.....

.....

.....

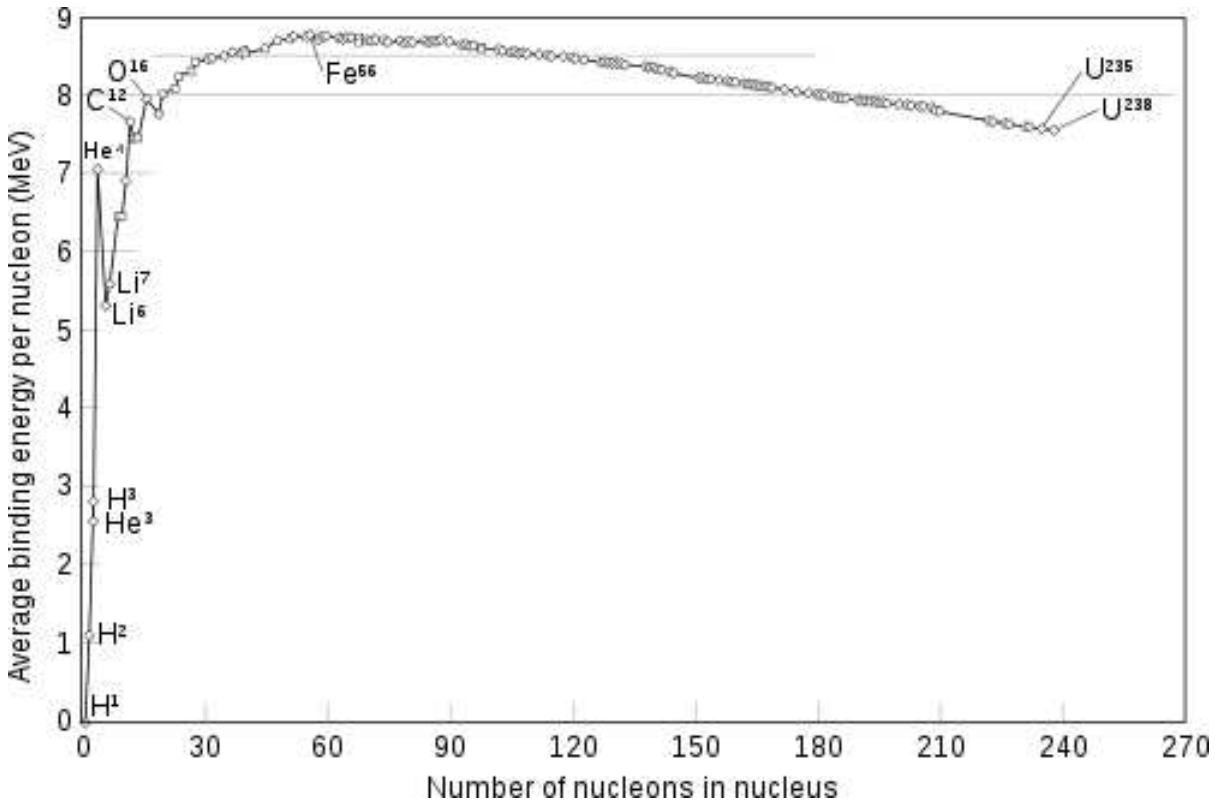
.....

.....

.....

Question 23 (3 marks)

The graph below shows how the average binding energy per nucleon varies with the number of nucleons in a nucleus. **3**



With reference to the graph, explain why the fission of uranium-238 releases energy, but the fission of helium-4 does not.

.....

.....

.....

.....

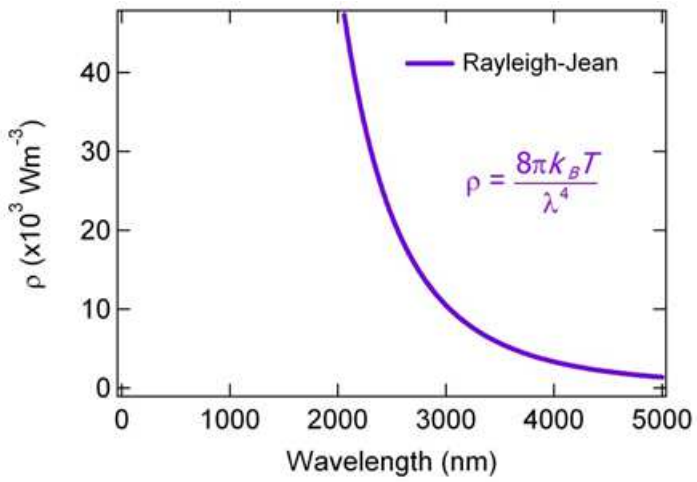
.....

.....

.....

.....

Question 24 (7 marks)
The graph below plots the Rayleigh-Jeans law.



(a) In regards to the radiation produced by a black body, describe the main issues with the Rayleigh-Jeans law and what this told scientists about the existing model of light. **3**

.....

.....

.....

.....

.....

.....

.....

.....

(b) Identify the scientist who solved the issues with the Rayleigh-Jeans law, and explain how they did this. **3**

.....

.....

.....

.....

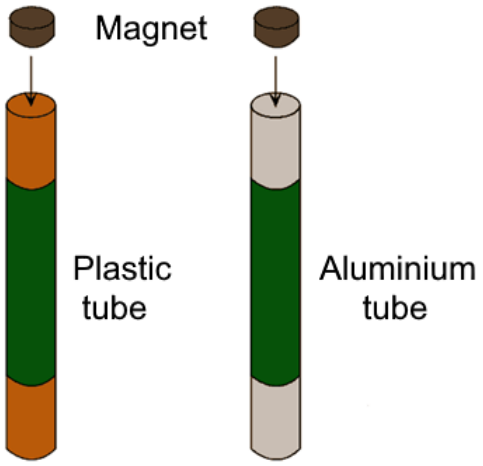
.....

.....

.....

(c) On the graph above, draw the black body radiation curve that was obtained experimentally. **1**

Question 25 (8 marks)
In an experiment, two identical magnets are simultaneously dropped down two tubes of identical dimensions. The first tube is made of plastic and the second tube is made of aluminium. Both magnets are dropped with their north poles facing downwards.



(a) What would be observed in regards to the time taken for the magnets to exit the tubes? **1**

.....

.....

(b) Explain the observation in part (a) using physics principles. **5**

.....

.....

.....

.....

.....

.....

.....

.....

.....

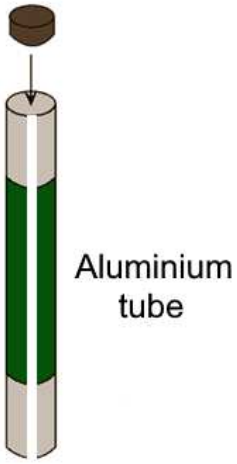
.....

.....

.....

.....

(c) A new tube, identical to the aluminium tube, is brought in. However, this tube has been cut through vertically, as shown in the diagram below. **2**



Explain what would be observed if the experiment is repeated once again with this new tube.

.....

.....

.....

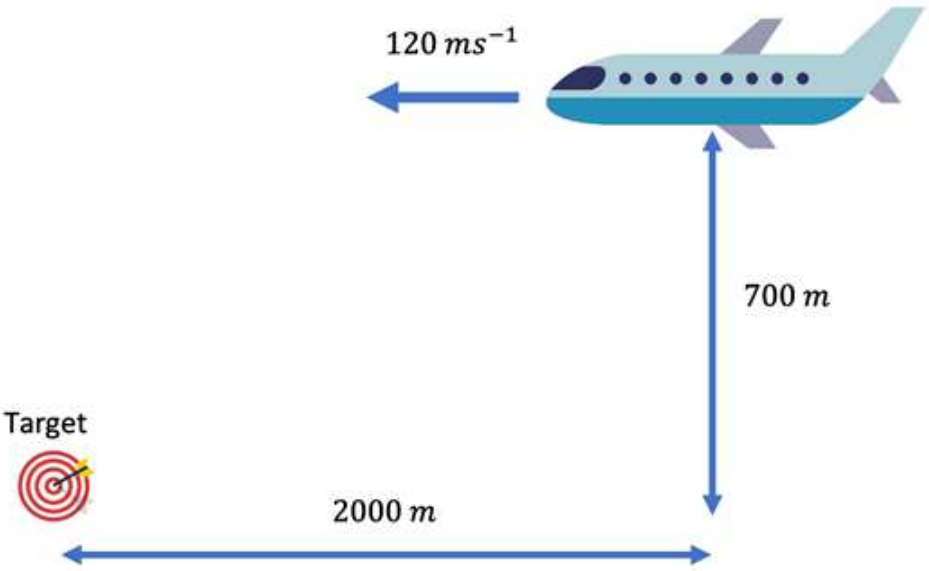
.....

.....

.....

Question 26 (3 marks)

A scientist is playing altitude bowling, where they are on a plane travelling horizontally at a constant speed of 120 m s^{-1} while 700 m above the ground. The scientist needs to drop a bowling ball such that it hits the target directly in order to get a strike. **3**



If they are currently 2000 m from the target, calculate the time the scientist needs to wait before dropping the ball if they want to get a strike.

.....

.....

.....

.....

.....

.....

.....

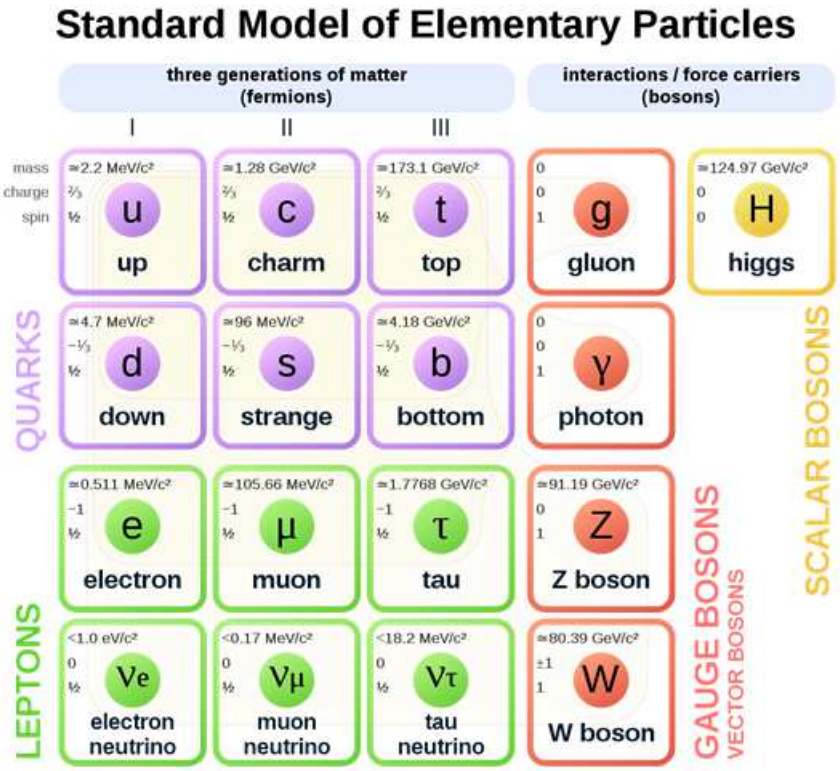
.....

Question 27 (8 marks)

Outline Newton and Huygens' proposed models of light and describe TWO subsequent experiments which provided evidence that supported either model. **8**

Question 28 (7 marks)

The Standard Model of Matter exists to classify all known elementary particles and attempts to explain the fundamental forces of the universe. A summary for this model is shown below:



(a) Describe and explain TWO pieces of evidence that led to the conclusion that baryons are not fundamental particles. **4**

.....

.....

.....

.....

.....

.....

.....

.....

(b) Identify the quark composition of a proton and a neutron. **2**

.....

