The following pages offer suggested solutions to the
2013 SACE Stage 2 Physics final examination.
These solutions are not the official set
of solutions used by the examiners of the SACE Board.

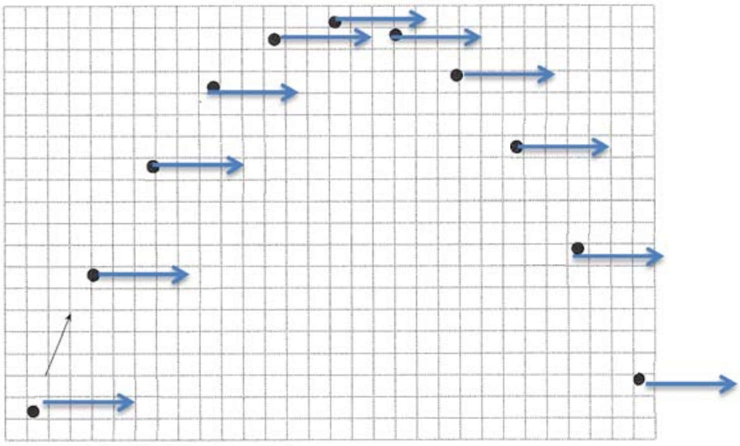
SECTION A

PART 1 (Questions 1 to 17)

(77 marks)

*Answer **all** questions in this part in the spaces provided.*

1. The multi-image diagram below shows the path of a projectile. The time between images was constant.



Using the multi-image diagram, show that the projectile did not undergo any horizontal acceleration.

The vector arrows depicting the horizontal displacement between consecutive images are the same length (see diagram) and therefore constant.
By definition the horizontal velocity is constant as velocity is defined as the displacement per unit time.

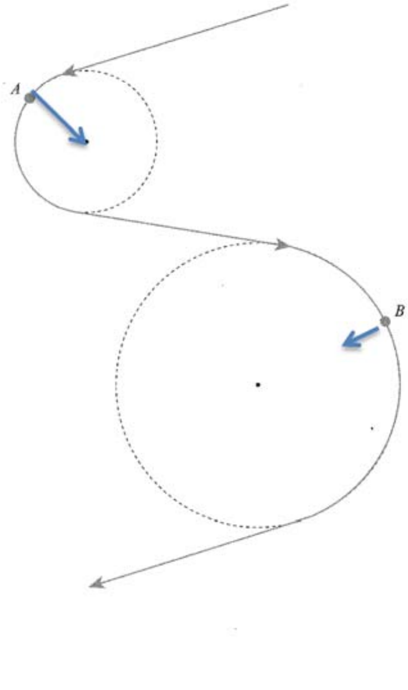
(3 marks)

Commented [IT1]: HINT
The arrows must be marked on the diagram to support this statement.

2.

Source: © iStockphoto.com/amriphoto

The path taken by a skier (as in the photograph above) is shown in the diagram below. The path includes two sections where the skier moves with uniform circular motion.



Point A in the diagram on page 6 is on a circular section with a radius of $20\,\mathrm{m}$, and point B is on a circular section with a radius of $40\,\mathrm{m}$.

The skier travels on all sections of the path at a constant speed of $18\,\mathrm{m\,s^{-1}}$.

(a) Determine the magnitude of the ratio $\dfrac{\text{centripetal acceleration at } A}{\text{centripetal acceleration at } B}$.

$$\frac{a_A}{a_B} = \frac{\frac{v^2}{r_A}}{\frac{v^2}{r_B}} = \frac{v^2}{r_A} x \frac{r_B}{v^2} = \frac{40}{20} = 2$$

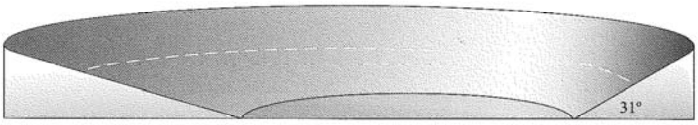
(3 marks)

Commented [IT2]: HINT
The speed is constant (18 ms^{-1}) at points A and B and therefore cancels out.

(b) *On the diagram on page 6*, draw vectors to show the *magnitude* and *direction* of the force causing the centripetal acceleration of the skier at points A and B. (2 marks)

Commented [IT3]: HINT
The arrows must point towards the centre of the circular path and the length of the arrow at A must be drawn twice as long as the arrow drawn at B as twice the acceleration is experienced (see part (a)).

3. The curves in a circular car-racing track are banked at different angles, as shown in the diagram below. The steepest curve is banked at 31°. The track has a constant radius of 150 m.



(a) Determine the speed at which a car can travel around the curve banked at 31° without relying on friction.

$$Tan\theta = \frac{v^2}{rg} \qquad v = \sqrt{rg\tan\theta} = \sqrt{150x9.8x\tan 31} = 27.9 = 30 \quad ms^{-1}$$

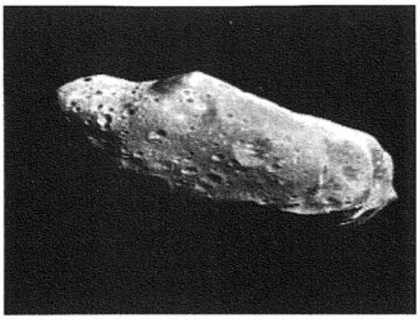
(3 marks)

(b) State why the car should be able to travel at the same speed on the entire track, despite the lower banking angles of some curves.

At sections along the track where the banking angle is less than that calculated in part (a), friction between the tyres of the racing car and the road provides the necessary additional centripetal acceleration for uniform circular motion.

(1 mark)

4. On 15 February 2013 the asteroid 2012 DA14 passed closer to the Earth than geostationary satellites. This was the closest an asteroid of this size had come to the Earth since regular sky surveys started. The asteroid had a mass of approximately 1.3×10^{8} kg.



Source: http://lupuvictor.blogspot.com.au

(a) Calculate the magnitude of the gravitational force that the Earth exerted on the asteroid when it was 2.8×10^{7} m from the centre of the Earth. The mass of the Earth is 6.0×10^{24} kg.

$$F = \frac{Gm_1m_2}{r^2} = \frac{6.67x10^{-11}x1.3x10^{8}x6x10^{24}}{(2.8x10^{7})^2} = 6.6x10^{7} \quad N$$

(2 marks)

(b) *On the diagram below*, draw vectors to show the *magnitude* and *direction* of the gravitational forces that the Earth and the asteroid exerted on each other.

