Semester 2 Examination, 2023

Question/Answer booklet

PHYSICS
Units 3 and 4

Name ___________________________________

Teacher ___________________________________

Time allowed for this paper

Reading time before commencing work:	ten minutes
Working time:	three hours

Materials required/recommended for this paper

To be provides by the supervisor
This Question/Answer booklet
Formulae and Data booklet

To be provided by the candidate

Standard items:	pens (blue/black preferred), pencils (including coloured), sharpener, correction fluid, eraser, ruler, highlighters.
Special items:	up to three non-programmable calculators approved for use in the WACE examinations, drawing templates, drawing compass and a protractor.

Important note to candidates

No other items may be taken into the examination room. It is **your** responsibility to ensure that you do not have any unauthorised material. If you have any unauthorised material with you, hand it to the supervisor **before** reading any further.

Structure of this paper

Section	Number of Questions	Questions to be answered	Suggested working time (minutes)	Marks available	Percentage of exam
Section One Short Response	11	11	50	54	30
Section Two Problem Solving	6	6	90	90	50
Section Three Comprehension	2	2	40	36	20
			Total	180	100

Instructions to candidates

1. The rules for the conduct of Western Australian external examinations are detailed in the *Year 12 Information Handbook 2023.* Sitting this examination implies that you agree to abide by these rules.

2. Write your answers in this Question/Answer booklet preferably using a black/blue pen. Do not use erasable or gel pens.

3. You must be careful to confine your answers to the specific questions asked and follow any instructions that are specific to a particular question.

4. When calculating or estimating answers, show all your working clearly. Your working should be in sufficient detail to allow your answers to be checked readily and for marks to be awarded for reasoning.

   In calculations, give final answers to three significant figures and include appropriate units where applicable.

   In estimates, give final answers to a maximum of two significant figures and include appropriate units where applicable.

5. Supplementary pages for planning/continuing your answers to questions are provided at the end of this Question/Answer booklet. If you use these pages to continue an answer, indicate in the original answer where the answer is continued, ie – give the page number.

6. The Formulae and Data booklet is not to be handed in with your Question/Answer booklet.

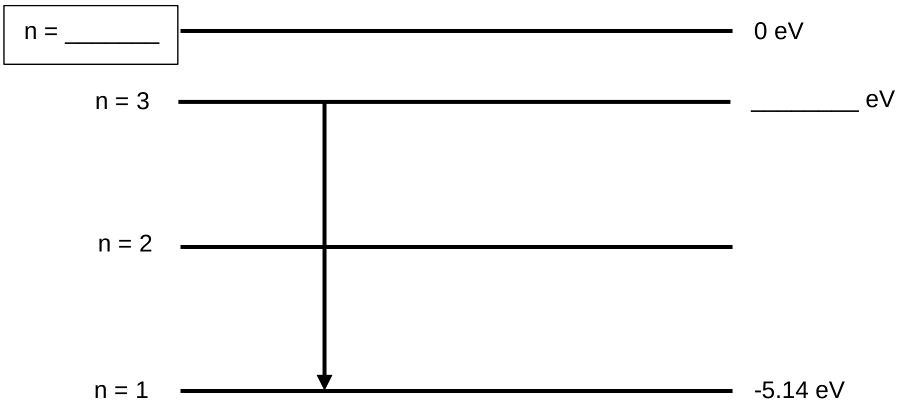
Section One: Short Response **30% (54 marks)**

This section has eleven (11) questions. Answer **all** questions. Write your answers in the spaces provided.

Suggested working time: 50 minutes.

Question 1 **(6 marks)**

Many of the streetlights in Perth are sodium vapour lamps. When switched on, solid sodium is vaporised, and the gas atoms are excited by the lamp's operating voltage. As these atoms de-excite, a characteristic yellow light is emitted. Two characteristic downward electron transitions are responsible for this yellow colour – one of these is indicated on the energy level diagram for sodium below (ie – from n = 3 to n = 1). Note that the energy level diagram is incomplete and is not drawn to scale.



The photon emitted due to the displayed downward electron transition has a wavelength of 589.6 nm.

a) Compete the missing value for 'n' in the energy level diagram. (1)

n = _______________

b) Use the information in the question to calculate the energy value (in eV) for n = 3. Show working. (5)

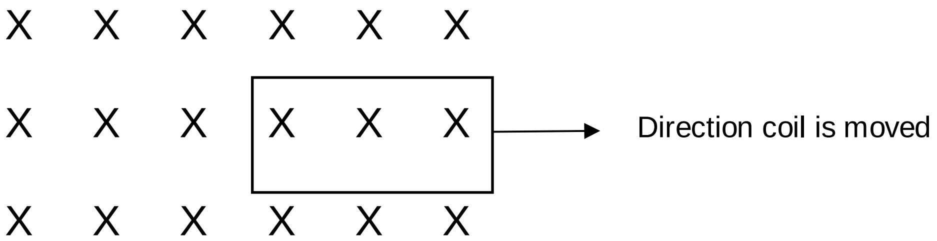
Answer: ________________ eV

Question 2 **(3 marks)**

The diagram below shows two negatively charged particles. Particle X has a charge of -3 and particle Y's charge is -1. On the diagram draw field lines to represent the electric field associated with the two particles.

Question 3 **(4 marks)**

A coil is withdrawn from the magnetic field as shown in the diagram below.



A current is observed flowing in the coil.

a) **Draw** an arrow on the coil in the diagram above to show the direction of the conventional current. (1)

b) Explain, referring to the Physics principles, why a current will flow and why in this direction. (3)

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Question 3 **(6 marks)**

In 2014, astronomers discovered a light emitting object far outside of our Local Group of galaxies that is blue shifted with a velocity relative to Earth of 1.03×10^6 ms^{-1}.

a) Explain why this observation appears to contradict Big Bang Theory.

(3)

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The current best direct measurement of Hubble's Constant is 73.8 km s^{-1} Mpc^{-1}.

b) Calculate an object's distance from the Earth (in light years) when its recessional velocity is equal to 1.03×10^6 ms^{-1}.

(3)

Answer: ______________ ly

Question 4 **(5 marks)**

Light of wavelength 391 nm is shone onto sodium metal in a photoelectric cell. A photo current results. The maximum speed with which electrons are ejected from the sodium metal's surface is calculated to be 3.88×10^5 ms^{-1}. Calculate the work function (in eV) for sodium metal.

