PΣΛK

2023

HIGHER SCHOOL CERTIFICATE
MOCK HSC 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
- NESA-approved calculators may be used
- A data sheet, formulae sheet and Periodic Table is 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 – 8

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

Section II Pages 9 – 22

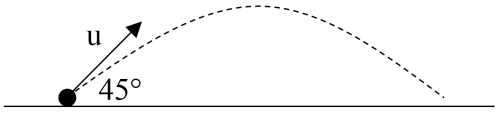
80 marks
- Attempt Questions 21 – 35
- Allow about 2 hours and 25 minutes for this part

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

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. A projectile is launched at 45° above the horizontal. The magnitude of acceleration due to gravity is given by g.



Which of the following is the correct expression for the horizontal distance, s, travelled by the projectile when it reaches its maximum height?

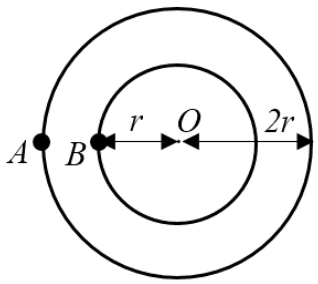
(A) $\frac{u^2}{2g}$
(B) $\frac{u^2}{g}$
(C) $\frac{u}{g^2}$
(D) $\frac{u}{2g^2}$

2. A satellite in low-Earth orbit moves from an orbital radius of r_1 to r_2. It is known that the kinetic energy of the satellite increases.

Which row of the table correctly identifies the change in gravitational potential energy (GPE) and mechanical energy (U) of the satellite?

	GPE	U
(A)	Increases	Increases
(B)	Increases	Decreases
(C)	Decreases	Increases
(D)	Decreases	Decreases

3. Two identical objects, A and B, are travelling in different circular paths about a centre O, as shown below. Object A is travelling at a constant speed of v_1, and object B at a constant speed of v_2.



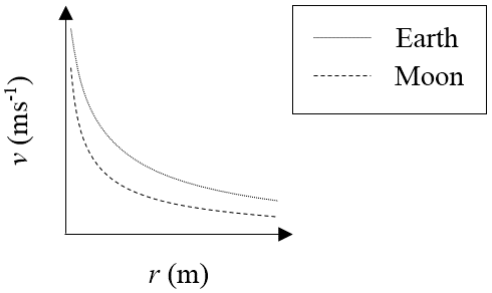
If both objects have the same angular velocity, what is the ratio of v_1 to v_2?

(A) 2:1
(B) 1:2
(C) 4:1
(D) 1:4

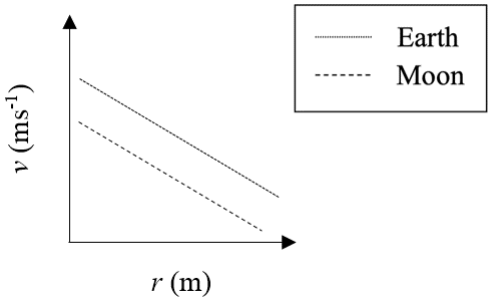
4. The velocity of two identical satellites are measured as their orbital radius is varied. Satellite 1 orbits the Earth whereas Satellite 2 orbits the Moon. You are given that the mass of the Moon is 7.35×10^{22} kg.

   Which graph correctly shows the relationship between the orbital velocity (v) and orbital radius (r) of both satellites?

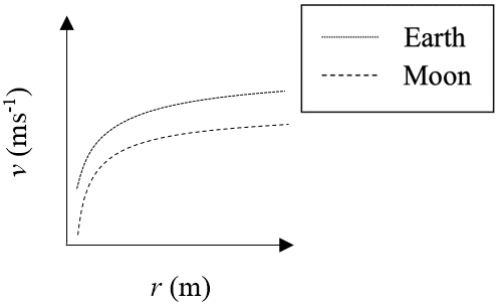
(A)



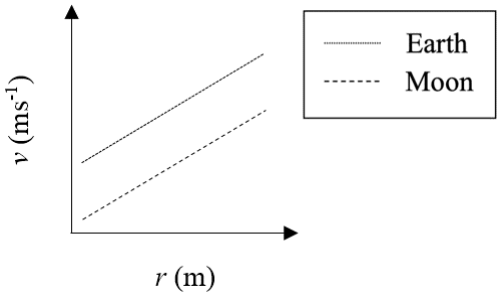
(B)



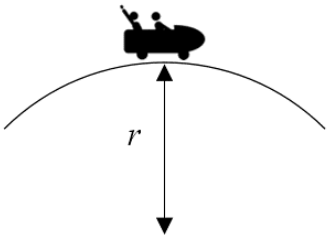
(C)



(D)



5. The track of a roller coaster forms a circular arc of radius r at one of its peaks. The total mass of a roller coaster cart and its occupants is 250 kg.



   What is the radius of the circular arc if its occupant feels no upward force when passing the peak at a speed of 28 $\mathrm{m\,s^{-1}}$?

   (A) 60 m
   (B) 70 m
   (C) 80 m
   (D) 90 m

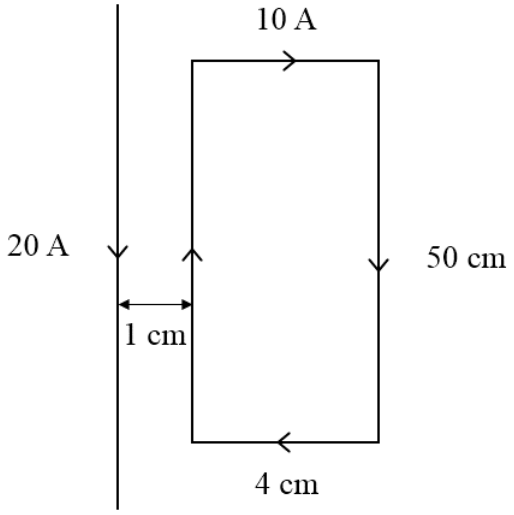
6. Three statements about DC motors are given below.

   1. The force acting on the coil is constant as the coil rotates.
   2. The torque acting on the coil is constant as the coil rotates.
   3. The magnetic flux through the coil is constant as the coil rotates.

   Which of the statements are NOT true?

   (A) 1 and 2
   (B) 1 and 3
   (C) 2 and 3
   (D) 1, 2 and 3

7. A rigid rectangular loop carrying a current of 10 A is placed next to a long wire carrying 20 A as shown below. The rectangular loop has dimensions 4 x 50 cm and its left edge is 1 cm away from the wire.



   What is the net force acting on the rectangular loop?

   (A) 1.6 mN left
   (B) 1.6 mN right
   (C) 2.0 mN left
   (D) 2.0 mN right

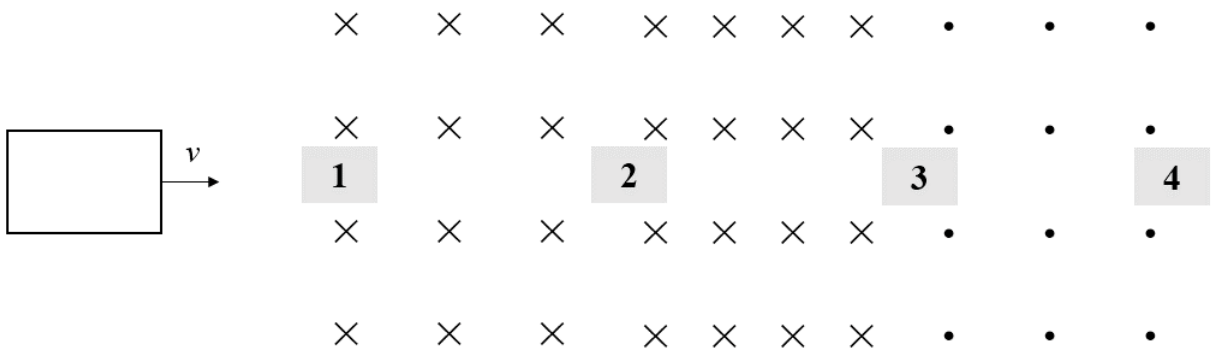
8. The wavelength of peak intensity radiation emanating from a source with temperature T_1 is measured as l_1.

   The temperature of the body is changed to T_2, where $T_2 = 2T_1$. What changes in the radiation from the source would be observed?

   (A) The peak wavelength would become $2l_1$
   (B) The peak wavelength would become $l_1/2$
   (C) The peak wavelength would remain unchanged.
   (D) The peak wavelength would increase a small amount.

9. In a simple DC generator, a coil is turned in a magnetic field to generate electricity. Which of the following changes would NOT increase the voltage output of the generator?
   (A) Increasing the area of the coil.
   (B) Decreasing the resistance of the coil.
   (C) Turning the coil faster.
   (D) Increasing the number of turns of wire in the coil.

10. A loop of wire is moved with a constant velocity across the page through three adjacent magnetic fields as shown below. It passes through points 1, 2, 3 and 4.



   At which point will there be a clockwise current flowing through the loop?

