The following pages offer suggested solutions to the 2012 SACE Stage 2 Physics final examination.
These solutions are not the official set
of solutions used by the examiners of the SACE Board.

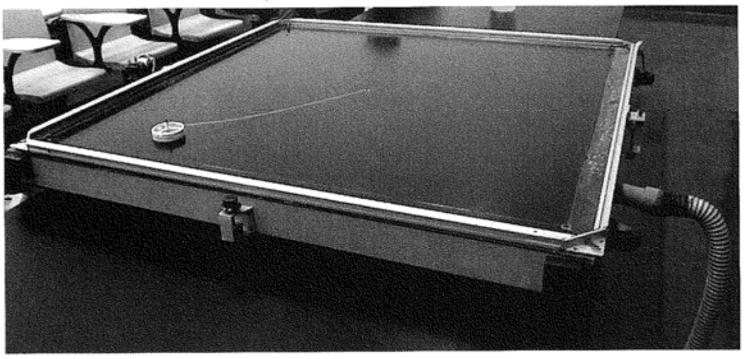
SECTION A

PART 1 (Questions 1 to 14)

(72 marks)

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

1. A piece of string is used to attach a puck to the centre of an air-table, as shown in the photograph below:



Source: www.columbia.edu/cu/physics/

The puck has a mass of 0.035 kg. It is made to move around the centre of the air-table in uniform circular motion, with a speed of $2.4\,\mathrm{m\,s^{-1}}$. The radius of the circular path is 0.32 m.

(a) State the force on the string that causes the centripetal acceleration of the puck.

Tension

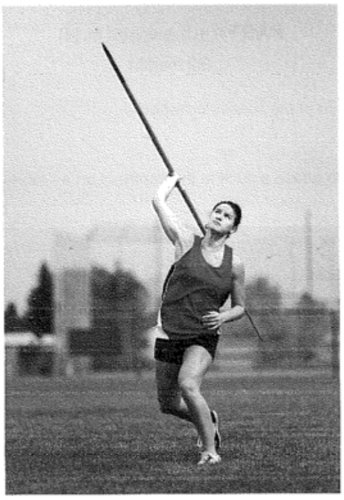
____ (1 mark)

(b) Calculate the magnitude of the force that causes the centripetal acceleration of the puck.

$$F = \frac{mv^2}{r} = \frac{0.035x2.4^2}{0.32} = 0.63 \quad N$$

____ (3 marks)

2. The photograph below shows an athlete competing in a javelin throw:



Source: © iStockphoto.com/songbird839

A javelin is thrown from a shoulder height of $1.50\,m$. The initial velocity of the javelin is $25.0\,m\,s^{-1}$, at an angle of $40.0°$ above the horizontal.

Ignore air resistance in all parts of this question.

(a) Show that the vertical component of the initial velocity of the javelin is $16.1\,m\,s^{-1}$.

$$v_H = v\sin\theta = 25\sin 40 = 16.1 \quad ms^{-1}$$

(1 mark)

(b) Calculate the maximum height of the javelin above the ground.

$$v^2 = v_o^2 + 2as \qquad v = 0 \quad \text{max} \quad height$$

$$0 = 16.1^2 - 2x9.8s$$

$$s = \frac{16.1^2}{2x9.8} = 13.2 \qquad m$$

Total height above the ground = 13.2 + 1.5 = 14.7 m

(4 marks)

COMMON ERROR
The release height must be added as the question asks for the maximum height above the ground.

(c) Athletes competing in a javelin throw try to achieve the maximum range.

Describe and explain the effect that increasing the launch height of a javelin has on the maximum range.

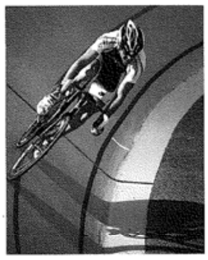
Increasing the launch height increases the range.

The javelin spends more time in the air as it falls the extra height.

Since the range is the product of the horizontal component of the initial velocity (v_H) and the time of flight. The horizontal component of the initial velocity is constant so an increase in the time of flight increases in the range.

