



# PHYSICS

## YEAR 12

### UNITS 3 & 4

/180

Name: DAVE

Teacher: PARTS 2 + 3.

#### TIME ALLOWED FOR THIS PAPER

Reading time before commencing work: Ten minutes

Working time for the paper: Three hours

#### MATERIALS REQUIRED/RECOMMENDED FOR THIS PAPER

##### To be provided by the supervisor:

- This Question/Answer Booklet; ATAR Physics Formulae and Data Booklet

##### To be provided by the candidate:

- Standard items: pens, pencils, eraser or correction fluid, ruler, highlighter.
- Special items: Calculators satisfying the conditions set by the SCSA for this subject.

#### 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 notes or other items of a non-personal nature in the examination room. 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 available	Number of questions to be answered	Suggested working time (minutes)	Marks available	Percentage of exam
Section One: Short answer	12	12	50	54	30
Section Two: Extended answer	6	6	90	90	50
Section Three: Comprehension and data analysis	2	2	40	36	20
<b>Total</b>				180	100

### Instructions to candidates

1. The rules for the conduct of Western Australian external examinations are detailed in the *Year 12 Information Handbook 2018*. Sitting this examination implies that you agree to abide by these rules.
2. Write answers in this Question/Answer Booklet.
3. When calculating numerical answers, show your working or reasoning clearly. Give final answers to **three** significant figures and include appropriate units where applicable.

When estimating numerical answers, show your working or reasoning clearly. Give final answers to a maximum of **two** significant figures and include appropriate units where applicable.

4. You must be careful to confine your responses to the specific questions asked and follow any instructions that are specific to a particular question.
5. Spare pages are included at the end of this booklet. They can be used for planning your responses and/or as additional space if required to continue an answer.
  - Planning: If you use the spare pages for planning, indicate this clearly.
  - Continuing an answer: If you need to use the space to continue an answer, indicate in the original answer space where the answer is continued, i.e. give the page number. Refer to the question(s) where you are continuing your work.

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

This section has **twelve (12)** questions. Answer **all** questions. Write your answers in the space provided.

When calculating numerical answers, show your working or reasoning clearly.

Give final answers to three significant figures and include appropriate units where applicable.

When estimating numerical answers, show your working or reasoning clearly. Give final answers to a maximum of two significant figures and include appropriate units where applicable.

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Suggested working time for this section is 50 minutes.

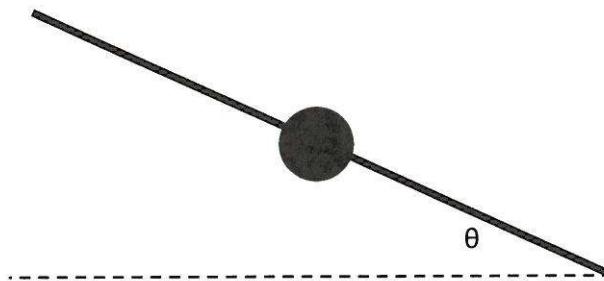
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**Question 1****(3 marks)**

An alien space ship is travelling at  $0.650c$  towards the Earth, relative to the Earth. It sends a signal to the Earth's inhabitants by flashing a light every 0.270 seconds in the ship's frame of reference. Calculate the time between each flash of light from the Earth's frame of reference.

**Question 2****(6 marks)**

When an aeroplane needs to turn, it tilts its wings towards the centre of its turn at an angle ' $\theta$ ' to the horizontal – see below:



- (a) Explain why the aeroplane must tilt its wings in the manner described to complete the turn.  
As part of your answer, draw a vector diagram below to show the forces acting and the net force produced.

[3]

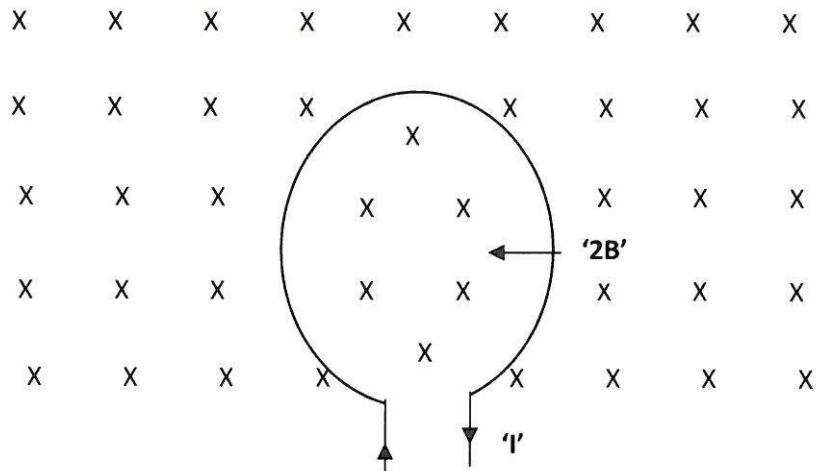
- (b) The diagram above shows the angle ' $\theta$ ' for a turn of a particular size of radius. Describe how the angle ' $\theta$ ' would change if the aeroplane had to complete a turn with a smaller radius. Explain your answer using relevant Physics formulae.

[3]

**Question 3****(3 marks)**

The diagram below shows a conducting loop carrying a current 'I'. The conventional current flows in a clockwise direction and produces a magnetic field through the centre of the loop of strength 'B' Tesla.

The loop is already sitting in an existing external magnetic field of strength '2B' Tesla; this external field is directed into the page through the centre of the loop and is shown below.



- (a) In terms of 'B', state the total magnitude of the resultant field at the centre of the loop.

[1]

- (b) The current in the loop is doubled to '2I' (its direction is maintained as clockwise). In terms of 'B', state the total magnitude of the resultant field in the centre of the loop.

[1]

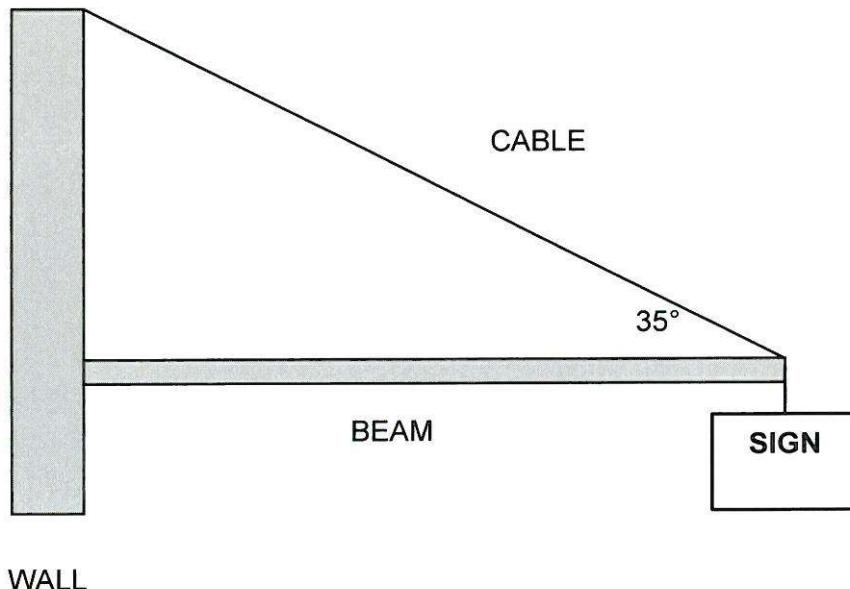
- (c) The direction of the current in the loop is reversed while its magnitude is maintained as 'I'. In terms of 'B', state the total magnitude of the resultant field in the centre of the loop.

[1]

**Question 4****(5 marks)**

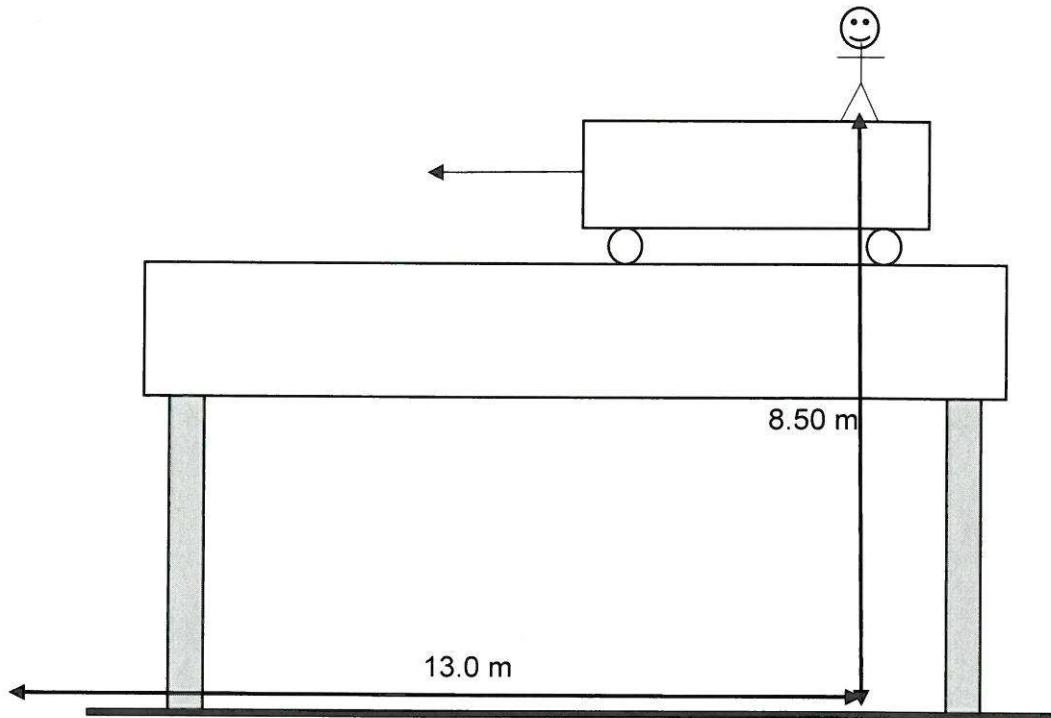
A 50.0 kg uniform cantilever beam supports a 15.0 kg sign as shown below. The beam is 1.80 m long and the sign is planned to be suspended from its end as shown. A cable is also attached to the end of the beam and connects it to the wall. The cable makes an angle of  $35^\circ$  with the beam. The maximum tension the cable can withstand is 650 N.

