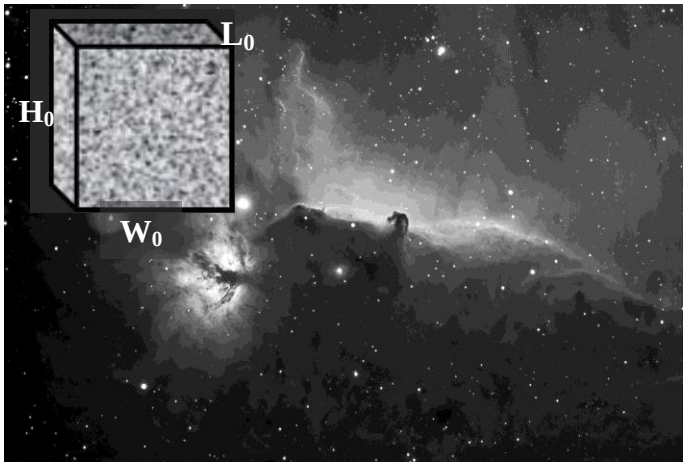
1. [4 Marks]

An astronaut is floating freely in space in the Orion Nebula.



The astronaut is stationary and the view in the diagram below is what he sees from his faceplate.

A "Borg" spaceship, in the form of a cube with side length 5 km, is travelling at 20% of the speed of light (i.e. 0.2 x c) and is on a heading directly towards the astronaut.

The dimensions of the Borg ship are labelled L_o, W_o, and H_o in the diagram.

1a) Which of the following options best describes the dimensions of the box as observed by the astronaut outside the spaceship compared to the measurements made by the passenger?

A. $L<L_o$, $W<W_o$, $H=H_o$

B. $L>L_o$, $W=W_o$, $H=H_o$

C. $L<L_o$, $W=W_o$, $H=H_o$

D. $L<L_o$, $W<W_o$, $H<H_o$ Answer: _____ [1 mark]

1b) Carefully explain why you selected your answer.

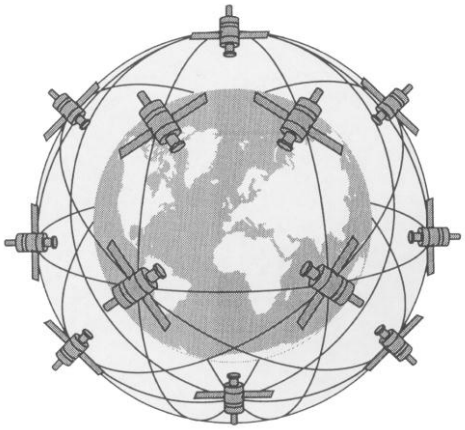
[3 marks]

2. [3 Marks]
Global positioning systems (GPS) are used to measure distances on Earth.

To provide accurate and reliable information, clocks on GPS satellites must be accurate to within 20 to 30 nanoseconds per day.

Relativity theories indicate that clocks on GPS satellites will run faster than clocks on the Earth by about 446 picoseconds per second.

If this error were not taken into account, calculate the distance error per second the GPS radio signal would produce.



[3 marks]

3. [3 Marks]
An aurora is the appearance of brilliant coloured 'curtains' of light in the sky near the north and south poles. Carefully explain how and why this phenomena occurs.

[3 marks]

4. [5 Marks]

Towards the end of the 20th century scientists suggested that quarks were the basic building blocks of protons and neutrons. Quarks have the following properties:

- They have mass.
- They can have electromagnetic charges of +1/3, +2/3, -1/3, and -2/3
- They have colour charge.
- They have spin.

4a) Protons and Neutrons are each made up of 3 quarks. List the charges on each quark for both particles.

Proton			
Neutron			

[2 marks]

Briefly justify your answer.

[1 mark]

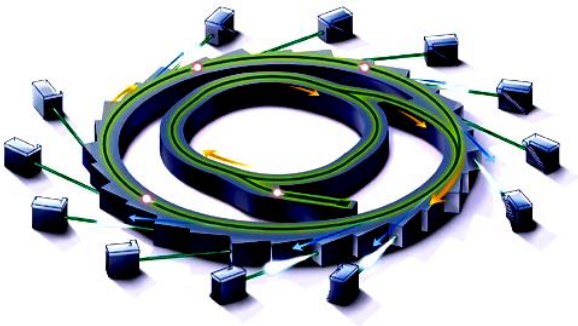
4b) Classify the following sub-atomic particles are either Hadrons, Leptons or Neither.

Proton		Neutrino	
Muon		Photon	

[2 marks]

5. [3 Marks]

Consider an electron, travelling at 99.999 998 55% of the speed of light through the storage ring of the Australian Synchrotron facility. Given that the electron is travelling perpendicular to a uniform magnetic field of strength 1.5 T, calculate the expected radius of its bending path through this section (ignoring the effects of relativity).



[3 marks]

6. [3 Marks]

Briefly describe the primary purpose of each of the following particle accelerators:

Particle Accelerator	Location	Primary Purpose
Mass Spectrometer	Laboratories	
Large Hadron Collider	Cern	
Australian Synchrotron	Melbourne	

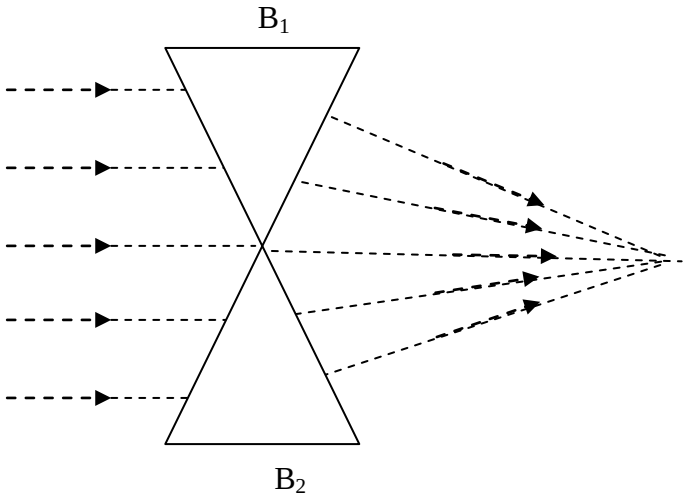
[3 marks]

7. [3 Marks]

An electron microscope uses a "magnetic lens" to focus a wide beam of electrons to a point as shown in the diagram. Assume that all electrons have the same speed.