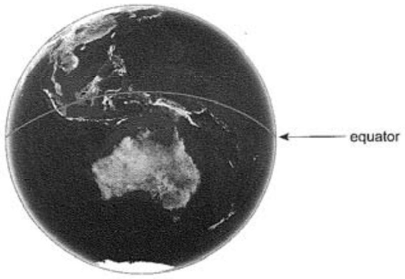
Source: © Cloki/Dreamstime.com

(2 marks)

Commented [IT4]: HINT
Direction is not required as only the magnitude is required.

Commented [IT5]: HINT
The gravitational force acts along the line joining the centres of the two objects.
Gravitational forces are consistent with Newton's third law and should be drawn the same length.

5. Some geostationary satellites are used for communications. A geostationary satellite cannot be in an orbit directly above Australia.



Source: © Cloki/Dreamstime.com

(a) Explain why a geostationary satellite cannot be in an orbit directly above Australia.

If the satellite were to move directly over Australia, the centre of its orbit would not coincide with the centre of the Earth.

The satellite's orbit wouldn't be stable because the gravitational force must act towards the centre of the Earth and toward the centre of the orbit in order to provide the centripetal acceleration for uniform circular motion.

(3 marks)

(b) (i) Derive the formula for the speed of a satellite moving in a circular orbit of radius r around the Earth:

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

The gravitational force provides the centripetal acceleration for uniform circular motion.

$$F = \frac{mv^2}{r} = \frac{GmM}{r^2} \quad \text{where } m \text{ is the mass of the satellite}$$

$$\text{and } M \text{ is the mass of the Earth}$$

$$v^2 = \frac{GM}{r} \qquad \therefore \quad v = \sqrt{\frac{GM}{r}}$$

(3 marks)

(ii) A satellite is in a geostationary orbit of radius 4.2×10^7 m.
Calculate the speed of the satellite. The mass of the Earth is 6.0×10^{24} kg.

$$v = \sqrt{\frac{GM}{r}} = \sqrt{\frac{6.67x10^{-11} x6x10^{24}}{4.2x10^7}} = 3.1x10^3 \quad ms^{-1}$$

(2 marks)

(c) Many communication satellites remain in geostationary orbits after they have served their purpose, occupying positions that new satellites could hold. Scientists have proposed attaching solar sails to these satellites to accelerate them to move them out of their orbits.

Explain how the reflection of photons can be used to accelerate a satellite with a solar sail attached.

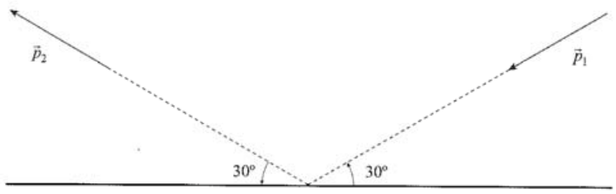
When photons are reflected from a solar sail they experience a change in direction and hence a change in momentum (even though the magnitude of the momentum does not change). This is because momentum is a vector quantity.

The solar sail therefore exerts a force on the photons ($\vec{F} = \frac{\Delta \vec{p}}{\Delta t}$).

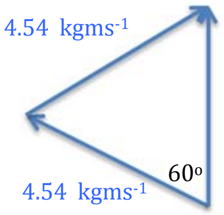
By Newton's third law, the photons exert an equal and opposite force on the solar sail. This will accelerate the solar sail and hence the satellite ($a = \frac{F}{m}$).

(3 marks)

6. A ball is bounced off flat ground. The initial momentum of the ball has a magnitude of $4.54\ \text{kg m s}^{-1}$, with the momentum vector making an angle of $30°$ to the ground. After leaving the ground, the ball travels at the same speed as before it hit the ground. The diagram below shows the momentum vectors of the ball, $\vec{p}_1$ and $\vec{p}_2$, immediately before and after it hit the ground:



Using a vector diagram, calculate the change in momentum $\Delta\vec{p}$ of the ball.



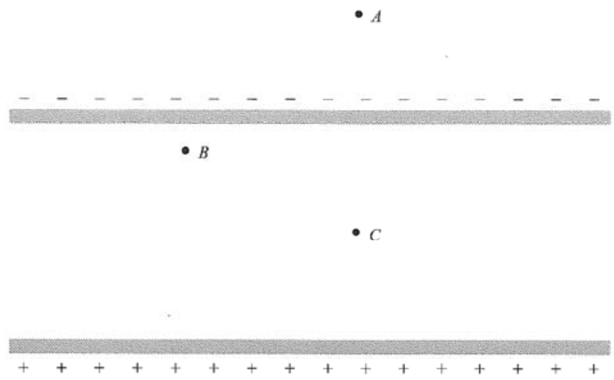
As can be seen by the vector triangle above, $\Delta\vec{p}_{ball}$ is directed 90^{o} away from the wall .

The triangle is equilateral, therefore $\Delta\vec{p}_{ball} = 4.54\ \text{kgms}^{-1}$

Commented [IT6]: Comment
sN can be used for the units of momentum

(4 marks)

7. The diagram below shows a section of two very long, oppositely charged parallel conducting plates:



Compare the magnitude of the electric field produced by the conducting plates at points *A*, *B*, and *C*. Give reasons for your answer.

The magnitude of the electric field at points B and C is the same because the electric field between parallel conducting plates is uniform.

The magnitude of the electric field at point A is zero (due to the principle of superposition).

(3 marks)

8. The diagram below shows two small charged conducting spheres q_1 and q_2, with a line through their centres. Sphere q_1 has a positive charge of $4.0\,\mu C$ and sphere q_2 has a positive charge of $2.5\,\mu C$. The distance between the centres of the spheres is 0.015 m.

(a) Calculate the electrostatic force that q_1 exerts on q_2.

$$\vec{F}_1 = \frac{1}{4\pi\varepsilon_0}\frac{q_1 q_2}{r^2} = \frac{9x10^9 x4x10^{-6} x2.5x10^{-6}}{0.015^2} = 400\ N \quad away\ \ from\ \ q_1$$

(3 marks)

Commented [IT7]:
HINT
SI units of charge are required.
To convert μC to C x10[-6]

Direction: The spheres are both positively charged. It follows that q_1 repels q_2.

(b) Sphere q_3 has a negative charge. It is to be placed on the line through the centres of q_1 and q_2 so that the total force on sphere q_2 is zero.

Explain why sphere q_3 must be placed to the left of sphere q_2.

The force on q_2 due to q_1 acts to the right.

The force on q_2 due to q_3 must therefore have the same magnitude but act to the left in order for the two forces on q_2 to cancel to zero.

This can only occur if q_3 is placed to the left of q_2.

(2 marks)

9. The photograph below shows a laser printer:

Source: © iStockphoto.com/by_nicholas

A corona wire transfers a negative charge to the paper so that it does not cling to the photoconductive surface of the drum of the laser printer.

Explain how a negative charge is transferred to the paper.