(3 marks)

3. Velodromes are cycle-racing tracks with banked curves that enable cyclists to travel at high speeds, as shown in the photograph below:

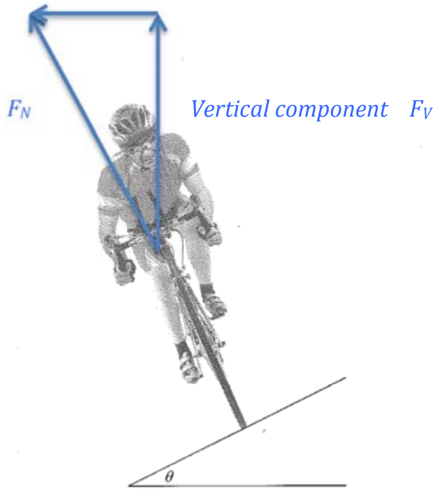


Source: http://popmiseryblog.blogspot.com.au

(a) *On the diagram below*:

(i) draw a vector to show the normal force $\vec{F}_n$ on a bicycle travelling with uniform circular motion around a banked curve. (1 mark)

(ii) resolve the normal force vector into its horizontal and vertical components, labelling each component. *Horizontal component* F_H (2 marks)



Source: Image adapted from iStockphoto.com/steamroller_blues

(b) (i) State why the vertical component of the normal force vector has a magnitude of mg, where m is the total mass of the cyclist and the bicycle.

The vertical component of the normal is equal in magnitude but opposite in direction to the weight, where weight $W = mg$.

(1 mark)

(ii) Derive the equation $\tan\theta = \frac{v^2}{rg}$, relating the banking angle θ to the speed v at which the cyclist is travelling and the radius of curvature r.

The horizontal component of the normal force F_H, provides all the centripetal acceleration for uniform circular motion.

$$\tan\theta = \frac{F_H}{F_V} = \frac{\frac{mv^2}{r}}{mg} = \frac{v^2}{rg}$$

(3 marks)

(c) A cyclist is travelling around a banked curve in a velodrome. The banked curve has a radius of 26 m and a banking angle of 42°.

Calculate the maximum speed at which the cyclist can travel around the banked curve without relying on friction.

$$Tan\theta = \frac{v^2}{rg}$$

$$v = \sqrt{\tan\theta x r g} = \sqrt{\tan 42 x 26 x 9.8} = 15 \quad ms^{-1}$$

(3 marks)

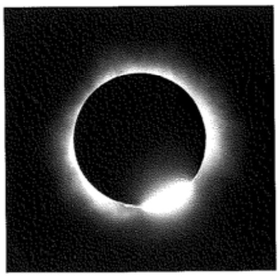
4. In November 2012 parts of the world will experience a total solar eclipse. During such an eclipse the Earth, the Moon, and the Sun are in a straight line. The Moon is between the Earth and the Sun.

In this alignment the distance between the Earth and the Moon is 3.85×10^8 m, and the distance between the Moon and the Sun is 1.50×10^{11} m.

The mass of the Earth is 5.97×10^{24} kg.

The mass of the Moon is 7.35×10^{22} kg.

The mass of the Sun is 1.99×10^{30} kg.



Source: © iStockphoto.com/oversnap

Determine the magnitude of the ratio $\frac{\text{force on the Moon due to the Earth}}{\text{force on the Moon due to the Sun}}$.

Force on the Moon due to the Earth

$$F_{ME} = \frac{Gm_M m_E}{r_{mE}^2} = \frac{6.67x10^{-11}x7.35x10^{22}x5.97x10^{24}}{(3.85x10^8)^2}$$

Force on the Moon due to the Sun

$$F_{MS} = \frac{Gm_M m_S}{r_{mS}^2} = \frac{6.67x10^{-11}x7.35x10^{22}x1.99x10^{30}}{(1.5x10^{11})^2}$$

$$\frac{\text{Force on the Moon due to the Earth}}{\text{Force on the Moon due to the Sun}} = \frac{\dfrac{6.67x10^{-11}x7.35x10^{22}x5.97x10^{24}}{(3.85x10^8)^2}}{\dfrac{6.67x10^{-11}x7.35x10^{22}x1.99x10^{30}}{(1.5x10^{11})^2}}$$

$$= \frac{5.97x10^{24}}{(3.85x10^8)^2} x \frac{(1.5x10^{11})^2}{1.99x10^{30}}$$

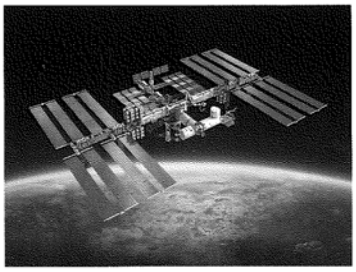
$$= 0.455$$

(4 marks)

5. The QuickBird satellite is used to create images of the Earth. One such image is shown below left. The satellite orbits at an altitude of 482 km, and has a mass of 9.5×10^2 kg.