   (A) 1
   (B) 2
   (C) 3
   (D) 4

11. A student observes a transmission line that is carrying current from east to west. The student also knows that the Earth's magnetic field points northwards.

   What is the direction of the force acting on the transmission line due to the Earth's magnetic field?

   (A) North
   (B) South
   (C) Away from the ground
   (D) Towards the ground

12. The Sun produces energy by fusing light elements such as helium into heavier elements. In this fusion process, mass is lost. The Sun's output is rated at 4.0×10^{26} W.

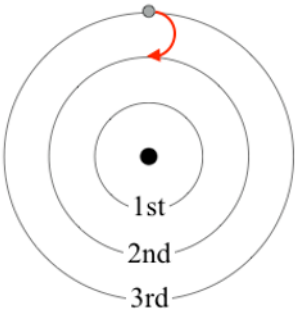
   How much mass does the Sun lose each second?

   (A) 4.4×10^9 kg
   (B) 3.4×10^9 kg
   (C) 4.0×10^9 kg
   (D) 5.1×10^9 kg

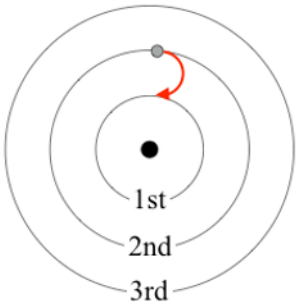
13. Which of the following equations show the correct decay of cobalt-60 to nickel-60?
   (A) ${}^{60}_{27}\text{Co} \longrightarrow {}^{60}_{28}\text{Ni} + {}^{0}_{-1}\beta + \bar{\nu}$
   (B) ${}^{60}_{27}\text{Co} \longrightarrow {}^{56}_{25}\text{Ni} + {}^{4}_{2}\text{He} + \text{energy}$
   (C) ${}^{60}_{27}\text{Co} \longrightarrow {}^{60}_{28}\text{Ni} + {}^{0}_{+1}\beta + \nu$
   (D) ${}^{60}_{27}\text{Co} \longrightarrow {}^{60}_{27}\text{Ni} + {}^{0}_{+1}\beta + \bar{\nu}$

14. Which of the following examples below of an electron moving between energy levels in a hydrogen atom would emit the shortest wavelength?

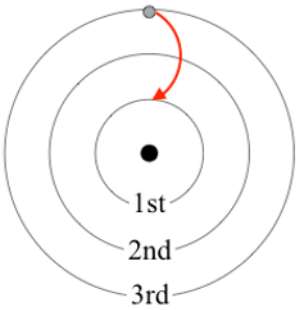
(A)



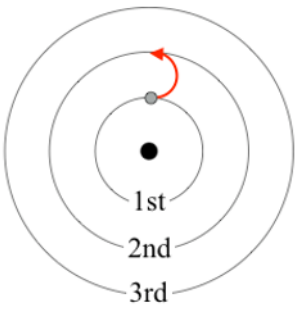
(B)



(C)



(D)



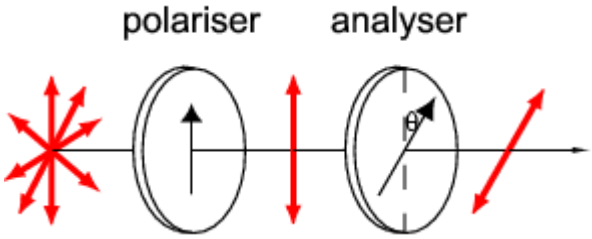
15. What significant change to the atomic model did the Rutherford gold foil experiment lead to?

(A) All atoms contained negative electrons
(B) Electrons existed in energy shells surrounding the nucleus
(C) The nucleus was a positive space
(D) The atom is mostly empty space

16. The purpose of the Michelson-Morley experiment was to
(A) Prove the existence of the aether
(B) Measure the relative velocity of the Earth through the aether
(C) Estimate the speed of light through an interferometer
(D) Analyse the electromagnetic spectrum

17. If a particular metal in a photocell releases a photocurrent when blue light is incident upon it, it also releases a photocurrent when it is incident with
(A) Red light
(B) Microwaves
(C) Ultraviolet light
(D) Radio waves

18. Unpolarized light with intensity 76 candela (cd) passes through a polarizer and then an analyser as shown in the diagram below.



The intensity of light after the analyzer if $\theta = 40°$ is

(A) 38 candela (cd)

(B) 29.11 candela (cd)

(C) 22.30 candela (cd)

(D) 44.60 candela (cd)

19. A spaceship is traveling at 70% the speed of light, headed for Sirius, 8.6 light years away from the Earth. The time taken to reach Sirius from an observer inside the spaceship is:

(A) 8.77 years

(B) 12.29 years

(C) 17.20 years

(D) 6.73 years

20. What contribution did Maxwell make to the classical theory of electromagnetism?

(A) Predicted the existence of electromagnetic waves

(B) Measured the speed of light to be 3×10^8 m s^{-1}

(C) Discovered the existence of radio waves

(D) Proved that magnetic monopoles do not exist

Section II: Short Answer Questions (80 marks)
Attempt Questions 21 – 35
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 (5 marks)
A car of mass 750 kg travelling at 40 km/h turns in a roundabout of radius 15.0 m.

(a) Calculate the minimum frictional force required to keep the car on the road. **2**

.....

.....

.....

.....

.....

(b) On a particular day with heavy rainfall, there is negligible friction between the road and the car tyres. **3**

Calculate the degree of banking required for the car to make the turn without side-tracking off the road.

.....

.....

.....

.....

.....

.....

.....

Question 22 (7 marks)

Two planets are orbiting a star of mass 1.02×10^{29} kg and radius 7.3×10^5 km.

The table below shows the mass of the planets, their diameter, orbital radius and period of orbit. Some of the data is missing. 1 AU is approximately 150×10^6 km.

Planet	Mass of Planet	Diameter of Planet	Period of Orbit	Radius of Orbit
A	4.5×10^{22} kg	13 000 km	43 days	
B	7.0×10^{22} kg		145 days	0.2 AU

(a) Calculate the radius of orbit of Planet A in AU. **3**

.....

.....

.....

.....

.....

.....

(b) Assume that the planetary bodies are perfect spheres, and that the planets are in perfect circular orbits. **2**

Calculate the diameter of Planet B in km if the shortest distance between the surface of Planet B and the surface of the star is 0.195 AU.

.....

.....

.....

.....

.....

.....

(c) An asteroid collides with Planet B causing the planet's orbital radius to double. Calculate the change in total mechanical energy of Planet B. **2**

.....

.....

.....

.....

.....

Question 23 (6 marks)

A transformer has a primary coil connected to a 30 kV power cable and has a current of 12 A flowing through it.

(a) Explain why this transformer needs to be cooled, with reference to relevant physics principles. **3**

.....

.....

.....

.....

.....

.....

.....

(b) The transformer has 500 and 200 turns in its primary and secondary coils respectively. Assuming that power losses are negligible, calculate the output voltage and current of the transformer. **2**

.....

.....

.....

.....

.....

(c) Identify a practical application of a step-down transformer. **1**

.....

Question 24 (4 marks)

A proton is released from rest in an electric field of strength 500 V/m.

(a) Calculate the speed of the proton after it has travelled 20 cm. **2**

.....

.....

.....

.....

.....

(b) After the proton travels 20 cm, the electric field is switched off. At the same instant, a uniform magnetic field is turned on. The proton then follows a circular path with a radius of 500 µm. **2**

Calculate the magnetic field strength.

.....

.....

.....

.....

.....

Question 25 (4 marks)

Describe the evidence supporting the Big Bang theory. **4**

.....

.....

.....

.....

.....

.....

.....

.....

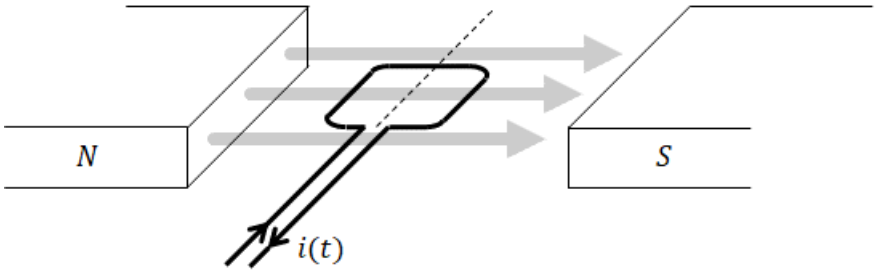
.....

.....

.....

Question 26 (6 marks)

A DC motor has a square armature of side length 25 cm. The armature carries a coil with 300 turns of wire and the magnetic field strength of the stator is 1.2 T. The current direction is as shown in the diagram below.



(a) State the direction of rotation of the coil when viewed from the front of the diagram. **1**

.....

(b) The motor is initially stationary. Once it is switched on, it accelerates until it reaches a constant speed. Describe and explain how the size of the current in the coil changes from startup to this time. **3**

.....

.....

.....

.....

.....

.....

.....

(c) Calculate the torque acting on the coil when the plane is at an angle of 38° to the horizontal and there is a current of 10 A in the coil. **2**

.....