7a) Illustrate the directions of the magnetic fields B_1 and B_2 on the diagram provided.

[1 mark]



7b) Calculate the deflecting force on electrons travelling with a velocity of 1.50×10^6 ms^{-1} if the magnetic field strength is 0.100 T.

[2 marks]

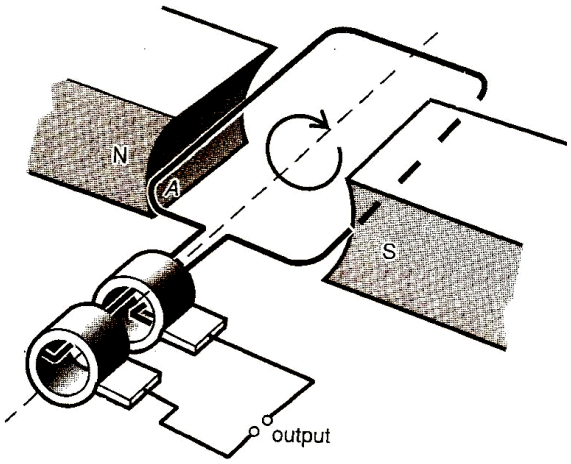
8. [8 Marks]

A simple single-phase generator has a coil of 200 turns.

The coil is 14 cm long and 9 cm wide.

The magnetic field in the generator is 0.15 T.

The generator coil is rotated at a rate of 3000 revolutions per minute.



8a) What type of generator (AC or DC) is shown? Justify your answer.

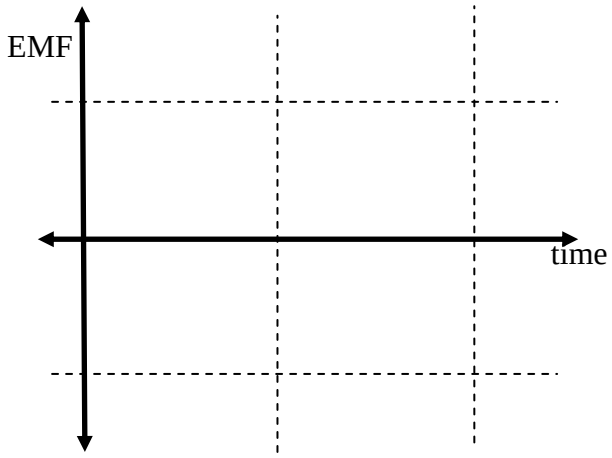
[1 mark]

8b) Determine the Emf produced by this generator.

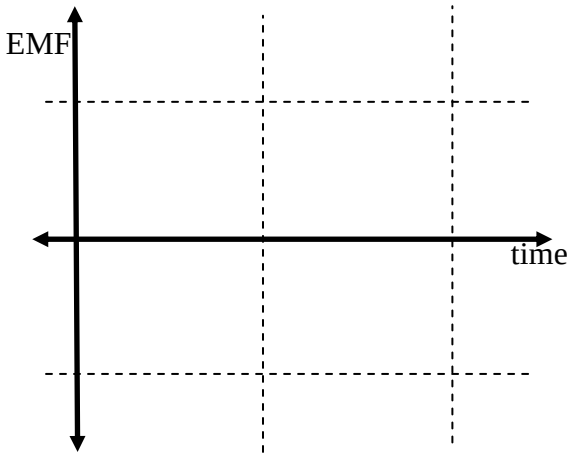
[3 marks]

8c) On the following axes, draw a graph of the Emf generated by this device at i) 3000 rpm and at ii) 6000 rpm. Mark a scale on each of the axes.

i) 3000 rpm



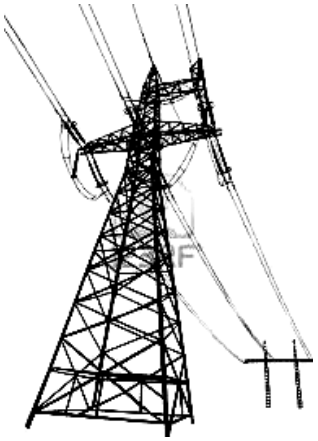
ii) 6000 rpm



[4 marks]

9. [3 Marks]

Briefly explain why our electrical energy is an AC supply that is transmitted at very high voltages between the power stations and the cities where it is used.

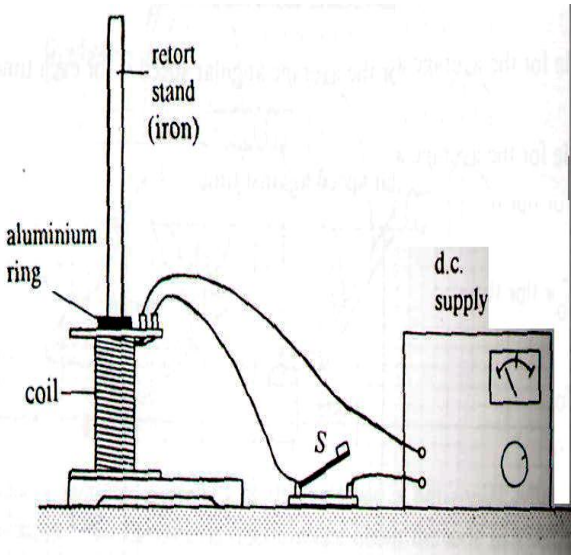


[3 marks]

10. [4 Marks]

Carefully describe what you would observe when the switch (S) is closed.

Explain in detail what is happening.