.....

(c) Outline a major limitation of the Standard Model of Matter at the moment. **1**

.....

Question 29 (4 marks)
A student is tracking a low-earth orbit satellite that orbits Earth every 120 minutes.

(a) Calculate the orbital velocity of this satellite. **2**

.....

.....

.....

.....

.....

.....

(b) The same satellite needs to be moved into geostationary orbit, 36 000 km above the Earth's surface. **2**

Calculate the work that must be done against gravity to accomplish this if the satellite has a mass of 800 kg.

.....

.....

.....

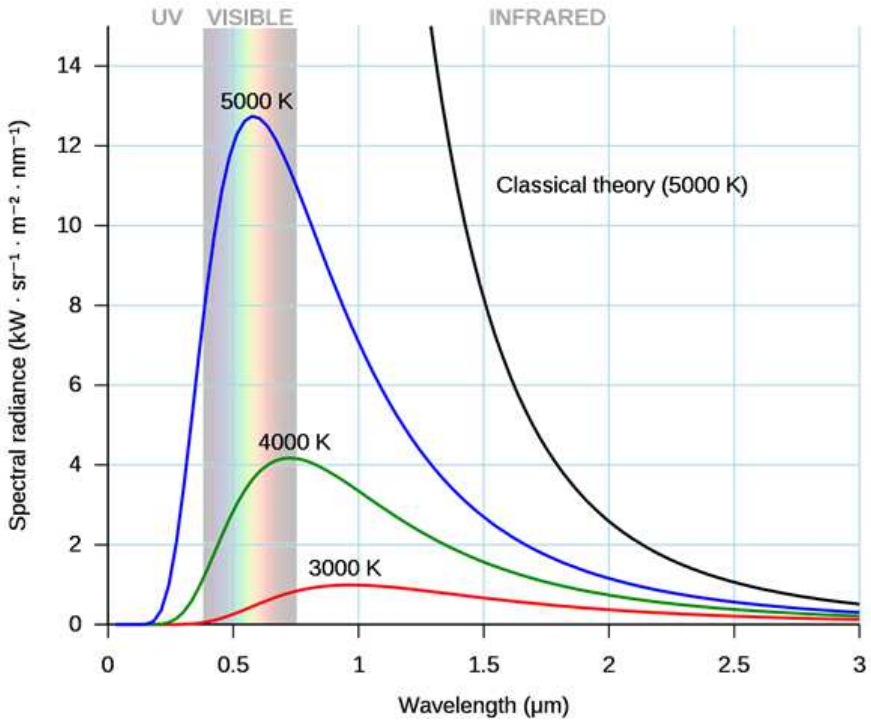
.....

.....

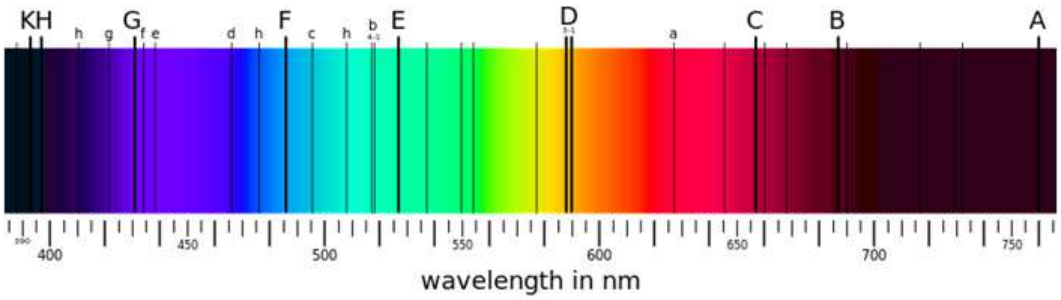
.....

Question 30 (3 marks)

A black body radiation curve is shown below. **3**



The spectra produced by reflected sunlight is shown below:



A scientist observing stars with his telescope is admiring the blue, white, yellow, orange and red stars that he can see. However, he notices that he cannot see any green stars.

Using your knowledge of electromagnetic radiation, propose and explain a reason for this.

.....

.....

.....

.....

.....

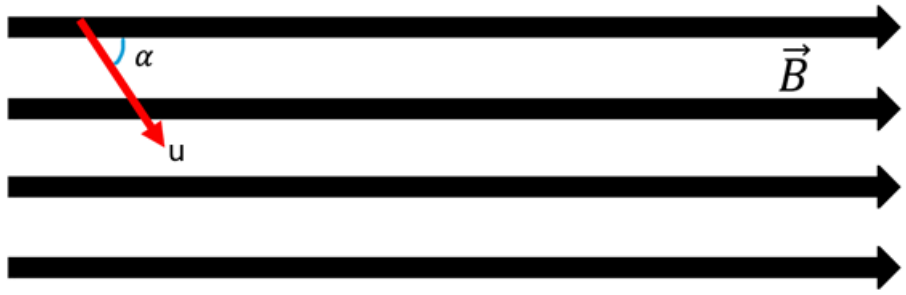
.....

.....

.....

Question 31 (7 marks)

A negatively charged particle is directed into a magnetic field with initial velocity u at an angle of α. The strength of the magnetic field is B. This is shown in the diagram below.



(a) Describe the motion and trajectory of the particle once it enters the magnetic field and justify your answer using physics principles. Assume that the particle does not leave the field. **4**

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

(b) Given that $\alpha = 40°$, $B = 0.060$ T and the particle is an antiproton with $u = 2.0 \times 10^6\,\text{m}\,\text{s}^{-1}$, calculate the initial radius of its path. **1**

.....

.....

.....

.....

.....

(c) The pitch of the particle refers to the distance that it can travel parallel to the magnetic field, in the time that it takes to complete one revolution. **2**

Calculate the pitch of this antiproton.

.....

.....

.....

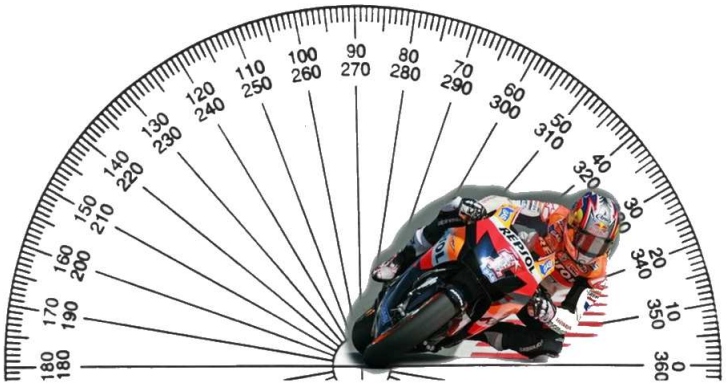
.....

.....

.....

Question 32 (3 marks)

Professional bike racers often lean into a turn, allowing them to move around a curve at higher speeds than someone turning while upright. **3**



Mathematically show that the speed of a racer around a curve will be higher when they lean in compared to when they are upright. Include relevant free body diagrams in your answer.

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

Question 33 (7 marks)
The Big Bang Theory is the prevailing cosmological model explaining the existence of the observable universe.

(a) Identify the fundamental forces and the order that they separated shortly after the Big Bang. **2**

.....

.....

.....

.....

(b) How does the existence of cosmic background radiation support the Big Bang Theory? **2**

.....

.....

.....

.....

.....

.....

(c) It is thought that shortly after the Big Bang, the ratio of free protons to neutrons was approximately 7:1. **3**

Using this information, explain why there was approximately a 3:1 mass ratio of hydrogen to helium in the early universe.

.....

.....

.....

.....

.....

.....

.....

Question 34 (4 marks)

Identify which type of device would contain an armature, split ring commutator and brushes, and outline the function of each of these components. **4**

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

Question 35 (3 marks)

Show how de Broglie used his hypothesis of $\lambda = \dfrac{h}{mv}$ to justify Bohr's postulate of stationary states. **3**

.....

.....

.....

.....

.....

.....

.....

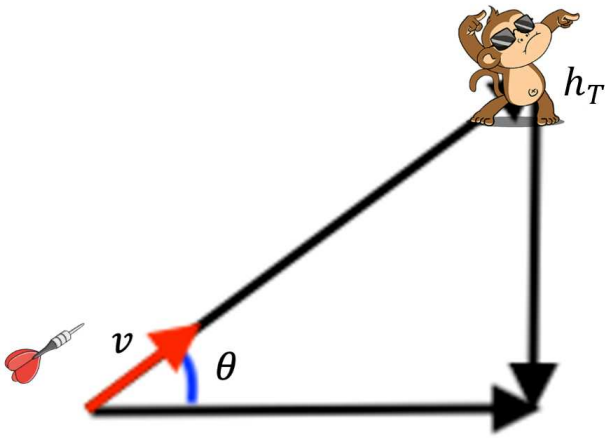
.....

.....

.....

Question 36 (4 marks)

The "monkey-dart problem" describes a scenario where a person on the ground throws a dart with initial velocity v directly at a monkey hanging on a tree at an initial height of h_{T} above the ground. However, at the same time that the dart is released from the person's hand, the monkey lets go of the branch and drops to the ground. This is shown in the diagram below. **4**



Assuming that the dart has enough initial velocity to actually reach the monkey, mathematically prove that the dart will always hit the monkey.

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

End of paper

Section II extra writing space

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

P Σ Λ K
PHYSICS & CHEMISTRY

2021

HIGHER SCHOOL CERTIFICATE
TRIAL EXAMINATION

Physics

General Instructions
- Reading time – 5 minutes
- Working time – 3 hours
- Write using blue or black pen
  Black pen is preferred
- Draw diagrams using pencil
- Board-approved calculators may be used
- A data sheet and a Periodic Table are provided at the back of this paper
- Write your name and class at the top of this page

Total marks – 100

Section I Pages 2 – 11

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

Section II Pages 12 – 28

80 marks
- Attempt Questions 21 – 36
- Allow about 2 hours and 25 minutes for this section

Section I: Multiple Choice Questions (20 marks)
Attempt Questions 1 – 20
Allow about 35 minutes for this section

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

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

1. What is the angular velocity of Earth around the Sun assuming a circular orbit?
   (A) 7.3×10^{-5} rad s^{-1}
   (B) 1.7×10^{-3} rad s^{-1}
   (C) 2.0×10^{-7} rad s^{-1}
   (D) 1.2×10^{-5} rad s^{-1}

2. Which of the following is not a limitation of the ideal transformer model?
   (A) Thermostatic homeostasis
   (B) Incomplete flux linkage
   (C) Hysteresis loss
   (D) Resistive heating

3. What is the frequency of the shortest wavelength of light in the Balmer series?
   (A) 4.57×10^{14} Hz
   (B) 6.17×10^{14} Hz
   (C) 7.31×10^{14} Hz
   (D) 6.91×10^{14} Hz

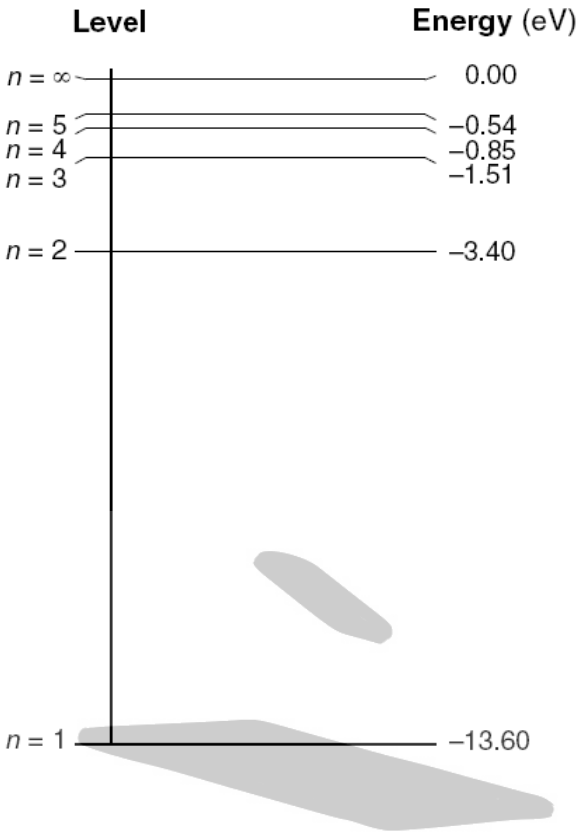
4. Sam rides his bicycle on a banked surface with an inclined angle of θ and radius r at the minimum possible speed required such that the bicycle does not slide up or down the banked track.