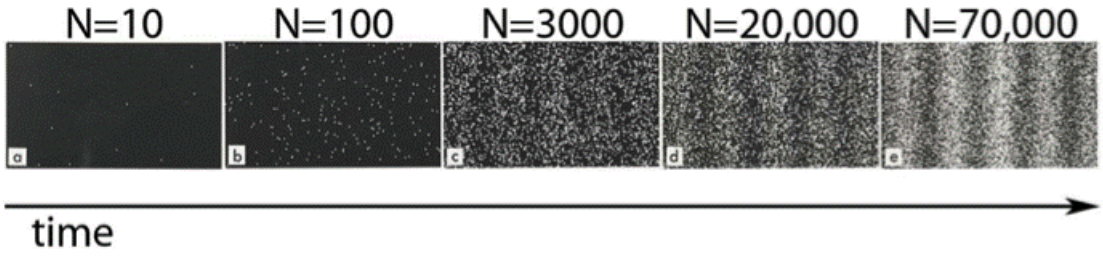
.....

.....

.....

Question 27 (4 marks)

A single electron is fired through a diffraction grating using a setup similar to Davisson and Germer's experiment. The experiment is repeated and the position of each electron as it passes through the double slit is recorded on the detection screen. The diagram below demonstrates how the results developed as more electrons were sent at the double slit, where N represents the number of times the experiment was repeated.



Explain and justify the observations from the diagram above. **4**

.....

.....

.....

.....

.....

.....

.....

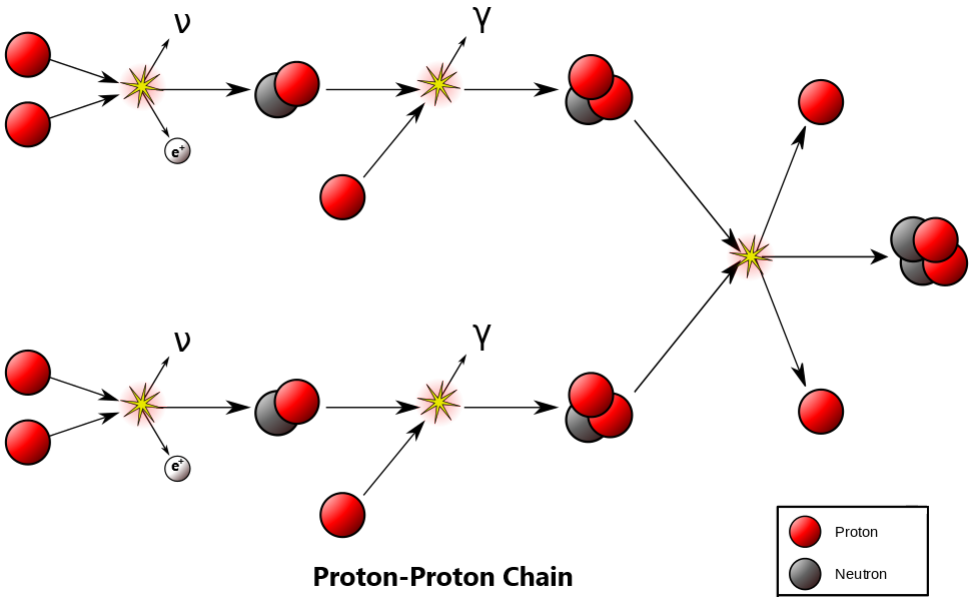
.....

.....

.....

Question 28 (9 marks)

The process of fusing hydrogen into helium is much more involved than simply combining enough hydrogen nuclei to create the desired helium nucleus. Instead, the overall fusion is achieved over multiple fusion processes occurring in a chain reaction. The most common example of this chain reaction is found in our Sun, known as the proton-proton chain.



Proton-Proton Chain

(a) With reference to the diagram, describe the steps of the proton-proton chain and correctly identify the products and reactants from each stage. **3**

.....

.....

.....

.....

.....

.....

.....

.....

.....

From the diagram, the white particle labelled (e^+) is observed to have an extremely short existence.

(b) Outline the process responsible for the particle's disappearance. **2**

.....

.....

.....

.....

.....

(c) Calculate the amount of energy produced from the process in part (b). **1**

.....

.....

.....

.....

(d) "Direct hydrogen-to-helium fusion makes up less than half of all nuclear reactions in our Sun and is responsible for less than half of the energy that the Sun eventually outputs." **3**

Assess the validity of this statement.

.....

.....

.....

.....

.....

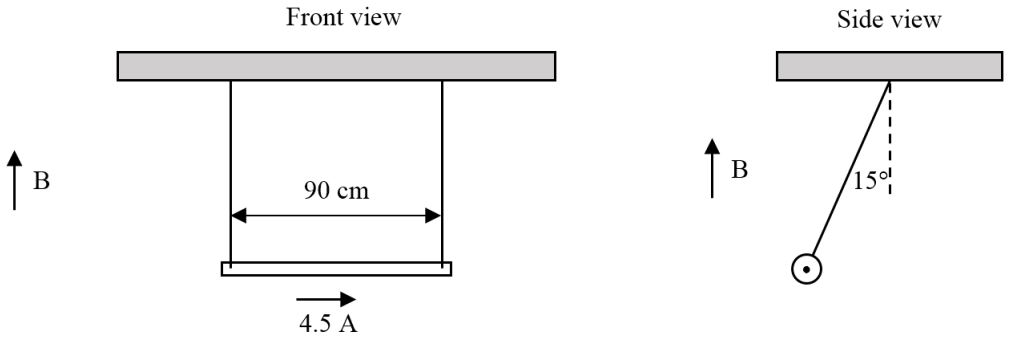
.....

.....

.....

Question 29 (4 marks)

A metal rod of length 90 cm and mass 500 g hangs suspended from two light wires as shown in the diagram. There is a constant magnetic field directed upwards. When a current of 4.5 A is passed through the rod, it deflects from the vertical by 15° and remains in that position.



Calculate the strength of the magnetic field. Include a force diagram in your answer. **4**

.....

.....

.....

.....

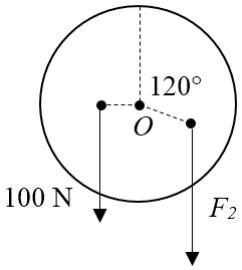
.....

.....

.....

Question 30 (3 marks)
A uniform disk is able to rotate about its fixed centre O.

A force F_1 of 100 N is applied 1.0 m away from the centre O as shown below. A second downward force, F_2, is to be applied 1.5 m away from O. The angle between the vertical axis and the line joining the point of contact of F_2 and O is 120°.



(a) Calculate the torque acting on the disc due to F_1. **1**

.....

.....

(b) Hence or otherwise, calculate the magnitude of F_2 if the disc remains stationary. **2**

.....

.....

.....

.....

Question 31 (4 marks)
Outline one piece of evidence that supports the predictions made by Einstein's special theory of relativity. **4**

.....

.....

.....

.....

.....

.....

.....

.....

.....

Question 32 (7 marks)

The work-function of a potassium photoelectric surface is 2.24 eV where incident photons release photoelectrons. The photoelectrons travel towards an electrode and complete a circuit. An ammeter is placed in series with the electrical circuit. A voltage source is placed across the electrodes such that a stopping potential can be created.

(a) Draw a diagram of this setup, labelling the polarities of the electrodes. **1**

(b) As the voltage across the electrodes is increased, the kinetic energy of the photoelectrons is decreased. Explain this observation. **2**

.....

.....

.....

.....

.....

(c) The voltage across the cathode and potassium surface is increased. The ammeter measures a constant current despite the voltage changing. Explain how this may occur. **2**

.....

.....

.....

.....

.....

(d) Calculate the threshold frequency of light required to release photoelectrons on the potassium surface. **2**

.....

.....

.....

.....

.....

Question 33 (4 marks)

Explain the ultraviolet catastrophe in relation to the violation of physics principles and how it was eventually resolved. **4**

.....

.....

.....

.....

.....

.....

.....

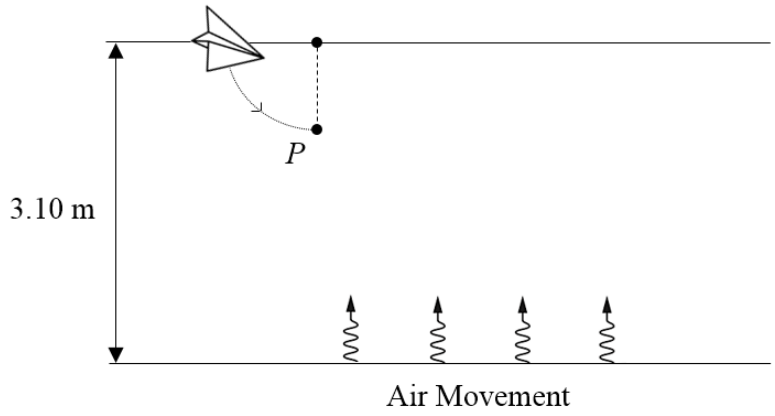
.....