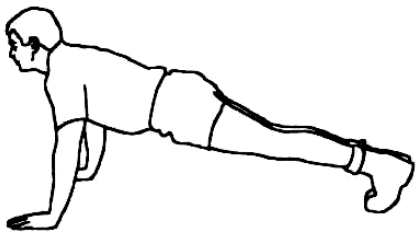


[4 marks]

11. [4 Marks]
A free body diagram shows all the forces exerted on a body and how they relate to each other and the resultant force on the body. Construct a clearly labelled free body diagram of an athlete running around a bend.

[4 marks]

12. [4 Marks]
Estimate the force that is exerted on each arm when you execute a perfect push-up. You must provide all the relevant data and state all reasonable assumptions in determining your answer. (show all working details)

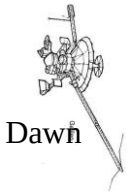


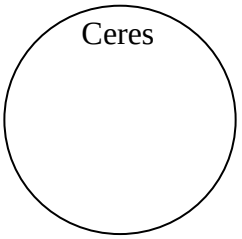
[4 marks]

13. [4 Marks]

The spacecraft "Dawn" was launched on 27 September 2007 and will reach the dwarf planet (asteroid) Ceres in 2015. Ceres has a mass of 9.40 x 10^{20} kg, radius of 480 km and rotates with a period of 9.07 hours.

13a) At what altitude above the surface would the spacecraft need to orbit in order to remain in a fixed position relative to the planet's surface?





[4 marks]

13b) Would this orbit be considered to be "geostationary"? Explain.

[2marks]

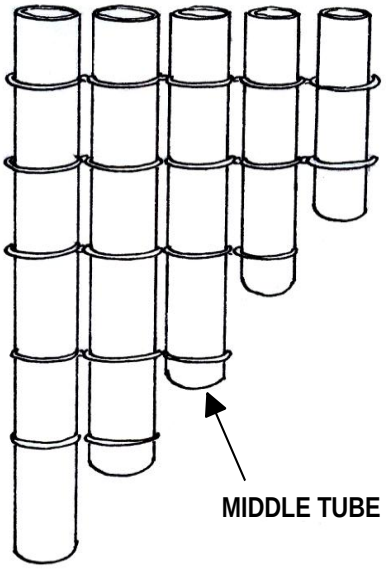
End of Section A

1. [14 Marks]

A crude musical instrument can be made by tying several lengths of hollow metal tube together as shown in the diagram below.

When a performer gently blows across the tops of the tubes, musical notes are produced.

For all parts of this question assume the performer blows with the same strength.



1a) If all the tubes are of equal diameter, which tube would you expect to produce the note with the highest fundamental frequency? Explain your answer.

[2 marks]

1b) If the fundamental resonant frequency of the middle tube is 440 Hz and the speed of sound in the tube is 346 m s^{-1}, calculate the length of the tube.

[2 marks]

1c) If the performer blocked the bottom end of the middle tube would you expect it to produce the same fundamental note as the open tube? Explain your answer.

[3 marks]

1d) Determine the fundamental frequency of the note produced by the middle tube when it is closed at one end.

[2 marks]

1e) If the diameter of all the tubes was increased, but the lengths remained the same, how would this affect the characteristics of the notes played?

[2 marks]

1f) The instrument relies upon standing waves being set up in the tubes. State the conditions that need to exist for standing waves to be produced in an air column.

[3 marks]

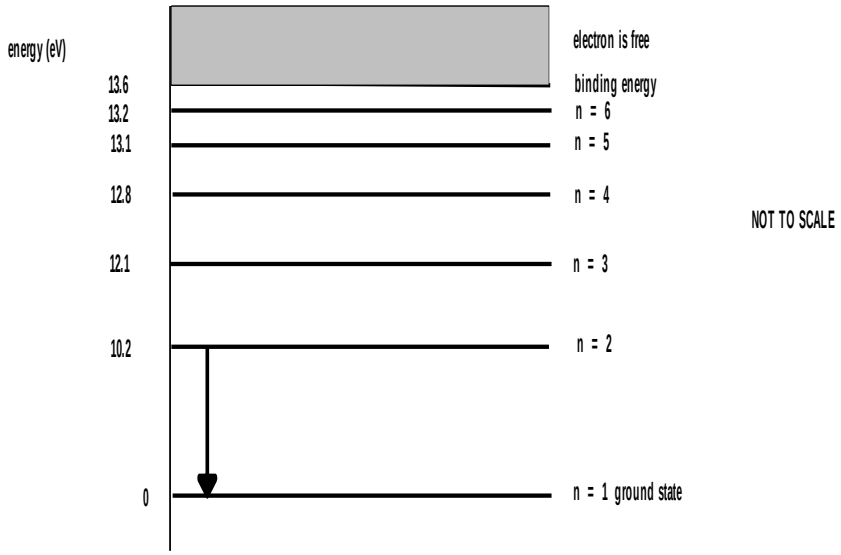
2. [15 Marks]

The emission spectra from excited hydrogen gas contain three distinct lines of wavelength 431.1 nm, 486.1 nm and 656.3 nm respectively.

2a) In which region of the electromagnetic spectrum do the three spectral lines appear?

[1 mark]

The diagram provided is an energy level diagram for the hydrogen atom.



2b) Calculate the amount of energy, in joules required to ionise an electron from the ground state.

[2 marks]

2c) Determine the shortest wavelength of photon that can be emitted when hydrogen atoms are excited by 13.0 eV bombarding electrons.

[3 marks]

2d) Determine how many distinct lines would be present in the emission spectrum produced when hydrogen atoms are excited by 13.0 eV bombarding electrons.

[1 mark]

2e) Determine the shortest wavelength of photon that can be absorbed when 13.0 eV photons are incident on hydrogen atoms. Explain your answer.

[2 marks]

The emission spectrum of light from the Sun is continuous with colours ranging from red to violet. Some black lines can be seen amongst the coloured spectrum.

2f) What is the name given to this type of spectrum?

[1 mark]

2g) What is the name given to these characteristic black lines observed in Solar spectra?

[1 mark]

2h) Explain why these dark lines are present in a Solar spectrum.

[2 marks]

2i) Would you expect to see similar black lines on a continuous emission spectrum produced by light from an incandescent globe? Explain your answer.