The International Space Station (shown in the image below right) orbits at an altitude of 390 km, and has a mass of 4.2×10^5 kg.

Source: www.digitalglobe.com/product-samples
© 2012 Digital Globe, Inc.



Source: © iStockphoto.com/scibak

(a) State whether the QuickBird satellite orbits the Earth at a faster or slower speed than the International Space Station. Give a reason for your answer.

Since speed of a satellite v is given by $v = \sqrt{\frac{GM}{R_o}}$ where M is the mass of Earth and G is the Gravitational constant then $v \alpha \sqrt{\frac{1}{r}}$ where r is the radius of orbit of the satellite. This is because both M and G are constant.

The QuickBird satellite has a larger radius of orbit and will therefore have a slower speed than the international space station.

(2 marks)

(b) State any effect that the different masses of the satellites will have on their speeds. Give a reason for your answer.

As explained above, the mass in the equation for the speed of a satellite is the mass of the Earth not the mas of the satellite. The different masses have no effect on their speeds.

(2 marks)

(c) State one advantage of the QuickBird satellite's low-altitude orbit.

Images with higher resolution are produced.

(1 mark)

MEANING
A low-altitude orbit means that the satellite is closer to the ground. The images produced show more detail. We refer to this as resolution.

6. Diagram 1 shows the momentum vector of ball A before it collides with ball B, which is stationary:

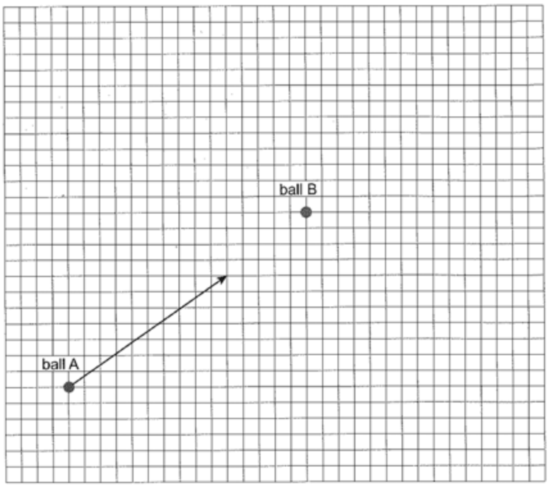


Diagram 1

Diagram 2 shows the momentum vector of ball A after the collision:

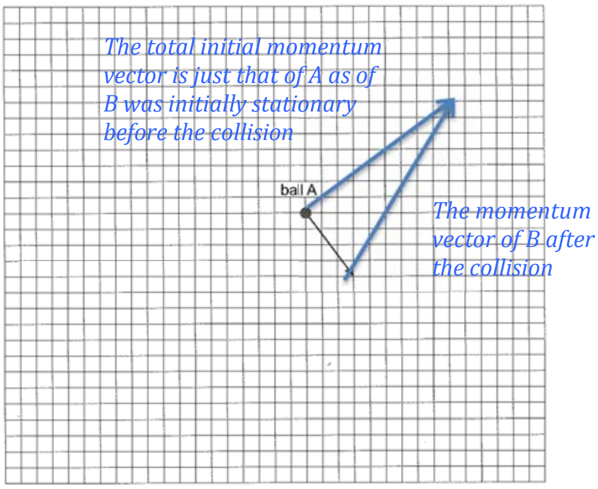


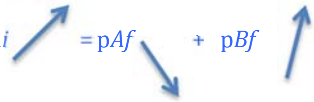
Diagram 2

On Diagram 2 on the page opposite, draw the momentum vector of ball **B** after the collision. Show your working.

Assume an isolated system.

Using the law of conservation of momentum, the total initial and final momentum is the same (both magnitude and direction).

Since pi = pf then pAi = pAf + pBf



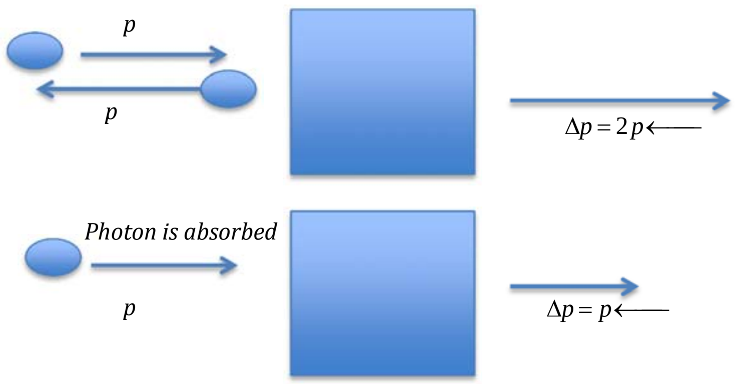
The final momentum vector is shown on the diagram above.