Calculate the maximum distance from the wall the sign can be suspended before the cable will break. Ensure you illustrate all the forces acting on the beam in a free-body diagram.



**Question 5****(6 marks)**

Recently, a Perth man pulled a dangerous stunt by stepping out of a moving train that was passing over the Fremantle Rail Bridge into the water about 8.50 metres below. As he fell, he experienced a horizontal displacement of 13.0 metres. See the figure below.



- (a) On the diagram above, draw the path taken by the man as he descends to the water. Air resistance can be ignored.

[2]

- (b) Calculate the velocity of the train. The bridge can be assumed to be horizontal.

[4]

**Question 6****(6 marks)**

Two small, neutrally charged objects are placed 25.0 cm apart in air. Electrons are transferred from one object to the other until an electrostatic force of magnitude 0.500 N exists between the two objects.

- (a) Is the electrostatic force attractive or repulsive? Explain.

[3]

- (b) Hence, calculate the size of the charge on each object that will create an electrostatic force of magnitude 0.500 N at this distance.

[3]

**Question 7****(4 marks)**

Here is an example of a particle interaction – the beta decay of a neutron that produces an anti-electron neutrino:

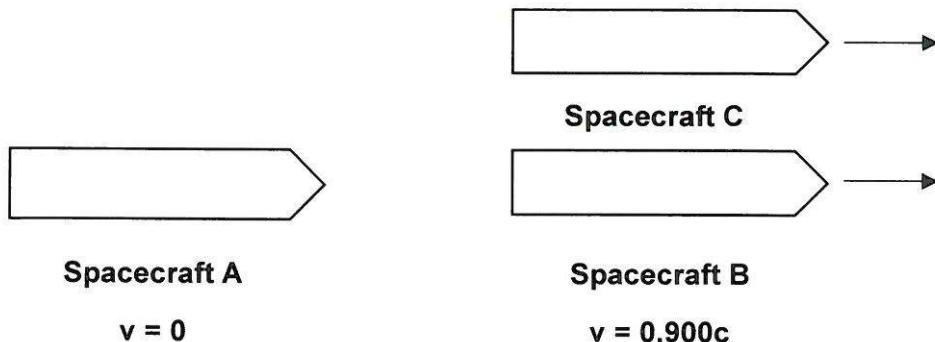
$$n \rightarrow p + e^- + \bar{\nu}_e$$

Complete the table below by adding the charge, baryon number and lepton number on each side of the equation (left-hand side ( $\Sigma LHS$ ); right-hand side ( $\Sigma RHS$ )). State which Conservation Laws are either (i) observed; or (ii) violated. Show any working in the space below the table.

Conservation Law	$\Sigma LHS$	$\Sigma RHS$	Observed or violated?
Conservation of Charge (Q)			
Conservation of Baryon Number			
Conservation of Lepton Number			

**Question 8****(4 marks)**

An observer in a spacecraft A, which is moving at  $v = 0$ , observes another spacecraft B moving past them at  $0.900c$ .



The observer also observes another spacecraft C moving at  $0.980c$  relative to their spacecraft A and in the same direction as spacecraft B.

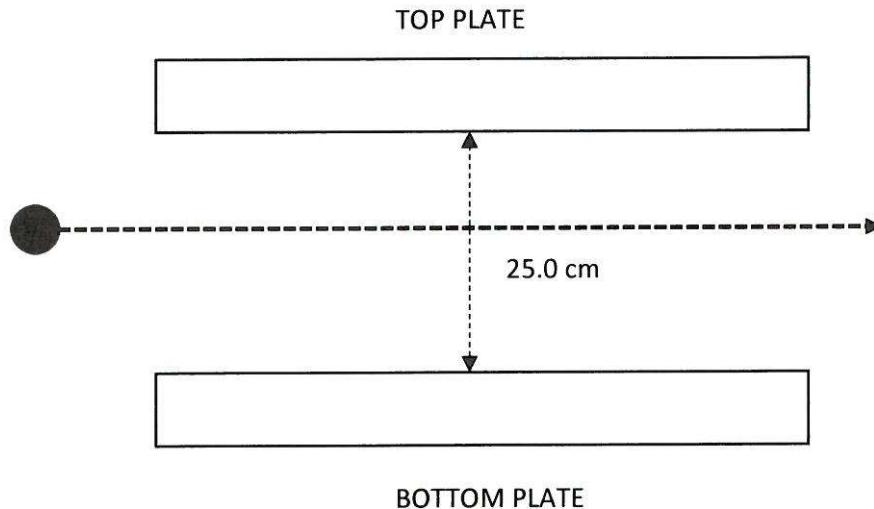
Calculate (in terms of 'c') how fast spacecraft C is moving with respect to spacecraft B.

**Question 9****(3 marks)**

The windings on the primary and secondary coils of an ideal transformer number 50 turns and 500 turns respectively. The primary RMS input voltage is measured to be 16.0 V; the secondary RMS current is measured to be 200 mA. Calculate the power generated in the primary coil of this transformer.

**Question 10****(5 marks)**

A positively charged droplet of oil enters a uniform electric field between two charged plates a distance of 25.0 cm apart. The plates are aligned horizontally. The droplet has a mass of 50.0 mg and possesses a charge of 10.0  $\mu\text{C}$ . Its path through the electric field is a horizontal straight line (see diagram below).



- (a) Use the data above to calculate the potential difference ( $V$ ) between the two plates.

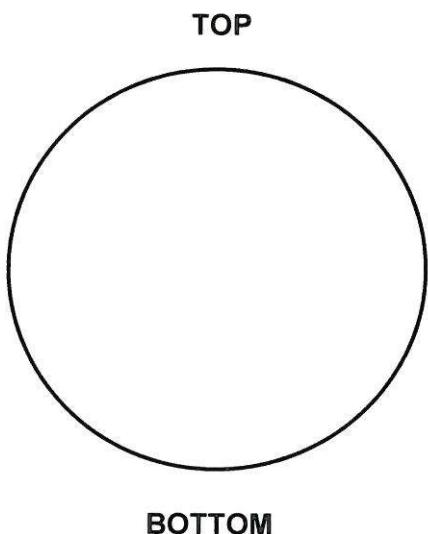
[4]

- (b) Draw symbols on the plates to indicate their polarity.

[1]

**Question 11****(5 marks)**

A pilot is navigating their jetfighter through a giant vertical circular loop.



The pilot knows that at particular points on the vertical circular path, they will feel 'weightless'. At other points they will feel so heavy that they will experience G-forces that may cause them to pass out.

- (a) At which point (TOP or BOTTOM) will the pilot feel 'heaviest'? Explain.

[2]

- (b) If the radius of the jetfighter's path is 1000 m, at what speed would it have to be travelling for the pilot to feel absolutely weightless.

[3]

**Question 12****(4 marks)**

Estimate the gravitational force between two Year 12 Physics students sitting next to each other at a science laboratory desk.

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**Section Two: Problem-solving****50% (90 Marks)**

This section has **six (6)** questions. You must answer **all** questions. Write your answers in the space provided.

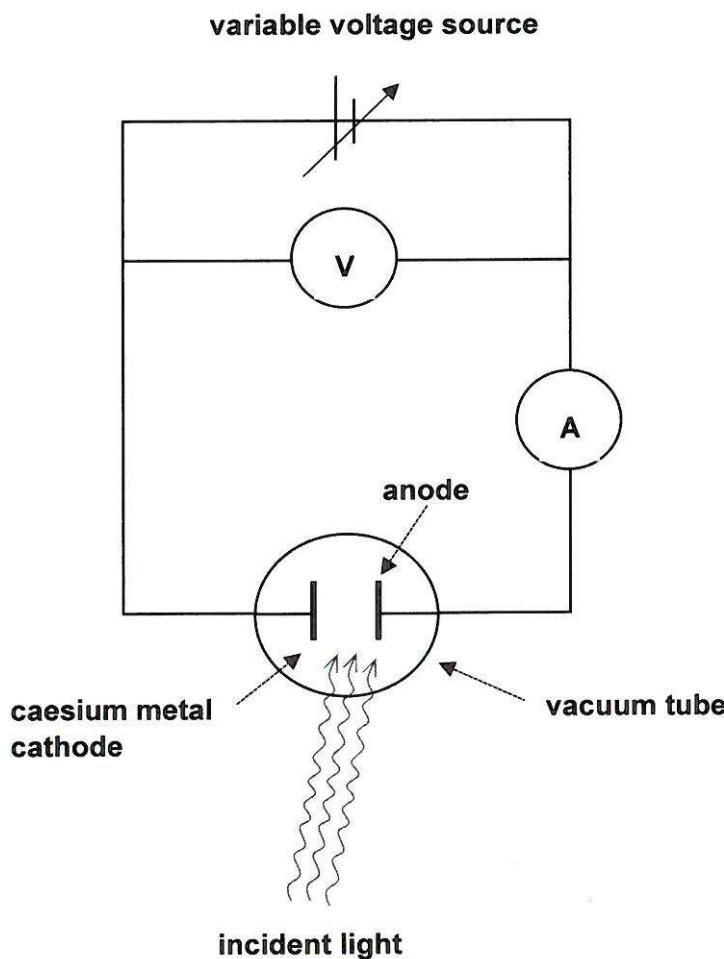
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Suggested working time for this section is 90 minutes.

**Question 13****(17 marks)**

A common apparatus used to investigate the photoelectric effect is shown below. The ‘variable voltage source’ is given a reverse bias to ultimately create a stopping voltage ( $V_0$ ). During the experiment, it was found that caesium has a work function of 1.90 eV.