[2 marks]

3. [15 Marks]

In 1928 George Thompson conducted an experiment firing electrons at aluminium foil. X rays and electrons passing through the foil were diffracted. The X ray photons had a frequency of 3.59×10^{17} Hz and the power of the X ray source was 15.0 kW

3a) Calculate the energy of the X ray photons.

[2 marks]

3b) If the electrons were to have the same energy as the X rays used in this experiment, at what speed would they need to travel?

[3 marks]

3c) Using your answer to part (3b) above, would the speed of the electrons be considered as a relativistic speed? Why or why not?

[2 marks]

3d) Calculate how many photons leave the X ray source each second.

[3 marks]

3e) When electrons pass through aluminium foil they are also diffracted and form similar patterns to X ray diffraction patterns. Why would you expect the diffraction patterns of electrons and X rays to be similar?

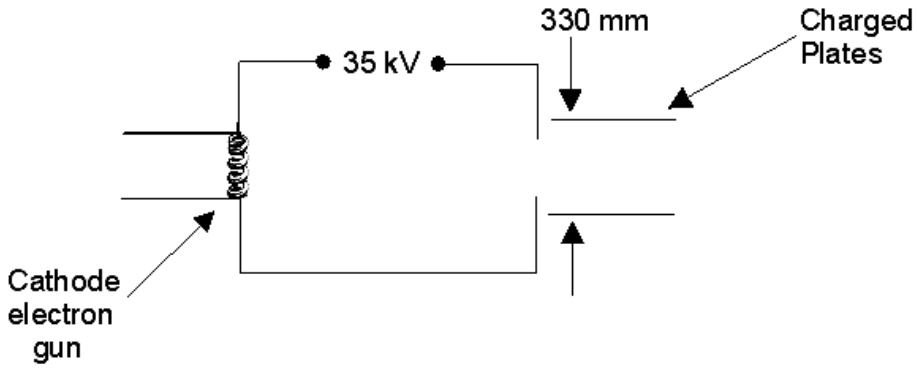
[1 mark]

3f) Sketch a simple labelled diagram of a typical X-ray tube and briefly describe how X-rays can be produced.

[4 marks]

4. [15 Marks]

An apparatus used for identifying minerals in mining samples involves releasing electrons from a cathode electron gun and accelerating them across a potential difference and through a pair of parallel charged plates and then impacting with the sample. The electrons are accelerated through a potential of 35 kV, and through a distance of 330 mm between the charged plates.



4a) Calculate the strength of the electric field between the charged plates.

[2 marks]

4b) Calculate the magnitude of the velocity of the electrons as they exit the electron gun.

[3 marks]

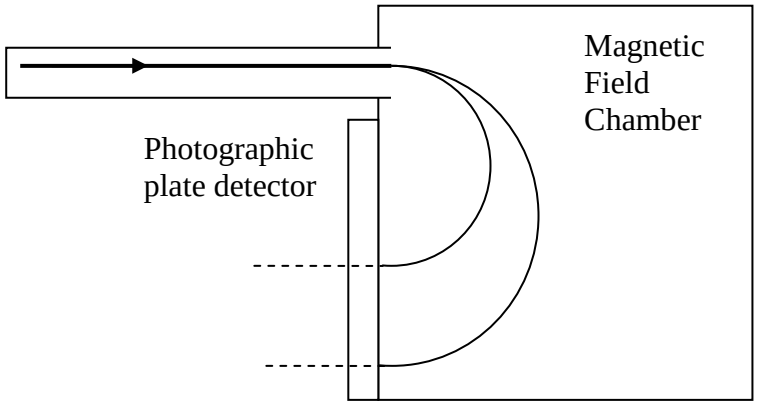
4c) After leaving the electron gun assembly, the electrons travel through a uniform magnetic field which is perpendicular to their direction of motion. If the magnetic field strength is 0.300T, through what radius will the electrons be deviated?

[4 marks]

Another useful analytical device utilising a particle accelerator is the mass spectrometer.

Carbon atoms of atomic mass 12.0 u are found to be mixed with another, unknown element. In a mass spectrometer, a sample of the mixture is first ionised to a single positive charge ($+1.60 \times 10^{-19}$ C), accelerated to a high velocity and then separated by a uniform magnetic field as shown in the diagram below:

It is found that the Carbon and the unknown element traverse paths of diameter 44.8 cm and 52.4 cm respectively.



4d) Illustrate the direction of the magnetic field. (on the diagram) [1 mark]

4e) Determine the mass and the likely identity of the unknown element.

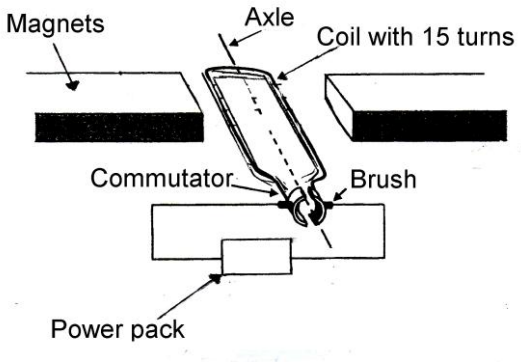
[5 marks]

5. [15 Marks]

Using an electric motor kit a student assembles a model motor.
In the kit are the following components:

- A 15 turn rectangular coil 5.0 cm x 3.0 cm
- mounted on an axle
- A pair of magnets
- A pair of brushes
- A commutator
- Electrical leads
- Power (pack) Supply

The diagram shows the assembled motor.



When assembled and tested it was found that a current of 1.5 A was required to turn the coil in a magnetic field of 1.0×10^{-3} T.

5a) Calculate the force exerted on the 5.0 cm side and also on the 3.0 cm side of the coil.

[3 marks]

5b) What additional measurement would the student need to make if he wanted to calculate the torque of the motor in the horizontal position?

[1 mark]

5c) In which position (vertical or horizontal) will the coil experience maximum torque? Carefully justify your answer.

[2 marks]

5d) Calculate the maximum torque of the motor.

[3 marks]

5f) List four practical ways in which the motor could be modified so the maximum torque could increased.