Answer: ______________ eV

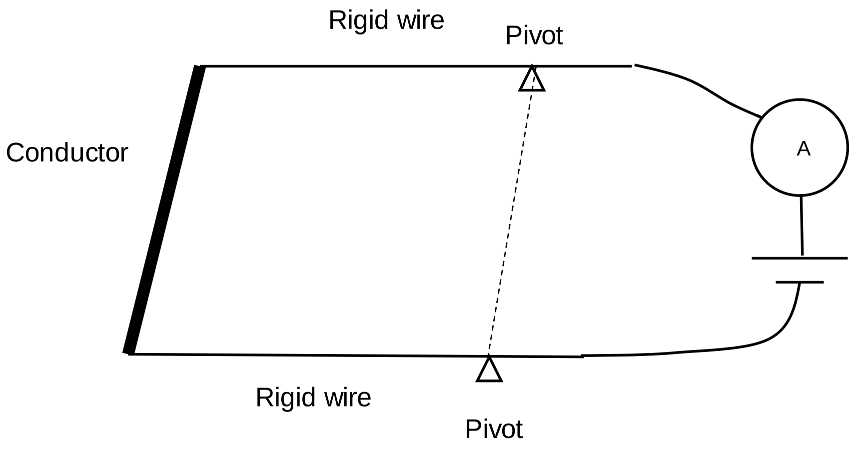
Question 5 **(4 marks)**

An electron is travelling with a speed of 0.990c. Calculate the kinetic energy of this electron (in Joules).

Answer: ___________________ J

Question 6 **(4 marks)**

A group of Physics students designed an apparatus to investigate the magnetic force acting on a conductor using torque. They decided to use this apparatus to determine the strength of a magnetic field. The apparatus is illustrated below.



A current is produced in the conductor which is exposed to an external magnetic field. The resulting magnetic force creates a clockwise torque on the conductor. More details are shown below:

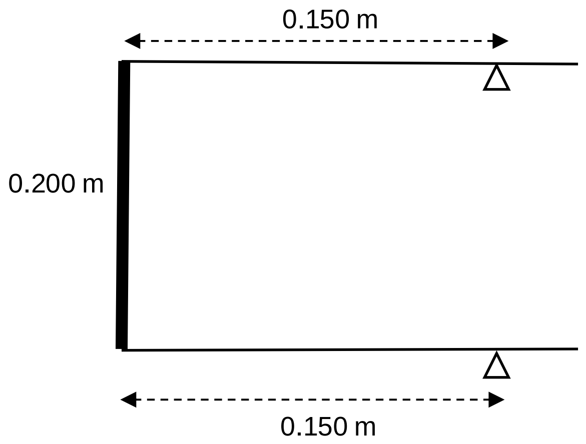


Figure 1: TOP VIEW

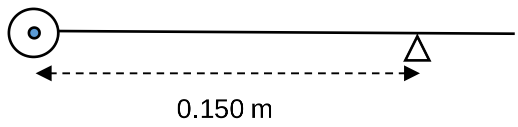


Figure 2: SIDE VIEW

The mass of the conductor is 50.0 g; the mass of the rigid wires is negligible; and friction can be ignored. When a current of 4.45 A is produced in the conductor, the resulting magnetic interaction creates an upward force on the conductor. The current's direction (as seen in Figure 2) is out of the page.

a) On **Figure 2**, draw five (5) arrows to indicate the direction of the external magnetic field in the region of the conductor.

(1)

Question 6 continued on next page

b) Using the information provided, calculate the magnitude of the external magnetic field utilised in this experiment.

(3)

Answer: ________________ T

Question 7 **(4 marks)**

A coherent electron beam travels through two narrow slits. An interference pattern is formed on a photographic plate behind the screen. The experiment is then repeated with a coherent proton beam. The speed of the proton beam is such that it produces the same interference pattern as the electron beam.

How does the speed at which the protons travel as they pass through the two narrow slits compare to that of the electrons? Explain your answer. Include any relevant formulae as part of your answer.

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Question 8 **(5 marks)**

Jupiter is believed to have as many as 90 moons orbiting around it. One of those moons is called Ganymede which has an average orbital radius of 628 million kilometres around the planet. At a particular instant in time, a 2.00×10^3 kg satellite is located at 75.0% of this orbital distance from Jupiter's centre of mass (see the diagram below). Other relevant data is listed in the table below the diagram.

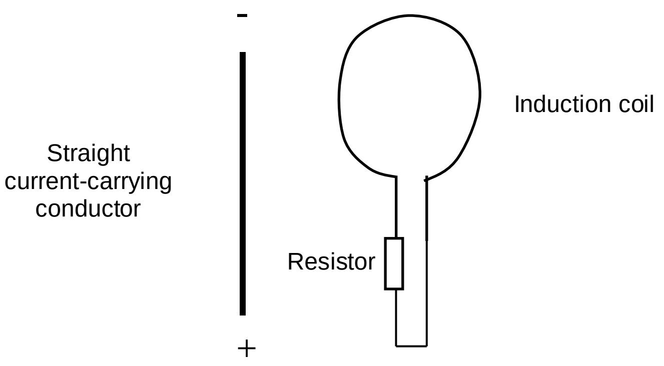
Radius of Jupiter	6.99×10^7 m
Radius of Ganymede	2.63×10^6 m
Mass of Jupiter	1.90×10^{27} kg
Mass of Ganymede	1.48×10^{23} kg

In which direction will the satellite accelerate? Answer this by calculating the ratio between the gravitational forces acting on the satellite due to Jupiter and Ganymede respectively.

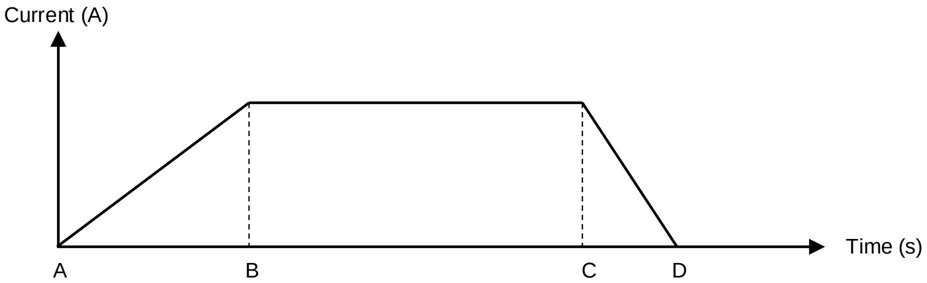
Ratio = ________:1 TOWARDS: ____________

Question 9 **(4 marks)**

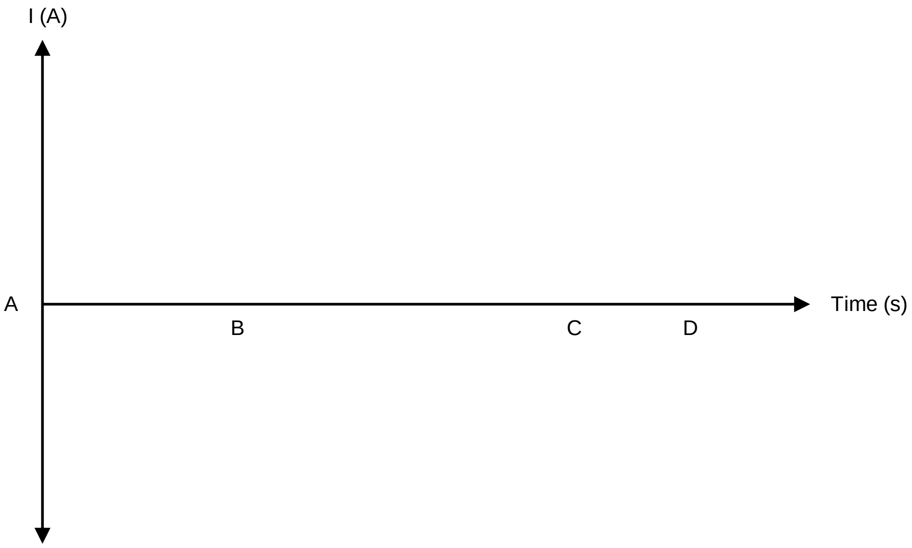
A straight current-carrying conductor is placed near an induction coil (see below). The polarity of the potential difference across the conductor is indicated on the diagram. Any induced current in the coil is measured by an ammeter. The following questions do not require any calculated answers.