(4 marks)

7. Solar sails can use the photons from the Sun to accelerate a spacecraft.

(a) Explain, with the aid of vector diagrams, why photons experience a greater change in momentum when they are reflected from, rather than absorbed by, a solar sail.

Consider only photons that are normally incident on the sail.



The change in momentum Δp is given by the final momentum of the photon subtract the initial momentum.

The final momentum of a photon that is absorbed is zero but the final momentum of a photon that is reflected is the same as the initial momentum but in the opposite direction.

The change in momentum of a photon that is absorbed is given by $\Delta p = p_f - p_i = 0 - p\longrightarrow = p\longleftarrow$ which is half that of a photon that is reflected $\Delta p = p_f - p_i = p\longleftarrow - p\longrightarrow = 2p\longleftarrow$.

(4 marks)

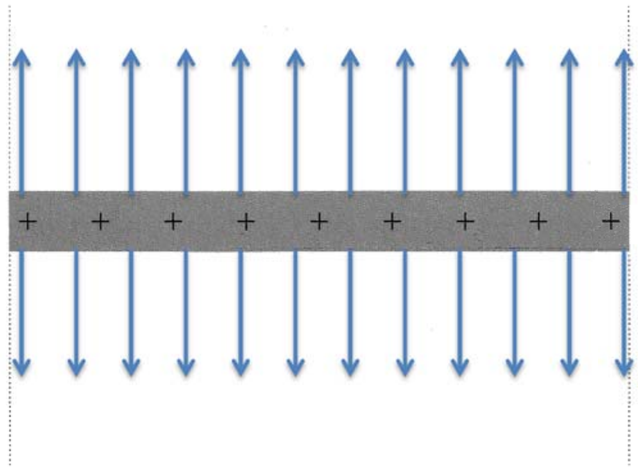
(b) Hence, explain why a solar sail that reflects photons will undergo a greater acceleration than a solar sail that absorbs photons.

Using the law of conservation of momentum, the change in momentum experienced by the solar sail is equal but opposite in direction to the change in momentum experienced by the photon.

Since $F_{sail} = \frac{\Delta p_{sail}}{\Delta t}$, then it follows that solar sails that reflect photons will experience a greater force (if the collision occurs over the same amount of time) and hence greater acceleration since $a_{sail} = \frac{F}{m_{sail}}$

(2 marks)

8. The diagram below shows a section of an infinitely long, positively charged conducting plate:



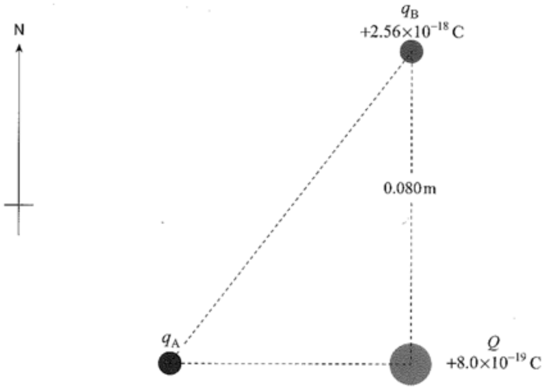
[*This diagram is not drawn to scale.*]

On the diagram above, draw the electric field due to the positively charged conducting plate in the region between the dotted lines. (3 marks)

HINT
The electric field is uniform. The electric field lines need to be evenly spaced.

The electric field lines point away from the conductor as they indicate the direction of the force on a positive test charge.

9. The diagram below shows three point charges positioned at the corners of a right-angled triangle. The direction of north is also shown on the diagram.



[*This diagram is not drawn to scale.*]

Charge q_B, which has a magnitude of $+2.56\times10^{-18}$ C, is 0.080 m from charge Q. The magnitude of charge Q is $+8.0\times10^{-19}$ C.

Charge Q experiences a force, towards the east, of magnitude 2.9×10^{-24} N due to q_A.