[2 marks]

5g) Motors can be used as generators if they are modified in a certain way. How could this motor be converted into a generator?

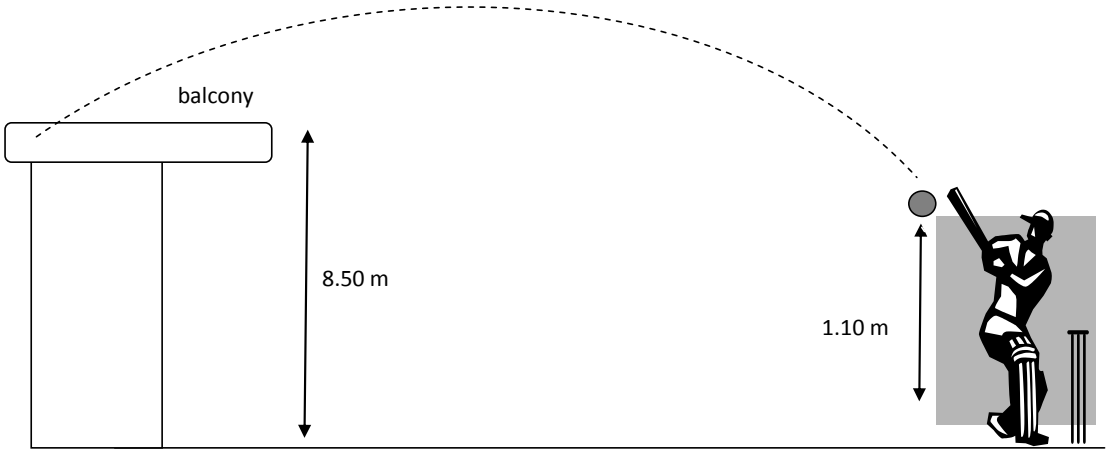
[2 marks]

5h) If the motor was modified and converted into a generator, would the generator produce AC or DC current? Justify your answer.

[2 marks]

6. [13 Marks]

During a cricket match a cricket ball is hit with an initial velocity of 45.0 m s^{-1} at an angle of 30.0^o to the horizontal from a height of 1.10 m above the ground. It lands in the spectators' balcony which is 8.50 m above the ground.



6a) Calculate the horizontal and vertical components of the cricket ball's initial velocity.

[2 marks]

6b) Determine the final vertical displacement of the ball.

[1 mark]

6c) Calculate the vertical velocity component of the ball when it lands in the spectators' balcony.

[3 marks]

6d) Calculate the time of flight of the ball.

[2 marks]

6e) Calculate the horizontal distance between the batsman and the point where the ball landed on the spectators' balcony. If unable to complete (d) use the value of 4.10 s for time of flight for this question.

[3 marks]

6f) Calculate the maximum height the ball achieved relative to the ground.

[2 marks]

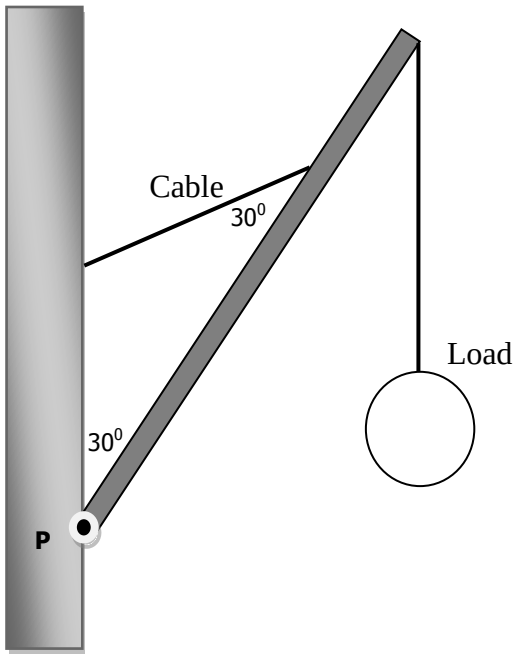
7. [9 marks]

A rod and tie arrangement with load, L, is shown in the diagram.

The rod is 10.0 m long and is attached to the wall at the hinge P.
The mass of the rod is 1.00×10^3 kg.

The tie is a light flexible cable attached 3.00 m from the end of the rod.

The load has a mass of 3.00×10^3 kg and is attached to the rod by a light wire.



7a) Find the tension, T, in the cable.

[5 marks]

7b) Find the reaction, R, which the hinge exerts on the rod.

[4 marks]

SECTION C : Comprehension and Interpretation

1. [18 marks]

Hubble's Law

When the source of a wave moves, the waves it emits change frequency relative to a stationary observer. This applies to both transverse and longitudinal (sound) waves. As a car moves away from you the frequency of the sound you hear is lower than the frequency it is emitting. A similar effect using radar waves is used by police to measure the speed of cars.

Thus if a source of electromagnetic waves such as a star is moving away from an observer on Earth then the frequencies of the lines in the star's emitted electromagnetic spectrum are shifted to lower values. This is known as red shift.

In 1920, Edwin Hubble measured the red shifts of several galaxies and discovered that most galaxies are moving away from the Earth, suggesting that the Universe is expanding. Hubble also found that the further away a galaxy is, the larger its red shift; that is, the faster it is moving.

The following data together with the associated errors were recorded by Hubble at Mount Wilson in California in the 1940s using an optical telescope.

Object name	**Speed of recession ($\times 10^4$ km s^{-1})**	**Distance ($\times 10^6$ light years)**
Virgo	0.2 ± 0.1	10.2
Corona Borealis	2.4 ± 0.2	400
Hydra	6.2 ± 0.3	1100
Kip	4.8 ± 0.2	900

Hubble's Law can be stated as $v_{galaxy} = (H_o)(\text{distance})$
where the term H_o is called Hubble's constant.