The current in the straight conductor is varied according to the graph below:

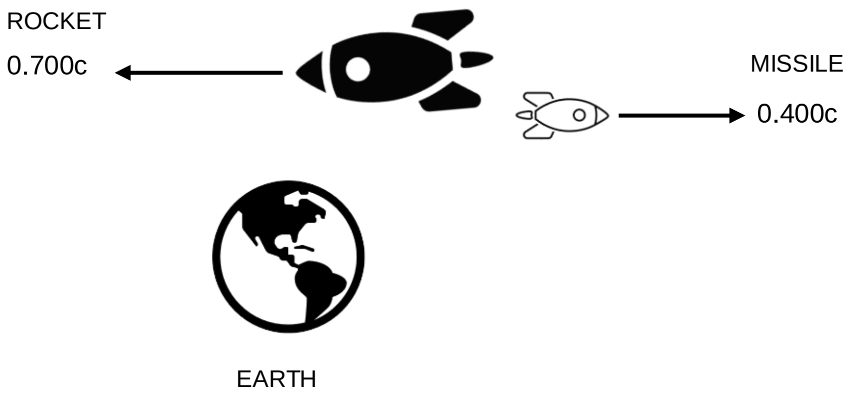


On the set of axes below, sketch a graph of the current induced in the resistor during the time intervals indicated (ie – A, B, C and D). Assume a current in an upward direction through the resistor is in a positive direction.



Question 10 **(5 marks)**

An observer on Earth observes a rocket travelling to the left at 0.700c relative to the Earth's frame of reference. The pilot of the rocket fires a missile in the opposite direction to the rocket's velocity (ie – to the right). The missile's speed is 0.400c relative to the rocket. Assume motion to the right is a positive direction.



a) Calculate the velocity of the missile relative to the observer on Earth.

(4)

Answer: _______________ c

b) In your own words, describe the direction of the missile's motion as viewed by the observer on Earth.

(1)

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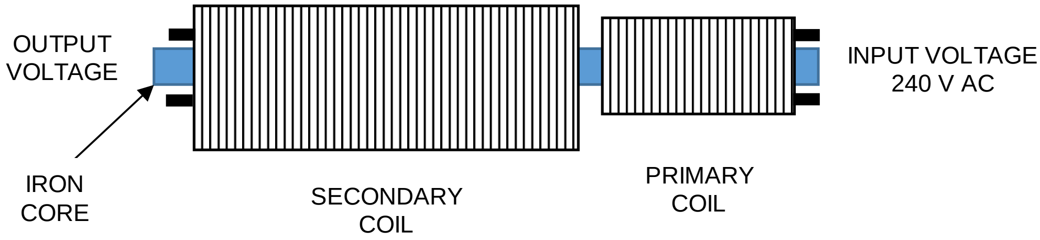
Question 11 **(4 marks)**

The diagram below shows the structure of a 'coaxial' transformer (ie – two coils wrapped around a common iron core).



a) Will the output voltage be less than or greater than 240 V. Explain.

(2)

a) Explain the role of the iron core.

(2)

END OF SECTION ONE

Section Two: Problem Solving **50% (90 marks)**

This section contains six (6) questions. Answer **all** questions. Answer the questions in the space provided.

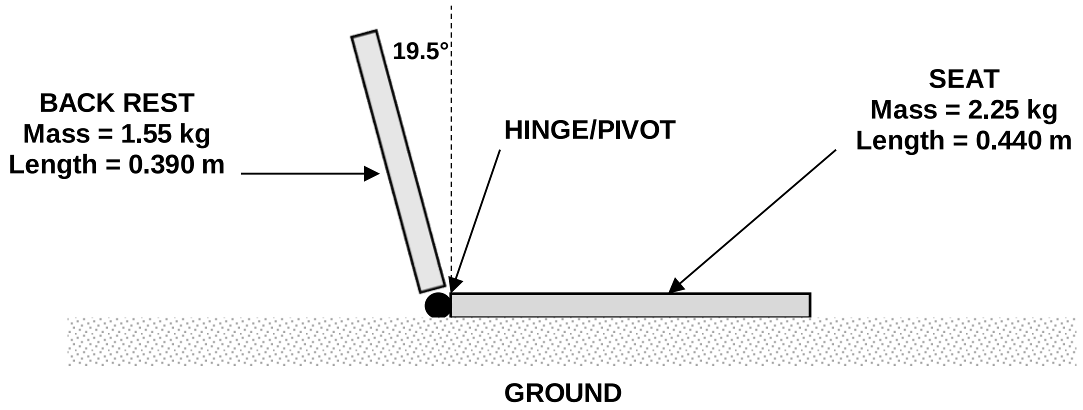
Suggested working time is 90 minutes.

Question 12 **(14 marks)**

A particular model of beach chair is illustrated below.

As can be seen by the photographs, the seat consists of three basic components: a horizontal seat which lays flat on the earth; a back rest whose angle with the horizontal can be adjusted; and a hinge, around which the back rest's angle can be changed. Once the angle of the back rest is set, the entire chair can be considered as one rigid object.

For the purposes of this question, the seat and back rest can be considered uniform.
The dimensions of the seat's components are shown in the diagram on the next page. It is resting on horizontal ground. As shown, the back rest is at an angle of 19.5° to the vertical.



A breeze begins to blow in such a way that the chair starts to tip backwards (ie – the seat just begins to lose contact with the ground). The breeze can be assumed to be horizontal and acts at the very top of the back rest.

a) Calculate the size of the force exerted by the breeze on the chair.

(4)

Answer: _______________ N

b) Hence, calculate the magnitude and direction of the force (to the horizontal) exerted by the ground on the hinge/pivot of the seat. [If you were unable to calculate an answer for part a), use a value of 10.6 N]

(5)

Answer: __________ N; Direction: ____________°

The position of the back rest can be adjusted so that the angle it makes with the vertical (θ) can be larger than 19.5°. The chair is designed in such a way that it will not tip over in still conditions with no breeze - regardless of the size of this angle (θ).