- (a) Light of a longer wavelength than 654 nm will NOT cause the emission of photoelectrons from the surface of caesium metal. Explain with suitable calculations.

$$\cdot W = hf = 1.9 \times 1.6 \times 10^{-19} = 3.04 \times 10^{-19} \text{ J} \quad [4]$$

$$\cdot \lambda_0 = \frac{c}{f_0} \quad \text{and} \quad f_0 = \frac{W}{h}$$

$$\cdot \therefore \lambda_0 = c \times \frac{1}{f} = c \times \frac{h}{W} = 3.0 \times 10^8 \times \frac{3.04 \times 10^{-19}}{6.63 \times 10^{-34}}$$

$$= 6.54 \times 10^{-7} \text{ m (ie } 654 \text{ nm)}$$

- Photons of light with  $\lambda > 654 \text{ nm}$  will have insufficient energy to meet the work function  $\Rightarrow$  no photoelectron emission.

- (b) Explain the purpose of the reverse bias voltage in this experiment. As part of your answer, explain the concept of 'stopping voltage' ( $V_0$ ) and how it is known when it has been reached in the experiment.

- The reverse bias voltage establishes an electric field that opposes the motion of ejected photo-electrons.
- The stopping voltage is the reverse bias voltage value that prevents all photoelectrons from reaching the anode.
- The ~~stop~~ stopping voltage is reached when the ammeter/current reads zero.

- (c) If light of wavelength 500 nm is incident on the caesium metal surface, calculate the stopping voltage ( $V_0$ ). [5]

$$\cdot f_{500\text{nm}} = \frac{C}{\lambda} = \frac{3.0 \times 10^8}{5.0 \times 10^{-7}} = 6.00 \times 10^{14} \text{ Hz}$$

$$\begin{aligned} \cdot \text{Max KE} &= E_{\text{photon}} - E_{\text{work fun.}} \\ &= (6.63 \times 10^{-34} \times 6.0 \times 10^{14}) - 3.04 \times 10^{-19} \\ &= 9.38 \times 10^{-20} \text{ J} \\ \cdot \text{KE (ieeV)} &= (9.38 \times 10^{-20}) \div (1.6 \times 10^{-19}) \\ &= 0.586 \text{ eV} \\ \cdot V_0 &= 0.586 \text{ V} \end{aligned}$$

- (d) For each of the following statements, decide whether it is TRUE or FALSE. [3]

STATEMENT	TRUE OR FALSE?
When light sources of the same intensity but different frequencies are used (both exceeding $f_0$ ), the lower frequency light has the higher stopping voltage ( $V_0$ ).	F
Increasing the intensity of the incident light ( $f > f_0$ ) will increase the stopping voltage.	F
Decreasing the intensity of the incident light ( $f > f_0$ ) will decrease the photocurrent detected in the ammeter.	T

- (e) The photoelectric effect is confirmation that light has a dual nature – it can act as both a wave or a particle. Give two (2) reasons as to why the wave model CANNOT explain the photoelectric effect. ANY TWO [2]

- Freq. should be irrelevant
- Low freq. light should build up enough energy to eject electrons over time.
- Int. does not affect  $KE_{\text{P.E.}}$  at any given freq.

**Question 14****(12 marks)**

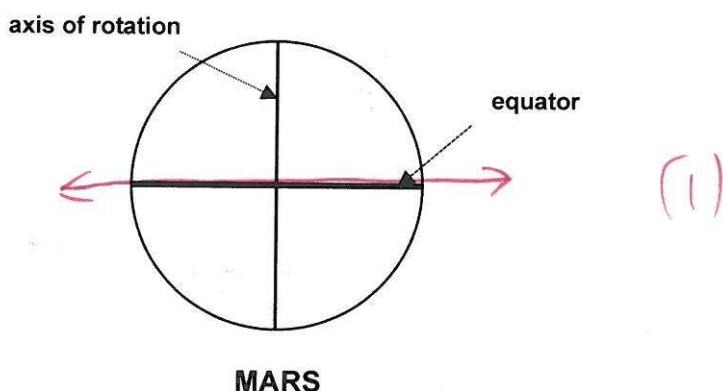
As part of its mission to colonise Mars, NASA will send a geostationary satellite to orbit Mars.

Mars has the following characteristics:

Mass	$6.39 \times 10^{23}$ kilograms
Radius of planet	3390 kilometres
Length of one day on Mars	24 hours, 39 minutes, 35 seconds
Length of one year on Mars	687 days
Orbital radius	228 million kilometres

- (a) On what plane must the geostationary satellite's orbit be? Show on the diagram below

[1]



- (b) Calculate the altitude of the geostationary satellite above Mars' surface.

$$r^3 = \frac{GMT^2}{4\pi^2} \cdot T = (24 \times 3600) + (39 \times 60) + 35 = 8.88 \times 10^4 \text{ s}$$

[4]

$$\therefore r^3 = \frac{6.67 \times 10^{-11} \times 6.39 \times 10^{23} \times (8.88 \times 10^4)^2}{4\pi^2}$$

$$\therefore r = 2.04 \times 10^7 \text{ m}$$

$$\therefore ALT = r_{\text{orbit}} - r_{\text{planet}}$$

$$= (2.04 \times 10^7) - (3.39 \times 10^6) \\ = 1.70 \times 10^7 \text{ m}$$

- (c) Calculate the gravitational field strength at the height of the geostationary satellite.  
[If you could not calculate a value for part (b), use an orbital radius of  $2.10 \times 10^7 \text{ m}$ ]

[2]

$$g = \frac{GM}{r^2} = \frac{6.67 \times 10^{-11} \times 6.39 \times 10^{23}}{(2.04 \times 10^7)^2} \\ = 1.02 \times 10^{-1} \text{ N kg}^{-1}$$

$$(g = 6.67 \times 10^{-2} \text{ N kg}^{-1} \text{ for } r = 2.10 \times 10^7 \text{ m})$$

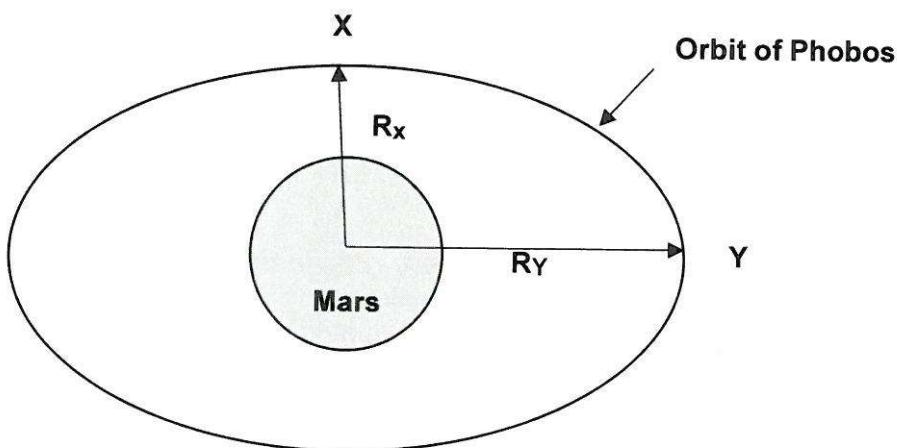
- (d) Objects inside the geostationary satellite will appear to be 'weightless'. Explain what this means and why this occurs.

[2]

- They appear to be weightless because both the satellite and object are in freefall.
- This means the satellite exerts no reaction force on the object.

- (e) Phobos is one of Mars' moons. It has an elliptical orbit (see below).

[3]



' $R_x$ ' is the minimum radius of the elliptical orbit at point X.

' $R_y$ ' is the maximum radius of the elliptical orbit at point Y.

Compare the orbital velocity at point X ( $v_x$ ) to that at point Y ( $v_y$ ).

Use an appropriate formula to help explain your answer.

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

ie  $v^2 = \frac{GM}{r}$  (1)

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

since  $R_y > R_x$  (1)

then

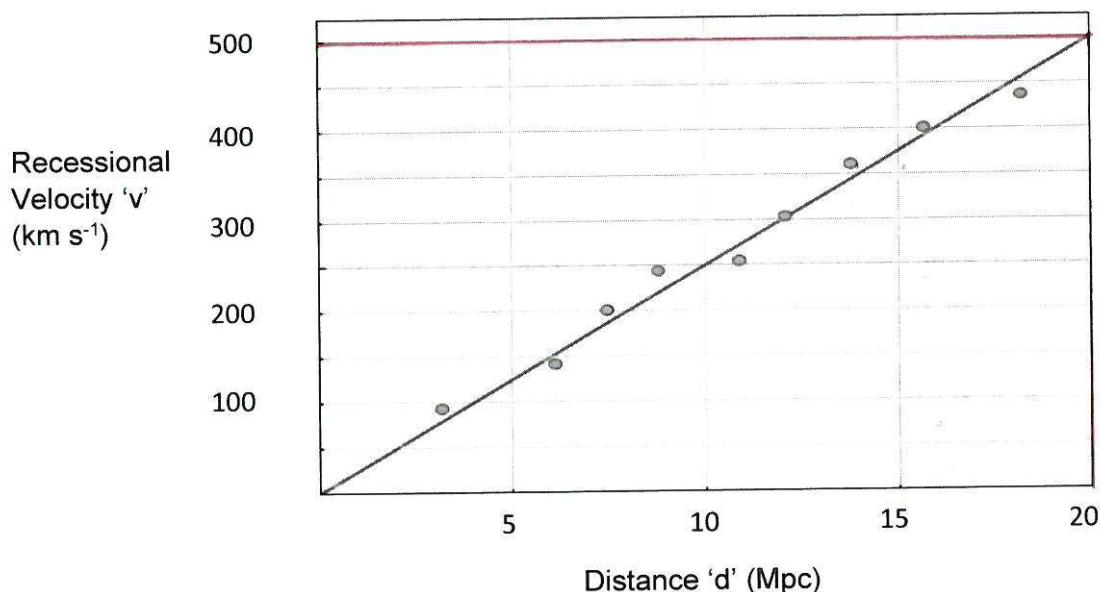
$v_y < v_x$  as  $GM$  is a constant. (1)

**Question 15****(14 marks)**

From 1914, an American astronomer Vesto Slipher was working at the Lowell Observatory (USA). He began recording the light absorption spectra of galaxies outside of the Milky Way. Most of these spectra were red-shifted due to the Doppler Effect; meaning the galaxies are moving away from the Earth. This discovery provided evidence that ultimately led to a fundamental rethink of the nature of our Universe.