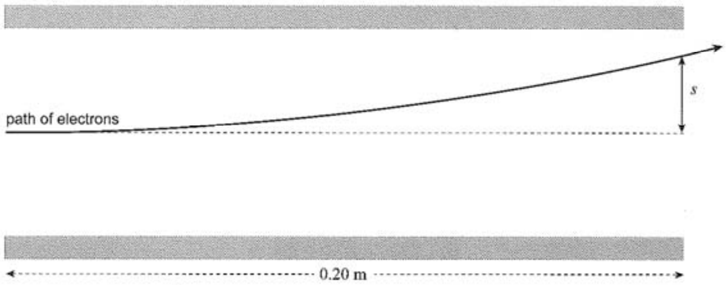
The corona wire acts as a sharp point (negatively charged) and has a strong electric field.

It is positioned under the path of the paper and runs along the length of the paper.

The strong field causes charges (negative) in the air between the wire and the paper to be repelled towards the paper.

(2 marks)

10. There is an electric field between two equally and oppositely charged parallel metal plates 0.20 m in length. Electrons enter the electric field midway between the plates, at a speed of 3.7×10^{7} m s^{-1}. The path of the electrons is shown in the diagram below:



Assume the electric field is uniform between the plates, and ignore the effect of gravity.

The electric field between the parallel plates causes the electrons to accelerate at 1.1×10^{15} m s^{-2}.

(a) Show that the time of flight of the electrons through the electric field between the parallel plates is 5.4×10^{-9} s.

$$v_H = \frac{s_H}{t} \Rightarrow t = \frac{s_H}{v_H} = \frac{0.2}{3.7x10^{7}} = 5.4x10^{-9} \quad s$$

(1 mark)

(b) Calculate the vertical displacement s of the electrons as they leave the electric field.

$$s = \frac{1}{2}at^2 \Rightarrow s = \frac{1}{2}x1.1x10^{15}x(5.4x10^{-9})^2 = 0.016 \quad m$$

(2 marks)

Commented [IT8]: HINT
A parabolic path is traced and the horizontal component of velocity remains constant.

Commented [IT9]: HINT
In the vertical direction, the electrons experience a constant acceleration.

(c) State how the vertical displacement s of the electrons would change if the distance between the parallel plates was increased, with the potential difference between the plates unchanged. Justify your answer.

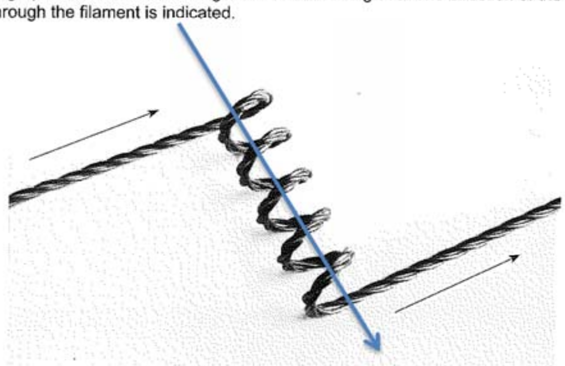
Since $E = \frac{\Delta V}{d}$, then increasing d, the distance between the plates with the same potential difference will decrease the electric field.

Since $a = \frac{Eq}{m}$, then decreasing E will decrease the acceleration a, because q and m are constant.

The vertical displacement will therefore be smaller.

(3 marks)

11. The photograph below shows the tungsten filament for a globe. The direction of the current flowing through the filament is indicated.



Source: http://image.made-in-china.com

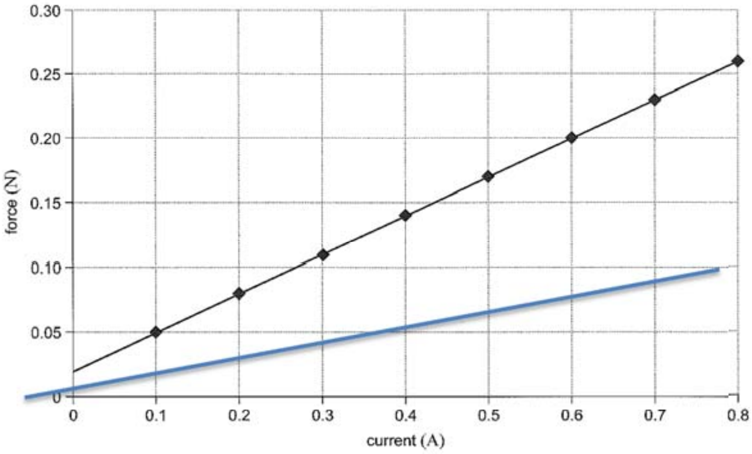
On the photograph above, show the direction of the magnetic field in the coil. (1 mark)

Commented [IT10]: HINT
The right hand rule is used to determine the direction of the magnetic field within the coil.

12. A group of students conducted an experiment to verify the relationship $F = I\Delta lB\sin\theta$.
A current-carrying conductor of fixed length was placed in a constant magnetic field. The force acting on the conductor was measured for different currents.

The graph below shows the results obtained by the students.

The equation of the line of best fit is $F = 0.3I + 0.02$.



(a) State one conclusion that can be drawn from the results of this experiment. Give a reason for your answer.

The students have not verified the relationship because the force is not directly proportional to the current ie a straight line of best fit through the origin did not result.

(2 marks)

(b) The students repeated the experiment, using a weaker magnetic field, to obtain a second set of results. There was no other change to the apparatus.

On the graph above, draw the line of best fit that you predict for the second set of results.

(2 marks)

Commented [IT11]: COMMENT
Another possible conclusion is that since force should be directly proportional to the current, a systematic error must have occurred. Ie all values of force recorded are larger than they should be by the same value and the line of best fit therefore doesn't pass through the origin.

Commented [IT12]: HINT
From F=BI*l*sinθ, the slope represents B*l*
The slope is reduced if B is weaker and the vertical axis intercept is smaller (systematic error is likely to be reduced).

13. A cyclotron is used to increase the energy of protons by 18 MeV. The cyclotron has a magnetic field of magnitude 0.020 T, and the potential difference across the dees is 45 V.

(a) Determine the period of the circular motion of the protons as they are accelerated by the cyclotron.

$$T = \frac{2\pi m}{qB} = \frac{2\pi x 1.673 x 10^{-27}}{1.6 x 10^{-19} x 0.02} = 3.3 x 10^{-6} \quad s$$

(2 marks)

(b) Calculate the time required for the energy of the protons to increase by 18 MeV.