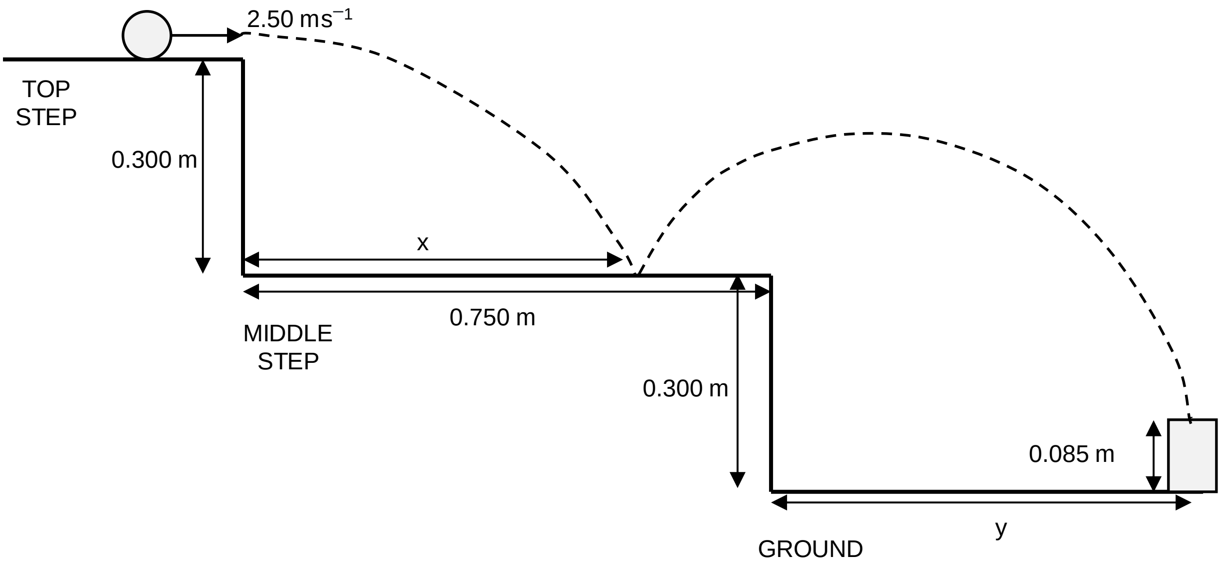
c) Show, via a calculation, that the chair will not tip over regardless of the angle ‘θ’.

(5)

Question 13 **(18 marks)**

A physics student is playing a game where they attempt to bounce a rubber ball of mass 55.0 g down some stairs into a cup. The aim of the game is to roll the rubber ball off the **top** step, on to the next (**middle**) step - where it bounces and (hopefully!) lands in a carefully placed cup on the **ground**.

The rubber ball is rolled off the top step with a horizontal speed of 2.50 ms^{-1}. The ball falls to the next step below, bounces off it, and then travels to the ground. The dimensions of the steps and the rubber ball's path to the cup are illustrated below.



Being a physics student, they decide to do some calculations prior to the game beginning to determine the horizontal distance 'y' from the bottom of the first step to where the cup should be placed (see diagram).

a) Calculate the vertical component of the rubber ball's speed when it lands on the **middle** step.

(3)

Answer: ____________ ms^{-1}

b) Hence, show that the landing velocity of the rubber ball when it bounces on the **middle** step is approximately 3.5 ms^{-1}, and it is at an angle of approximately 45° to the horizontal.

(4)

Answer: ____________ ms^{-1}; Angle = _____________°

c) Calculate the distance 'x'.

(4)

Answer: _____________ m

The student assumes that when the rubber ball bounces off the lower step it experiences an elastic collision and obeys the law of reflection.

d) Show with a calculation that the time taken by the rubber ball to reach the top of the cup from the **middle** step is about 0.6 s.

(4)

Answer: ___________ s

e) Hence, calculate the distance ‘y’. It can be assumed that the rubber ball enters the middle of the top of the cup.

(3)

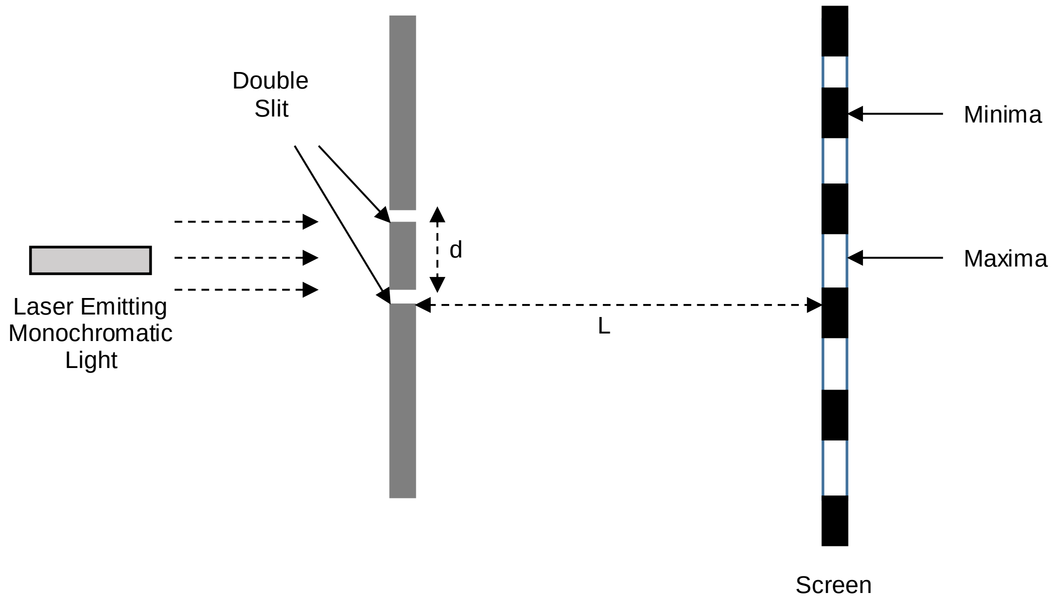
Answer: y = _____________ m

Question 14 **(17 marks)**

Some students decided to determine the wavelength (λ) of the light from a laser using the techniques utilised by Thomas Young in his famous 'double slit experiment' in 1804.

In this experiment, Young was trying to confirm one of the dual properties of light – the wave nature. He did this by shining monochromatic light through two closely positioned narrow slits. An 'interference pattern' (ie – a series of 'maxima' and 'minima') was formed on a screen positioned behind the double slits. [Note – the film consists a photographic film sensitive to visible and non-visible radiation]

The students arranged their equipment in the following manner to create the interference pattern.



The students have a range of different sets of double slits (filters), with varying slit widths (d) in each filter. They decide to keep the distance between the double slit filters and the screen (L) a constant value of 1.10 m. They record the interference patterns formed by the laser light as they change the filters.

a) Explain how the pattern (ie – the bright and dark fringes) is formed on the screen. Name the phenomenon involved and why this is confirmation of the wave nature of light.