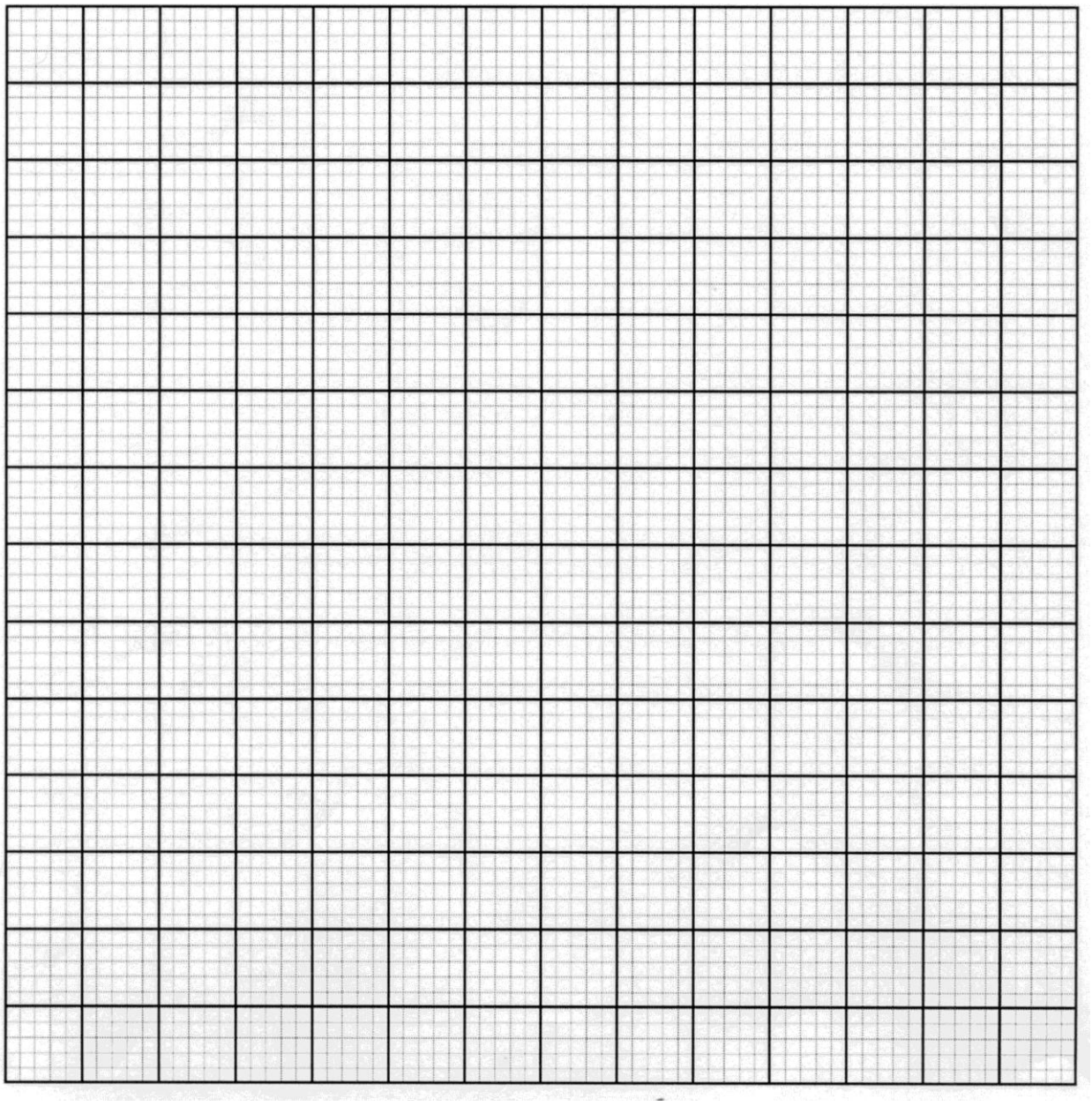
The shift in wavelength $\Delta\lambda$ due to recession of a spectral line of wavelength λ is given by the formula:

$$v_{galaxy} = \left(\frac{\Delta\lambda}{\lambda}\right)c$$

where c is the speed of light, 3×10^8 m $s^{-1.}$

QUESTIONS:

1a) Graph these data on the graph paper provided below, including error bars.
Plot recession speed (*y*-axis) against distance (*x*-axis) and draw a line of best fit.



[5 marks]

1b) **Use the graph** to predict the recession speed of a galaxy that is 710×10^6 light years from Earth.

[2 marks]

1c) **Use your graph** to calculate a value for H_o.
You must convert to the correct units of kms^{-1} Mpc. [Note: 1 pc = 3.26 ly]

[4marks]

1d) A line in the spectrum of ionised calcium has wavelength 393.3 nm when measured in the laboratory. When similar light from the elliptical galaxy NGC 4889 is measured its wavelength is 401.8 nm. Determine the recession speed of this galaxy.

[3marks]

1e) Edwin Hubble could estimate the age of the Universe from his data by calculating the time for which one of the galaxies has been receding. Determine Hubble's value for the age of the Universe by using the data for Corona Borealis.

[4marks]

2. [17 marks]