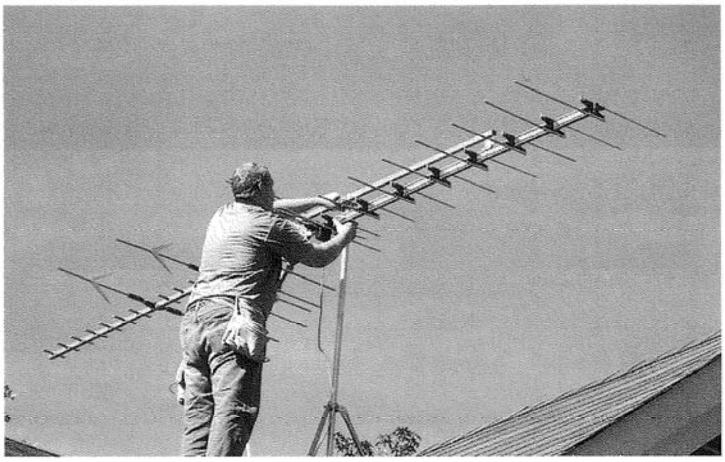
Every time the protons pass through the electric field they gain 45 eV of kinetic energy (*W*=*K*=*q*Δ*V*).

One complete rotation/circle = 90 eV

Total time = period x number of rotations=$3.2x10^{-8}$ x ($18x10^{6}$/90)=0.66 s

(3 marks)

14. The photograph below shows a television antenna being attached to the roof of a house:



Source: http://tvantennainstallations.weebly.com

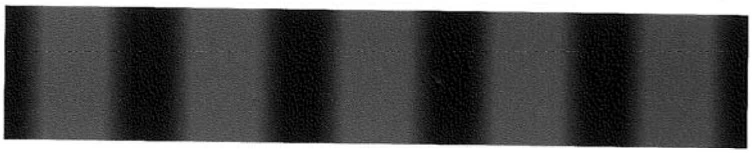
State the plane of polarisation of the electromagnetic waves received by the antenna shown above. Give a reason for your answer.

Charges in the antenna oscillate horizontally. The electric field component of the electromagnetic wave produced is therefore restricted to the horizontal plane only and therefore the plane of polarisation is in the horizontal plane.

The receiving antenna needs to be horizontal in order to receive a strong signal ie the electric field.

______________________________ (2 marks)

15. A two-slit interference pattern, such as the one shown below, can be produced in the laboratory.



(a) State and explain one characteristic of the pattern shown above that confirms that it was produced from two slits rather than from many slits.

Altenating dark and bright fringes of equal width result.

Many slits will produce bright, thin lines with large regions of darkness between them.

(2 marks)

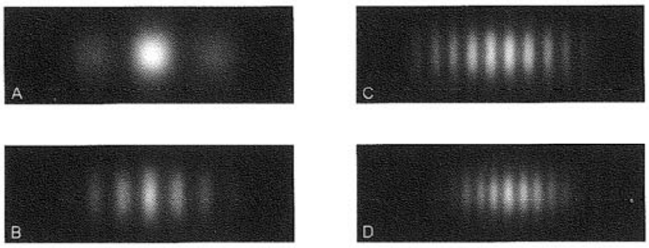
(b) Explain how the dark fringes in the pattern above are produced.

The two coherent light sources at the double slits travel different distances in reaching points on the screen. This produces a path difference.

If the light arrives out of phase (path difference of $(m+1/2)\lambda$ where m= 0, 1, 2 etc) , the light undergoes destructive interference and a dark fringe results due to the amplitudes of the incident light waves cancelling to zero.

(2 marks)

(c) Researchers in Germany have produced two-slit interference patterns, using the wave properties of electrons. The images below show four examples of these patterns:



Source: Adapted from www.quantum.physik.uni-mainz.de

The slit-to-screen distance and the wavelength of the matter waves were kept constant for all four images.

Identify the change that has caused the differences between the images. Justify your answer.

Fringe separation is given by $\Delta y = \frac{\lambda L}{d}$.

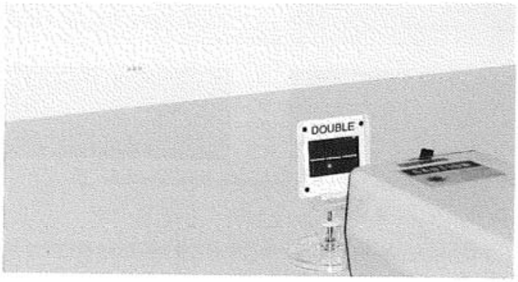
The images labeled A to D indicate that the distance between adjacent maxima (fringe separation) is decreasing.

This could only be caused by an increasing distance between the double slits *d*, because the wavelength λ and the slit-to-screen distance *L* remain constant.

(3 marks)

16. A student performs two experiments to determine the wavelength of a helium–neon laser.

(a) In the first experiment the student uses two-slit interference, as shown in the photograph below:



The distance between the slits is 6.5×10^{-5} m and the slit-to-screen distance is 0.42 m. The student measures the distance between two adjacent maxima at the centre of the interference pattern on the screen as 4.0 mm.

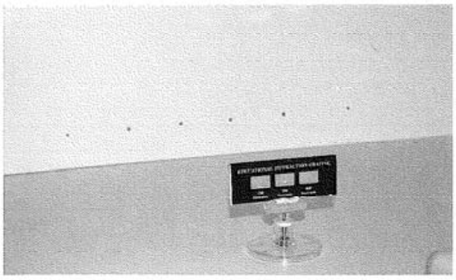
Calculate the wavelength of the laser, using the student's results.

$$\Delta y = \frac{\lambda L}{d} \quad \therefore \quad \lambda = \frac{\Delta y d}{L} = \frac{4x10^{-3} x 6.5x10^{-5}}{0.42} = 6.2x10^{-7} \ m$$

(3 marks)

Commented [IT13]: COMMON ERROR
Fringe separation must be converted from 4 mm to m (x10^{-3})

(b) In the second experiment the student uses a diffraction grating, as shown in the photograph below:



The diffraction grating has 300 lines per millimetre. The student determines that the angle of the first-order maxima is $11°$.

Calculate the wavelength of the laser, using the student's results.

$$d = \frac{1mm}{300} = \frac{1x10^{-3}m}{300} = 3.33x10^{-6} \quad m$$

$$d\sin\theta = m\lambda$$

$$\lambda = \frac{d\sin\theta}{m} = \frac{3.33x10^{-6}\sin 11}{1}$$

$$\lambda = 6.4x10^{-7}m$$

(3 marks)

(c) The true value of the wavelength of the laser is 632.8 nm.

State which experiment has produced the more accurate value. Give a reason for your answer.

Accuracy is a measure of how close the experimental value is to the true value.

The value obtained using the diffraction grating therefore gives a more accurate value as it is closer to 632.8 nm.