(3)

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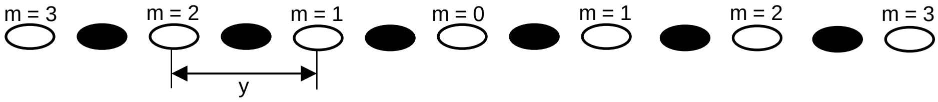
The interference pattern formed during the experiment looks like the diagram below (light spots = maxima; dark spots = minima).



The average 'fringe distance' (y) between successive maxima is indicated on the diagram above. The student's research indicates that this measurement – along with the dimensions of the equipment in the experiment (ie – 'L'; 'd' and 'm') – enables them to calculate an experimental value for the wavelength (λ) of the laser's light.

These quantities are related by the equation below:

$$\boldsymbol{\lambda = \frac{1}{mL}\, yd; \ \therefore y = \frac{\lambda m L}{d}}$$

Where:

λ = wavelength of the laser's monochromatic light (m)
m = maxima number
L = the distance from the double slit to the screen = 1.10 m
y = average fringe distance (m)
d = width between double slits (m)

The students produce interference for all of the double slit filters and calculate the average fringe distance (y) for each. They do this by finding the average distance to the LEFT of the central maxima (y_{left}); and then to the right (y_{right}); and then averaging these two measurements. They use the maxima between m = 0 and m = 3 to do this.

Their table of results is below.

d (× 10^{-3} m)	$^{1}/_{d}$ (× 10^{5} m^{-1})	y_{left} (m)	y_{right} (m)	y (m)
0.00500	2.00	0.0460	0.0464	0.0462
0.00800		0.0285	0.0293	0.0289
0.0100	1.00	0.0227	0.0235	0.0231
0.0120	0.833		0.0198	0.0192
0.0170	0.588	0.0133	0.0139	0.0136

b) Complete the table by calculating the missing values. Show any working below.

(2)

c) On the grid below, plot a graph of average fringe distance (y) against the inverse of double slit filter width ($^1/_d$). Place '$^1/_d$' on the x-axis. Draw a line of best fit for the data.

(4)

d) Calculate the gradient of the line of best fit. Clearly state the units.

(3)

Answer: _______________

Units: _________________

e) Use the gradient from part d) to calculate an experimental value for the wavelength of the laser's light.

(3)

Answer: ___________________ m

f) Describe and explain how the interference pattern would change if a laser with light of a higher frequency was used. Explain.

(2)

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Question 15 **(14 marks)**

The pion is any of three subatomic particles: the positive pion, π^+ (consisting of an up quark and an anti-down quark); its antimatter particle, the negative pion, π^-; and a third particle, the neutral pion, π^0. The rest masses of these particles are shown below:

Pion Particle	Rest Mass (MeV/c^2)
π^+ and π^-	**139.6**
π^0	**135.0**

Most of the time, the neutral pion decays to two identical photons: $\pi^0 \rightarrow 2\gamma$.

a) Convert the mass of the neutral pion into kilograms (kg).

(2)

Answer: ________________kg

b) Hence, calculate the energy (in Joules) of each photon.

(2)

Answer: ________________J

c) Calculate the wavelength of the photons in part b) and, hence, identify the region in the electromagnetic spectrum from which they originate.

(3)

Answer: ____________________ m

Region: ________________________________

The positive pion (π^+) undergoes a decay; the incomplete particle interaction for this decay is shown below:

$$\pi^+ \rightarrow \mu^+ + \_\_\_\_\_\_\_\_$$

d) Show why the charge on a positive pion (π^+) is equal to +1.

(1)

e) Write the baryon number and lepton number for the positive pion (π^+) in the spaces provided below:

(2)

BARYON NUMBER	
LEPTON NUMBER	

Question 15 continued on next page

f) Write the following for the unidentified particle in the incomplete particle interaction (π^+ decay).

$$\pi^+ \rightarrow \mu^+ + \_\_\_\_\_\_\_\_$$

(4)

CHARGE	
BARYON NUMBER	
LEPTON NUMBER	
NAME and SYMBOL	

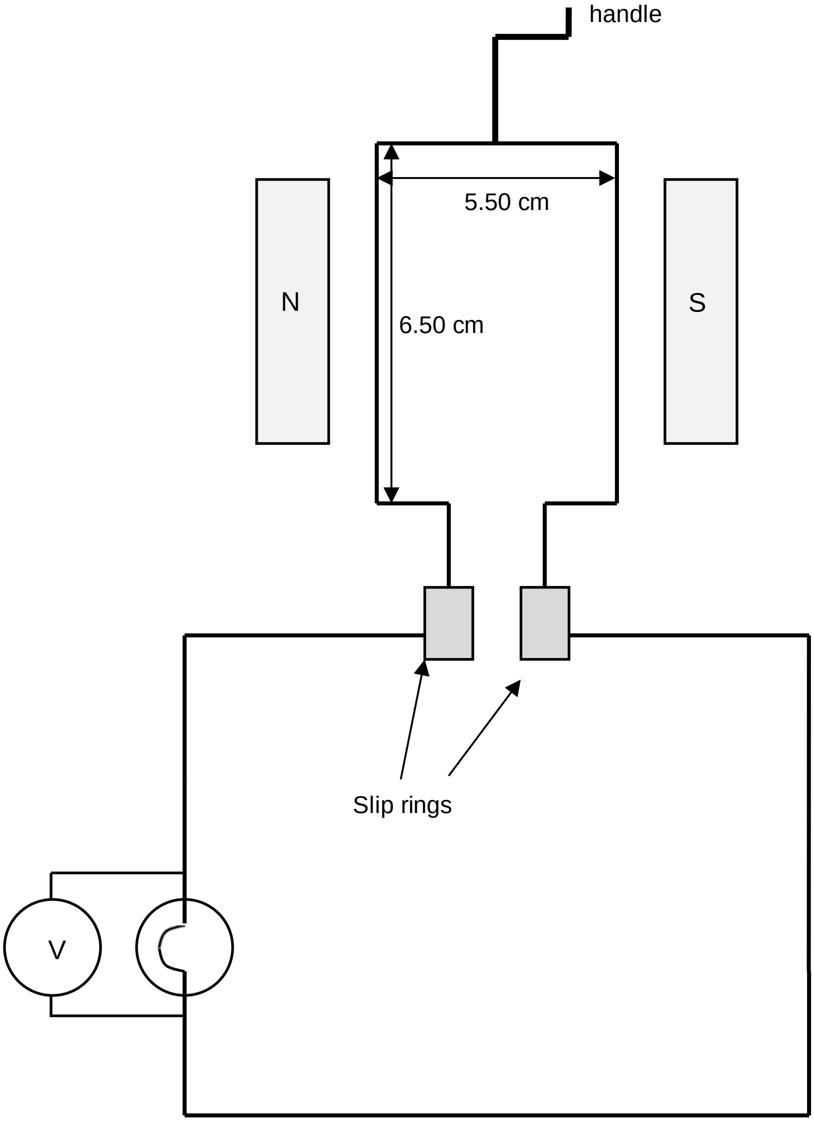
Question 16 **(15 marks)**

As part of a physics experiment, some students construct a 'home-made' AC generator. The generator has 125 turns and has dimensions 5.50 cm by 6.50 cm. The coil is turned by a handle between the poles of a unform magnetic field.