During the early 1920s, two American astronomers - Edwin Hubble and Milton Humanson – built on Slipher's work and recorded images of 46 galaxies using the largest optical telescope in the world. Due to recent breakthroughs in astronomy at that time, Hubble and Humanson were able to measure the distance 'd' (in megaparsecs) to these 46 galaxies using special fixed-period pulsating stars called Cepheid variables. By measuring the size of the red-shift for each galaxy, the recessional velocity 'v' can be calculated.

The graph below shows some of Hubble's and Humanson's original data for 'd' and 'v' which, to their surprise, showed a distinct linear relationship.



The data yielded the first iteration of Hubble's Law which states the following relationship:

$$v = H_0 d$$

where:

$v$  = recessional velocity of the galaxy (km s<sup>-1</sup>);

$H_0$  = Hubble's constant;

$d$  = distance to the galaxy (Mpc).

- (a) The slope of the graph on the previous page is equal to Hubble's Constant. Use the graph to estimate Hubble's Constant ( $H_0$ ) for this data.

- Show points on graph.
  - calc.
  - $H_0 \approx 25 \text{ km s}^{-1} \text{ Mpc}^{-1}$
- } - 1 for any not done. [2]

- (b) Hubble's Constant can be used to estimate the age of the Universe (T).

$$T = \frac{1}{H_0}$$

Use this equation and the fact that  $1 \text{ Mpc} = 3.08 \times 10^{22} \text{ m}$  to calculate the age of the Universe in years.

[If you could not calculate a value for Hubble's Constant in part (b), use a value of  $30 \text{ km s}^{-1} \text{ Mpc}^{-1}$ .]

$$H_0 = 25 \times \frac{1000}{3.08 \times 10^{22}} = 8.11 \times 10^{-19} \text{ s}^{-1} \quad [3]$$

$$T = \frac{1}{H_0} = \frac{1}{8.11 \times 10^{-19}} = 1.23 \times 10^{18} \text{ s}$$

$$\frac{T}{365 \times 24 \times 60 \times 60} = 3.91 \times 10^{10} \text{ yrs} = 3.9 \times 10^{10} \text{ yrs}$$

$(3.26 \times 10^{10} \text{ yrs for } H_0 = 30) \quad (2s^t)$

When investigating the Doppler Effect, the recessional velocity 'v' for a galaxy can be calculated by the equation:

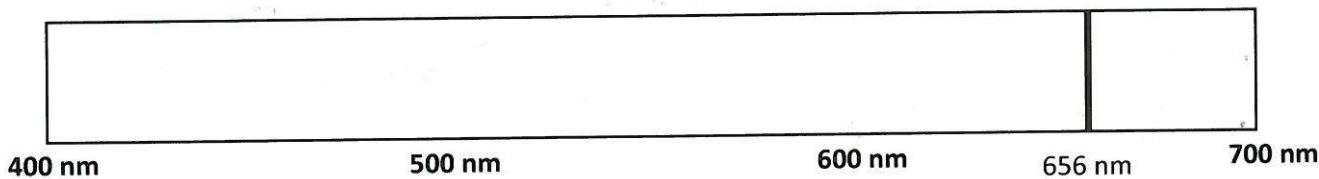
$$v = \frac{\Delta\lambda}{\lambda_{rest}} \cdot c$$

$$\Delta\lambda = \lambda_o - \lambda_r$$

$\lambda_o$  = the wavelength of spectral lines from the receding galaxy; and

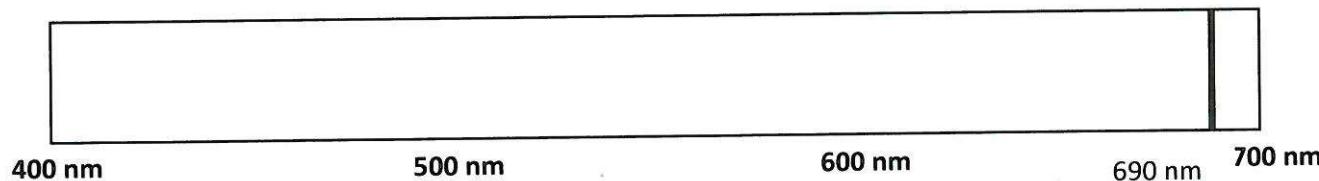
$\lambda_r$  = the wavelength of spectral lines from a light source at rest.

- (c) The diagram below shows one of the spectral lines in the Hydrogen spectrum ( $\lambda = 656 \text{ nm}$ ) when the light source and hydrogen sample is at rest.

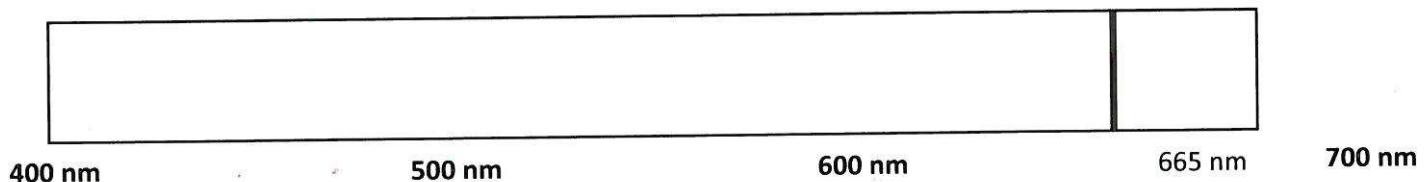


The diagrams below show the same spectral line when the light from three different distant galaxies A, B and C is observed.

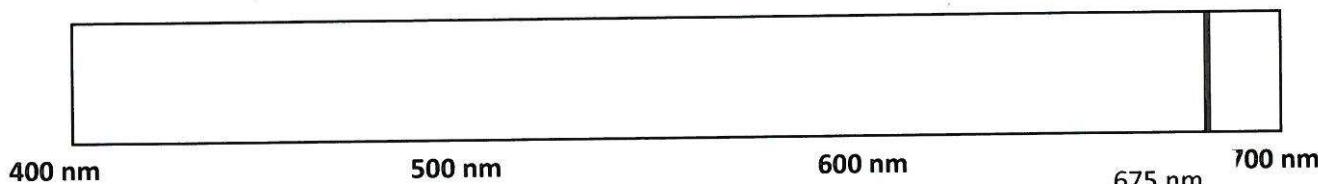
**GALAXY 'A'**



**GALAXY 'B'**



**GALAXY 'C'**



Rank the three galaxies (A, B and C) in order of closest to Earth to furthest from Earth.

[2]

CLOSEST: B

-1 for  
each incorrect.

MIDDLE: C

FURTHEST: A

- (d) Use the data for galaxy C and the equation provided in part (b) to calculate its recessional velocity.

$$\begin{aligned} \Delta \lambda &= \lambda_0 - \lambda_r = 675 - 656 & [3] \\ &= 19 \text{ nm} = 1.9 \times 10^{-8} \text{ m} \end{aligned}$$

$$\begin{aligned} v &= \frac{\Delta \lambda}{\lambda_{\text{rest}}} \times c = \frac{19}{656} \times 3.0 \times 10^8 \\ &= 8.69 \times 10^6 \text{ m s}^{-1} \end{aligned}$$

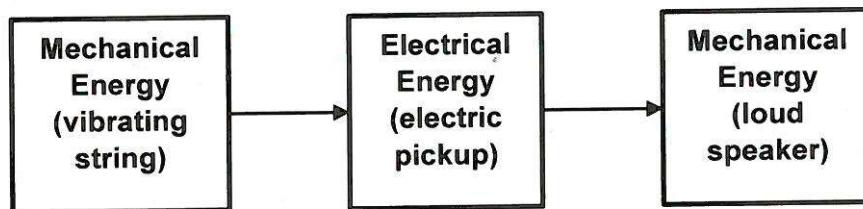
- (e) A more recent measurement of Hubble's Constant ( $H_0$ ) yielded a value of  $75 \text{ km s}^{-1} \text{ Mpc}^{-1}$ . Use the recessional velocity from part (d) to calculate how far from Earth galaxy C is in metres.

[If you could not calculate a value in part (d), use  $8.70 \times 10^6 \text{ m s}^{-1}$ ]

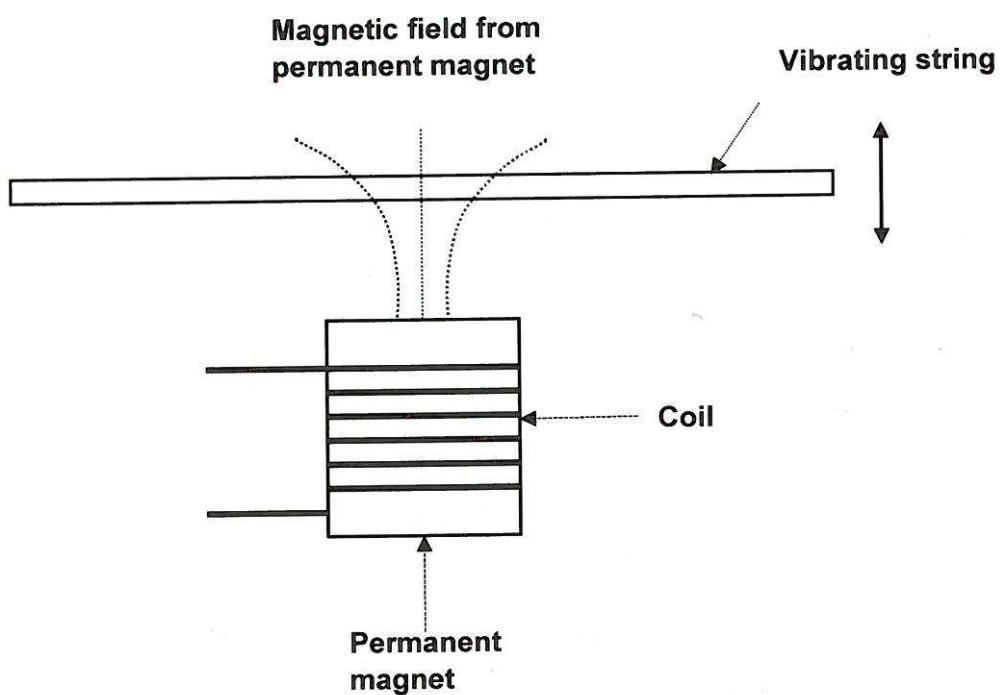
$$\begin{aligned} v &= H_0 d \quad \therefore d = \frac{v}{H_0} & [4] \\ d &= \frac{8.69 \times 10^6}{75} \\ &= 1.16 \times 10^2 \text{ Mpc} \\ \therefore d &= 1.16 \times 10^2 \times 3.08 \times 10^{22} \\ &= 3.57 \times 10^{24} \text{ m} \end{aligned}$$

**Question 16****(18 marks)**

Electric guitars are able to convert the mechanical energy of a vibrating string into electrical energy via a device called an 'electric pickup'. These electrical signals are then transformed back into mechanical energy by a loudspeaker – creating the sound we hear.