The Doppler Effect

Para 1

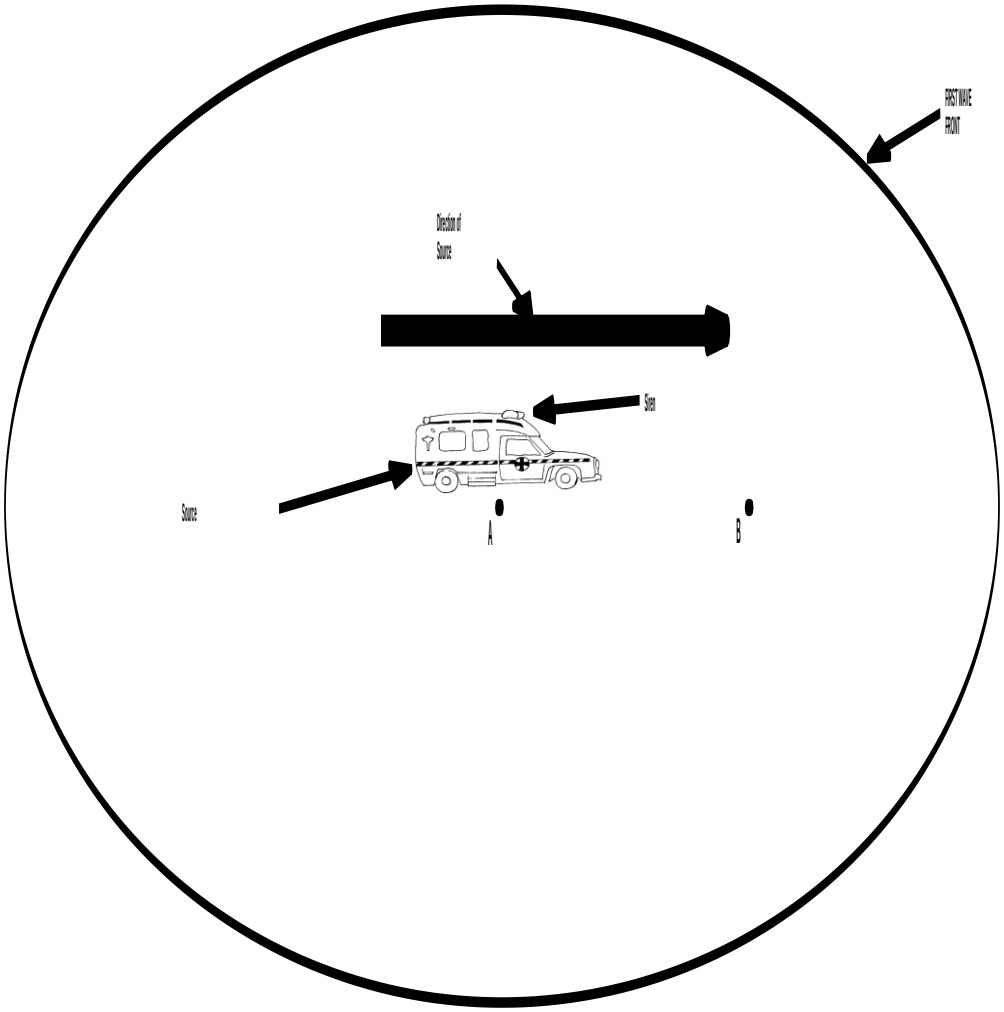
When a source of waves, whether light, sound or any other, is moving towards an observer, the wavelength detected by the observer will appear to be different to the actual wavelength emitted by the source. This is because each wave is emitted a little closer to the observer than the previous one and is not so far behind the previous wave as it would be if the source was stationary. The reverse is the case if the source is moving away from the observer.

Para 2

In the particular case of sound waves, a stationary observer hears a change in the pitch of a sound that is being emitted by a moving source. For instance if a speeding ambulance emitted a high pitched sound, then as it approached the observer he would hear a variation in pitch. As the ambulance passed and sped away the observer would also hear a change in pitch.

Para 3

The diagram below shows a source of sound moving to the right with a speed of **u.** The outer circle represents a sound wave front, which was emitted when the source was at position A. The period of this wave front is **T**, the velocity is **v** and wavelength is λ.



Para 4
When the source has moved to position B, a second wave front is emitted. This now means that the distance between the wave fronts in the forward direction and those in the reverse direction are different. These distances are the wavelengths as perceived by observers to the front and rear, respectively.

Para 5
When light waves are emitted by moving sources such as galaxies, astronomers are interested in the apparent change in wavelength $\Delta\lambda$. The wavelength change is known as redshift or blueshift depending on whether the source is moving away from or towards the observer.

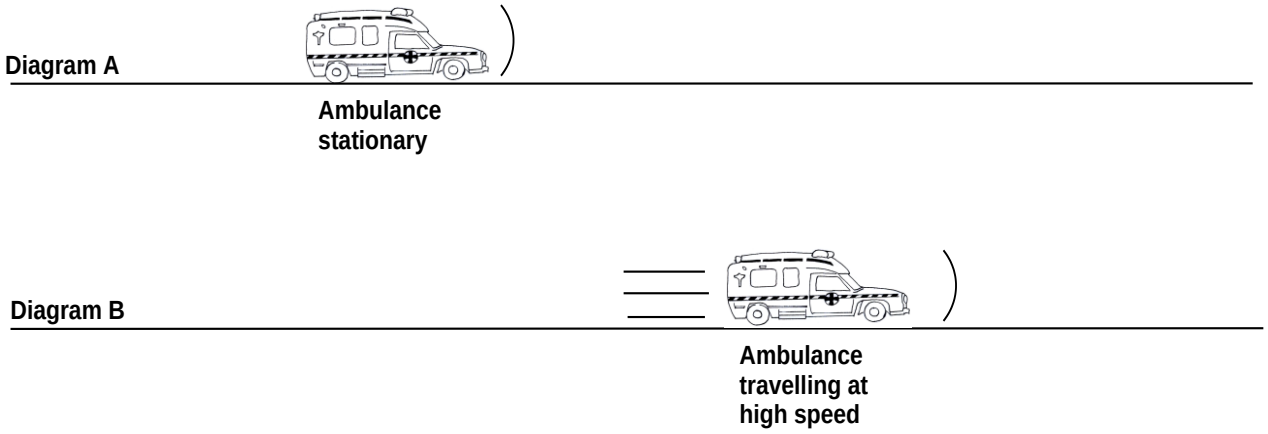
Questions

2a) Upon what property of sound waves does pitch depend?

[1 mark]

2b) In the diagrams below, the ambulance's siren is emitting a **constant** frequency.

Complete the diagrams by carefully drawing wave fronts to the front and rear of the ambulance. Note that in diagram A, the ambulance is stationary and in diagram B it is travelling to the right at high speed.