(2 marks)

Commented [IT14]:
REASONING
The slit separation given there are 300 per mm must be expressed in SI units ie metres.

17. A laser airborne depth sounder (LADS) has been used to measure the depth of a body of water.

The laser pulses are detected 2.52 μs and 2.88 μs after transmission. The speed of the light in the water is 2.3×10^8 m s^{-1}.

Calculate the depth of the water.

Time for the laser to cross the water once

$$t_w = \frac{t_b - t_s}{2} = (\frac{2.88x10^{-6} - 2.52x10^{-6}}{2}) = 1.8x10^{-7} \quad s$$

$$depth = v_{laser \quad in \quad water} \, xt_w$$

$$= \quad 2.3x10^8 \quad x1.8x10^{-7}$$

$$= \quad 41.4 \quad m \quad = 41 \quad m \quad (2sf)$$

(3 marks)

Commented [IT15]:
COMMON ERROR
SI units are required for time.
μs to s x10^{-6}

SECTION A

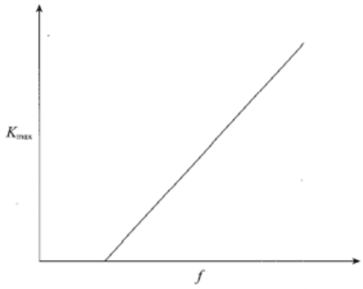
PART 2 (Questions 18 to 29)

(73 marks)

*Answer **all** questions in this part in the spaces provided.*

18. In the photoelectric effect the maximum kinetic energy of the emitted electrons depends on the frequency of the incident light.

    The values of the maximum kinetic energy K_{max} for the emitted electrons can be graphed against frequency f, as shown in the diagram below. The gradient of the line of best fit can give a value for Planck's constant.



    Using the law of conservation of energy, show that $K_{max} = hf - W$, and hence explain why the gradient of the line of best fit can give a value for Planck's constant.

When photons of energy $E=hf$ are incident on the surface of a metal, one electron in the metal can absorb the energy of one photon.

Electrons in the metal need different amounts of energy to be ejected depending on how deep within the metal they are found.

Using the law of conservation of energy, the energy of the photon is used to eject the electron, and any left over energy becomes the kinetic energy of the released electron.

$$E_{photon} = E_{eject} + K$$

Electrons closest to the surface require the least amount of energy to be ejected. They are ejected with maximum kinetic energy.

$$E_{photon} = E_{eject} + K$$
$$hf = W + K_{max}$$
$$K_{max} = hf - W$$

When this equation is compared to the equation of a straight line, $y=mx+c$, it can be seen that the gradient or slope of the line would give Planck's constant h.

(3 marks)

19. The photograph on the right shows a medical scientist using an electron microscope.

In an electron microscope a beam of short-wavelength electrons is produced by accelerating electrons through a potential difference.

Medical scientists often use electron microscopes because they can produce a higher resolution than light microscopes.

(a) Using the law of conservation of energy, show that the magnitude of the momentum p of the electrons (of mass m and charge e) that have been accelerated by a potential difference of ΔV is given by

$$p = \sqrt{2me\Delta V}.$$

Source: © iStockphoto.com/LoggNet

The electrons are accelerated by a uniform electric field. Using the law of conservation of energy, the work done by the field is equivalent to their kinetic energy.

$$W = K = \frac{1}{2}mv^2 = e\Delta V$$

The speed of the electrons is given by $v = \sqrt{\frac{2e\Delta V}{m}}$.

Their momentum is given by $p = mv = m\sqrt{\frac{2e\Delta V}{m}} = \sqrt{2me\Delta V}$.

(4 marks)

(b) The resolution of an electron microscope can be improved by changing the potential difference.

State whether the potential difference must be increased or decreased to improve the resolution. Justify your answer, using the equation in part (a).

Resolution is the ability to distinguish between two points that are very close together.

Resolution is limited due to diffraction effects. Diffraction becomes noticeable if the separation of the point is comparable to the wavelength. The smaller the wavelength, the greater the resolution.

Increasing the potential difference will increase the momentum of the electrons. This will decrease the wavelength ($\lambda = \frac{h}{p}$) and hence increase resolution.

(4 marks)

20. X-rays are produced by accelerating electrons towards a target in an evacuated tube. The target must be cooled.

(a) State why the target gets hot.

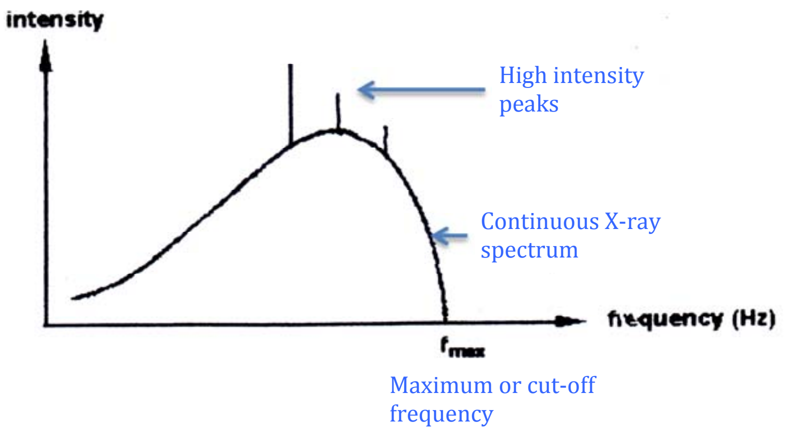
As the electrons collide with the target metal, they lose kinetic energy. 99% of this kinetic energy is converted to heat. This is why the target gets hot.

(1 mark)

(b) *On the axes below*, sketch a graph of a typical X-ray spectrum.

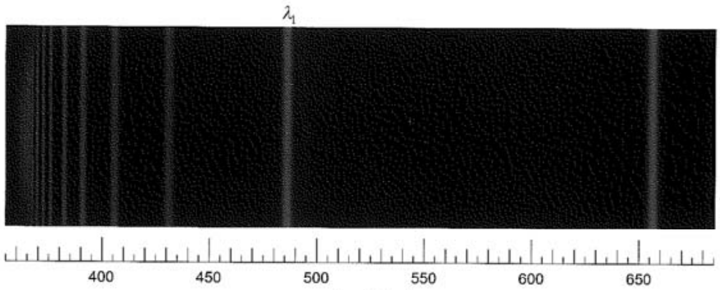
Label the:

- quantities represented on each axis
- three main features of the spectrum.



(4 marks)

21. The diagram below shows the spectrum emitted by excited hydrogen gas:



Source: Adapted from www.learner.org

(a) Using the scale on the diagram above, determine the value of λ_1.