A simple schematic diagram of an electric pickup is shown below.



The permanent magnet creates a steady magnetic field near the guitar string. The guitar strings must be made of steel. When the steel guitar string is plucked, an induced EMF (and current) is formed in the coil. This AC electric signal is sent to the loudspeaker to be converted back into mechanical energy.

- (a) Describe and explain what will happen to the steel guitar strings when they are placed near the permanent magnetic field.

[2]

- Steel is a ferro-magnetic material.
- Hence the strings will become magnetised.

- (b) Describe how an EMF is induced in the electric pickup's coil.

[2]

- The vibrating string causes its magnetic field to interact with the permanent mag. field.
- This interaction causes a change in flux in the coil and has a corresponding EMF induced in it.

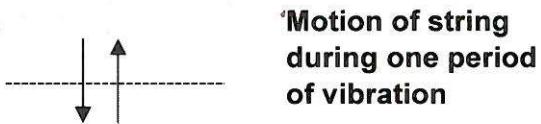
- (c) An AC signal is produced in the electric pickup's coil with the same frequency as the vibrating string. Using Lenz's Law, explain how the AC signal is produced.

[3]

- The induced EMF has its own mag. field which always opposes the direction of the mag. field of the string, according to Lenz's Law.
- As the vibrating string changes direction, so to does the direction of the induced EMF  $\Rightarrow$  AC.
- The induced EMF freq. must be the same as the vibrating freq. of the string.

- (d) The cross-sectional area of the coil in the electric pickup is  $1.26 \times 10^{-5} \text{ m}^2$  and consists of 1000 turns.

The string is vibrating at 100 Hz. In one complete vibration, the string will move towards the coil from rest position and then away (see below).



As the string moves towards the coil, the coil experiences a change in magnetic field strength of  $2.00 \times 10^{-3} \text{ T}$ .

This part of the string's motion will take **one-quarter of the period** of the string's vibration.

Calculate the average EMF generated in the coil as the string moves towards the coil.

[4]

$$\text{EMF}_{\text{AVE}} = -\frac{N\Delta\Phi}{\Delta t} = -\frac{NBA}{\Delta t}$$

$$N = 1000$$

~~$B$~~  =  $2.00 \times 10^{-3} \text{ T}$

$$t = \frac{T}{4}$$

$$= 100 \div 4$$

$$= 2.50 \times 10^{-3} \text{ s.}$$

$$A = 1.26 \times 10^{-5} \text{ m}^2$$

$$\therefore \text{EMF}_{\text{AVE}}$$

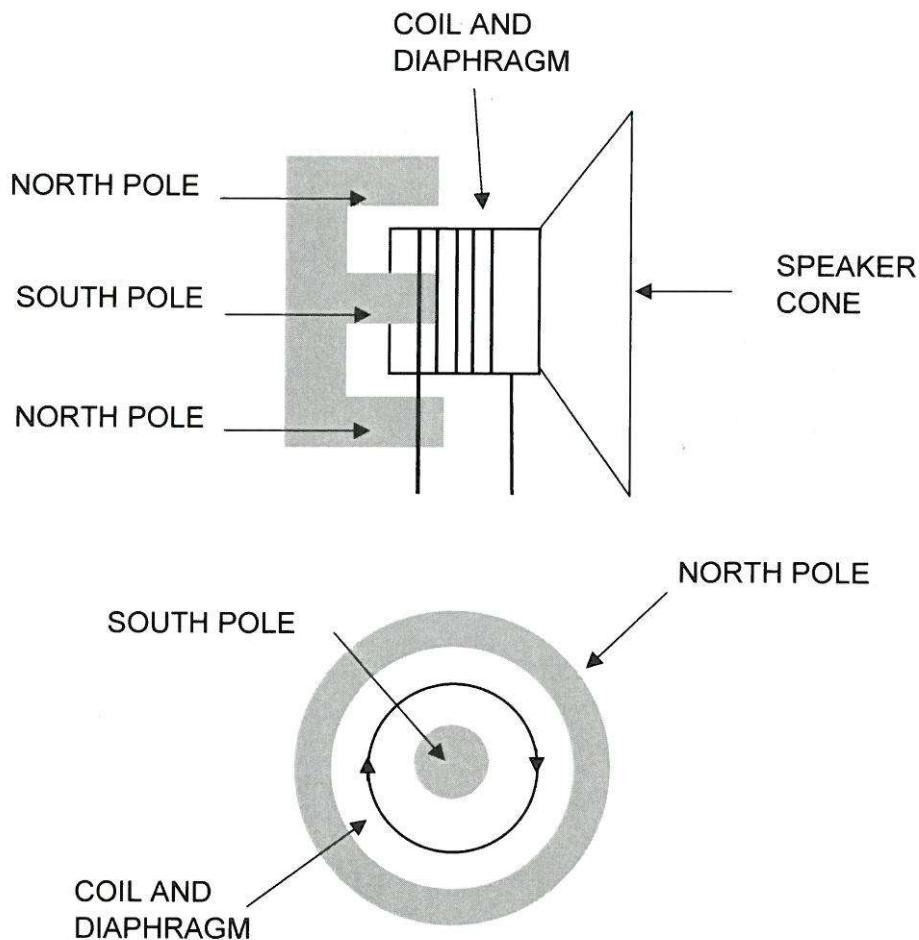
$$= \frac{-1000 \times 2.0 \times 10^{-3} \times 1.26 \times 10^{-5}}{2.50 \times 10^{-3}}$$

$$= 0.0101 \text{ V}$$

$$= 1.01 \times 10^{-2} \text{ V}$$

Question 16 continued in the next page

The AC signal from the pickup coil is sent to a coil in the loudspeaker. The speaker cone is connected to a diaphragm which has the coil wrapped around it. The coil and the diaphragm sit in a permanent radial magnetic field. Any force or movement experienced by the coil and diaphragm will be experienced by the speaker cone. The top diagram below shows the arrangement from side-on. The bottom diagram shows the coil/diaphragm/magnet arrangement.



- (e) At the instant that the coil is carrying a clockwise conventional current, state whether the magnetic force experienced by the coil is 'into the page' or 'out of the page'.

*Into the page.*

[1]

- (f) Hence, describe how the speaker produces the same frequency sound as the guitar string.

- The speaker coil sits in a constant mag. field. [3]
- The AC signal from the pickup causes an AC current in the coil, with ~~the~~ associated mag. fields.
- The coil/cone experiences a mag. force due to the interaction of its changing field and the constant field leading to vibrations at the same freq. as the string,  $\Rightarrow$  sound produced.

- (g) The diameter of the coil is 2.00 cm and it consists of 50 turns. The magnetic field has a strength of 0.500 T and the maximum current carried by the coil is 2.00 A. Hence, calculate the maximum force experienced by the coil.

$$F = IlBn \quad = 2.0 \times 0.5 \times 6.28 \times 10^{-2} \times 50 \quad [3]$$

$$n = 50 \quad = 3.14 \text{ N}$$

$$I = 2A$$

$$l = 2\pi r \\ = \pi d = \pi \times 0.02 \\ = 6.28 \times 10^{-2} \text{ m}$$

$$B = 0.50 \text{ T}$$

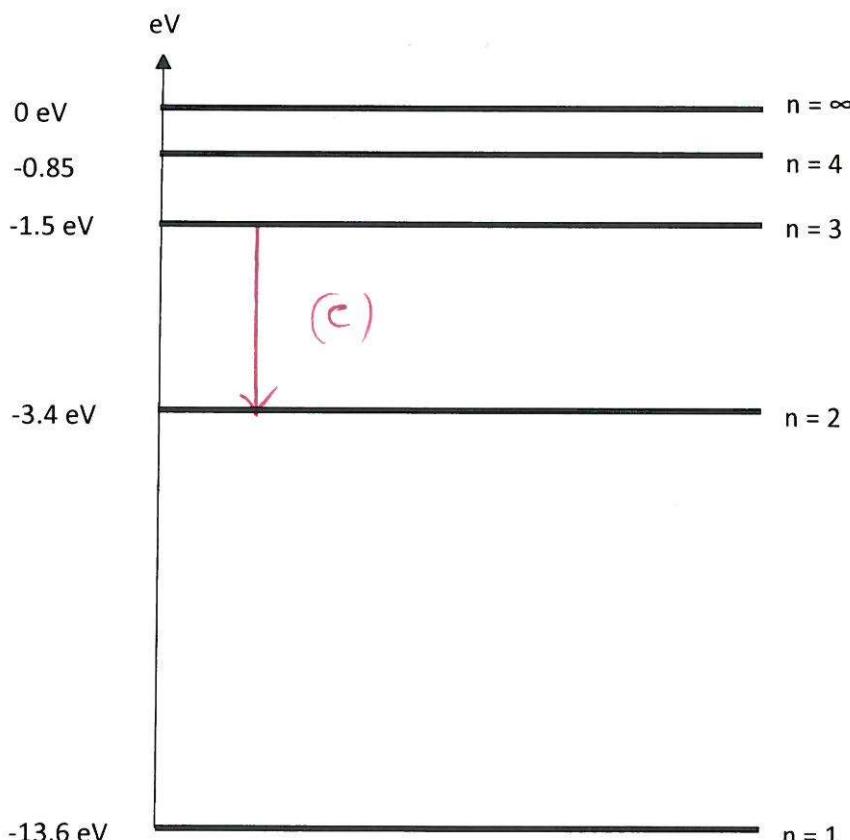
**Question 17**

(17 marks)

A solar prominence is a large, bright gaseous feature extending outward from the sun's surface in a continuous loop. These huge red flames consist of superheated gases whose composition is now known to be mainly hydrogen.