   If the coefficient of static friction between his bike tyres and the surface is μ_s, which of the following equations best represents the minimum speed (v) of his bike?

   (A) $v = \sqrt{mg(\dfrac{\tan\theta - \mu_s}{1 + \mu_s \tan\theta})}$
   (B) $v = \sqrt{gr(\dfrac{\tan\theta - \mu_s}{1 + \mu_s \tan\theta})}$
   (C) $v = \sqrt{mg(\dfrac{\tan\theta + \mu_s}{1 - \mu_s \tan\theta})}$
   (D) $v = \sqrt{gr(\dfrac{\tan\theta + \mu_s}{1 - \mu_s \tan\theta})}$

5. Who proposed that there was a relationship between the peak intensity wavelength and the temperature of a black body?
   (A) Planck
   (B) Maxwell
   (C) Wien
   (D) Young

6. Some energy levels of the hydrogen atom are shown below.



An electron of hydrogen is excited to the −0.54 eV energy level.

Based on the above model, how many different wavelengths of light can be emitted when the electron becomes de-excited?

(A) 10

(B) 8

(C) 6

(D) 4

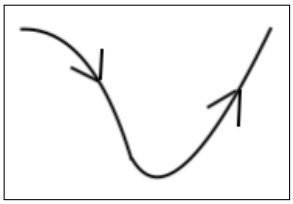
7. A boy is on a plane flying at a constant horizontal velocity, far enough above the Earth's surface that air resistance is negligible. He drops his toy helicopter off the plane. Luckily, he is able to activate the thrusters on his toy which applies a force directly upwards and is greater than the force of gravity.

Which of the following correctly shows the trajectory of the toy helicopter?

(A) 

(B) 

(C) 

(D) 

8. A particle of charge q and mass m is placed in a uniform electric field of voltage V and is released from rest. The velocity of the particle is denoted as v.

Which of the following expressions is correct?

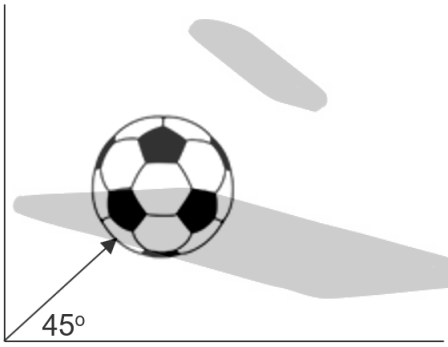
(A) $v = \sqrt{\dfrac{2q}{Vm}}$

(B) $q = \dfrac{Vm}{v^2}$

(C) $m = \dfrac{2qV}{v^2}$

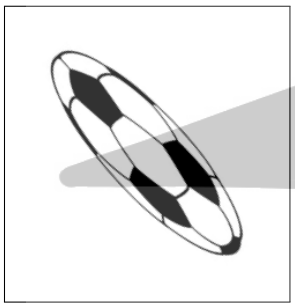
(D) $V = \dfrac{mv}{2q}$

9. Ronaldo kicks a soccer ball in the trajectory shown below at relativistic speeds.



What would the ball look like to the fans at the stadium?

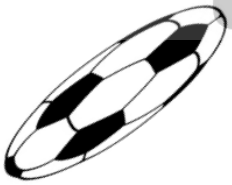
(A)



(B)

(C)

(D)



10. A spaceship is sent to colonise another planet. It is capable of moving at $0.95c$ and maintains this speed for the duration of the journey to the planet, which is 3 light years away.

    How long will this journey take according to the personnel remotely controlling the spaceship from Earth?

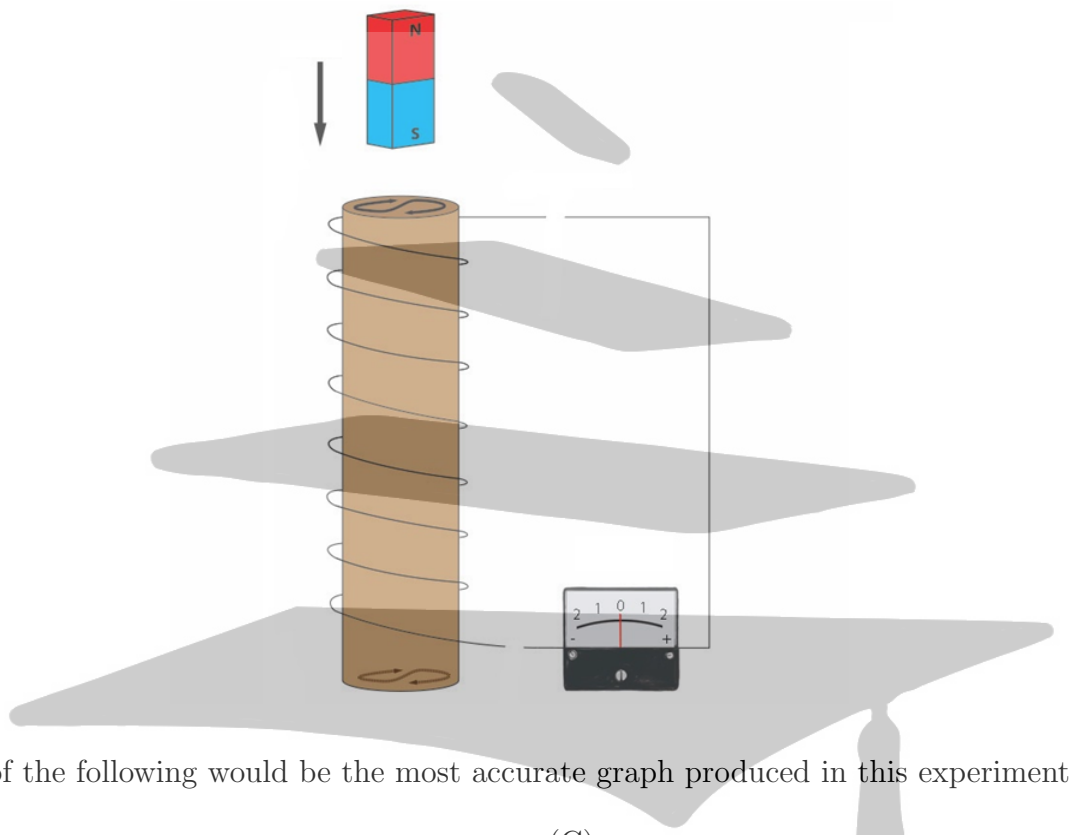
    (A) 1153 days

    (B) 3691 days

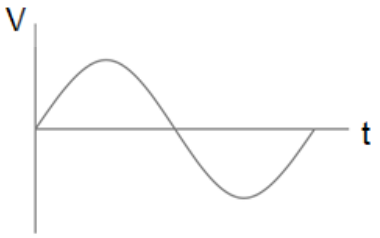
    (C) 360 days

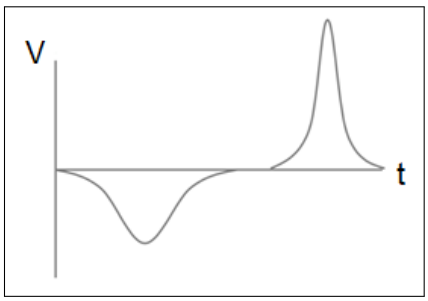
    (D) 894 days

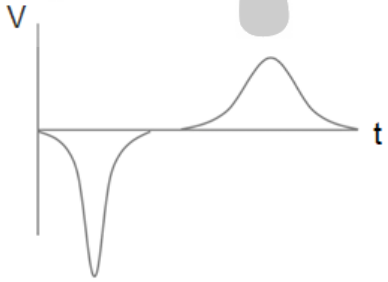
11. A student conducts an experiment where they drop a magnet through a coil and then records a voltage versus time graph using a galvanometer.

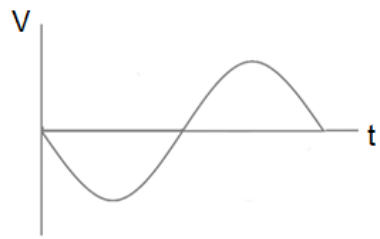


Which of the following would be the most accurate graph produced in this experiment?

(A)


(B)


(C)


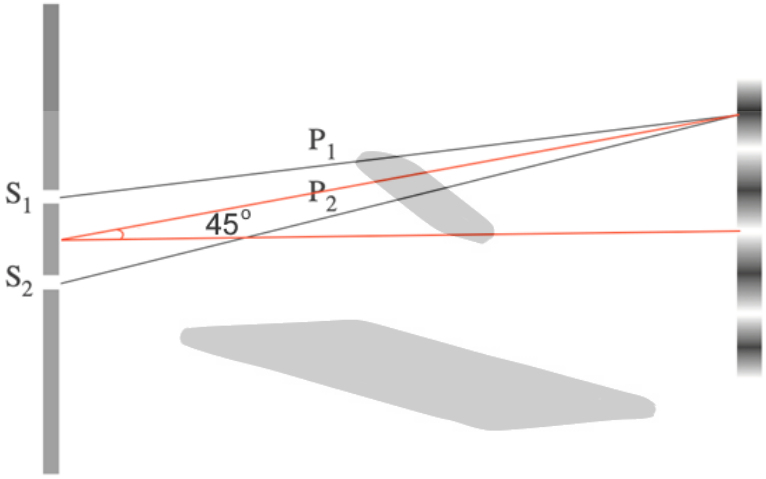
(D)


12. A student is working with 6.0×10^{-18} kg of radioactive technetium-99m which has a half-life of 6 hours. He comes back after 4 hours and to his dismay, realises that much of it is gone.

How much technetium-99m has decayed during the 4 hours?

(A) 3.9×10^{-18} kg
(B) 3.0×10^{-18} kg
(C) 2.2×10^{-18} kg
(D) 1.7×10^{-18} kg

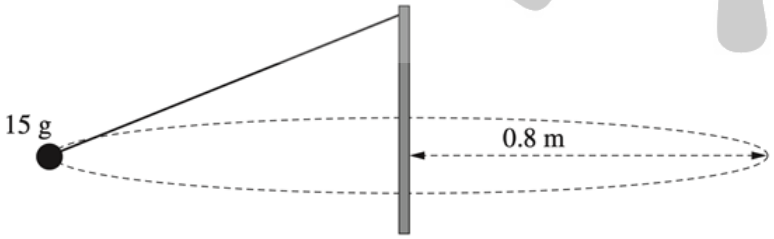
13. Monochromatic light of wavelength λ strikes a double slit as shown in the diagram below.



What is the distance between the two slits?

(A) 4λ
(B) 3λ
(C) 2λ
(D) λ

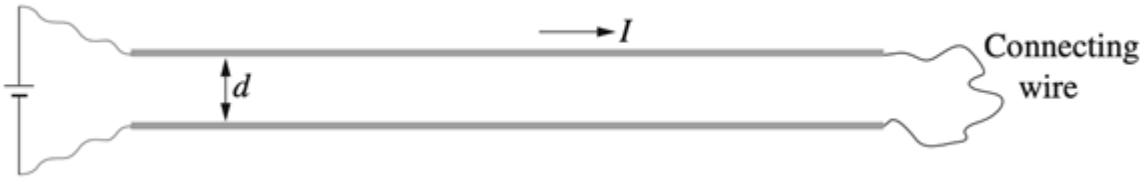
14. A 15 g ball is swung in a circular path around a pole in a horizontal plane as shown below.