485 nm

(1 mark)

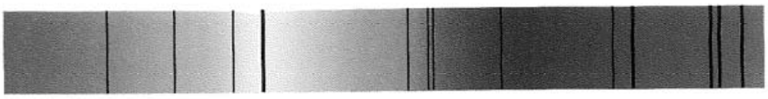
(b) Calculate the energy of the photons of wavelength λ_1.

$$E = hf = \frac{hv}{\lambda} = \frac{6.63x10^{-34}x3x10^{8}}{485x10^{-9}} = 4.10x10^{-19} \quad J$$

(2 marks)

Commented [IT16]: COMMON ERROR
SI units are required: nm must be converted to m (x10-9)

22. The image below shows the line absorption spectra of a mixture of different atoms in gaseous state:



Account for the presence of absorption lines in the spectra shown above.

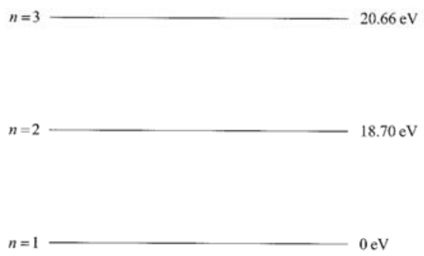
Consider light containing a continuous range of frequencies incident on the mixture of gases.

Photons that exactly match the energy levels in the atom are absorbed in promoting electrons in the atoms to higher energy levels.

These photons disappear from the continuous spectrum and appear as dark lines.

(3 marks)

23. The diagram below shows some of the energy levels of neon:



(a) State why neon will not absorb photons of 20.10 eV.

The energy of the photon must exactly match the energy difference between energy levels in order to promote an electron to a higher energy level. There is no gap between the ground state and any of the higher energy levels of exactly 20.10 eV.

(1 mark)

(b) The $n = 3$ energy level is a metastable state.

Explain how the presence of a metastable state makes neon a suitable gain medium for a laser.

A metastable state means that electrons remain in that energy level for a longer period of time.

This will enable a population inversion (a greater proportion of excited atoms than atoms found in the ground state).

These two conditions are required for stimulated emission to predominate over spontaneous emission. This results in a greater number of emitted photons. This makes neon a suitable gain medium.

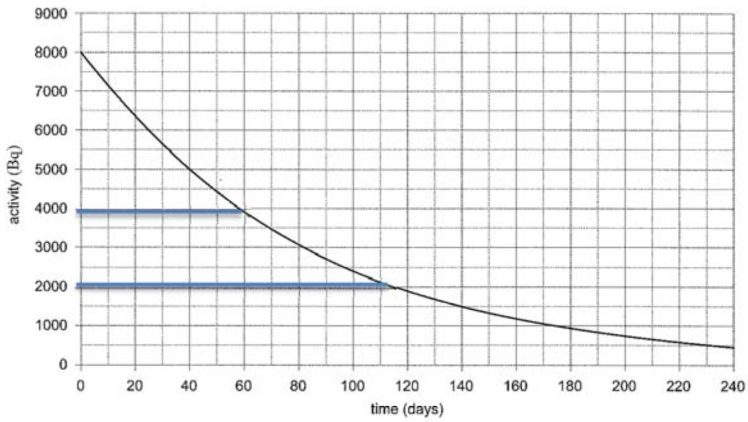
(3 marks)

24. The following two radioisotopes of iodine undergo gamma decay:

- iodine-123, which has a half-life of 13 hours
- iodine-125.

Both isotopes can be used in medical imaging because the gamma photons can be detected outside the body.

The graph below shows the activity of a sample of iodine-125 measured over 240 days:



(a) (i) Determine the half-life of iodine-125.

From the graph it can be seen that the activity halves (8000 to 4000 and 4000 to 2000 etc) every 58 days.

_______________ (2 marks)

(ii) Hence explain why a smaller dose of iodine-123 than of iodine-125 can be used in medical imaging.

Iodine-123 has a much shorter half-life that Iodine-123.

The number of gamma photons emitted and detected in order to create the image can occur from a smaller dose.

_______________ (2 marks)

(b) A patient is given a dose of iodine-123.

Determine the time needed for the activity of the dose to drop to 3.125% of its original activity.

Number of half lives	% remaining
0	100
1	50
2	25
3	12.5
4	6.25
5	3.125

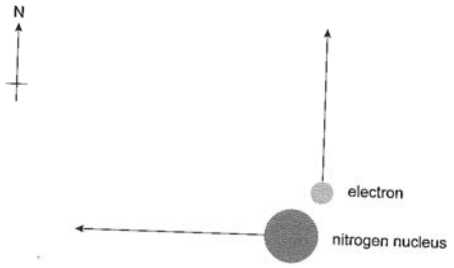
5 half lives have passed.

Time taken = 5x13 = 65 hours

(3 marks)

25. Carbon-14 undergoes beta minus decay, releasing an electron and producing a nitrogen nucleus.

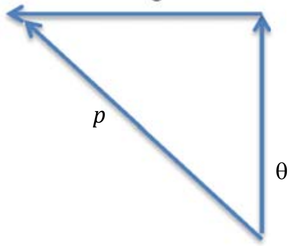
In a particular decay of a stationary carbon-14 nucleus, the electron and the nitrogen nucleus travel at right angles to each other, as shown in the diagram below. The diagram also shows the direction of true north.



The electron travels with a momentum of 4.6×10^{-23} kg m s^{-1}. The nitrogen nucleus travels with a momentum of 4.5×10^{-23} kg m s^{-1}.

(a) Determine the magnitude and direction of the sum of the momenta of the nitrogen nucleus and the electron.

$$p = p_{nitrogen} + p_{electron} = 4.5x10^{-23} \longleftarrow + 4.6x10^{-23} \uparrow$$



$$p = \sqrt{(4.6x10^{-23})^2 + (4.6x10^{-23})^2} = 6.4x10^{-23} \quad kgms^{-1}$$

$$\tan\theta = \frac{4.5x10^{-23}}{4.6x10^{-23}} \qquad \theta = 44^o$$

$$p = 6.4x10^{-23} \quad kgms^{-1} \quad N44^oW$$

(4 marks)

Commented [IT17]: COMMENT
The diagram shows the direction of true north. This helps give the final direction of the momentum vector.

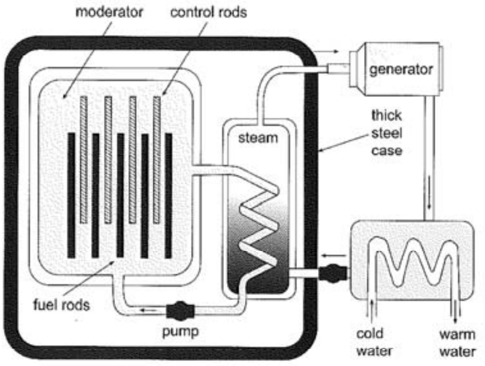
(b) Using the law of conservation of momentum, justify the emission of an antineutrino in this decay of carbon-14.