The students rotate the coil with a frequency of 240 rpm and measure the maximum EMF generated with a voltmeter. The generator is also connected to a light globe.

Using this data, the students determine the strength of the uniform magnetic field.

A diagram of the top view of the AC generator is shown below.



The students turn the handle and measure a maximum EMF of 0.139 V on the voltmeter.

a) Calculate the root-mean square voltage produced by the generator.

(1)

Answer: _____________ V

b) Calculate the strength of the uniform magnetic field (in mT).

(5)

Answer: ____________ mT

c) The students apply a force to the handle in such a way that the coil rotates with a constant circular speed. Explain why this force cannot have a constant magnitude. Describe how its magnitude changes as the coil rotates.

(4)

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QUESTION 16 continued on the next page

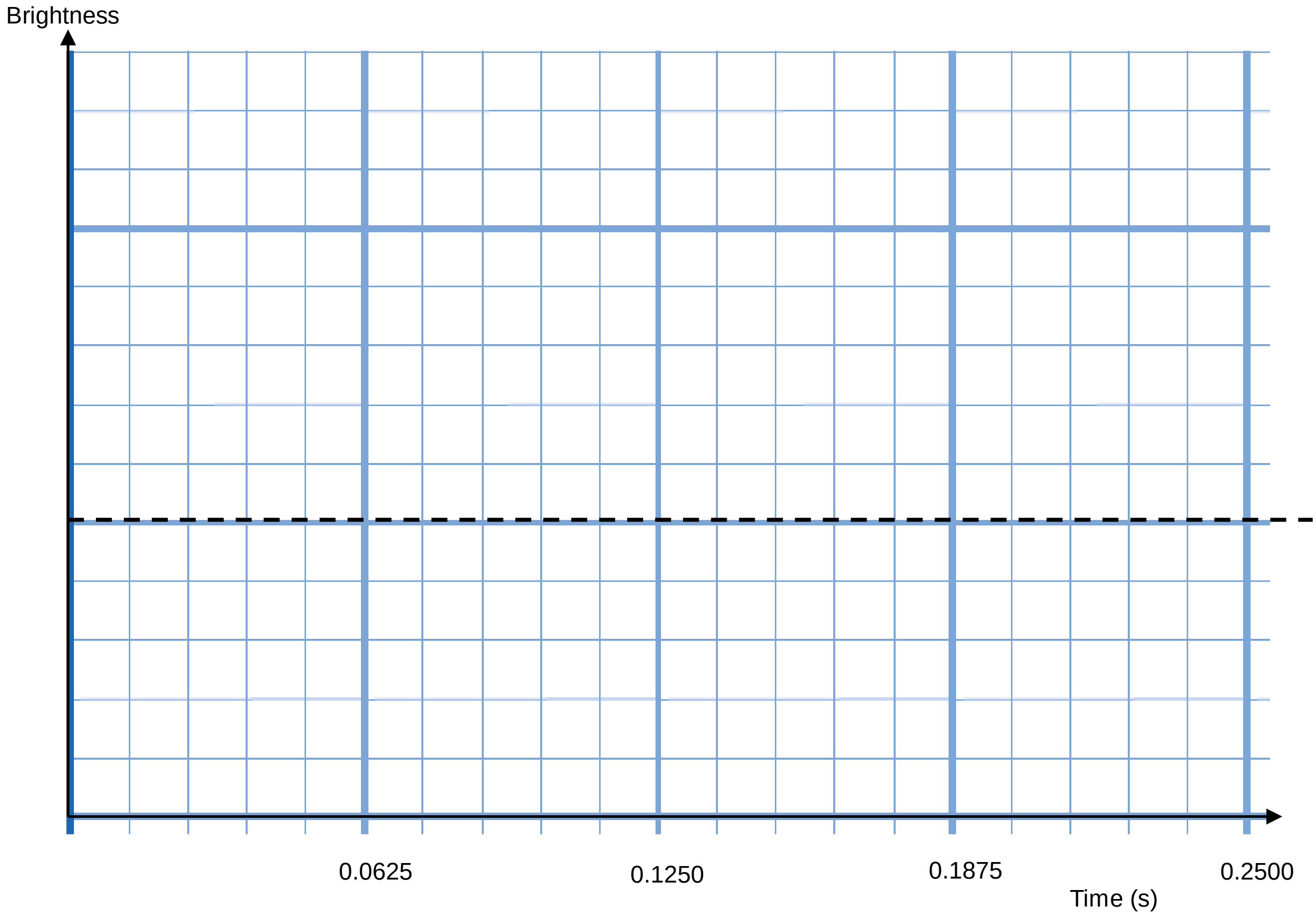
The students observe the brightness of the light globe in the circuit as it turns through one complete rotation. They start their observations when the coil is parallel to the magnetic field.

d) (i) On the set of axes below, sketch a graph showing how the **brightness** of the light globe changes while the coil completes one full rotation.

An accurate scale is provided on the time axis. The brightness axis has no scale and is only meant to be qualitative.

The horizontal dashed line shows the maximum brightness achieved by the light globe during this rotation.

(3)



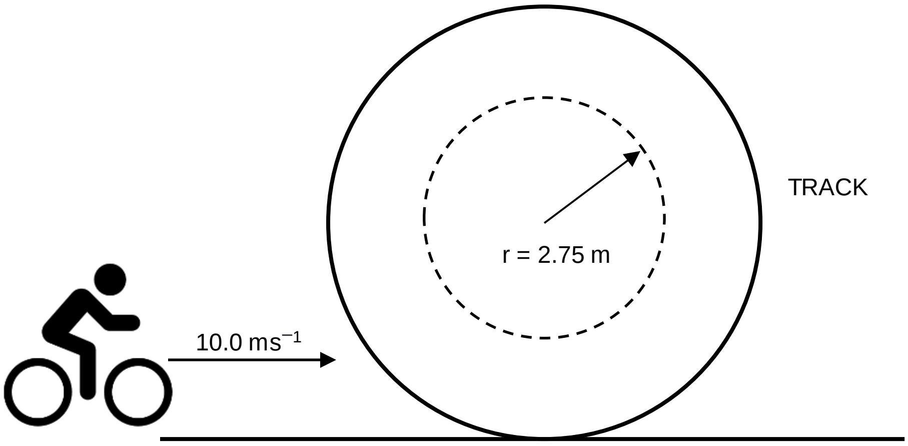
The students now double the frequency at which they rotate the coil.

(ii) On the set of axes in part (i), sketch a graph showing how the brightness of the light globe now varies over the same time period of 0.2500 s. Again, assume the coil starts parallel to the magnetic field.