If the angular velocity of the ball is 4 rad s^{-1}, what is the horizontal component of the tension in the string that is required to maintain the motion of the ball?

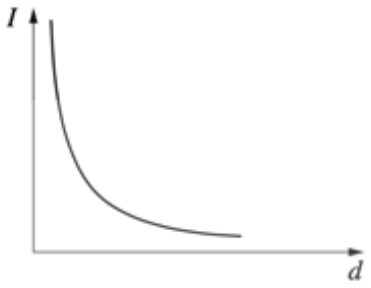
(A) 1.2 N
(B) 1.9 N
(C) 2.4 N
(D) 3.8 N

15. Two parallel conducting rods are connected by a wire and carry a current I. They are separated by a distance d and repel each other with a force F.

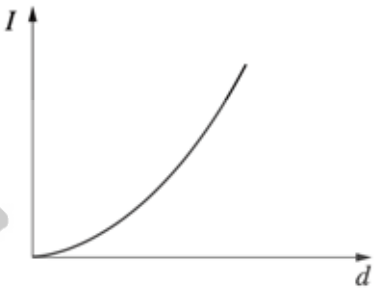


Which graph shows the relationship between current and distance if the repulsive force between the two rods is kept constant?

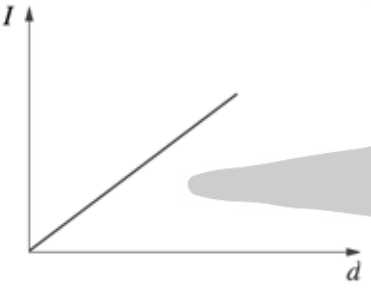
(A)



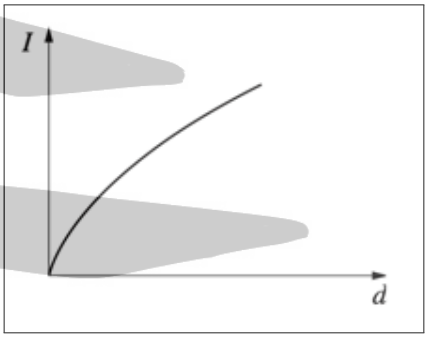
(C)



(B)



(D)



16. A scientist playing with his synchrotron decides to accelerate a proton to a speed of $0.85c$.

If the orbital radius of the proton is 100 m, what is the magnitude of the magnetic field required to keep the proton in orbit?

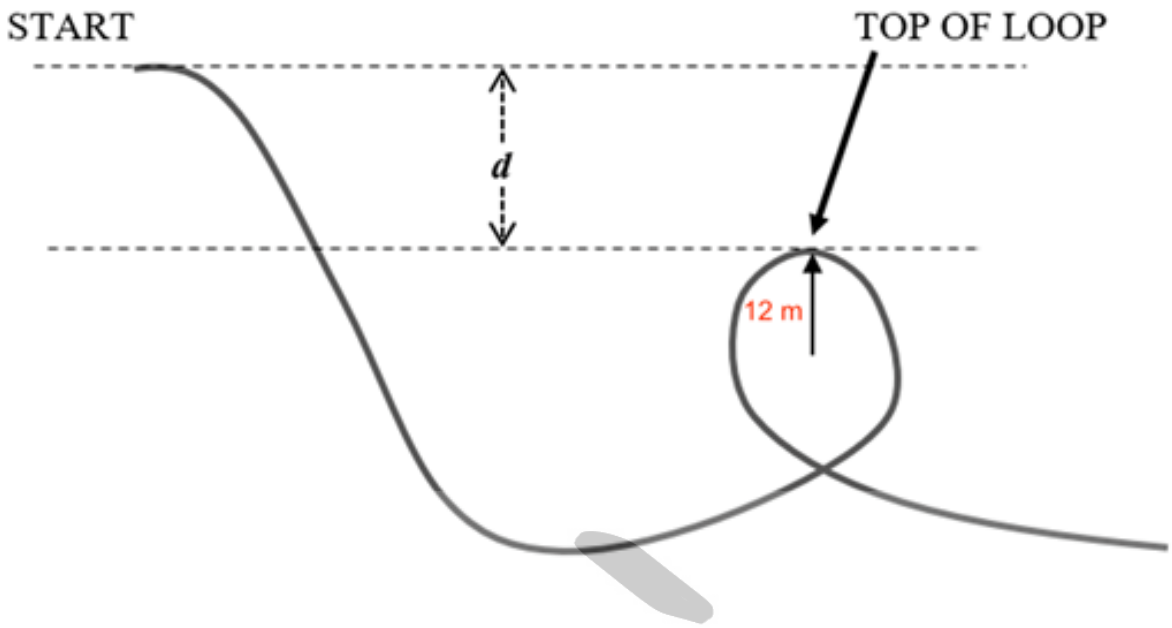
(A) 0.051 T

(B) 0.027 T

(C) 0.014 T

(D) 0.039 T

17. The diagram below shows a roller coaster ride that is being designed.



At the top of the loop, the designer wants the passengers to be upside down and undergo an acceleration equal to g while in their seats, making them feel weightless. The radius of the loop is 12 m. The ride begins with negligible speed and friction can be ignored.

What does the distance between the starting position and the top of the loop, d, need to be such that this is possible?

(A) 4.7 m

(B) 12.0 m

(C) 8.5 m

(D) 6.0 m

18. A scientist observes the annihilation of an electron and positron. Both particles were stationary when they were annihilated.

What is the minimum energy of a gamma ray produced by this event?

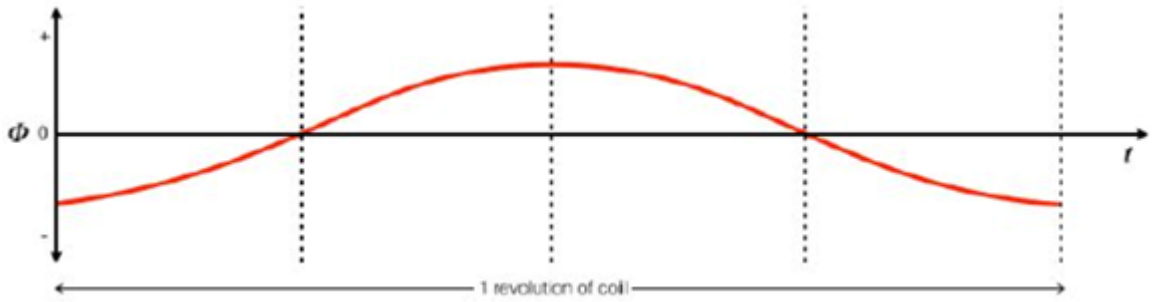
(A) 5.12×10^5 eV

(B) 1.64×10^{-13} J

(C) 8.20×10^{-14} eV

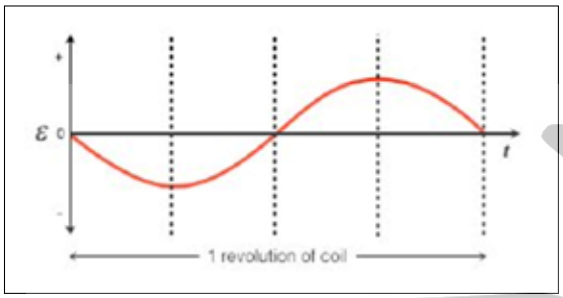
(D) 2.01 MeV

19. The graph below shows the variation of flux of a generator coil as it completes a single revolution.

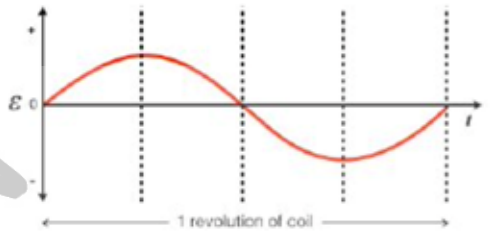


Which of the following graphs shows the corresponding EMF in the generator?

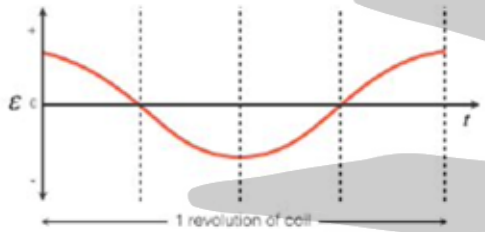
(A)



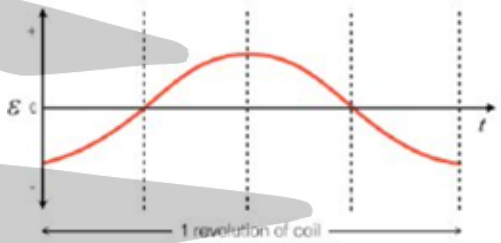
(C)



(B)



(D)



20. Consider the following nuclear reaction:

$$W + X \rightarrow Y + Z$$

Information about W, X and Y are given in the table below.

Species	**Mass defect (u)**	**Total binding energy (MeV)**	**Binding energy per nucleon (MeV)**
W	0.00238817	2.224566	1.112283
X	0.00910558	8.481798	2.827266
Y	0.03037664	28.29566	7.073915

Based on the above information, which of the following statements is correct?

(A) The properties of Z must be known before any conclusions can be made about whether the reaction releases or requires energy

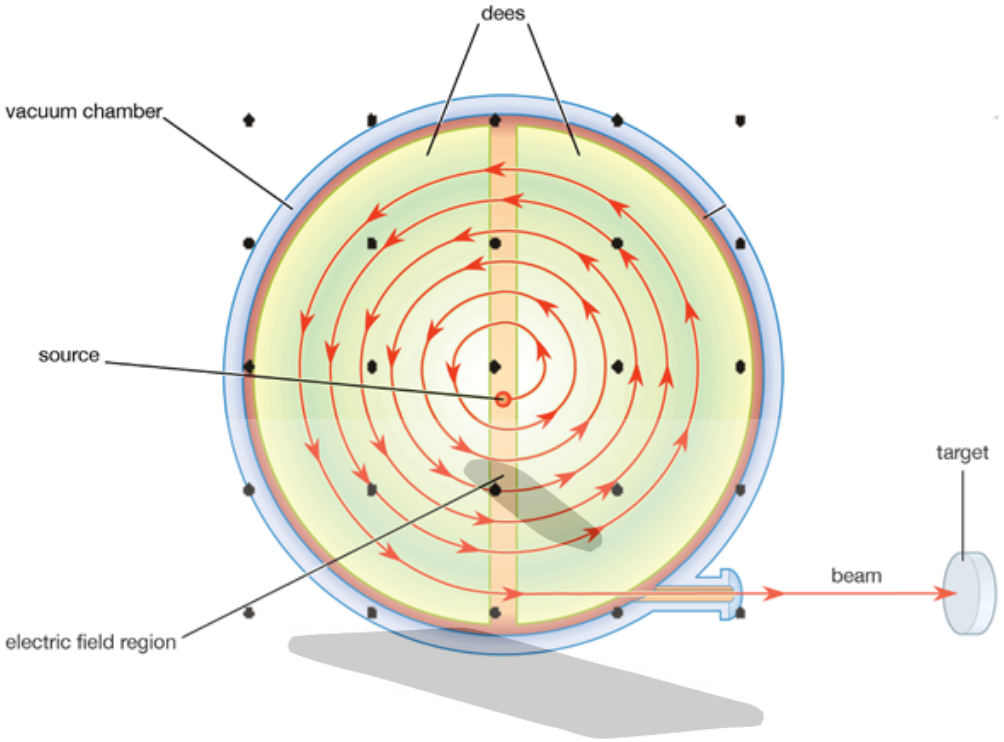
(B) Since the mass defect of Y is greater than both W and X, we can conclude that this is an exothermic nuclear fission reaction

(C) At least one product is more stable than the reactants and hence the reaction releases energy

(D) The difference in total binding energy leads to the conclusion that product Y is smaller than W and X, making this an endothermic reaction where the reactants undergo decay to preserve nuclear stability

Section II: Short Answer Questions (80 marks)

Question 21 (6 marks)
A charged particle is accelerated inside a cyclotron as shown below.