(a) Calculate the magnitude of the force that charge Q experiences due to q_B.

$$\vec{F}_B = \frac{1}{4\pi\varepsilon_0}\frac{Qq_B}{r^2} = \frac{9x10^9 x8x10^{-19} x2.56x10^{-18}}{0.08^2} = 2.9x10^{-24} \quad N \qquad \downarrow \quad (south)$$

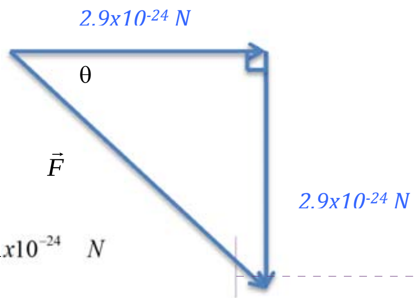
(2 marks)

(b) Calculate the magnitude and direction of the total force acting on charge Q.

Force due to q_A *$2.9x10^{-24}$ N east*

Force due to q_B *$2.9x10^{-24}$ N south*

$$\vec{F} = \vec{F}_A + \vec{F}_B$$



$$F = \sqrt{(2.9x10^{-24})^2 + (2.9x10^{-24})^2} \quad = 4.1x10^{-24} \quad N$$

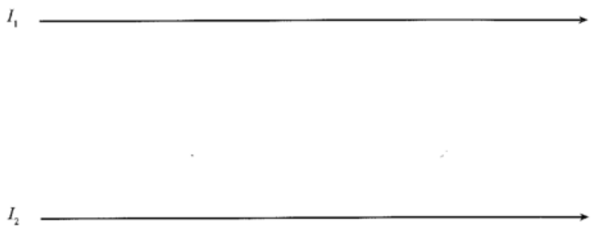
$$\theta = \tan^{-1}\left(\frac{2.9x10^{-24}}{2.9x10^{-24}}\right) = 45^0$$

$$\vec{F} = 4.1x10^{-24}\,N \qquad SE$$

(5 marks)

HINT
The triangle is right angled – Pythagoras applies.

10. The diagram below shows two parallel conductors. The conductors carry currents I_1 and I_2 in the directions shown.



Each conductor is within the magnetic field created by the other conductor.

Determine, giving reasons, whether the two conductors attract or repel each other.

The magnetic field due to I_1 acts into the page in the position where conductor 2 lies.

Using the right hand rule the force on conductor 2 due to conductor 1 is up the plane of the page.

The magnetic field due to I_2 acts out of the page in the position where conductor 1 lies.

Using the right hand rule the force on conductor 1 due to conductor 2 is down the plane of the page.

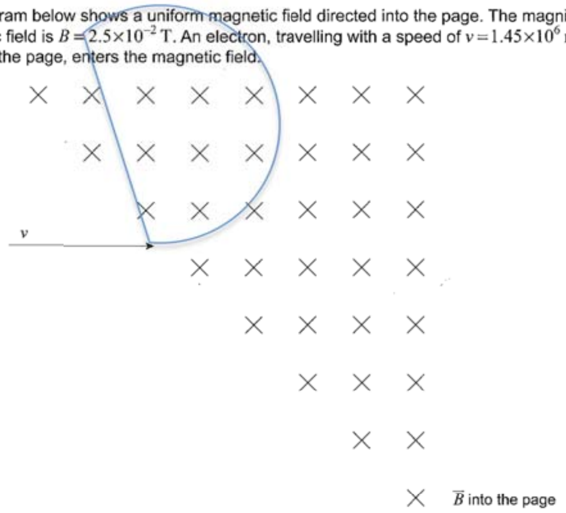
The conductors attract each other.

(3 marks)

HINT
Use the right hand rule for the magnetic field around a straight conductor.

HINT
Again use the right hand rule for the magnetic field around a straight conductor.

11. The diagram below shows a uniform magnetic field directed into the page. The magnitude of the magnetic field is $B = 2.5 \times 10^{-2}$ T. An electron, travelling with a speed of $v = 1.45 \times 10^{6}$ m s^{-1} in the plane of the page, enters the magnetic field.