.....

.....

Question 34 (5 marks)

A toy plane is attached to a piece of string tied to the ceiling of a 3.10 m high room. The plane is initially at rest with the string parallel to the ceiling, as shown below.



The plane is then released. When the plane reaches the base of the circular path at P, the string is cut. The toy plane is allowed to fall to the ground.

(a) Calculate the length of the string if the speed of the plane is measured at 3.56 $\mathrm{m\,s^{-1}}$ when the string is cut. **1**

.....

.....

.....

.....

.....

(b) An air conditioner built into the floor blows air upwards such that the toy plane experiences an upwards force of F_L after point P. The toy plane lands 3.56 m away from where the string is cut. **4**

Show that the upwards force acting on the plane is given by $F_L = \frac{1}{2}mg$.

.....

.....

.....

.....

.....

.....

.....

Question 35 (8 marks)

Describe how the spectrum of a star can be used to determine its key features. **8**

End of paper

PΣΛK

2023

HIGHER SCHOOL CERTIFICATE
MOCK HSC EXAMINATION
SOLUTIONS

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
- NESA-approved calculators may be used
- A data sheet, formulae sheet and Periodic Table is 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 – 8

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

Section II Pages 9 – 22

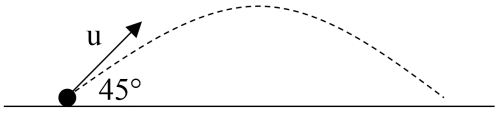
80 marks
- Attempt Questions 21 – 35
- Allow about 2 hours and 25 minutes for this part

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

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

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

1. A projectile is launched at 45° above the horizontal. The magnitude of acceleration due to gravity is given by g.



Which of the following is the correct expression for the horizontal distance, s, travelled by the projectile when it reaches its maximum height?

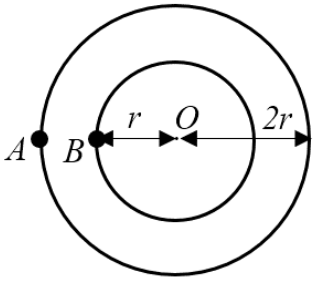
(A) $\frac{u^2}{2g}$
(B) $\frac{u^2}{g}$
(C) $\frac{u}{g^2}$
(D) $\frac{u}{2g^2}$

2. A satellite in low-Earth orbit moves from an orbital radius of r_1 to r_2. It is known that the kinetic energy of the satellite increases.

Which row of the table correctly identifies the change in gravitational potential energy (GPE) and mechanical energy (U) of the satellite?

	GPE	U
(A)	Increases	Increases
(B)	Increases	Decreases
(C)	Decreases	Increases
(D)	Decreases	Decreases

3. Two identical objects, A and B, are travelling in different circular paths about a centre O, as shown below. Object A is travelling at a constant speed of v_1, and object B at a constant speed of v_2.



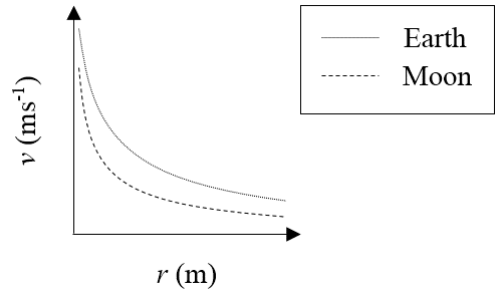
If both objects have the same angular velocity, what is the ratio of v_1 to v_2?

(A) 2:1
(B) 1:2
(C) 4:1
(D) 1:4

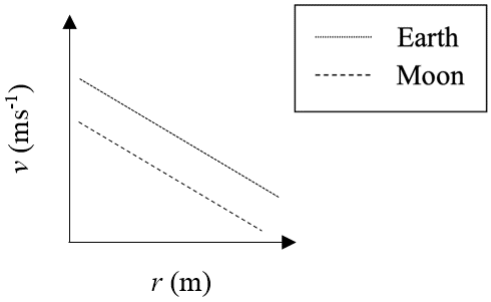
4. The velocity of two identical satellites are measured as their orbital radius is varied. Satellite 1 orbits the Earth whereas Satellite 2 orbits the Moon. You are given that the mass of the Moon is 7.35×10^{22} kg.

   Which graph correctly shows the relationship between the orbital velocity (v) and orbital radius (r) of both satellites?

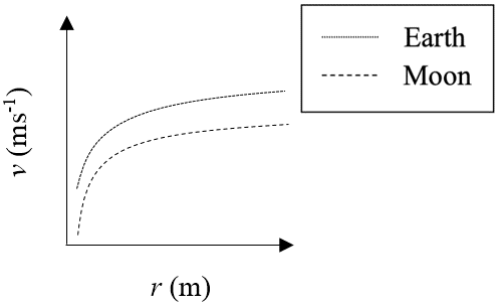
(A)



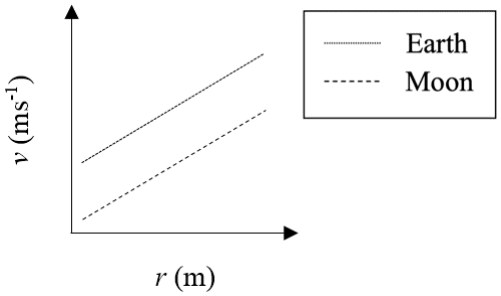
(B)



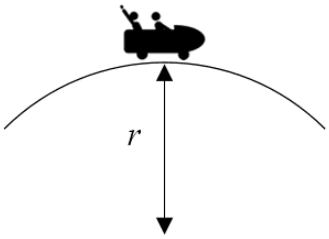
(C)



(D)



5. The track of a roller coaster forms a circular arc of radius r at one of its peaks. The total mass of a roller coaster cart and its occupants is 250 kg.



   What is the radius of the circular arc if its occupant feels no upward force when passing the peak at a speed of 28 $\mathrm{m\,s^{-1}}$?

   (A) 60 m
   (B) 70 m
   (C) 80 m
   (D) 90 m

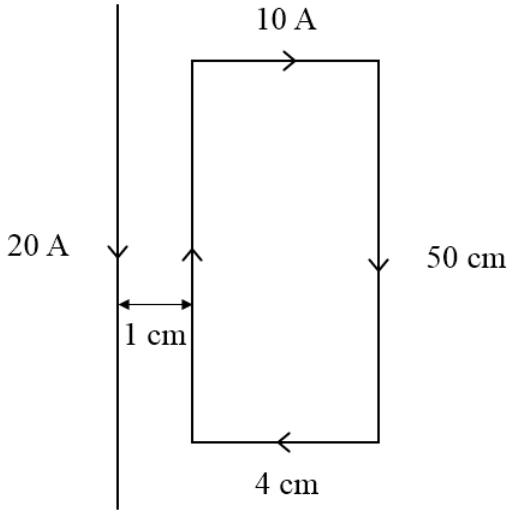
6. Three statements about DC motors are given below.

   1. The force acting on the coil is constant as the coil rotates.
   2. The torque acting on the coil is constant as the coil rotates.
   3. The magnetic flux through the coil is constant as the coil rotates.

   Which of the statements are NOT true?

   (A) 1 and 2
   (B) 1 and 3
   (C) 2 and 3
   (D) 1, 2 and 3

7. A rigid rectangular loop carrying a current of 10 A is placed next to a long wire carrying 20 A as shown below. The rectangular loop has dimensions 4 x 50 cm and its left edge is 1 cm away from the wire.



   What is the net force acting on the rectangular loop?

   (A) 1.6 mN left
   (B) 1.6 mN right
   (C) 2.0 mN left
   (D) 2.0 mN right

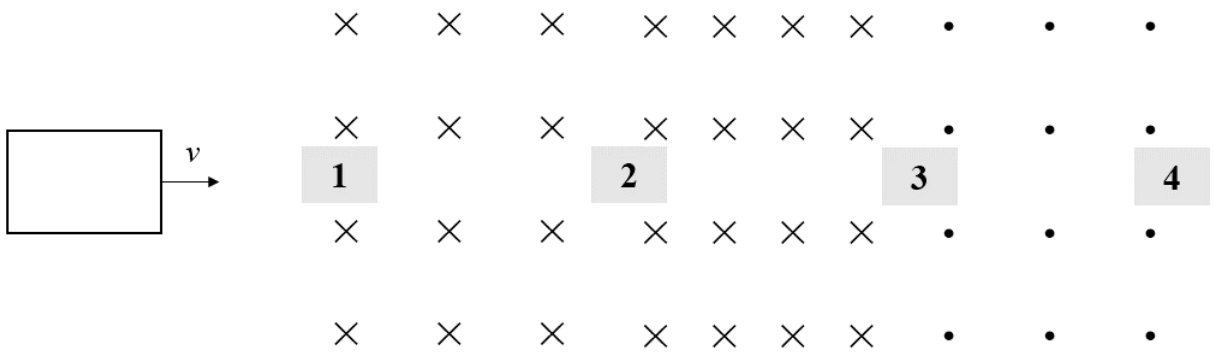
8. The wavelength of peak intensity radiation emanating from a source with temperature T_1 is measured as l_1.