- (a) Explain how a superheated atom can produce a line emission spectrum and why it can be used to identify the element that produced it.

- The heat can excite electrons, moving them to higher energy states.
  - The electrons can then spontaneously transition back towards the ground state, emitting photons.
  - The  $\lambda/\text{energy}$  of the photons match the differences in transition energies of the electron energy states.
  - Different elements have different/characteristic photon emissions leading to identification via spectral analysis.
- The red colour of the prominences is thought to be mainly due to an emission from the superheated hydrogen atoms. The characteristic wavelength of this red light is measured to be about 656 nm. The diagram below shows the energy levels in a hydrogen atom (not to scale).



- (b) Calculate the photon energy (in eV) of this red emission line.

$$\begin{aligned}
 E &= \frac{hc}{\lambda} = \frac{6.63 \times 10^{-34} \times 3.0 \times 10^8}{6.56 \times 10^{-7}} \\
 &= 3.03 \times 10^{-19} \text{ J} \\
 &= 1.90 \text{ eV}
 \end{aligned}$$

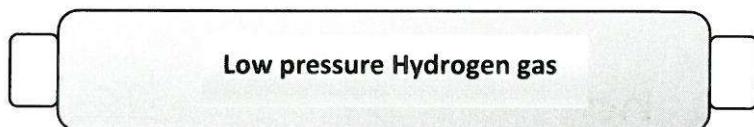
- (c) Use the energy level diagram for hydrogen to determine the electron transition responsible for this emission line. Show this transition with an arrow. Show your working below.

[2]

$$\begin{aligned}
 1.90 \text{ eV} &= 3.4 - 1.5 \\
 \text{so } n = 3 \text{ to } n = 2
 \end{aligned}
 \tag{1}$$

(1) arrow

The hydrogen line emission spectrum can also be produced in an emission tube. A high voltage is applied to the tube accelerating electrons to high speeds. The hydrogen atoms in the tube are then excited via bombardment by these electrons. Once these collisions between the accelerated electrons and hydrogen atoms occur, the electrons will possess varying degrees of energy. In the emission tube below, the tube has an accelerating potential ( $V_{TUBE}$ ) of 1000 V.



- (d) Determine the maximum energy (in eV) an accelerated electron in this tube could possess. [1]

$$\begin{aligned} E &= V \times z \\ &= 1000 \text{ eV} ! \\ &= 1.00 \times 10^3 \text{ eV} \end{aligned}$$

- (e) An accelerated electron collides with a Hydrogen atom and ionises it. Hence, calculate the amount of energy the electron retains after this collision. Show working. [3]

$$\text{from } n=1 \text{ to } n=\infty = 13.6 \text{ eV}$$

$$\begin{aligned} E_{\text{elect.}} &= 1000 - 13.6 = 986.4 \text{ eV} \\ &= 986 \text{ eV.} \end{aligned}$$

$$\left( = 1.58 \times 10^{-16} \text{ J} \right)$$

- (f) Calculate the minimum wavelength electromagnetic radiation that will be emitted by the hydrogen atoms in the tube. Identify this type of electromagnetic radiation.

[4]

$$\cdot \lambda_{\min} \Rightarrow E_{\max} = 13.6 \text{ eV}$$

$$= 2.18 \times 10^{-18} \text{ J}$$

$$\cdot \lambda = E = \frac{hc}{\lambda} \therefore \lambda = \frac{hc}{E}$$

$$= \frac{6.63 \times 10^{-34} \times 3.0 \times 10^8}{2.18 \times 10^{-18}}$$

$$= 9.14 \times 10^{-8} \text{ m}$$

$$= 91.4 \text{ nm}$$

• UV

**Question 18****[12 marks]**

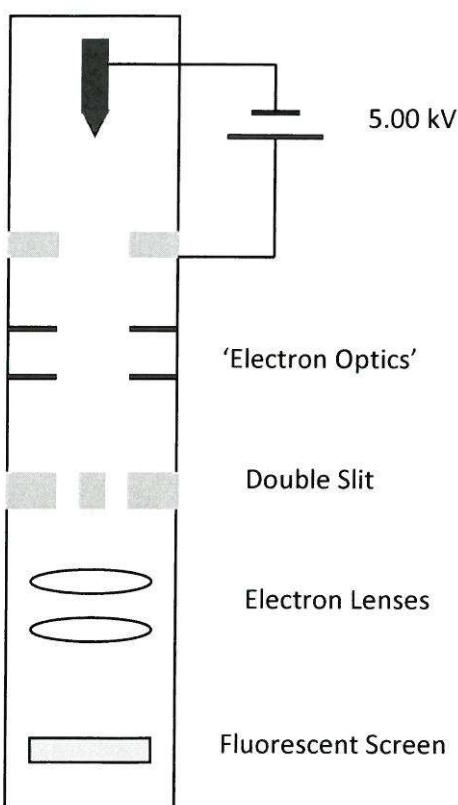
In 1989, the now deceased Japanese Physicist Akira Tonomura and his team achieved fame by performing the 'single electron interference' experiment. Tonomura modified a transmission electron microscope to develop his experimental set up. At the time, the magazine Physics World described it as the 'most beautiful Physics experiment in the world'.

In this experiment, electrons are emitted from a very sharp tungsten tip and have an accelerating potential of 5.00 kV applied to them.

An array of 'electron optics' then attenuates and focuses the electron beam until it consists of barely 100 electrons per second.

The electrons are then aimed at a double slit with gaps about 1 μm in width. The electrons pass through the double slit and are then passed through electron lenses to produce a magnified image of their impact on a fluorescent screen.

This experimental set up is shown schematically below.



- (a) Calculate the maximum velocity achieved by electrons in the beam after they have the 5.00 kV accelerating potential applied to them. **Show working.**

$$KE = W = qV = \frac{1}{2}mv^2 \quad [4]$$

$$\text{i.e. } v = \sqrt{\frac{2qV}{m}}$$

$$v = \sqrt{\frac{2 \times 5000 \times 1.6 \times 10^{-19}}{9.11 \times 10^{-31}}}$$

$$= 4.19 \times 10^7 \text{ ms}^{-1}$$

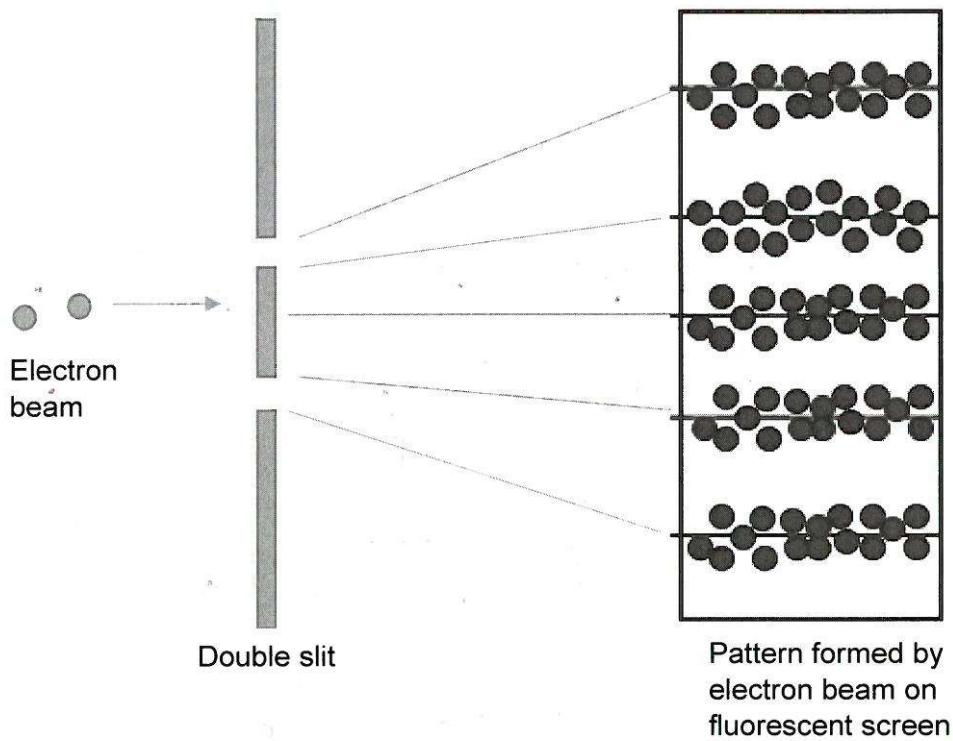
(b) Hence, calculate the de Broglie wavelength for the electrons when they are travelling at this maximum speed. [If you were unable to calculate part (a) use  $v = 4.00 \times 10^7 \text{ ms}^{-1}$ ]

$$\lambda = \frac{h}{mv} = \frac{6.63 \times 10^{-34}}{9.11 \times 10^{-31} \times 4.19 \times 10^7} \text{ m}$$

$$= 1.74 \times 10^{-11} \text{ m}$$

$(1.82 \times 10^{-11} \text{ m} \text{ for } v = 4.00 \times 10^7 \text{ ms}^{-1})$

After the electron beam passed through the double slit, the following pattern formed on the fluorescent screen.