When the orbital radius is 20 m, the velocity of the particle is $0.8c$ and the magnitude of the magnetic field is 113.7 µT. It is known that the particle is a first generation fundamental particle.

(a) Calculate the mass to charge ratio of this particle. **3**

$$\begin{aligned} F_c &= F_B \\ \frac{mv^2}{r} &= qvB\sin\theta \\ \Longrightarrow \frac{m}{q} &= \frac{rB\sin\theta}{v} \\ \frac{m}{q} &= \frac{rB\sin\theta}{v} \\ &= \frac{20\times 113.7\times 10^{-6}\times \sin 90}{0.8\times 3\times 10^8} \\ &= 9.475\times 10^{-12}\ \text{kg C}^{-1} \end{aligned}$$

However, the particle is moving at relativistic speeds so mass dilation occurs:

$$\begin{aligned} \frac{m_o}{\sqrt{1-\dfrac{v^2}{c^2}}\times q} &= 9.475\times 10^{-12}\ \text{kg C}^{-1} \\ \frac{m_o}{q} &= 9.475\times 10^{-12}\times\sqrt{1-\frac{(0.8c)^2}{c^2}} \\ &= 5.685\times 10^{-12}\ \text{kg C}^{-1} \end{aligned}$$

1 mark – Equates the magnetic field force with centripetal force

2 marks – Calculates the correct mass to charge ratio (units recommended but NOT required) of either 9.475×10^{-12} kg C^{-1} OR 5.685×10^{-12} kg C^{-1} (see note below)

Note to markers and students:

- Ideally, the question would have specified to calculate the mass to charge ratio of this particle **at rest**.
- If mass dilation wasn't taken into account, then a mass to charge ratio of 9.475×10^{-12} kg C^{-1} would be the final answer – full marks will be provided for this answer too BUT mass dilation will then need to be taken into account in part (b).

(b) Identify the particle and justify your conclusion. **3**

Testing the mass to charge ratio of an electron at rest,

$$\begin{aligned}\frac{m}{q} &= \frac{9.109 \times 10^{-31} \text{ kg}}{1.602 \times 10^{-19} \text{ C}} \\ &= 5.686 \times 10^{-12} \text{ kg C}^{-1}\end{aligned}$$

$\therefore$ The particle has the same mass to charge ratio as an electron. Furthermore, the magnetic field is pointing out of the page and applying the right hand rule allows us to conclude the particle must have a negative charge. The particle is a first generation fundamental particle so it must be an electron.

1 mark – Calculates the mass to charge ratio of an electron

1 mark – Deduces that the particle must have a negative charge

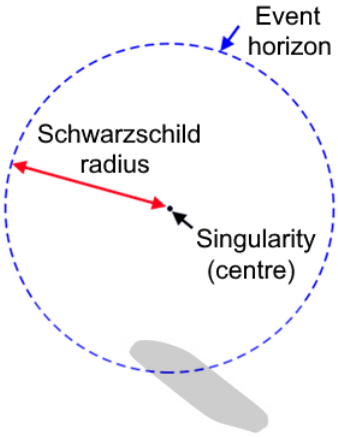
1 mark – Identifies the particle as an electron

Note: If mass dilation wasn't taken into account in part (a), then it must be taken into account here in part (b) for full marks to be obtained.

Question 22 (3 marks)

A student is is studying black holes for their depth study. They come across the concept of the Schwarzschild radius which is defined below: **3**

"The Schwarzschild radius is the radius of the event horizon surrounding a non-rotating black hole. The event horizon of a black hole is a boundary where gravity is powerful enough such that the velocity required for an object to escape exceeds the speed of light."



Derive an expression for the Schwarzschild radius (r) of a non-rotating black hole in terms of the mass of the black hole (M) and physical constants. Assume a point source of gravity at the centre of the black hole.

By the law of conservation of energy,

$$\begin{aligned} E_i = E_\infty &= 0 \\ E &= U + K \\ U_i + K_i &= U_\infty + K_\infty \\ \frac{-GMm}{r} + \frac{1}{2}mv_e^2 &= 0 + 0 \\ \frac{1}{2}mv_e^2 &= \frac{GMm}{r} \\ \implies v_e &= \sqrt{\frac{2GM}{r}} \end{aligned}$$

At the furthest boundaries of the event horizon, the escape velocity would be c.

$$\begin{aligned} c &= \sqrt{\frac{2GM}{r}} \\ \implies r &= \frac{2GM}{c^2} \end{aligned}$$

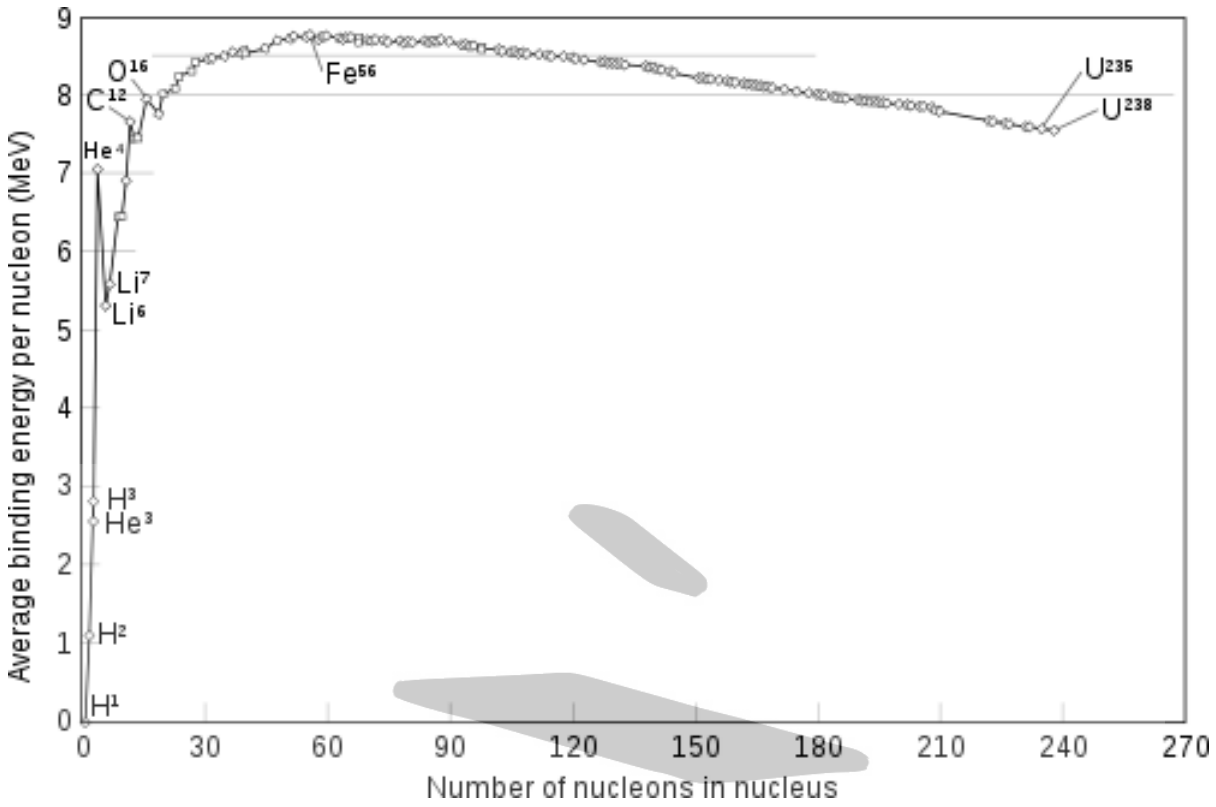
2 marks – Derives an expression for escape velocity using GPE and KE

1 mark – Derives an expression for the Schwarzschild radius (may contain an inequality)

Note: If students simply start from $\frac{1}{2}mv_e^2 = \frac{GMm}{r}$ without any indication of the negative sign, 2 marks max.

Question 23 (3 marks)

The graph below shows how the average binding energy per nucleon varies with the number of nucleons in a nucleus. **3**



With reference to the graph, explain why the fission of uranium-238 releases energy, but the fission of helium-4 does not.

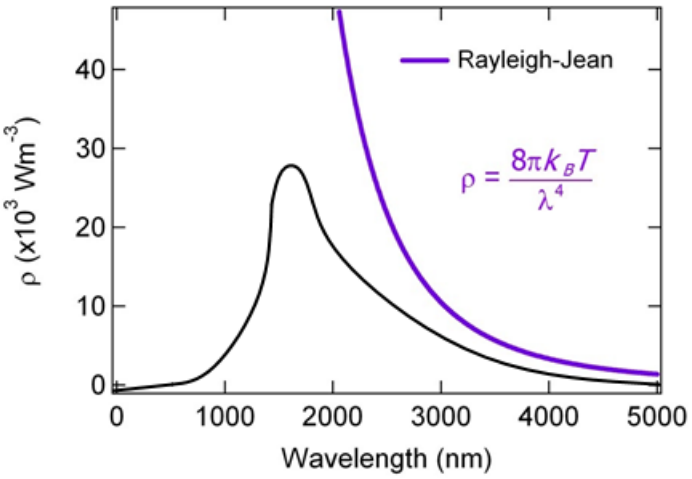
From the graph, it is evident that nuclei smaller than uranium have a higher binding energy per nucleon, meaning the products of uranium fission are more stable. The opposite is true for helium fission; the products would be less stable than helium since the binding energy per nucleon is lower. Species tend towards a more stable state, which releases energy. However, the fission of helium would require energy since it is forming products more unstable than itself.

1 mark – Explains that the products of uranium fission are more stable

1 mark – Explains that the products of helium fission are less stable

1 mark – Explains that the fission of helium would require an energy input

Question 24 (7 marks)
The graph below plots the Rayleigh-Jeans law.



(a) In regards to the radiation produced by a black body, describe the main issues with the Rayleigh-Jeans law and what this told scientists about the existing model of light. **3**

As seen in the graph, Rayleigh-Jeans law predicted that as the wavelength of light decreased, the intensity would approach infinity. There were several problems with this prediction. The first problem was that while the graphs matched well enough for longer wavelengths, there was a complete mismatch with lower wavelengths. The experimental evidence showed that there was a peak wavelength according to Wien's law: $\lambda_{max} = \frac{b}{T}$.

The second issue was that the prediction by Rayleigh-Jeans law violated the law of conservation of energy, since it predicted that intensity would approach infinity. This led to the conclusion that the classical wave model of light could not sufficiently explain black body radiation curves, meaning that the model either needed to be modified or changed completely.

3 marks – Describes TWO problems with the Rayleigh-Jeans law (mismatch with experimental evidence for Wien's law + violation of the law of conservation of energy) and states that the existing model of light needed to be modified

(b) Identify the scientist who solved the issues with the Rayleigh-Jeans law, and explain how they did this. **3**

Planck was the scientist who managed to solve these issues (the UV catastrophe) by introducing a new radical idea which was the first step away from the classical model of light. He realised that if electromagnetic radiation (EMR) could only be emitted or absorbed in discrete amounts by a black body, this would solve the mismatch between the Rayleigh-Jeans curve and the experimental curve. Mathematically, he hypothesised that if the EMR was absorbed and emitted in quanta integer multiples of a single quantum of energy that corresponded with his formula $E = hf$, the value of h would be small enough such that the discrete energy spectrum would look continuous and hence fit the experimental curve.