   The temperature of the body is changed to T_2, where $T_2 = 2T_1$. What changes in the radiation from the source would be observed?

   (A) The peak wavelength would become $2l_1$
   (B) The peak wavelength would become $l_1/2$
   (C) The peak wavelength would remain unchanged.
   (D) The peak wavelength would increase a small amount.

9. In a simple DC generator, a coil is turned in a magnetic field to generate electricity. Which of the following changes would NOT increase the voltage output of the generator?
   (A) Increasing the area of the coil.
   (B) Decreasing the resistance of the coil.
   (C) Turning the coil faster.
   (D) Increasing the number of turns of wire in the coil.

10. A loop of wire is moved with a constant velocity across the page through three adjacent magnetic fields as shown below. It passes through points 1, 2, 3 and 4.



   At which point will there be a clockwise current flowing through the loop?

   (A) 1
   (B) 2
   (C) 3
   (D) 4

11. A student observes a transmission line that is carrying current from east to west. The student also knows that the Earth's magnetic field points northwards.

    What is the direction of the force acting on the transmission line due to the Earth's magnetic field?

   (A) North
   (B) South
   (C) Away from the ground
   (D) Towards the ground

12. The Sun produces energy by fusing light elements such as helium into heavier elements. In this fusion process, mass is lost. The Sun's output is rated at 4.0×10^{26} W.

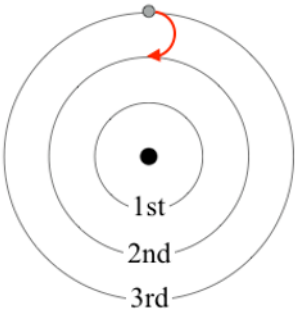
    How much mass does the Sun lose each second?

   (A) 4.4×10^{9} kg
   (B) 3.4×10^{9} kg
   (C) 4.0×10^{9} kg
   (D) 5.1×10^{9} kg

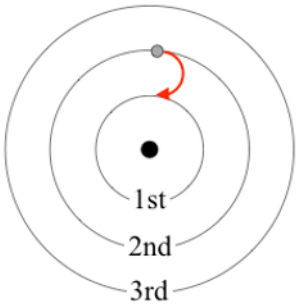
13. Which of the following equations show the correct decay of cobalt-60 to nickel-60?
   (A) ${}^{60}_{27}\mathrm{Co} \longrightarrow {}^{60}_{28}\mathrm{Ni} + {}^{0}_{-1}\beta + \bar{\nu}$
   (B) ${}^{60}_{27}\mathrm{Co} \longrightarrow {}^{56}_{25}\mathrm{Ni} + {}^{4}_{2}\mathrm{He} + \text{energy}$
   (C) ${}^{60}_{27}\mathrm{Co} \longrightarrow {}^{60}_{28}\mathrm{Ni} + {}^{0}_{+1}\beta + \nu$
   (D) ${}^{60}_{27}\mathrm{Co} \longrightarrow {}^{60}_{27}\mathrm{Ni} + {}^{0}_{+1}\beta + \bar{\nu}$

14. Which of the following examples below of an electron moving between energy levels in a hydrogen atom would emit the shortest wavelength?

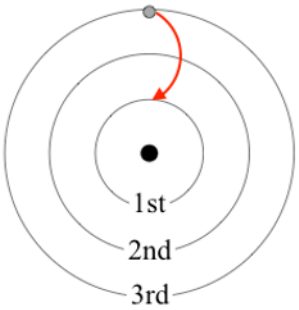
(A)



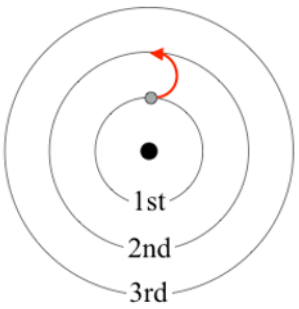
(B)



(C)



(D)



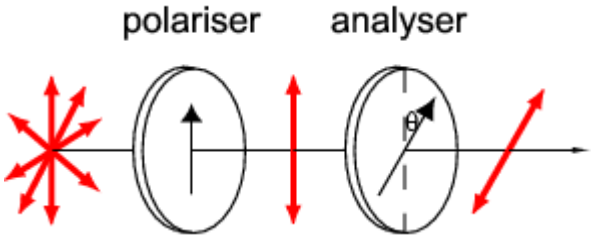
15. What significant change to the atomic model did the Rutherford gold foil experiment lead to?

(A) All atoms contained negative electrons
(B) Electrons existed in energy shells surrounding the nucleus
(C) The nucleus was a positive space
(D) The atom is mostly empty space

16. The purpose of the Michelson-Morley experiment was to
(A) Prove the existence of the aether
(B) Measure the relative velocity of the Earth through the aether
(C) Estimate the speed of light through an interferometer
(D) Analyse the electromagnetic spectrum

17. If a particular metal in a photocell releases a photocurrent when blue light is incident upon it, it also releases a photocurrent when it is incident with
(A) Red light
(B) Microwaves
(C) Ultraviolet light
(D) Radio waves

18. Unpolarized light with intensity 76 candela (cd) passes through a polarizer and then an analyser as shown in the diagram below.



The intensity of light after the analyzer if $\theta = 40°$ is

(A) 38 candela (cd)

(B) 29.11 candela (cd)

(C) 22.30 candela (cd)

(D) 44.60 candela (cd)

19. A spaceship is traveling at 70% the speed of light, headed for Sirius, 8.6 light years away from the Earth. The time taken to reach Sirius from an observer inside the spaceship is:

(A) 8.77 years

(B) 12.29 years

(C) 17.20 years

(D) 6.73 years

20. What contribution did Maxwell make to the classical theory of electromagnetism?

(A) Predicted the existence of electromagnetic waves

(B) Measured the speed of light to be 3×10^8 m s^{-1}

(C) Discovered the existence of radio waves

(D) Proved that magnetic monopoles do not exist

Section II: Short Answer Questions (80 marks)
Attempt Questions 21 – 35
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 (5 marks)
A car of mass 750 kg travelling at 40 km/h turns in a roundabout of radius 15.0 m.

(a) Calculate the minimum frictional force required to keep the car on the road. **2**

$$\begin{aligned} F_f &= F_c \\ &= \frac{mv^2}{r} \\ &= \frac{750 \times \left(\frac{40}{3.6}\right)^2}{15} \\ &= 6172.84\,\text{N} \end{aligned}$$

1 mark – Equates frictional force with centripetal force

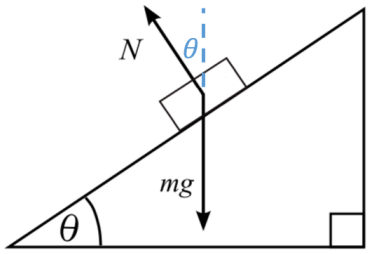
1 mark – Correct answer

(b) On a particular day with heavy rainfall, there is negligible friction between the road and the car tyres. **3**

Calculate the degree of banking required for the car to make the turn without side-tracking off the road.

Let the angle of the slope be θ. Resolving forces,

$$N \sin\theta = \frac{mv^2}{r} \quad (1)$$
$$N \cos\theta = mg \quad (2)$$
$$(1) \div (2)$$
$$\tan\theta = \frac{v^2}{rg}$$
$$= \frac{\left(\frac{40}{3.6}\right)^2}{9.8 \times 15}$$
$$\theta = 40^\circ$$



1 mark – Resolves forces

1 mark – Obtains an expression for $\tan\theta$

1 mark – Correct angle

Question 22 (7 marks)

Two planets are orbiting a star of mass 1.02×10^{29} kg and radius 7.3×10^5 km.

The table below shows the mass of the planets, their diameter, orbital radius and period of orbit. Some of the data is missing. 1 AU is approximately 150×10^6 km.