The total initial momentum before the decay is zero as the nucleus is stationary. According to the law of conservation of momentum, the total initial and final momentum remains unchanged. This means that the total final momentum is zero.

The vector triangle representing the total momentum of the decay products is not zero. It follows that another particle (the antineutrino) must be emitted to conserve momentum.

(2 marks)

26. The diagram below shows the main components of a nuclear fission reactor:



Boron is used in some nuclear fission reactors because of its ability to absorb neutrons. The table below shows some of the properties of boron:

Element	Atomic Number	Ability to Scatter Neutrons	Ability to Absorb Neutrons
boron	5	medium	high

(a) State whether boron is likely to be used as a moderator or within control rods in a nuclear fission reactor. Give a reason for your answer.

Since boron readily absorbs neutrons, it is likely to be used in control rods.

Control rods absorb neutrons in order to control the chain reaction that is a result of fission.

(2 marks)

Commented [IT18]: REASONING
The moderator slows the neutrons down but does not absorb neutrons readily.

(b) A typical neutron-absorption reaction of boron is shown below:

$$^{10}_{5}B + ^{1}_{0}n \rightarrow ^{7}_{3}Li + ^{4}_{2}He.$$

The masses of the particles involved in the reaction are shown in the table below:

Particle	Mass (kg)
$^{10}_{5}B$	1.6627×10^{-26}
$^{1}_{0}n$	1.6749×10^{-27}
$^{7}_{3}Li$	1.1650×10^{-26}
$^{4}_{2}He$	6.6465×10^{-27}

Determine the amount of energy released in this nuclear reaction. Give your answer in MeV.

Mass of products $m_{Li} + m_{He}$ = 1.1650x10^{-26} + 6.6465x10^{-27} = 1.82965x10^{-26} kg

Mass of reactant $m_{B} + m_{n}$ = 1.6627x10^{-26} + 1.6749x10^{-27} = 1.83019x10^{-26} kg

$$\Delta m = m_{reactants} - m_{products} = 1.83019x10^{-26} - 1.82965x10^{-26} = 5.4x10^{-30} \quad kg$$

$$E = \Delta mc^2 = 5.4x10^{-30}x(3x10^8)^2 = 4.86x10^{-13} \quad J = \quad 3.04 \quad MeV \qquad (3sf)$$

(5 marks)

Commented [IT19]: COMMON ERROR
To convert J to eV divide by the charge of an electron.
Divide by a further 10^6 to get the answer in MeV.

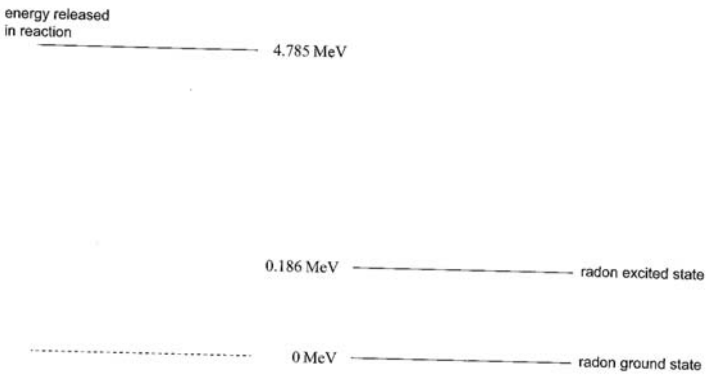
27. A stationary radium nucleus decays to the radon nucleus $^{222}_{86}\mathrm{Rn}$ by alpha decay.

(a) Balance the decay reaction below by writing the atomic and mass numbers of the radium nucleus and the alpha particle.

$$^{226}_{88}\mathrm{Ra} \rightarrow {}^{222}_{86}\mathrm{Rn} + {}^{4}_{2}\alpha$$

(3 marks)

(b) The alpha decay of radium to radon can be shown on the diagram below:



(i) Determine the maximum kinetic energy emitted in the alpha decay of radium to radon. Give your answer in MeV.

4.785 MeV

(1 mark)

(ii) Determine the maximum-energy gamma photon that can be emitted after the alpha decay of radium to radon. Give your answer in MeV.

0.186 MeV

(1 mark)

28. Using the properties of the strong nuclear force and the electrostatic force between nuclei, explain why high kinetic energies are needed for fusion to occur.

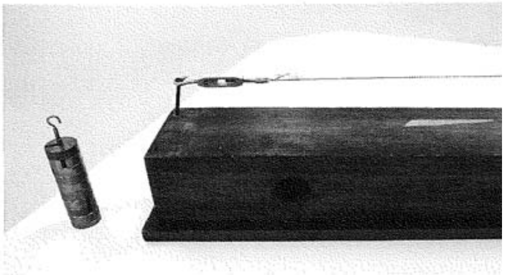
A large amount of kinetic energy is required to overcome the long-range repulsive coulomb forces that exist as the two positive nuclei try to fuse.

The closer the nuclei become the greater the repulsive force becomes.

If the repulsive force is overcome and the nuclei move to within a few nucleon diameters of each other, they will be drawn in by the short-range attractive nuclear forces.

(3 marks)

29. The photograph below shows a sonometer. A metal wire (similar to a
the sonometer by suspended masses. The wire vibrates when it is pl



Students conduct an experiment, using a sonometer. The tension in the wire is varied by increasing the mass that is suspended from one end of the wire. The lowest frequency of the vibrating wire is measured (in hertz), using an appropriate app (application) on a smartphone, as shown in the photograph on the right.

The length of the wire is held constant at $L = 0.325$ m during the experiment.

Research undertaken by the students before conducting the experiment revealed the expected relationship between the frequency (f, in hertz) and the mass (m, in kilograms) to be

$$f^2 = \frac{mg}{4\rho L^2},$$

where ρ is the linear density of the wire (in kg m^{-1}) and g is the acceleration due to gravity.

(a) Write in the boxes below to show which quantities should be
axis and the vertical axis so that, when graphed, the data will
relationship between the independent and dependent variable

Commented [IT20]: HINT
The independent variable is plotted on the horizontal axis.