1 mark – Identifies that Planck solved the issues with the Rayleigh-Jeans law

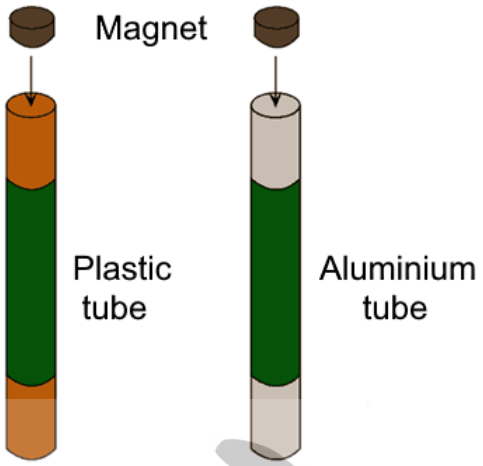
1 mark – Explains that Planck introduced the idea that EMR could only be emitted or absorbed in discrete amounts

1 mark – Explains that the energy absorbed/emitted corresponds with $E = hf$

(c) On the graph above, draw the black body radiation curve that was obtained experimentally. **1**

1 mark – Draws a black body curve that is under the Rayleigh-Jeans curve with a peak and approaches similar values at higher wavelengths

Question 25 (8 marks)
In an experiment, two identical magnets are simultaneously dropped down two tubes of identical dimensions. The first tube is made of plastic and the second tube is made of aluminium. Both magnets are dropped with their north poles facing downwards.



(a) What would be observed in regards to the time taken for the magnets to exit the tubes? **1**

The magnet will exit the plastic tube faster than the aluminium tube.

1 mark – Identifies the correct observation

(b) Explain the observation in part (a) using physics principles. **5**

The plastic tube is non-conductive. The magnet falling through this tube will induce a change in flux but not a current and will only have the force of gravity acting upon it. The magnet falling through the aluminium tube will also have the force of gravity acting upon it. However, the magnet will produce a change in magnetic flux, and since the aluminium tube is conductive, this will produce an electromotive force (EMF) by Faraday's law (when magnetic flux cuts a conductor, an EMF will be induced with magnitude proportional to the rate of change of magnetic flux). The EMF will produce a current in the tube that acts to oppose the change in flux via Lenz's law (if an induced EMF gives rise to an induced current which flows in a conductor, the current will flow in a direction such that the induced magnetic field always acts to oppose the change in magnetic flux that caused it).

When the magnet enters the tube completely, there will be different currents above and below it that act to impede its movement. Below the magnet the induced current will flow counterclockwise, setting up a north magnetic pole that repels the north pole of the magnet, applying a force upwards. Above the magnet the induced current will flow clockwise, setting up a north magnetic pole that attracts the south pole of the magnet, also applying a force upwards. Both these forces act against the force of gravity and slow the magnet, which is why it will take longer to fall down the aluminium tube compared to the plastic tube.

1 mark – Explains that the magnet in the plastic tube only has the force of gravity acting upon it since the tube is non-conductive

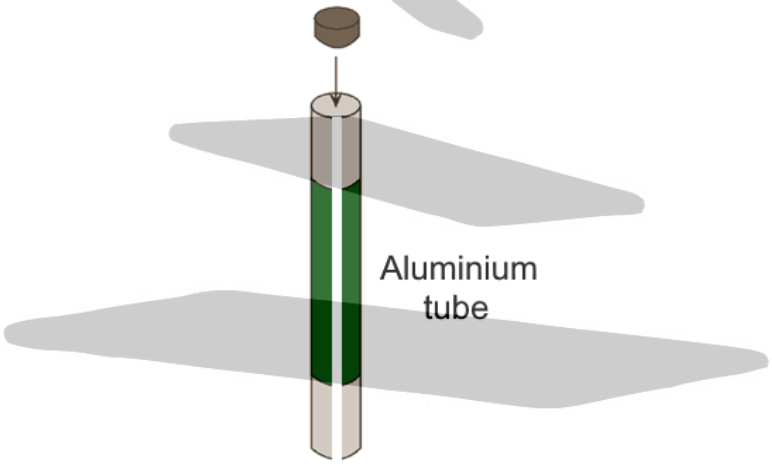
1 mark – Explains that the magnet falling through the aluminium tube will produce a change in magnetic flux, an EMF by Faraday's law and hence a current since aluminium is conductive

1 mark – States that Lenz's law predicts that the induced current will be in such a direction that a magnetic field is produced that opposes the change in flux that caused it

1 mark – Explains that below the magnet the induced current flows counterclockwise and above the magnet the current flows clockwise, setting up magnetic fields on either side to oppose the change in flux

1 mark – Explains that the magnetic fields will produce an upwards force on the magnet to slow it down

(c) A new tube, identical to the aluminium tube, is brought in. However, this tube has been cut through vertically, as shown in the diagram below. **2**



Explain what would be observed if the experiment is repeated once again with this new tube.

The magnet falling through the cut aluminium tube will exit the tube at the same time as the magnet falling through the plastic tube. The reason that the magnet's movement is impeded is because a current flowing around the aluminium tube can be induced. When there is a gap, this current cannot fully form and therefore the magnet will not experience a force that opposes its motion.

1 mark – Identifies that the magnet will exit the cut aluminium tube at the same time as the plastic tube

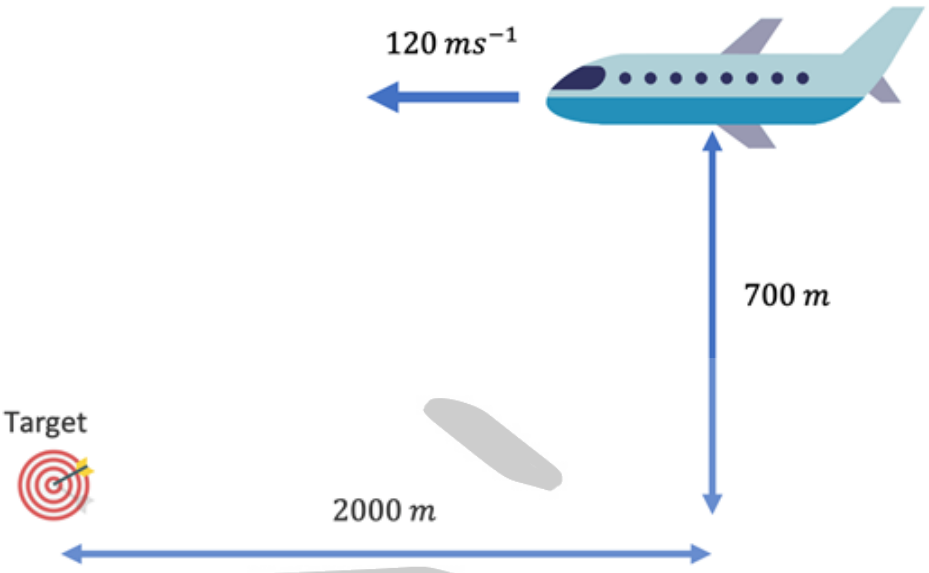
1 mark – Explains why in terms of the current not being able to form

Note:

- If students argue that smaller currents, are induced causing the magnet to move through the cut aluminium tube faster than the normal aluminium tube but slower than the plastic tube, can award 1 mark.
- This can be very controversial but a previous HSC question has indicated that their preferred answer would be the one provided here (refer to HSC 2005 Q9).

Question 26 (3 marks)

A scientist is playing altitude bowling, where they are on a plane travelling horizontally at a constant speed of 120 m s^{-1} while 700 m above the ground. The scientist needs to drop a bowling ball such that it hits the target directly in order to get a strike. **3**



If they are currently 2000 m from the target, calculate the time the scientist needs to wait before dropping the ball if they want to get a strike.

$$\begin{aligned} s_y &= u_y t + \frac{1}{2}at^2 \\ 700 &= 0(t) + \frac{1}{2}(9.8)t_{drop}^2 \\ \implies t_{drop} &= 11.95 \text{ s} \end{aligned}$$

During this time, the plane travels:

$$\begin{aligned} s_x &= 120 \times 11.95 \\ &= 1434.27 \text{ m} \\ d_{wait} &= 2000 - s_x \\ &= 2000 - 1434.27 \\ &= 565.72 \text{ m} \\ t_{wait} &= \frac{d_{wait}}{u_{plane}} \\ &= \frac{565.72}{120} \\ &= 4.71 \text{ s} \end{aligned}$$

1 mark – Calculates the time taken for the ball to drop

1 mark – Calculates the distance travelled by the plane in this time or equivalent merit

1 mark – Calculates the correct waiting time

Question 27 (8 marks)

Outline Newton and Huygens' proposed models of light and describe TWO subsequent experiments which provided evidence that supported either model. **8**

Newton proposed a corpuscular model of light where light was made of very small particles that could interact with matter via the laws of mechanics. His model could explain the refraction (different coloured corpuscles had different masses and hence inertia, with red light having the highest inertia) and reflection of light (he explained reflection as corpuscles bouncing off surfaces), but lacked a solid explanation for other properties such as diffraction, interference and polarisation. Newton's model concluded that light would be attracted to matter and would therefore speed up in water and bend towards the normal, which is a denser medium.

Huygen proposed that light existed as a wave that propagated perpendicular to its vibration and had a very small wavelength. He hypothesised that every point on a wavefront would act as a point source of secondary wavelets which propagated in the small direction and with the same velocity as the original wave. The tangent of the secondary wavelets would form a new wavefront and the process would repeat. With this model, wavefronts could be reflected off a surface which would be observed as the reflection of light and refraction occurred when a portion of the wavefront changes velocity as it entered the other medium, which we observe as a bending of light . Huygens' model predicted that light would slow down in water, which was the crucial difference between the wave and particle model of light.

Young's double slit experiment involved shining a monochromatic light through a small slit to observe a pattern of consecutive dark and light bands, with the brightest band in the middle, which he understood represented regions of destructive and constructive interference of light respectively. The diffraction and interference of light were wave properties readily explained by Huygens' but not Newton's model. Thus, Young's experiment provided evidence that supported Huygens' wave model.

Foucault used a rotating mirror to reflect light over large distances and measured the angle of reflection to approximate the speed of light. In a modified experiment, he placed a water tank over the rotating mirror and found that the angle the mirror travelled through before reflecting the light was greater than without the water tank, indicating that light travels slower in water compared to air, which confirmed Huygens' theory of light behaving as a wave.