Planet	Mass of Planet	Diameter of Planet	Period of Orbit	Radius of Orbit
A	4.5×10^{22} kg	13 000 km	43 days	
B	7.0×10^{22} kg		145 days	0.2 AU

(a) Calculate the radius of orbit of Planet A in AU. **3**

$$\frac{r_A^3}{T_A^2} = \frac{r_B^3}{T_B^2}$$
$$\frac{r_A^3}{43^2} = \frac{0.2^3}{145^2}$$
$$r_A^3 = 0.0007$$
$$r_A = 0.09 \text{ AU}$$

1 mark – Writes down Kepler's third law (ratio form acceptable)

1 mark – Substitutes correctly into equation

1 mark – Correct radius in AU

(b) Assume that the planetary bodies are perfect spheres, and that the planets are in perfect circular orbits. **2**

Calculate the diameter of Planet B in km if the shortest distance between the surface of Planet B and the surface of the star is 0.195 AU.

$$r_{orbit} = r_{surfaces} + r_B + r_S$$
$$0.2 = 0.195 + r_B + r_S$$
$$r_B = 0.005 \times 150 \times 10^6 - 7.3 \times 10^5$$
$$= 20000 \text{ km}$$
$$\therefore d_B = 40000 \text{ km}$$

1 mark – States relationship between orbital radius, planet/sun radii and surface to surface distance

1 mark – Correct diameter

(c) An asteroid collides with Planet B causing the planet's orbital radius to double. Calculate the work done by the asteroid on Planet B. **2**

$$
\begin{aligned}
W &= \Delta E \\
&= -\frac{GMm}{2}\left(\frac{1}{r_2} - \frac{1}{r_1}\right) \\
&= -\frac{GMm}{2}\left(\frac{1}{0.4 \text{ AU}} - \frac{1}{0.2 \text{ AU}}\right) \\
&= \frac{GMm}{2} \times \frac{5}{2 \text{ AU}} \\
&= \frac{6.67 \times 10^{-11} \times 1.02 \times 10^{29} \times 7 \times 10^{22}}{2} \times \frac{5}{2 \times 150 \times 10^{9}} \\
&= 3.97 \times 10^{30} \text{ J}
\end{aligned}
$$

1 mark – Expresses work as the difference in final and initial energy, with the correct formula for energy used

1 mark – Correct answer

Question 23 (6 marks)

A transformer has a primary coil connected to a 30 kV power cable and has a current of 12 A flowing through it.

(a) Explain why this transformer needs to be cooled, with reference to relevant physics principles. **3**

The transformer core experiences a change in flux due to the changing direction of the primary current and magnetic field. By Faraday's law, this induces emf which gives rise to eddy currents. The eddy currents and the current in the transformer coils cause resistive heating, so the transformer needs to be cooled.

2 marks – Explains the production of eddy currents with reference to Faraday's law

1 mark – Relates eddy currents to heat production

(b) The transformer has 500 and 200 turns in its primary and secondary coils respectively. Assuming that power losses are negligible, calculate the output voltage and current of the transformer. **2**

$$\begin{aligned}
\frac{V_p}{V_s} &= \frac{N_p}{N_s} \\
\frac{30}{V_s} &= \frac{500}{200} \\
V_s &= \frac{2}{5} \times 30 \\
&= 12 \text{ kV} \\
V_p I_p &= V_s I_s \\
30 \times 12 &= 12 \times I_s \\
I_s &= 30 \text{ A}
\end{aligned}$$

1 mark – Correct voltage

1 mark – Correct current

(c) Identify a practical application of a step-down transformer. **1**

In power distribution system from transmission lines to homes, in devices household devices running from mains e.g. phone charger or adapter, ... etc.

1 mark – Identifies an appropriate application

Question 24 (4 marks)

A proton is released from rest in an electric field of strength 500 V/m.

(a) Calculate the speed of the proton after it has travelled 20 cm. **2**

$$\begin{aligned} W &= K \\ qEd &= \frac{1}{2}mv^2 \\ v &= \sqrt{\frac{2qEd}{m}} \\ v &= \sqrt{\frac{2 \times 1.602 \times 10^{-19} \times 500 \times 0.20}{1.673 \times 10^{-27}}} \\ &= 1.38 \times 10^5 \,\text{m s}^{-1} \end{aligned}$$

1 mark – Equates expressions for work and kinetic energy

1 mark – Calculates the velocity

(b) After the proton travels 20 cm, the electric field is switched off. At the same instant, a uniform magnetic field is turned on. The proton then follows a circular path with a radius of 500 µm. **2**

Calculate the magnetic field strength.

$$\begin{aligned} F_B &= F_c \\ qvB &= \frac{mv^2}{r} \\ B &= \frac{mv}{qr} \\ B &= \frac{1.673 \times 10^{-27} \times 1.38 \times 10^5}{1.602 \times 10^{-19} \times 500 \times 10^{-6}} \\ &= 2.89 \text{ T} \end{aligned}$$

1 mark – Equates magnetic force and centripetal force

1 mark – Correct magnetic field strength

Question 25 (4 marks)
Describe the evidence supporting the Big Bang theory.

The Big Bang theory describes how the universe expanded from a singularity of extremely high density and temperature. It is supported by Hubble's law and observations of cosmic microwave background radiation (CMR).

Hubble noticed that the spectral lines in distant galaxies were redshifted when compared to that of the Sun, with farther galaxies showing more redshift. The redshifting implied that the distant galaxies were in fact moving away and that more distant galaxies were moving away at a greater speed. This provides evidence that the universe is expanding as in the Big Bang theory.

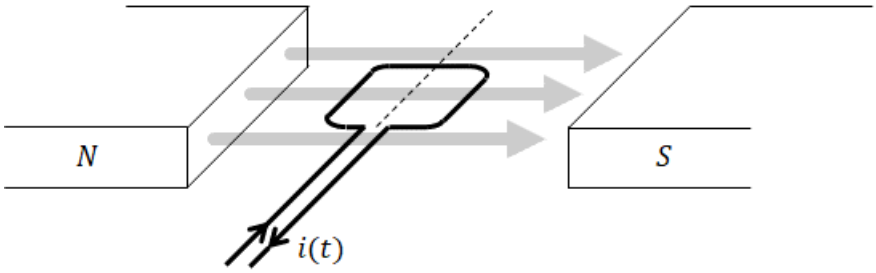
The radiation released when the early universe became transparent should still be present today. An expanding universe would cause the wavelength of this initially high energy/frequency radiation to increase and be redshifted to the microwave/radio wave region. This has been detected today as cosmic background radiation (CMR). CMR has been observed from all directions of the universe with strongest frequencies in the microwave region of the radio spectrum. Hence, the detection of this radiation supports the the Big Bang theory.

2 marks – Describes Hubble's law and how it supports the Big Bang theory

2 marks – Describes cosmic background radiation and how it supports the Big Bang theory

Question 26 (6 marks)

A DC motor has a square armature of side length 25 cm. The armature carries a coil with 300 turns of wire and the magnetic field strength of the stator is 1.2 T. The current direction is as shown in the diagram below.



(a) State the direction of rotation of the coil when viewed from the front of the diagram. **1**

Anticlockwise

1 mark – Correct direction

(b) The motor is initially stationary. Once it is switched on, it accelerates until it reaches a constant speed. Describe and explain how the size of the current in the coil changes from startup to this time. **3**

When the motor is switched on and the coil is stationary, there is a large current in the coil. As the coil speeds up due to the force and torque on the coil, it experiences a change in flux. By Faraday's law, this induces a back emf and current. By Lenz's law, the direction of this will oppose the change that caused it, so it will oppose and reduce the original current. As the coil's speed increases further, there is a greater rate of change of flux and more back emf induced. Hence the current in the coil continues to decrease until the coil reaches a constant speed.

1 mark – Identifies that the current decreases over time

1 mark – Explains the production of back emf

1 mark – Explains why increasing speed results in decreasing current

(c) Calculate the torque acting on the coil when the plane is at an angle of 38° to the horizontal and there is a current of 10 A in the coil. **2**

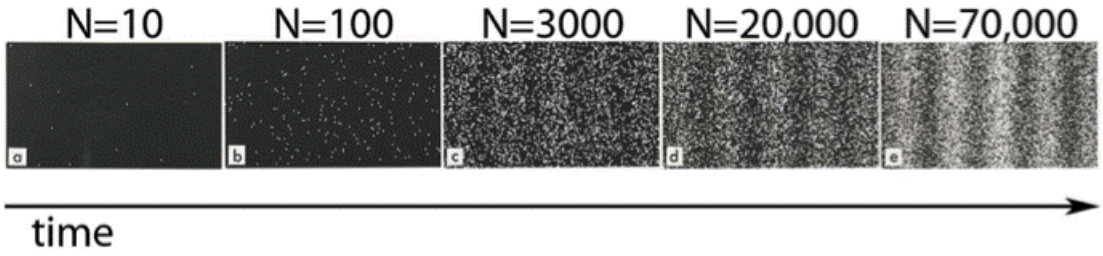
$$\begin{aligned}\tau &= nBIA\cos\theta \\ &= 300 \times 1.2 \times 10 \times 0.25^2 \times \cos 38^\circ \\ &= 177.3\,\text{N m}\end{aligned}$$

1 mark – Writes down the correct formula

1 mark – Calculates the torque

Question 27 (4 marks)

A single electron is fired through a diffraction grating using a setup similar to Davisson and Germer's experiment. The experiment is repeated and the position of each electron as it passes through the double slit is recorded on the detection screen. The diagram below demonstrates how the results developed as more electrons were sent at the double slit, where N represents the number of times the experiment was repeated.



Explain and justify the observations from the diagram above. **4**

The detection screen shows bright and dark fringes similar to those seen in two slit interference from the diffraction of light waves. This indicates that the electrons are undergoing diffraction and then constructive and destructive interference at the bright and dark fringes respectively as it passes through the grating.