(2)

Question 17 **(13 marks)**

A stunt man on a bicycle is attempting to navigate a vertically circular loop-the-loop. As he does this, his centre of mass moves in a circular path with a radius of 2.75 m. The combined mass of the man and his bicycle is 150 kg; and as he enters the loop-the-loop, he is travelling at 10.0 ms^{-1}. This situation is illustrated in the diagram below. Assume that frictional forces are negligible in this question.



a) When the cyclist enters the bottom of the loop-the-loop after a full circuit, they observe that they 'feel heavier' than they usually do. Explain.

(4)

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b) Calculate the minimum speed the cyclist must attain to navigate the top of the loop-the-loop safely.

(3)

Answer: ______________ ms^{-1}

c) Does the cyclist make it all the way around the top of the loop-the-loop? Answer this question by calculating the minimum speed required at the bottom of the loop for the cyclist to make it all the way around. [If you were unable to calculate an answer for part b), use a value of 5 ms^{-1}]

(6)

Answer: ______________ ms^{-1}

END OF SECTION TWO

Section Three: Comprehension **20% (36 marks)**

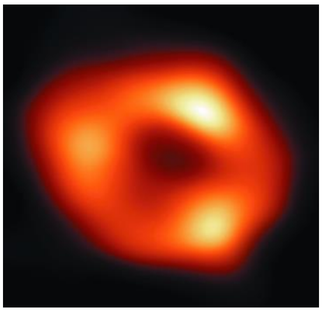
This section has two (2) questions. Answer **both** questions. Answer the questions in the spaces provided.

Suggested working time: 40 minutes.

Question 18 **(18 marks)**

Mystery Object Orbiting the Massive Black Hole at the Centre of the Milky Way

On 12th May 2022, an image of the black hole called Sagittarius A* - which lurks near the centre of our Milky Way Galaxy - was released by the Event Horizon Telescope collaboration (see image below).



From https://static.scientificamerican.com/sciam/cache/file/17878279-B6DC-4232-ABC6972F3E4125EC_source.jpg?w=2000&h=1123&EB49FA96-EBA5-4240-94D90150224A4446

Whilst black holes are not visible to the naked eye, their gravitational influence on other bodies nearby can be observed. The motion and behaviour of these bodies allows astronomers and physicists to determine many black hole properties, such as their mass.

Recently, astronomers have begun to research the area around Sagittarius A* called the ‘accretion disk’. This lies just beyond the black hole’s ‘event horizon’, which is the distance at which the escape velocity for any object near the back hole surpasses the speed of light. Any objects (including light) that fall within the ‘event horizon’ will, therefore, be unable to escape the black hole’s extreme gravitational pull and will fall into it.

The accretion disk consists of plasma, dust and particles that orbit in the black hole’s extreme gravitational field just outside the event horizon. This area is of great interest to astronomers who are researching the effect that extreme gravity has on space and the magnetic fields predicted to be very close to a black hole.

It has been theorised that hot bubbles of gas should form in the accretion disk and should be detectable as they orbit the black hole. These bubbles could provide evidence for the behaviour of space and magnetic fields near the event horizon.

Until recently, this accretion disk around Sagittarius A* had remained a mystery and the theorised hot bubbles of orbiting gas had not been detected. However, in April 2017, that changed.
At this time, the Chandra X-Ray Observatory (a space-based telescope sensitive to high-energy electromagnetic radiation) made a very important observation: a huge X-ray flare that appeared to emanate from the region close to Sagittarius A*.

It had long been theorised by researchers such as astronomers Avery Broderick (University of Waterloo, Ontario Canada) and Avi Loeb (Harvard-Smithsonian Centre for Astrophysics) that these flares should be produced by hot bubbles of gas orbiting in the accretion disk of a black hole such as Sagittarius A*.

In addition to Chandra's images, researchers were able to gather extra data from other telescopes sensitive to radiation in other regions of the electromagnetic spectrum. Images of the flare were now produced in the infrared and radio waves regions along with the X-ray emissions. This extra data indicated that the flares were cooling down over time – another prediction of the behaviour of these hot bubbles of gas near the accretion disk.

In addition, the X-ray emissions were strongly polarised which indicated the presence of a very strong magnetic field in the accretion disk. This is also predicted by theory and is due to the rotation of charged particles (ie – plasma) in the accretion disk.

Based on these observations, astronomers were able to model many properties of the black hole and the region surrounding it. For example, they observed a giant hot bubble of gas orbiting Sagittarius A* in an orbit comparable to that of Mercury (~0.4 AU) in a period of about 70 minutes. To achieve this orbit, the bubble moves at a mind-boggling orbital speed of about 30% of the speed of light!

The discovery of this orbiting hot bubble of gas not only confirms many theories about the region surrounding a black hole, but also provides insight into the effect that extreme gravity has on the geometry of space itself, as well as the magnetic fields surrounding it.

a) Chandra's images and extra data gathered from other telescopes indicated that these flares were cooling down over time. In terms of black body radiation, explain how the data illustrates evidence of cooling.

(3)

b) The X-ray emissions from the flare were strongly polarised.

Explain what is meant by the term "polarised" and describe whether this is evidence of the wave or particle nature of light.

(3)

c) Using the information from the article, show that the hot gas bubble must have an average orbital speed of about 30% of the speed of light.

(4)

d) Use Kepler's 3rd Law and data from the article to show that the mass of Sagittarius A* is over three and half million solar masses.

(4)

e) An event lasting 70 minutes occurs in an inertial frame of reference and is viewed by a stationary observer on Earth. Relative to the stationary observer, the inertial frame of reference is moving at 30% of the speed of light. Calculate how long the duration of this event would appear to be to the stationary observer on Earth. Show working.

(4)

Answer: ____________ minutes

Question 19 **(18 marks)**

Thomson's CRT Electron Experiment

Prior to 1897, according to Dalton's atomic theory, it was believed that the atom was a fundamental particle. However, after JJ Thomson's discovery of the electron in that year, the search for the subatomic particles that comprise the atom began in earnest.

Thomson's discovery was made in experiments using a device called a cathode ray tube (CRT). The basic structure of the tube is shown in Figure 1. A glass tube filled with hydrogen gas is evacuated using a pump until the pressure inside is reduced to about 10^{-6} atmospheres. Electrodes are placed at either end of the glass tube and a high voltage (15 000 V) is applied. The electrons are accelerated to high speeds and travel towards a fluorescent screen at the other end of the tube.