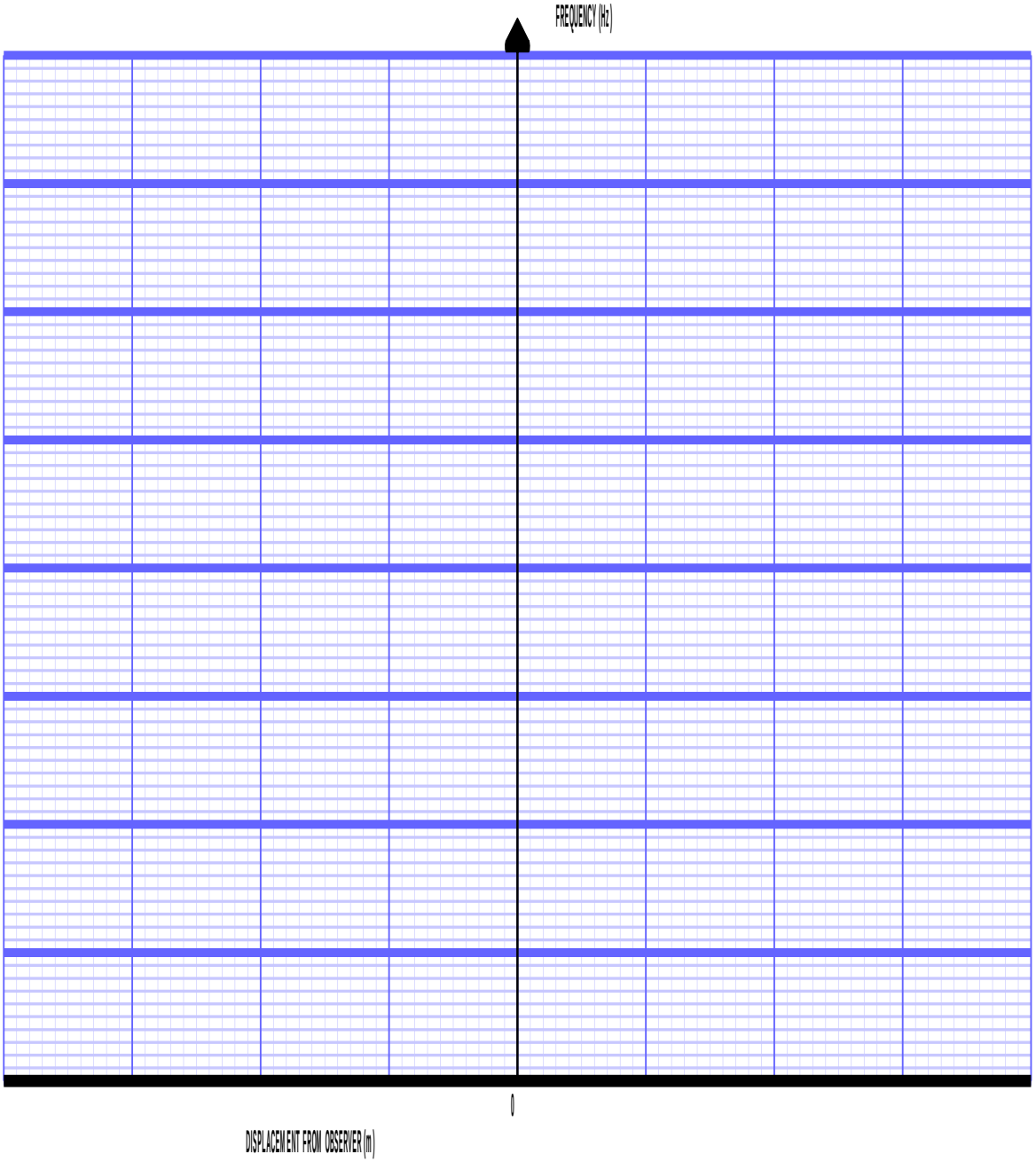
[4 marks]

2c) Does the actual pitch of a sound emitted by the ambulance, change as it approaches and passes an observer? Explain your answer.

[2 marks]

2d) A stationary observer hears the siren of an emergency vehicle as it approaches, passes and travels onwards. The siren is emitting a sound of constant pitch of 330 Hz.

On the grid below, sketch a graph to show the variation in frequency as experienced by the observer as the vehicle approaches, passes and travels onwards.



[2 marks]

2e) Write a mathematical formula which includes **λ, T** and **v** that could be used to calculate the wavelength of the wave front described in paragraph 3.

[1 mark]

2f) In terms of **u** and **T** how far has the source moved between emitting the first and second wave fronts?

[1 mark]

2g) Write a mathematical expression involving **v**, **u** and **T** that represent the following:

i The distance between wave fronts in the forward direction.

[1 mark]

ii The distance between wave fronts in the backward direction.

[1 mark]

2h) (paragraph 5) What is the meaning of the term "redshift"?

[2 marks]

2i) (paragraph 5) What is the meaning of the term "blueshift"?

[2 marks]

2j) If an observer travelled at speed towards a stationary siren that was emitting a single frequency, would he experience the Doppler Effect? Explain your answer.

[2 marks]

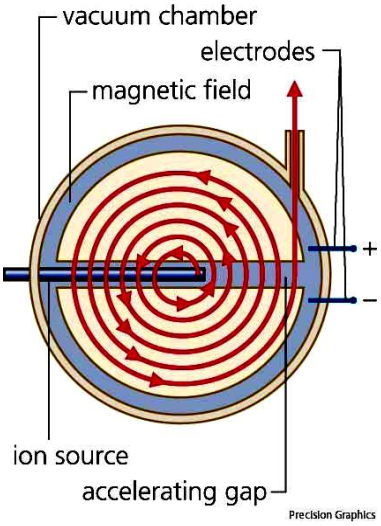
Spare [5 Marks]

A cyclotron accelerates small charged particles in a circular path to very high speeds. It then releases them to strike a target and make radio-isotopes.

The cyclotron shown accelerates protons that start at its centre.

These travel in a circular path due to two magnetic fields in two semi circles called "dees".

An alternating electric field in the gap between the dees accelerates the protons to higher velocities.



7a) Illustrate the direction of the magnetic field provided by the dees that would result in the path shown.

[1 mark]

7b) Given a magnetic field strength of 1.55 T, and a maximum radius of 40.5 cm for the path of the accelerated proton, determine the exit velocity.

[4 marks]