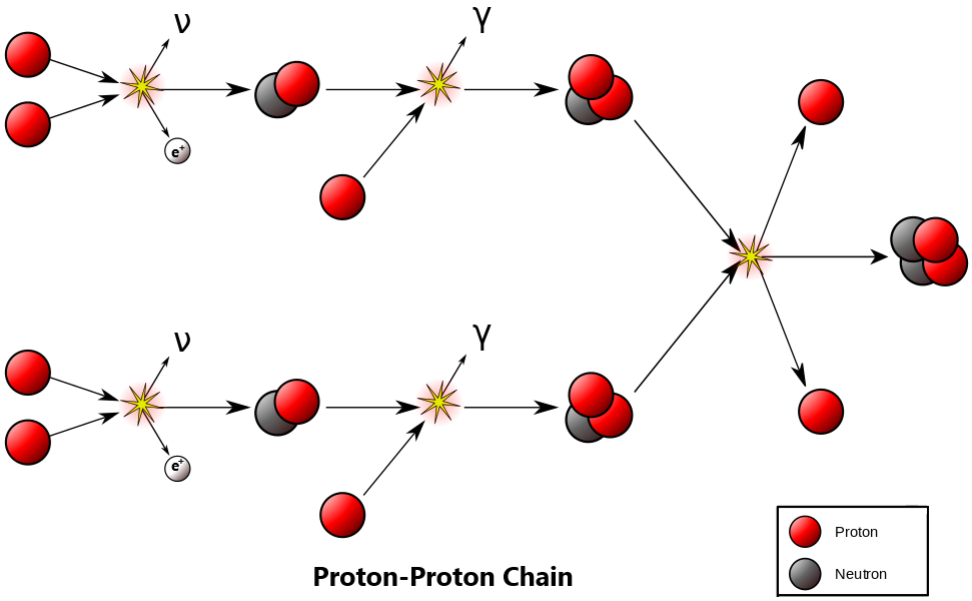
This observation is explained by de Broglie's matter wave hypothesis, which proposes that all particles have a wave nature with associated wavelength given by $\lambda = h/mv$. This suggests that electrons can exhibit wave behaviour. If their momentum is high enough for their associated wavelength to be of comparable size to the slit separation distance, then the diffraction of electrons can be observed as in the given diagrams.

2 marks – Identifies the fringes and how it implies that the electrons are somehow interfering with itself as it passes through the grating

2 marks – Uses de Broglie's matter wave and relates this to how electrons can demonstrate wave behaviour

Question 28 (9 marks)

The process of fusing hydrogen into helium is much more involved than simply combining enough hydrogen nuclei to create the desired helium nucleus. Instead, the overall fusion is achieved over multiple fusion processes occurring in a chain reaction. The most common example of this chain reaction is found in our Sun, known as the proton-proton chain.



(a) With reference to the diagram, describe the steps of the proton-proton chain and correctly identify the products and reactants from each stage. **3**

The proton-proton chain is initiated when there is enough energy to fuse one hydrogen-1 into another hydrogen-1. This first step creates hydrogen-2 (also known as deuteron) whilst also releasing a positron, neutrino, and some energy. The deuteron then must fuse with another hydrogen-1 nucleus to produce helium-3, gamma rays and some more energy. The previous two steps need to occur twice to create two helium-3 nuclei which can finally fuse to create the final products: helium-4 and two hydrogen-1.

3 marks – Describes the products and reactants of each step (1 mark each):

- Fusion of hydrogen-1 into hydrogen-2, positron and neutrino
- Fusion of hydrogen-2 into helium-3 and gamma rays
- Fusion of helium-3 into a helium-4 and two protons

From the diagram, the white particle labelled (e^+) is observed to have an extremely short existence.

(b) Outline the process responsible for the particle's disappearance. **2**

The positron collides with one of the many electrons inside the Sun and undergoes particle-antiparticle annihilation. In this annihilation, the mass of the positron and electron are converted entirely to energy by Einstein's $E = mc^2$. The energy is released in the form of gamma rays.

1 mark – Identifies the process as positron-electron annihilation

1 mark – Identifies that annihilation produces energy in the form of gamma rays

(c) Calculate the amount of energy produced from the process in part (b). **1**

$$\begin{aligned} E &= mc^2 \\ &= 2 \times 9.109 \times 10^{-31} \times (3 \times 10^8)^2 \\ &= 1.64 \times 10^{-13} \text{ J} \\ &= 1.02 \text{ MeV} \end{aligned}$$

1 mark – Correct answer in J or eV

(d) "Direct hydrogen-to-helium fusion makes up less than half of all nuclear reactions in our Sun and is responsible for less than half of the energy that the Sun eventually outputs." **3**

Assess the validity of this statement.

The proton-proton chain is made up of five individual fusion processes. Not all processes involve the fusion of hydrogen into helium. Hydrogen-to-helium fusion, occurring only when hydrogen-2 fuses with the hydrogen-1 to make helium-3 makes up only about 40% of the energy. The other processes found in the proton-proton chain fuse hydrogen/helium into heavier isotopes of themselves. With only two out of the five processes involving hydrogen-to-helium fusion, it is safe to assume the statement is valid.

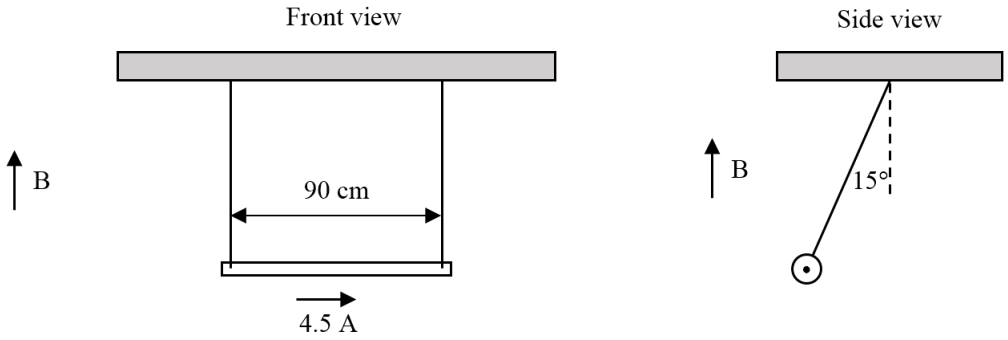
1 mark – Identifies that the proton-proton chain is made up of 5 separate fusion processes, where only two are hydrogen-to-helium fusion

1 mark – Identifies that the other processes simply involve the fusion of hydrogen into a heavier isotope of hydrogen or helium into a heavier isotope of helium

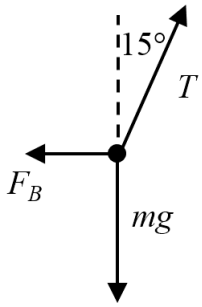
1 mark – Gives a final assessment agreeing with the statement

Question 29 (4 marks)

A metal rod of length 90 cm and mass 500 g hangs suspended from two light wires as shown in the diagram. There is a constant magnetic field directed upwards. When a current of 4.5 A is passed through the rod, it deflects from the vertical by 15° and remains in that position.



Calculate the strength of the magnetic field. Include a force diagram in your answer. **4**



$$
\begin{aligned}
T\cos 15 &= mg \\
T &= \frac{0.5 \times 9.8}{\cos 15} \\
&= 5.07 \text{ N} \\
F_B &= T\sin 15 \\
BIl &= T\sin 15 \\
B &= \frac{5.07\sin 15}{4.5 \times 0.9} \\
&= 0.32 \text{ T}
\end{aligned}
$$

1 mark – Correct force diagram

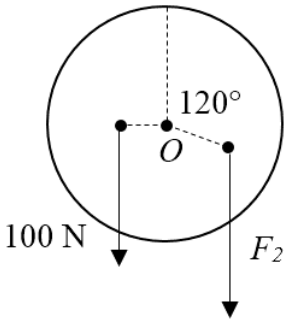
1 mark – Resolves forces

1 mark – Calculates the tension force

1 mark – Calculates the magnetic field strength

Question 30 (3 marks)
A uniform disk is able to rotate about its fixed centre O.

A force F_1 of 100 N is applied 1.0 m away from the centre O as shown below. A second downward force, F_2, is to be applied 1.5 m away from O. The angle between the vertical axis and the line joining the point of contact of F_2 and O is 120°.



(a) Calculate the torque acting on the disc due to F_1. **1**

$$\begin{aligned}\tau &= F_{\perp} d \\ &= 100 \times 1 \\ &= 100 \text{ Nm}\end{aligned}$$

1 mark – Correct answer

(b) Hence or otherwise, calculate the magnitude of F_2 if the disc remains stationary. **2**

$$\begin{aligned}\tau_1 &= \tau_2 \\ &= F_2 d \sin\theta \\ 100 &= F_2 \times 1.5 \times \sin 120 \\ F_2 &= \frac{100}{1.5 \sin 120} \\ &= 76.98\text{N}\end{aligned}$$

1 mark – Equates the torque from F_1 and F_2

1 mark – Calculates F_2

Question 31 (4 marks)

Outline one piece of evidence that supports the predictions made by Einstein's special theory of relativity. **4**

The predictions of special relativity include time dilation and length contraction. These predictions have been supported by observations of cosmic-origin muons at the Earth's surface. Without special relativity, the short lifetime of muons (2.2 µs) would mean that most would decay in the time taken to travel between the Earth's atmosphere and surface. However, in an experiment where detectors were placed at the top and bottom of a mountain, scientists observed significantly more muons at the Earth's surface than expected without relativity. This is due to time dilation, where less time and liftetimes pass for the muons than for observers on Earth. Alternatively, from the muons' perspective, the distance between the Earth's atmosphere and surface appears to undergo length contraction. Hence the muons reach the surface in fewer lifetimes, allowing more muons to be detected. These relativistic effects are observed since the muons are travelling close to the speed of light, hence providing evidence for special relativity.