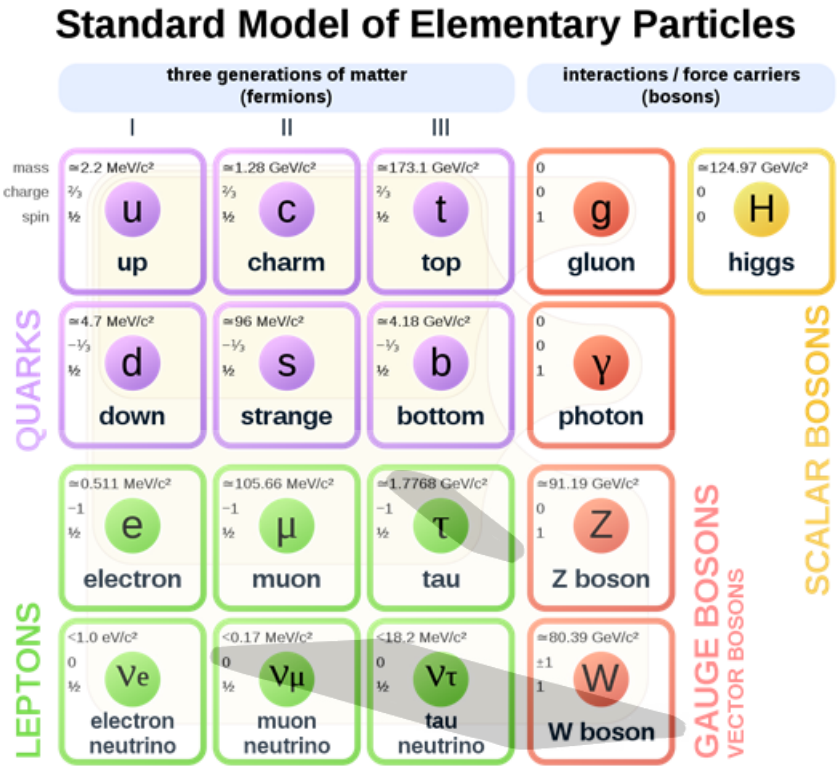
2 marks – States the Newton and Huygens' proposed models of light (1 mark each)

2 marks – Outlines the predictions made by each model (e.g. whether light speeds up or slows down in water)

4 marks – Describes TWO experiments (e.g. Young's double slit and Foucault's rotating mirror) that supported either theory

Question 28 (7 marks)

The Standard Model of Matter exists to classify all known elementary particles and attempts to explain the fundamental forces of the universe. A summary for this model is shown below:



(a) Describe and explain TWO pieces of evidence that led to the conclusion that baryons are not fundamental particles. **4**

Neutrons, though electrically neutral, possess an intrinsic magnetic field. This was unexpected for a neutral particle, suggesting that the neutron was made up of moving charged particles and thus was not an elementary particle.

Physicists used a particle accelerator to direct high energy electrons at protons and neutrons. The scattering pattern observed suggested the existence of point charges within the baryons internal structure, meaning they could not be fundamental particles

4 marks – Describes and explains two pieces of evidence that indicate baryons are not fundamental particles (2 marks each)

(b) Identify the quark composition of a proton and a neutron. **2**

Proton = uud (up, up, down)
Neutron = udd (up, down, down)

2 marks – Clearly identifies the quark composition of a proton and neutron

(c) Outline a major limitation of the Standard Model of Matter at the moment. **1**

It currently fails to explain gravity, one of the four fundamental forces of the universe.

1 mark – Outlines a limitation of the Standard Model

Question 29 (4 marks)
A student is tracking a low-earth orbit satellite that orbits Earth every 120 minutes.

(a) Calculate the orbital velocity of this satellite. **2**

$$\begin{aligned}
\frac{r^3}{T^2} &= \frac{GM}{4\pi^2} \\
r &= \sqrt[3]{\frac{GMT^2}{4\pi^2}} \\
&= \sqrt[3]{\frac{6.67 \times 10^{-11} \times 6.0 \times 10^{24} \times (120 \times 60)^2}{4\pi^2}} \\
&= 8.07 \times 10^6 \text{ m}
\end{aligned}$$

$$\begin{aligned}
v_o &= \frac{2\pi r}{T} \\
&= \frac{2\pi \times 8.07 \times 10^6}{120 \times 60} \\
&= 7042 \text{ m s}^{-1}
\end{aligned}$$

1 mark – Calculates the correct radius or equivalent merit

1 mark – Calculates the correct orbital velocity

(b) The same satellite needs to be moved into geostationary orbit, 36 000 km above the Earth's surface. **2**

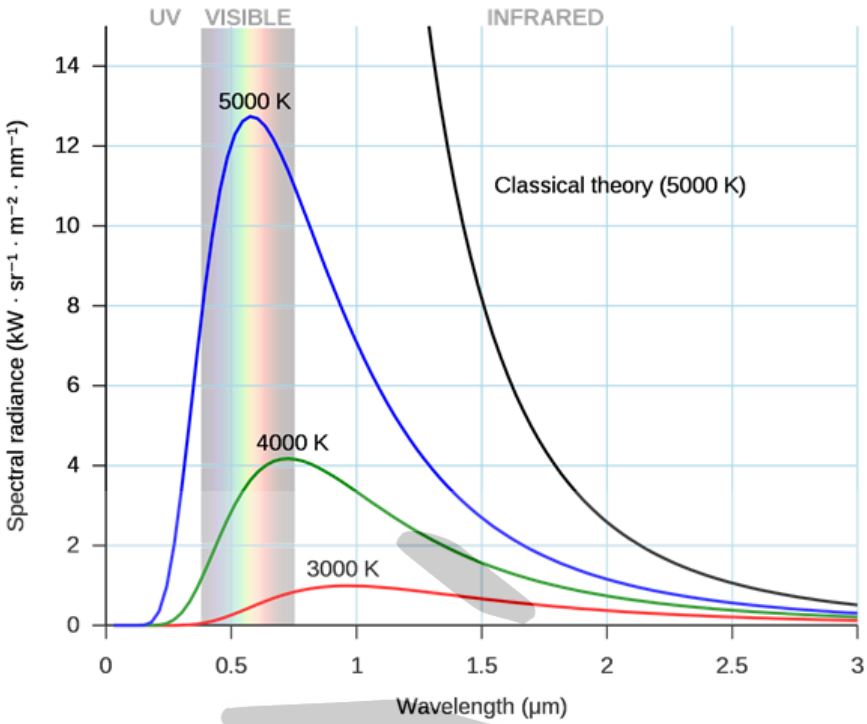
Calculate the work that must be done against gravity to accomplish this if the satellite has a mass of 800 kg.

$$\begin{aligned}
r_2 &= 36000 \times 10^3 + 6.371 \times 10^6 \\
&= 4.24 \times 10^7 \text{ m} \\
W &= \Delta U \\
&= U_2 - U_1 \\
&= -GMm(\frac{1}{r_2} - \frac{1}{r_1}) \\
&= -6.67 \times 10^{-11} \times 6.0 \times 10^{24} \times 800(\frac{1}{4.24 \times 10^7} - \frac{1}{8.07 \times 10^6}) \\
&= 3.21 \times 10^{10} \text{ J}
\end{aligned}$$

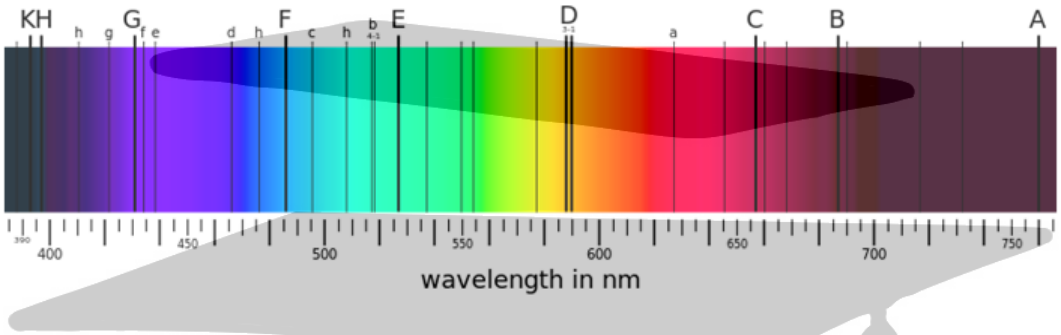
2 marks – Calculates the correct work done

Question 30 (3 marks)

A black body radiation curve is shown below. **3**



The spectra produced by reflected sunlight is shown below:



A scientist observing stars with his telescope is admiring the blue, white, yellow, orange and red stars that he can see. However, he notices that he cannot see any green stars.

Using your knowledge of electromagnetic radiation, propose and explain a reason for this.

The colour of a star is determined by its surface temperature and the peak wavelength emitted which corresponds with Wien's law: $\lambda_{max} = \frac{b}{T}$. There are stars which emit a peak wavelength that we would consider to be green, but due to the distribution of the black body radiation curve and the fact that green is in the middle of the continuous visible spectrum, it would also emit the entire visible spectrum of light at a high intensity. The colours closer to green, such as yellow and orange would be produced at an almost equal intensity as green. Thus, this star would be observed to have a white colour, due to the polychromatic nature of the light emitted by the star.

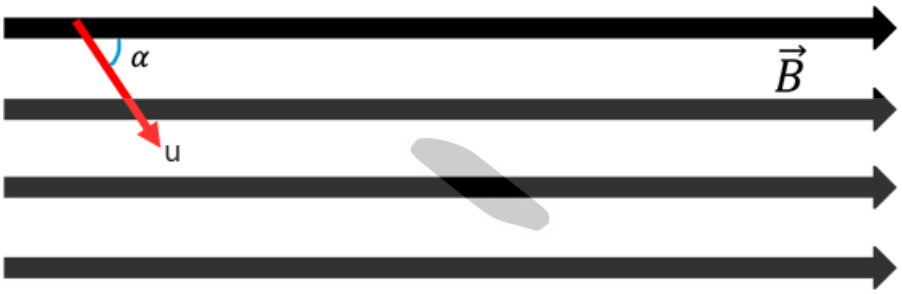
1 mark – States that the colour of a star is determined by its surface temperature

1 mark – Explains that many visible wavelengths are emitted due to the distribution of the black body curve

1 mark – Explains that the star with a peak wavelength that is green would be observed to be white

Question 31 (7 marks)

A negatively charged particle is directed into a magnetic field with initial velocity u at an angle of α. The strength of the magnetic field is B. This is shown in the diagram below.



(a) Describe the motion and trajectory of the particle once it enters the magnetic field and justify your answer using physics principles. Assume that the particle does not leave the field. **4**

The horizontal component of the particle's motion ($u\cos\alpha$) is parallel to the direction of the magnetic field and experiences no force, since $F = qvB\sin\theta$. Thus, there is no acceleration for the horizontal component, meaning the particle travels at a constant speed to the right. The vertical component of the particles motion ($u\sin\theta$) is perpendicular to the magnetic field and will experience a magnetic force into the page. This force acts as a centripetal force, causing the vertical component to undergo uniform circular motion while inside the magnetic field.

Combined, this produces a helical trajectory that goes in the clockwise direction as observed from the left of the magnetic field as the particle spirals to the right. Due to the circular motion of the particle, it is constantly accelerating and therefore emitting electromagnetic radiation, losing energy in the process. Thus, it will slowly spiral towards the centre and the radius of the helix gradually decreases as the particle travels further.