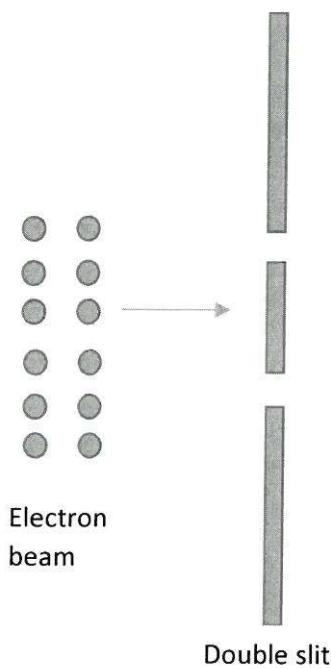


- (c) The pattern formed on the fluorescent screen by the electrons as they passed through the double slit one at a time showed evidence that electrons possessed a 'wave nature'. Explain using your knowledge of wave properties.

- The electrons appeared to pass through both slits, like a wave.
- and diffract out from these slits, like waves.
- The resulting interference pattern is characteristic of waves.

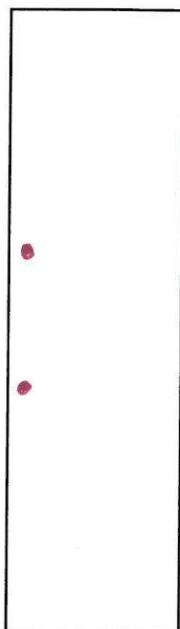
- (d) On the empty fluorescent screen below, draw the pattern you would expect if electrons only behaved as particles. Support your answer with a reason.

[2]



Electron  
beam

Double slit



Pattern formed by  
electron beam on  
fluorescent screen

particles would pass straight through only one of the slits.

**Section Three: Comprehension and Data Analysis****20% (36 Marks)**

This section contains **two (2)** questions. You must answer both questions. Write your answers in the space provided.

Spare pages are included at the end of this booklet. They can be used for planning your responses and/or as additional space if required to continue an answer.

- Planning: If you use the spare pages for planning, indicate this clearly at the top of the page.
- Continuing an answer: If you need to use the space to continue an answer, indicate in the original answer space where the answer is continued, i.e. give the page number. Fill in the number of the question that you are continuing to answer at the top of the page.

Suggested working time for this section is 40 minutes.

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**Question 19****(18 marks)****The ‘Near Perfect’ Liquid**

On the 18<sup>th</sup> April, 2005, a team of physicists at Brookhaven National Laboratory, New York, announced that they appeared to have discovered a new state of matter. Up until then, states of matter appeared to be limited to the Bose-Einstein Condensate, solids, liquids, gases and plasma. This new state of matter appeared to be composed of the fundamental particles that are the building blocks of atomic nuclei – quarks and gluons.

The researchers believed that amongst the many implications of their discovery, one of the most significant would be new insight into the composition of the universe just moments after the Big Bang.

The new state of matter was created and discovered by four different teams at the Brookhaven Relativistic Heavy Ion Collider (RHIC). In the RHIC experiment, two beams of heavy gold ions were accelerated to relativistic velocities. Once the ions in both beams reached the required velocities, they were directed towards each other allowing the gold ions to ‘smash’ into each other and produce extremely high temperatures - more than one million times the temperature of the core of the sun. Thousands of subatomic collisions occurred every second and the trajectories of the particles produced after these collisions were measured and analyzed.

The results of the experiment revealed that at these temperatures a ‘near perfect liquid’ was created. The particles produced appeared to move in a coordinated and collective fashion – almost like a school of fish. The high degree of collective interaction between the particles and the extremely low viscosity of the matter created at the RHIC led the Brookhaven team of physicists to describe this as the most nearly perfect liquid ever observed.

The viscosity of a liquid can be defined as the resistance of a liquid to flow and can be measured in several ways – the most common being kinematic viscosity. **Kinematic viscosity** can be obtained by dividing the absolute **viscosity** of a fluid with the fluid mass density. The kinematic viscosity of water at 20°C is measured to be  $1.0034 \text{ mm}^2 \text{ s}^{-1}$ ; the kinematic viscosity of honey at 20°C is much higher than this -  $9927.9 \text{ } 1 \text{ mm}^2 \text{ s}^{-1}$ . The higher the kinematic viscosity of a liquid, the more resistance the liquid displays to flow; this is due to the ‘thickness’ of the liquid and its high internal friction – meaning it flows more slowly.

Just microseconds after the Big Bang it is theorized that the Universe was dominated by a type of ultra-hot matter called the quark-gluon plasma (QGP). As the team of physicists at Brookhaven made their observations of the ‘super liquid’ they had created at the RHIC, they realized that these matched some of the theoretical properties of the ultra-hot QGP.

The ‘near perfect liquid’ (QGP) has since been studied more closely in the Large Hadron Collider (LHC) (where lead ions were used) at CERN; at Vienna University of Technology in 2012; and more recently, at the Berkeley National Laboratory. These studies have further refined the key property of ‘near perfect liquids’ – that they have the lowest viscosity-to-density ratio allowed by quantum mechanics which means that they can flow with almost no friction whatsoever.

Quantum mechanics has imposed a theoretical limit on how ‘liquid’ or how low the viscosity of a fluid could be. In fact, in 2004, scientists predicted that the lowest possible kinematic viscosity possible was equal to:

$$\hbar = \frac{h}{4\pi}, \text{ where } h = \text{Planck's Constant}$$

In 2005, measurements showed that QGP has a viscosity just above this value and far below the previously least viscous liquid known, super fluid helium. However, recent experiments are pointing to a viscosity that may be even lower than this theoretical limit. More studies of this exotic, hot-plasma soup of quarks and gluons are ongoing and will no doubt reveal more information about the early Universe.

- (a) State the name of the family of particles that a gluon comes from. Briefly describe the function of these particles.

[2]

- *Boson*

- *Force carrying particles.*

- (b) Explain why quarks and gluons have been ‘inseparable’ for most of the Universe’s existence – but were separate in the first few microseconds of the Universe.

[3]

- *Gluons mediate the (very) strong force.*
- *Gluons bind (up / down) quarks together.*
- *In the first few microseconds, conditions (ie temp.) were large enough to break these bonds.*

(c) Explain what is meant by the term 'relativistic velocities'.

[2]

- Velocities that approach 'c'
- At these velocities relativistic effects become significant. (length cont., time dil. and KE inaccr.)

(d) At the RHIC, gold ions are accelerated to about 99.7% of the speed of light. Calculate the amount of energy possessed by a gold ion at this speed (mass of a gold ion is 196.966569 u; 1 u =  $1.66 \times 10^{-27}$  kg).

$$M_{\text{rest}} = 196.966569 \times 1.66 \times 10^{-27} = 3.27... \times 10^{-25} \text{ kg} \quad [4]$$

$$\begin{aligned} E &= \frac{mc^2}{\sqrt{1 - \frac{v^2}{c^2}}} \\ &= \frac{3.27 \times 10^{-25} \times (3.0 \times 10^8)^2}{\sqrt{1 - \frac{(0.997)^2}{1^2}}} \\ &= 3.80 \times 10^{-7} \text{ J} \\ &\quad (2.38 \times 10^{12} \text{ eV}) \end{aligned}$$

(e) Explain what scientists mean by the term a 'perfect liquid'.

[2]

- Has zero viscosity.
- Will flow with zero internal friction.

- (f) The article describes the conditions experienced during the collision experiments that create the hot-plasma soup of quarks and gluons. These conditions are said to be simulating those present in the Universe microseconds after the Big Bang. Describe how these conditions are replicated in the RHIC.

[3]

- Extremely high temps.
- High temps. simulated by accelerating particles to extremely high velocities.
- These fast, heavy ions undergo collisions which produce similar temps to microseconds after big bang.

- (g) Calculate the theoretical lowest possible kinematic viscosity for a liquid ( $\eta$ ) using the formula in the article (no units are required).

[2]

$$\begin{aligned}\eta &= \frac{\hbar}{4\pi} = \frac{6.63 \times 10^{-34}}{4\pi} \\ &= 5.28 \times 10^{-35}\end{aligned}$$

**Question 20****(18 marks)**

A group of students performed an experiment to investigate Ampere's Force Law. This Law allows the mutual magnetic force between two parallel, current carrying conductors a set distance apart to be calculated.

The students knew that this force can be calculated using the following expression:

$$\frac{F_m}{L} = \frac{\mu_0}{2\pi} \frac{I_1 I_2}{r}$$

Where:  $F_m$  = mutual magnetic force exerted on equal lengths of each parallel conductor (N);

$L$  = equal parallel length of each conductor (m);

$\mu_0$  = magnetic constant ( $N A^{-2}$ );

$I_1$  = current in conductor 1 (A);

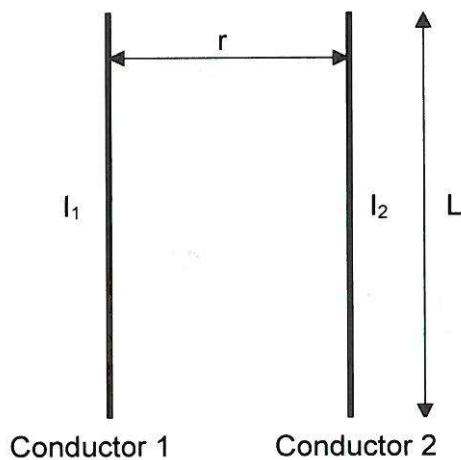
$I_2$  = current in conductor 2 (A);

$r$  = perpendicular distance between conductor 1 and conductor 2 (m).

The students set up some equipment that allowed them to use sensitive force probes to detect and measure the mutual magnetic force,  $F_m$ , between two parallel, current carrying conductors a set distance ' $r$ ' apart.

The direction and magnitude of the current in each conductor was kept constant; and the distance ' $r$ ' between them was varied and measured. The corresponding mutual magnetic force on each conductor was then measured with the force probes.

This set up is shown below:



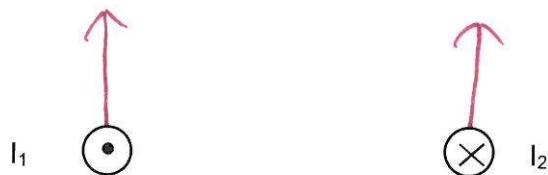
The students found that the mutual magnetic force,  $F_m$ , could be 'attraction' or 'repulsion' depending on the direction of the currents  $I_1$  and  $I_2$ .