(b) The data recorded by the students are shown below:

grams	frequency
500	197
750	211
1000	263
1250	291
1500	314

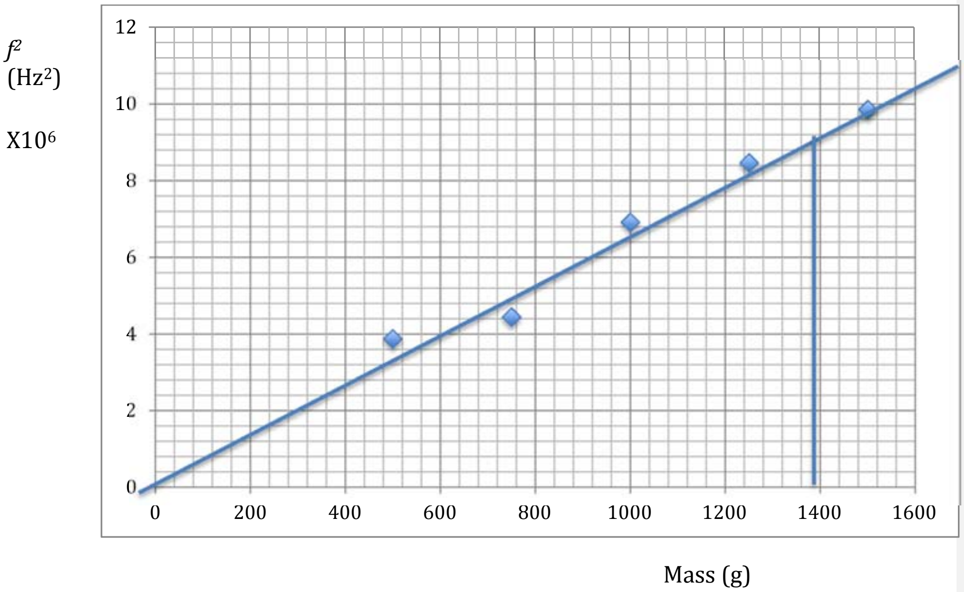
Present the data collected in the experiment, and any values calculated from the data, in a table to enable you to draw the graph described in part (a) on page 17.

Mass (g)	Frequency (Hz)	f^2 (Hz^2) x10^4
500	197	3.88
750	211	4.45
1000	263	6.92
1250	291	8.47
1500	314	9.86

(3 marks)

(c) *On the page opposite*, plot the data and draw a line of best fit. (6 marks)

How the value of frequency squared varies with mass



(d) Determine the gradient of your line of best fit. Include the units of the gradient.

$$gradient = \frac{rise}{run} = \frac{9.2x10^6}{1400} = 67.7 = 68 \quad Hz^2 g^{-1}$$

(3 marks)

(e) Using the gradient of your line of best fit, find the magnitude of ρ, the linear density of the wire.

Compare $f^2 = \frac{mg}{4\rho L^2}$ to the equation of the line of best fit f^2=68m

Gradient = 68= $\frac{g}{4\rho L^2}$

$$\rho = \frac{g}{4x68xL^2} = \frac{9.8}{4x68x0.325^2} = 0.34 \quad kgm^{-1}$$

(3 marks)

(f) Suggest one way of improving the experiment.

Explain how your suggestion would improve the experiment.

Random errors can be reduced by repeating the measurement of frequency several times for each mass that is added.

(2 marks)

30. Two balls are launched with the same initial velocity, at an angle θ above the horizontal, as shown in the diagram below. If different forces of air resistance act on the balls, the motion of the balls will be different.

- Identify *two* properties of the balls that affect the size of the forces of air resistance, and describe how each of these properties affects the forces of air resistance.
- Explain the effect that air resistance has on the time the balls take to reach their maximum height.

(16 marks)

One property of the ball that affects the amount of force it experiences due to air resistance is its shape. If the ball is streamline/aerodynamic, then it experiences a smaller force due to air resistance. This is because air can easily flow over and around the ball causing fewer collisions with air particles.

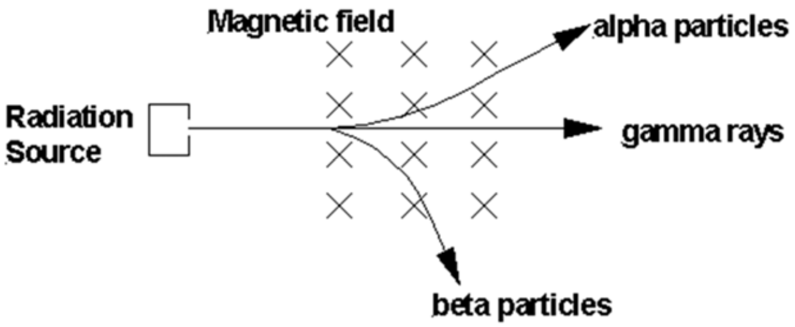
Another property of the ball that affects the amount of force due to air resistance is the size (cross sectional area) of the ball. Assuming the shape is the same and the ball is spherical, then a larger ball experiences a larger force due to air resistance. This is because there is a greater area of the ball in contact with the air and hence more collisions with air particles.

Air resistance will reduce the time it takes a ball to reach its maximum height. This is because air resistance is the unbalanced force that opposes the motion of an object as it moves through the air. This means that the ball will decelerate at a greater rate as it rises and hence come to rest sooner. In fact, the acceleration without air resistance would be the gravitational acceleration (9.8 ms^{-2} and down) but when air resistance acts the acceleration would be greater than this value.

31. Alpha, beta, and gamma radiations can be identified by the paths they take in a uniform magnetic field.

- Explain how the features of the different paths allow the different radiations to be identified.

(14 marks)



http://webs.mn.catholic.edu.au/physics/emery/prelim_cosmic.htm#surface

When charges enter perpendicularly to a uniform magnetic field, the force due to the magnetic field is constant and always acts at 90º to the velocity of the charges. The magnetic force therefore provides the centripetal acceleration for uniform circular motion.

The magnitude of the force is given by $F = Bqv\sin\theta$ where F is the magnetic force, B is the magnitude of the magnetic field, q is the magnitude of the charge, v is the speed of the charges and θ is the angle that the charges make with the magnetic field.

Gamma radiation has no charge and will therefore pass through the magnetic field un-deflected.

Referring to figure 1, alpha decay and beta plus decay would deflect upwards. The direction of the force is given by the right hand rule. The thumb points in the direction of motion of the positive charges, the outstretched fingers point in the direction of the magnetic field and the force acts away from the palm of your hand. This means that alpha decay and beta plus decay (both positive) are deflected upwards. Beta minus has a negative charge and therefore deflects downwards.

To distinguish between alpha and beta plus decay, the equation $r = \frac{mv}{Bq}$ indicates that for alpha and beta decay entering the same magnetic field B with the same speed v, the radius of curvature r is proportional to the mass to charge ratio. Since the mass to charge ratio for alpha decay is greater than the mass to charge ratio for beta decay, the radius of curvature for alpha decay is greater.