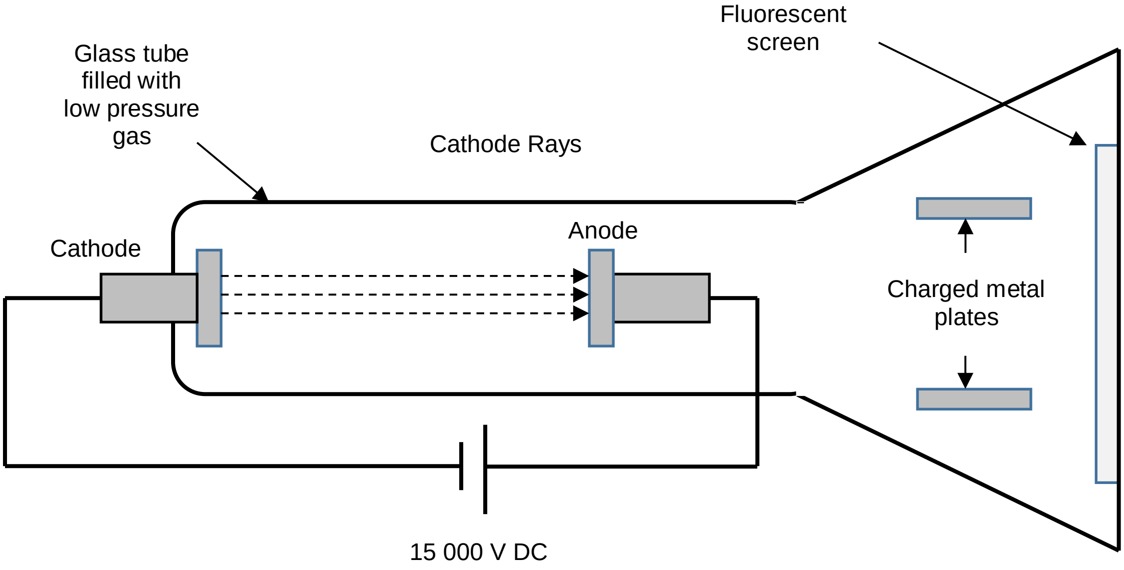


Figure 1: Structure of a Cathode Ray Tube (CRT)

This device had been used by physicists since its discovery in 1654 and had detected the 'cathode rays' that were produced once the voltage is applied. These rays had been observed via the faint green glow produced in the gas, and the dots produced on the zinc sulphide fluorescent screen positioned at the end of the tube.

Thomson had theorised that these mysterious rays must be sub-atomic particles that came from the atoms of hydrogen gas within the tube. The aim of his CRT experiments was to determine the properties of these particles: in particular, their mass to charge ratio.

Thomson knew that these particles must have a negative charge. In the first part of the experiment, a pair of charged metal plates was used to create a uniform electric field (see Figure 2). As predicted, the cathode rays were deflected upwards as if they have a negative charge. The rays' deflection was observed and measured by their landing points on the fluorescent screen.

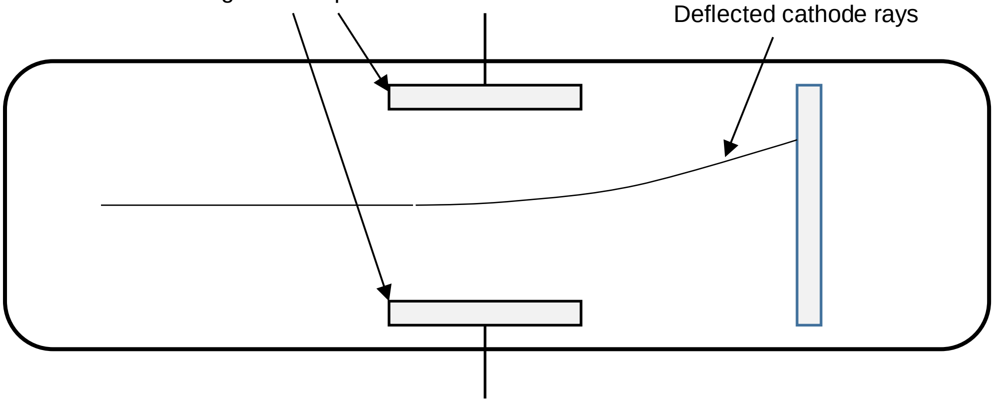


Figure 2: Cathode Rays Deflected by Charged Metal Plates

Thomson theorised that these negatively charged cathode ray particles should also be deflected by a magnetic field. In the second part of the experiment, whilst still being influenced by the electric field created by the charged plates, Thomson applied a magnetic field to the rays so that they experienced a downward magnetic force. The strength of the magnetic field was then adjusted until the cathode rays travelled through the charged plates undeflected. At this point, the forces due to the electric field and magnetic field were in equilibrium.

After this undeflected trajectory was achieved, the third part of the experiment began. The electric field was turned off, and the rays were now only under the influence of the magnetic field achieved at the end of the second part of the experiment. Hence, the rays were now deflected downwards in a circular path whose radius was measured. The centripetal force acting on the rays was due to the force provided by the magnetic field.

This result confirmed that the cathode rays consisted of negatively charged particles. Since the values of the electric field strength (E); magnetic field strength (B); and radius of curvature in part three of the experiment (r) were known, the charge to mass ratio of these particles was able to be determined by Thomson. He calculated this value to be 1.76×10^{11} C kg^{-1} – 1800 times larger than that for hydrogen ions. This led to the conclusion that these particles (which Thomson called 'electrons') must be 1800 times lighter than a proton and, hence, were subatomic.

Thomson's discovery led to the discovery of further subatomic properties – the proton and the neutron. Unlike the electron, it is now known that these two particles themselves are not fundamental. Further studies of the electron by Paul Dirac led to the discovery of the positron and antimatter. Some questions remain, however; such as – why do the fundamental particles that comprise the proton combine for a positive electric charge exactly equal to the negative charge on the electron?

Despite these mysteries, Thomsons' discovery of the electron - and the experimental methods he used to do this – remain one of science's most profound and important moments.

a) Calculate the maximum speed that could be achieved by the electron in the CRT in Figure 1. Ignore relativistic effects.

(3)

Answer: ____________ ms^{-1}

b) On Figure 2, show the polarity of the plates to create an upward deflection on an electron. Label the plates with the appropriate symbols.

(1)

c) In the space between the plates on Figure 2, draw and label the direction of a magnetic field that creates a downward deflection.

(1)

d) When the cathode ray (ie – electron beam) is undeflected during the second part of the experiment, both electric force and magnetic force are in equilibrium. Derive a formula for the electron beam's speed in terms of the electric field strength 'E' and the magnetic field strength 'B'.

(3)

e) When the electric field is turned off in the third part of the experiment, the magnetic force from part 2 acts as a centripetal force on the electrons. Hence, use your answer from part d) to show that the derived expression for the charge to mass ratio $\left(\frac{q}{m}\right)$ for the electron is given by:

$$\mathbf{\frac{q}{m} = \frac{E}{rB^2}}$$

(3)

f) Thomson calculated the charge to mass ratio for electrons to be 1.76×10^{11} C kg^{-1} – 1800 times larger than that for hydrogen ions. Explain how this experimental finding led him to the conclusion that these particles were subatomic.

(3)

g) The electron is a 'fundamental' particle; the proton is a 'composite' particle. State the difference between these two types of particles.

(1)

h) The charge on the electron and proton is the same in magnitude, but opposite in polarity. Explain this statement. As part of your answer describe the quark structure of a proton.

(3)

END OF EXAMINATION

Supplementary page

Question number: ____________

Supplementary page

Question number: _____________

Spare grid for graph

Acknowledgements

WATP acknowledges the permission of School Curriculum and Assessment Authority in providing instructions to students.