1 mark – Explains that there is no acceleration for the horizontal component

1 mark – Explains that the vertical component will result in the particle undergoing uniform circular motion due to a centripetal force

1 mark – Describes the helical trajectory (clockwise as seen from the left, and spiralling towards the right)

1 mark – Explains that the radius of the helix gradually decreases

(b) Given that $\alpha = 40°$, $B = 0.060$ T and the particle is an antiproton with $u = 2.0 \times 10^6\,\text{m s}^{-1}$, calculate the initial radius of its path. **1**

$$\begin{aligned} F_c &= F_B \\ \frac{mv_y^2}{r} &= qv_yB\sin\theta \\ \implies r &= \frac{mv_y}{qB} \\ &= \frac{1.673 \times 10^{-27} \times 2.0 \times 10^6 \times \sin(40)}{1.602 \times 10^{-19} \times 0.060} \\ &= 0.22 \text{ m} \end{aligned}$$

1 mark – Calculates the correct radius

(c) The pitch of the particle refers to the distance that it can travel parallel to the magnetic field, in the time that it takes to complete one revolution. **2**

Calculate the pitch of this antiproton.

$$\begin{aligned} v_y &= \frac{2\pi r}{T} \\ \implies T &= \frac{2\pi r}{v_y} \\ &= \frac{2\pi \times 0.22}{2.0 \times 10^6 \times \sin(40)} \\ &= 1.09 \times 10^{-6} \text{ s} \end{aligned}$$

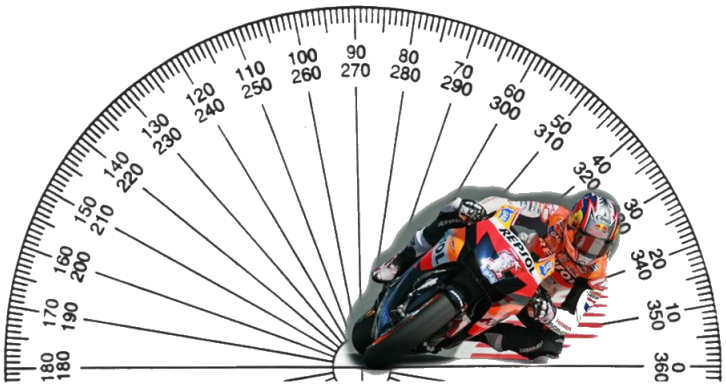
$$\begin{aligned} d &= u_xT \\ &= 2.0 \times 10^6 \times \cos(40) \times 1.09 \times 10^{-6} \\ &= 1.7 \text{ m} \end{aligned}$$

1 mark – Calculates the correct period or equivalent merit

1 mark – Calculates the correct pitch

Question 32 (3 marks)

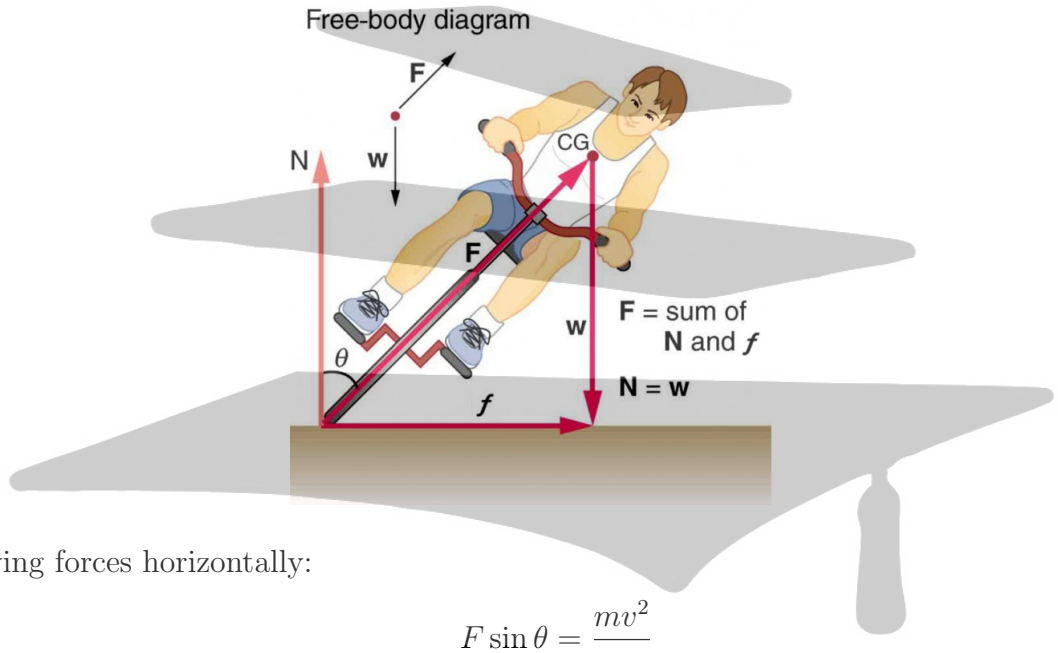
Professional bike racers often lean into a turn, allowing them to move around a curve at higher speeds than someone turning while upright. **3**



Mathematically show that the speed of a racer around a curve will be higher when they lean in compared to when they are upright. Include relevant free body diagrams in your answer.

Let the angle of inclination from the vertical be θ.

While leaning:



Resolving forces horizontally:

$$F \sin\theta = \frac{mv^2}{r}$$

Resolving forces vertically:

$$F \cos\theta = mg$$
$$F = \frac{mg}{\cos\theta}$$

$$\implies \frac{mg}{\cos\theta} \sin\theta = \frac{mv^2}{r}$$
$$mg \tan\theta = \frac{mv^2}{r}$$
$$\implies v = \sqrt{gr \tan\theta}$$

When upright, $\theta = 0°$,

$$\begin{aligned} v &= \sqrt{gr \tan 0} \\ &= 0 \end{aligned}$$

It is actually impossible to turn a bike without leaning since the velocity towards the centre of the circle would be 0. For $0° < \theta < 90°$, $v > 0$, so leaning in would increase the velocity (and furthermore, as θ increases, v increases).

1 mark – Draws a suitable free body diagram

1 mark – Derives an expression for the speed while leaning in ($v = \sqrt{gr \tan \theta}$ for a vertical inclination angle or $v = \sqrt{gr \cot \theta}$ for a horizontal inclination angle)

1 mark – Provides ANY reasonable attempt to explain the higher velocity while leaning in (see note below)

Note to markers and students:

- The question was likely very confusing since it actually isn't possible to turn a bike without leaning in.
- If the students used a free body diagram to derive a correct relationship and provided any reasonable attempt to link θ with an increased speed, award full marks (does NOT need to be a perfect explanation and CAN accept attempts to compare $\tan \theta$ with μ_s).
- Note that some students will derive an equation of $v = \sqrt{gr\mu_s}$ for the upright case. This equation doesn't actually hold here since there would not be a horizontal force towards the centre of the circle without leaning in to begin with (do NOT penalise if students have this expression though).

Question 33 (7 marks)
The Big Bang Theory is the prevailing cosmological model explaining the existence of the observable universe.

(a) Identify the fundamental forces and the order that they separated shortly after the Big Bang. **2**

1. Gravity
2. Strong nuclear force
3. Weak nuclear force and electromagnetic force

1 mark – Identifies the four fundamental forces

1 mark – Identifies the correct order in which they separated

(b) How does the existence of cosmic background radiation support the Big Bang Theory? **2**

The Big Bang Theory predicts that the early universe had very high temperatures while undergoing rapid inflation and expansion. Thus, the universe should be filled with remnant heat in the form of radiation which would be isotropic and homogeneous. This fit the description of cosmic background radiation, and therefore its existence provides evidence for the Big Bang.

2 marks – Explains how the cosmic background radiation supports the Big Bang Theory

(c) It is thought that shortly after the Big Bang, the ratio of free protons to neutrons was approximately 7:1. **3**

Using this information, explain why there was approximately a 3:1 mass ratio of hydrogen to helium in the early universe.

Shortly after the Big Bang, there will be 14 protons for every 2 neutrons. 2 protons and 2 neutrons can combine to form a helium nucleus (4 amu total). The remaining 12 protons form 12 hydrogen nuclei (1 amu each; 12 amu total). The mass ratio of hydrogen to helium is therefore 12:4 = 3:1.

3 marks – Explains the 3:1 mass ratio of hydrogen to helium using the information given

Question 34 (4 marks)

Identify which type of device would contain an armature, split ring commutator and brushes, and outline the function of each of these components. **4**

DC motor.

- The armature is a cylinder of laminated iron mounted on an axle. The iron core concentrates the external magnetic field, increasing torque while the lamination reduces eddy currents that may overheat it. The armature carries the coil.
- A split ring commutator consists of two metal half rings electrically insulated from each other which provide electrical contact between the coil and brushes. They reverse the direction of current in the coil every half cycle to provide unidirectional torque and allow the coil to maintain the same direction of rotation.
- The brushes are spring loaded, usually made of graphite (a conductor lubricant). They maintain electrical contact between the rotating commutator and the external DC power supply without the tangling of wires.

1 mark – Identifies a DC motor OR DC generator would contain these components

3 marks – Outlines the function of each component (1 mark each)

Question 35 (3 marks)

Show how de Broglie used his hypothesis of $\lambda = \dfrac{h}{mv}$ to justify Bohr's postulate of stationary states. **3**

de Broglie knew that stationary states were possible if the matter waves of electrons could interfere constructively to form standing waves, since standing waves do no radiate energy. He realised that for this to happen, the orbital circumference of Bohr's postulated electron shells must be integer multiples of of the wavelength of the electrons.

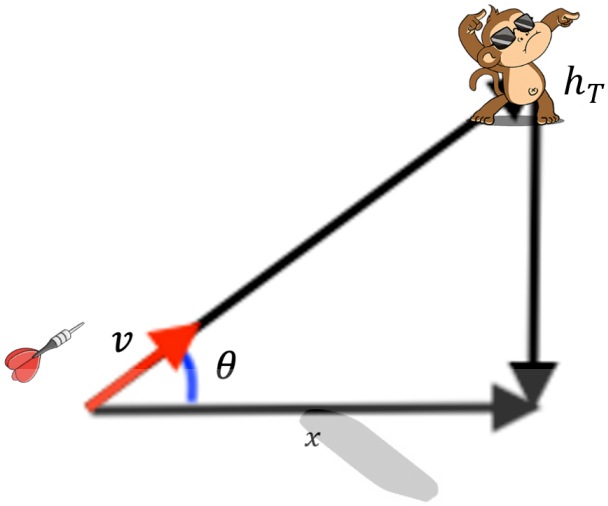
$$n\lambda = 2\pi r$$
$$n\left(\frac{h}{mv}\right) = 2\pi r$$
$$mvr = \frac{nh}{2\pi} = l$$

This was Bohr's postulate of quantised angular momentum, which he knew must be true for the stationary states to be achieved. Thus, de Broglie provided a reasonable justification for Bohr's stationary state postulate.

3 marks – Shows how the de Broglie hypothesis can be used to justify Bohr's stationary states

Question 36 (4 marks)

The "monkey-dart problem" describes a scenario where a person on the ground throws a dart with initial velocity v directly at a monkey hanging on a tree at an initial height of h_{T} above the ground. However, at the same time that the dart is released from the person's hand, the monkey lets go of the branch and drops to the ground. This is shown in the diagram below. **4**



Assuming that the dart has enough initial velocity to actually reach the monkey, mathematically prove that the dart will always hit the monkey.

- Let x be the horizontal distance between the person and the monkey, h_M be the height of the monkey and h_D be the height of the dart at time t.
- Take the downwards direction as positive.

For the monkey:

$$\begin{aligned} s_y &= u_y t + \frac{1}{2}at^2 \\ &= 0(t) + \frac{1}{2}gt^2 \\ &= \frac{1}{2}gt^2 \\ h_M &= h_T - s_y \\ &= h_T - \frac{1}{2}gt^2 \end{aligned}$$

For the dart:

$$\begin{aligned} s_y &= u_y t + \frac{1}{2}at^2 \\ -h_D &= -v\sin\theta \times t + \frac{1}{2}gt^2 \\ h_D &= v\sin\theta \times t - \frac{1}{2}gt^2 \end{aligned}$$

$$\begin{aligned} s_x &= u_x t \\ x &= v\cos\theta \times t \\ \implies t &= \frac{x}{v\cos\theta} \end{aligned}$$

When $t = \dfrac{x}{v\cos\theta}$, the dart is at the same horizontal position as the monkey. At this point,

$$\begin{aligned} h_D &= v\sin\theta \times \frac{x}{v\cos\theta} - \frac{1}{2}gt^2 \\ &= x\tan\theta - \frac{1}{2}gt^2 \end{aligned}$$

However,

$$\begin{aligned} \tan\theta &= \frac{h_T}{x} \\ \implies h_D &= x\frac{h_T}{x} - \frac{1}{2}gt^2 \\ &= h_T - \frac{1}{2}gt^2 \\ &= h_M \end{aligned}$$

Therefore, the height of the dart and monkey are equal (and also their horizontal positions) when $t = \dfrac{x}{v\cos\theta}$, so the dart never misses the monkey.

4 marks – Proves that the dart never misses the monkey (different approaches are likely possible)