1 mark – Identifies an experiment that investigates the predictions made by Special Relativity

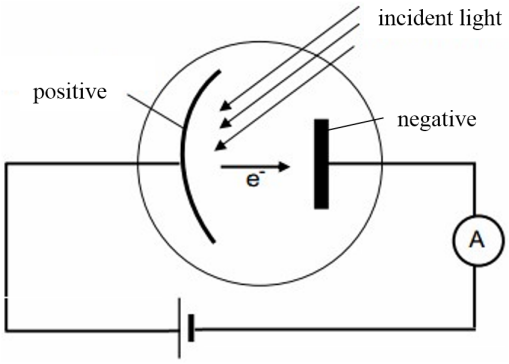
1 mark – Describes the experiment setup and findings

2 marks – Explains how the results of the experiment supports Special Relativity, making a link to the consequences of Special Relativity (time dilation, length contraction, etc.

Question 32 (7 marks)

The work-function of a potassium photoelectric surface is 2.24 eV where incident photons release photoelectrons. The photoelectrons travel towards an electrode and complete a circuit. An ammeter is placed in series in the electrical circuit. A voltage source is placed across the electrodes such that a stopping potential can be created.

(a) Draw a diagram of this setup, labelling the polarities of the electrodes. **1**



1 mark – Correct diagram with electrode polarities labelled. The electrons must be travelling towards the cathode/negative electrode.

(b) As the voltage across the electrodes is increased, the kinetic energy of the photoelectrons is decreased. Explain this observation. **2**

The force from the electric field created by the increased stopping voltage opposes the velocity of the ejected photoelectrons with the negative cathode repelling approaching electrons. Hence the electric field does work against the photoelectrons, decreasing their kinetic energy.

2 marks – Links decreasing KE of electrons to stopping voltage potential setting up an electric field of polarity that repels electrons at the cathode

(c) The voltage across the cathode and potassium surface is increased. The ammeter measures a constant current despite the voltage changing. Explain how this may occur. **2**

While the increased voltage decreases the electrons' kinetic energy, as long as the electrons can still reach the other side, the current will be independent of kinetic energy and will remain unchanged.

2 marks – Explains that the current in the circuit is independent of KE of electrons striking the cathode

(d) Calculate the threshold frequency of light required to release photoelectrons on the potassium surface. **2**

$$\begin{aligned} KE_{max} &= hf - \phi \\ 0 &= hf_0 - \phi \\ f_0 &= \frac{\phi}{h} \\ &= \frac{2.24 \times 1.602 \times 10^{-19}}{6.626 \times 10^{-34}} \\ &= 5.42 \times 10^{14} \text{ Hz} \end{aligned}$$

1 mark – Equates hf with the work function

1 mark – Calculates the threshold frequency

Question 33 (4 marks)
Explain the ultraviolet catastrophe in relation to the violation of physics principles and how it was eventually resolved.

The ultraviolet catastrophe refers to the discrepenacy between experimental observations of black body radiation and the theoretical result as predicted by classical physics. Classical physics predicted that the intensity of emitted radiation would increase to infinity as wavelength decreased. Not only did this dramatically deviate from the experimental curve at around UV wavelengths and shorter, but the concept of infinite energy radiated also violated the law of conservation of energy.

The catastrophe was eventually resolved by Planck's hypothesis that the energy absorbed and emitted by black body radiation was quantised, with each quanta of energy given by $E = hf$. Using this hypothesis, the predicted black body curve aligned much more closely with the experimental curve. We now know that this quantisation of energy reflects the particle or photon nature of electromagnetic waves.

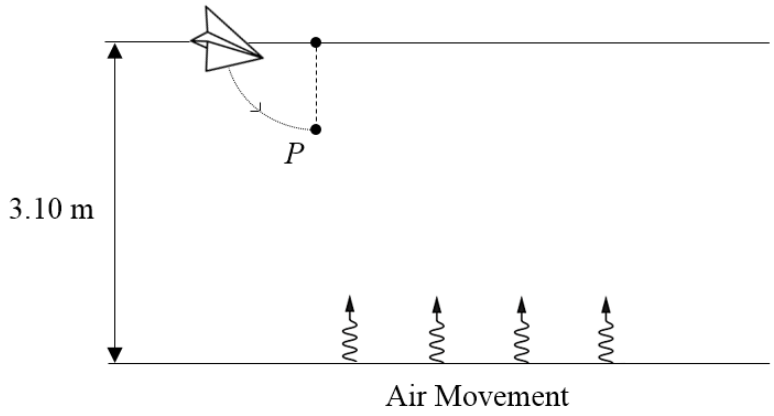
1 mark – Identifies the ultraviolet catastrophe by linking to black body radiation and the black body radiation curve

1 mark – Describes how the ultraviolet catastrophe violates The Law of Conservation of Energy

2 marks – Describes how Planck's quantisation of energy was able to solve the black body radiation curve

Question 34 (5 marks)

A toy plane is attached to a piece of string tied to the ceiling of a 3.10 m high room. The plane is initially at rest with the string parallel to the ceiling, as shown below.



The plane is then released. When the plane reaches the base of the circular path at P, the string is cut. The toy plane is allowed to fall to the ground.

(a) Calculate the length of the string if the speed of the plane is measured at 3.56 m s^{-1} when the string is cut. **1**

$$\begin{aligned} \Delta GPE &= \Delta KE \\ mgl &= \frac{1}{2}mv^2 \\ l &= \frac{v^2}{2g} \\ &= \frac{3.56^2}{2 \times 9.8} \\ &= 0.6466 \text{ m} \end{aligned}$$

1 mark – Correct answer

(b) An air conditioner built into the floor blows air upwards such that the toy plane experiences an upwards force of F_L. The toy plane lands 3.56 m away from where the string is cut. **4**

Show that the upwards force acting on the plane is given by $F_L = \frac{1}{2}mg$.

Take upwards to be positive.

$$
\begin{aligned}
s_x &= u_x t \\
3.56 &= 3.56t \\
t &= 1\,\text{s} \\
s_y &= u_y t + \frac{1}{2}a_y t^2 \\
-(3.10 - 0.6466) &= 0 + \frac{1}{2}a_y \times 1^2 \\
a_y &= -4.907\,\text{m s}^{-2} \\
&\approx -\frac{g}{2} \\
F_{net} &= F_L - F_g \\
ma &= F_L - mg \\
F_L &= m(g + a) \\
&= m(g - \frac{g}{2}) \\
&= \frac{1}{2}mg
\end{aligned}
$$

1 mark – Finds the time of flight

1 mark – Approximates a_y to $\frac{1}{2}g$

1 mark – Writes F_{net} in terms of weight and lift force

1 mark – Shows that $F_L = \frac{1}{2}mg$

Question 35 (8 marks)
Describe how the spectrum of a star can be used to determine its key features. **8**

A star's spectrum allow astronomers to determine many of its features, including surface temperature, chemical composition, translational velocity, rotational velocity and density.

Surface temperature: Since stars can be thought of as black bodies, Wien's law can be applied to determine their surface temperature. Wien's law states that the peak wavelength in black body radiation is inversely proportional to the black body's temperature ($\lambda_max = \frac{b}{T}$), that is hotter objects will have a shorter peak wavelength. Hence, the peak wavelength in a star's spectrum can be used to determine its surface temperature.

Chemical composition: A star's chemical composition can be determined from the spectral lines in the star's absorption spectrum. Since elements, molecules and ions have unique spectral lines, the star's spectral lines can be referenced with known spectral lines on Earth to deduce the chemical composition of the star. From the relative strength of stars' spectral lines, astronomers can also deduce the relative amount of different elements and molecules present between various stars.

Translational (radial) velocity: The Doppler effect also applies to electromagnetic waves. Hence stars moving towards Earth will have blueshifted spectral lines (shorter wavelength), while stars moving away from Earth will have redshifted spectral lines (longer wavelength). The amount of redshift or blueshift will indicate the radial velocity of the star.

Rotational velocity: the rotation of a star results in broader absorption spectral lines, with a greater rotational velocity producing broader lines. This is because the part of the star rotating towards us will be blueshifted while the part of the star rotating away from us appears redshifted. Together, this results in a broadening of spectral lines.

Density: the density or pressure of a star will also have broader spectral lines, referred to as pressure broadening. Denser stars will have thicker spectral lines.

2 marks – Explains in sufficient detail how the star's spectra can be used to determine each feature (2 marks per feature, so only 4 features minimum required)

End of paper