- (a) The diagrams below indicate the directions of the currents  $I_1$  and  $I_2$  in two scenarios. For each scenario:

- Draw a vector on each conductor indicating the direction of the magnetic field at that point due to the current in the other conductor.
- Indicate whether the mutual magnetic force,  $F_m$ , acting on the conductors are 'attraction' or 'repulsion'. Circle your choice.

[4]

(i) ATTRACTION / REPULSION



(ii) ATTRACTION / REPULSION



The students collected data using the experimental set up shown earlier to determine an experimental value for the magnetic constant,  $\mu_0$ . The data they collected is summarised below:

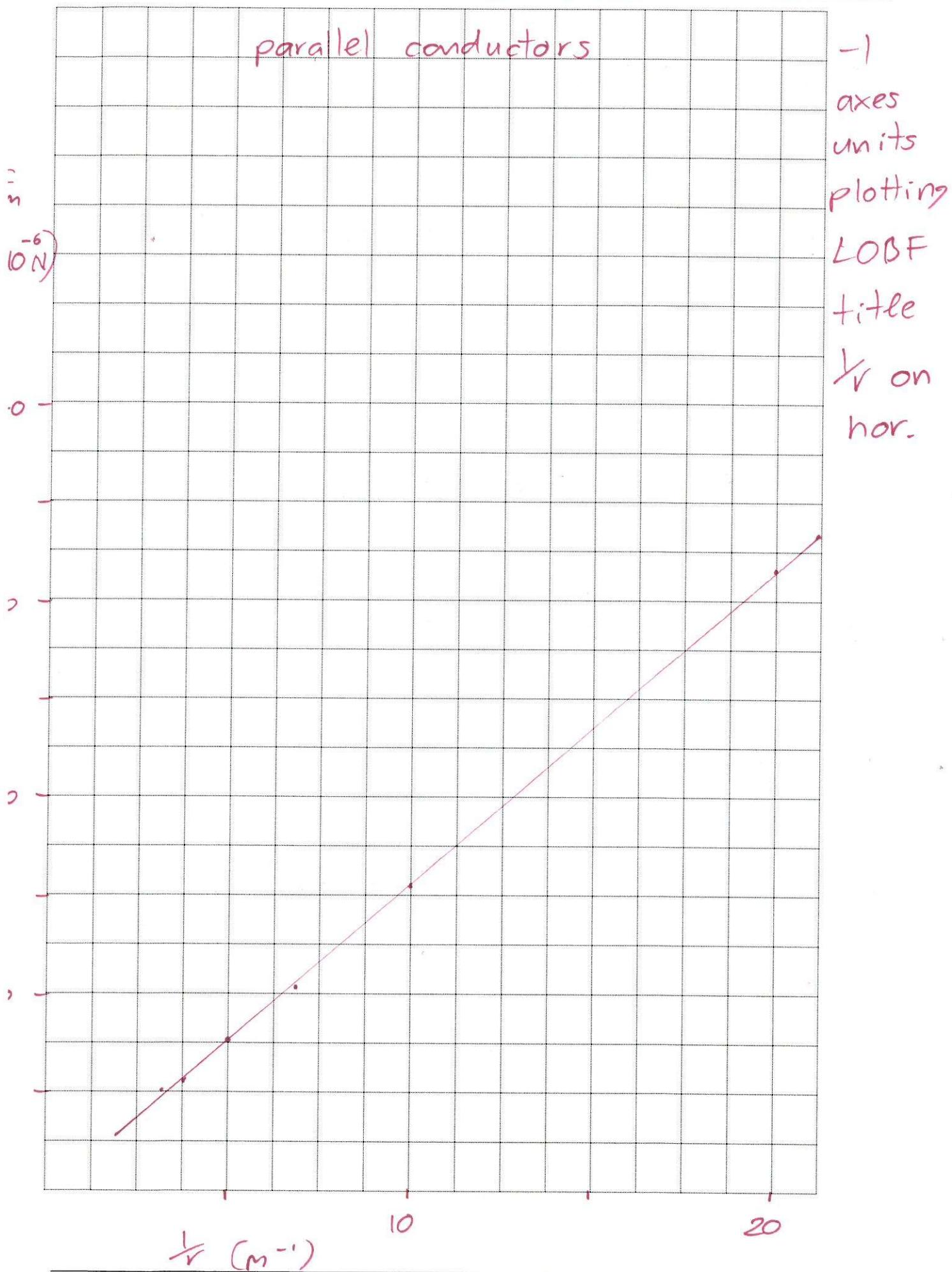
$$I_1 = 2.50 \text{ A}; I_2 = 3.10 \text{ A}, L = 1.00 \text{ m}$$

r (m)	Average $F_m$ ( $\times 10^{-6}$ N)	$1/r$ ( $m^{-1}$ )
0.0500	31.8	20
0.100	15.6	10.0
0.150	10.4	6.70
0.200	7.78	5.00
0.250	6.62	4.00
0.300	5.19	3.33

- (b) Fill in the missing values in the table. Show any working below. Also, write the units for  $1/r$  in the space provided at the top of the column. [2]

$$\frac{1}{r} = \frac{1}{0.05} = 20 \text{ m}^{-1}$$

- (c) On the axes provided, plot the values for 'Average  $F_m$ ' against  $1/r$ . Place  $1/r$  on the horizontal axis. Draw a line of best fit for this data. [5]



- (d) Use the graph to calculate the slope of your line of best fit, including units.

[3]

- Picks two points  $\rightarrow$  shown

- Calc.

- $m = 1.5 \text{ to } 1.65 \times 10^{-6} \text{ N m}$

- (e) Use the value of the slope you calculated in part (d) to calculate an experimental value for ' $\mu_0$ '.

[4]

- Slope  $= \frac{F_m}{r} = F_m \times r$

- from EQN  $= F_m r = \frac{\mu_0 I_1 I_2 L}{2\pi}$

- $1.57 \times 10^{-6} = \frac{\mu_0 \times 2.5 \times 2 - 1 \times 1}{2\pi}$

$$\mu_0 = 1.27 \times 10^{-6} \text{ (no units)}$$

$$\text{range} = 1.20 \rightarrow 1.35 \times 10^{-6} \text{ NA}^{-2}$$

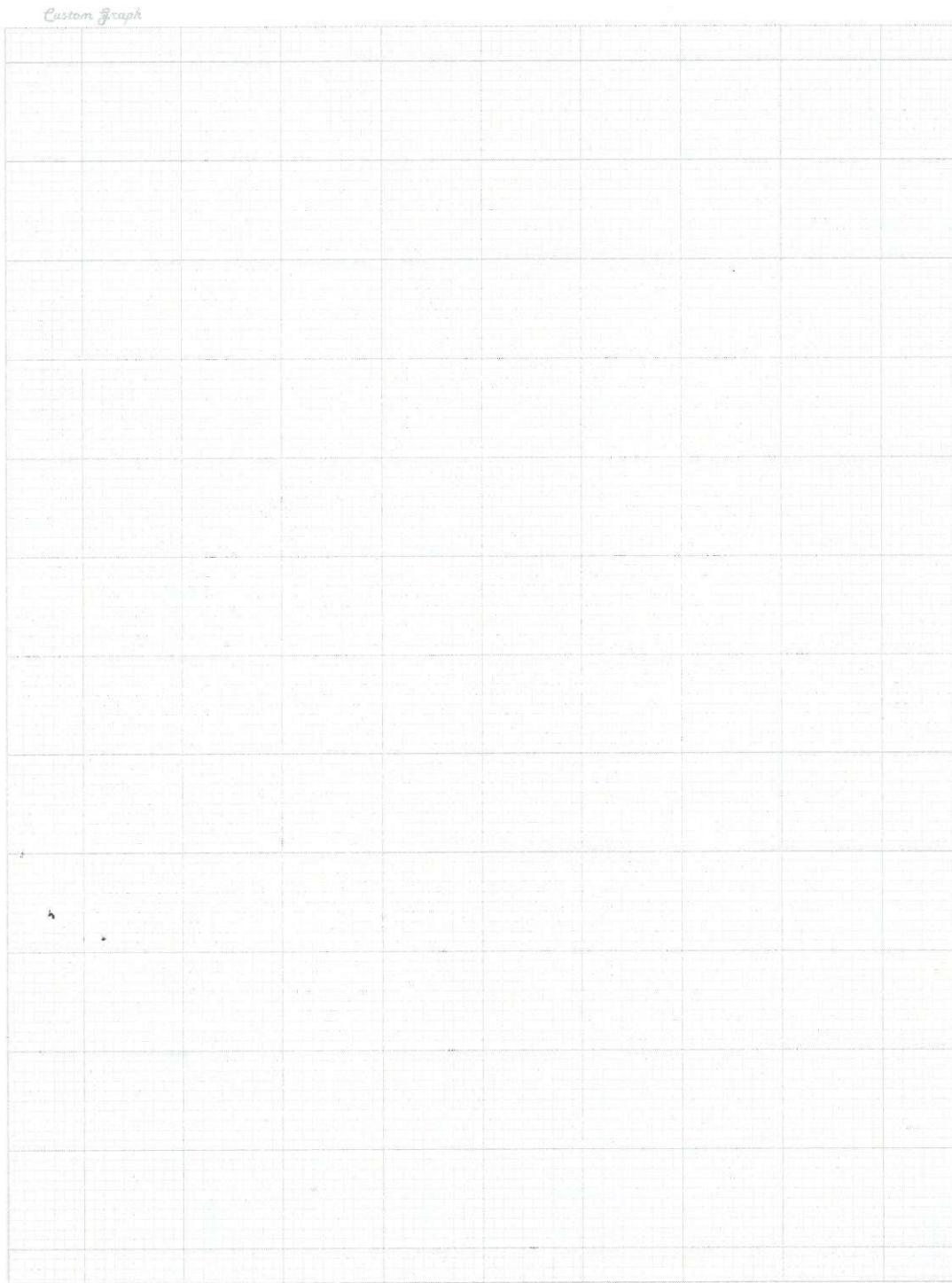
End of Section 3

## Additional working space

## Additional working space

**Additional working space**

**Additional graph if required.**



**End of examination**

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