[*This diagram is not drawn to scale.*]

(a) *On the diagram above*, sketch the path taken by this electron in the magnetic field.
(1 mark)

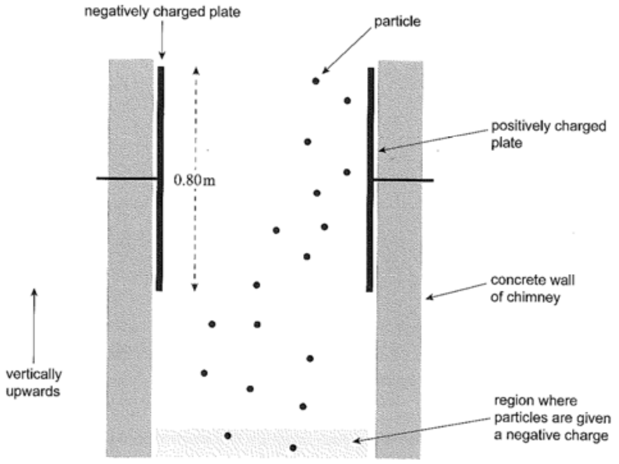
(b) Calculate the magnitude of the magnetic force acting on the electron.

$$F = Bqv\sin\theta = 2.5x10^{-2}x1.6x10^{-19}x1.45x10^{6}x\sin 90 = 5.8x10^{-15}N$$

(2 marks)

12. Electrostatic precipitators are used in industrial chimneys to remove dust particles from emissions produced as a result of smelting processes.

The diagram below shows an electrostatic precipitator that uses a corona discharge to give the particles a charge of -1.6×10^{-19} C. The particles then enter the region between two oppositely charged parallel plates. The positively charged plate acts as a particle collector.



[*This diagram is not drawn to scale.*]

The parallel plates, which are separated by a distance of 0.45 m, are 0.80 m in length. The potential difference between the plates is 6.0×10^{4} V.

Ignore air resistance and the effect of gravity in all parts of this question.

(a) Calculate the magnitude of the force acting on a singly charged particle between the parallel plates.

$$E = \frac{\Delta V}{d} = \frac{6x10^4}{0.45} = 1.3x10^5 \quad Vm^{-1}$$

$$F = Eq = 1.3x10^5 x(1.6x10^{-19}) = 2.1x10^{-14} \quad N$$

(3 marks)

(b) Show that a particle travelling vertically upwards at $2.0\,\mathrm{ms^{-1}}$ takes $0.40\,\mathrm{s}$ to travel across the electric field between the parallel plates.

$$v_v = \frac{s_v}{t} \Rightarrow t = \frac{s_H}{v_H} = \frac{0.8}{2} = 0.40 \quad s$$

(1 mark)

REASONING
This component of velocity is perpendicular to the uniform electric field between the plates and is constant. The equation for constant speed applies.

(c) A singly charged particle travelling vertically upwards at $2.0\,\mathrm{ms^{-1}}$ enters the electric field exactly halfway between the parallel plates.

Determine the greatest possible mass of such a particle that can be collected by the positively charged plate.

Maximum deflection in the direction of the electric field is $\frac{0.45}{2} = 0.225 \quad m$

This can be used to find the maximum acceleration.

$$s = v_o t + \frac{1}{2}at^2 \qquad v_o \quad = 0$$

$$\therefore a = \frac{2s}{t^2} = \frac{2x0.225}{0.4^2} = 2.81 \quad ms^{-2}$$

$$a = \frac{Eq}{m} \Rightarrow m = \frac{Eq}{a} = \frac{1.3x10^5 x1.6x10^{-19}}{2.81} = 7.4x10^{-15} kg$$

(5 marks)

13. A television channel broadcasts waves with a horizontal plane of polarisation.

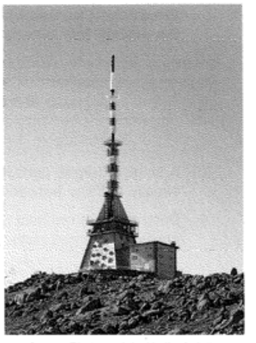
(a) State the orientation of the oscillating magnetic field in such waves.

Vertical _______________ (1 mark)

(b) Calculate the wavelength of television signals broadcast at 64.25 MHz.

$v = f\lambda \qquad \lambda = \frac{v}{f} = \frac{3x10^8}{64.25x10^6} = 4.67\ m$

(3 marks)



Source: Photograph by Nedim Ardoğa, http://en.wikipedia.org/wiki/File

REASONING
The plane of polarisation is defined as the plane of the electric field. The plane of the magnetic field is perpendicular to the plane of the electric field.

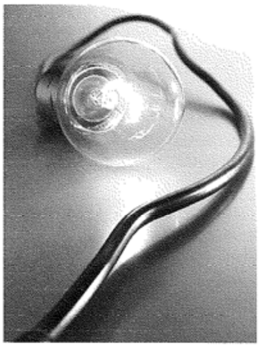
COMMON ERROR
SI units are required.
MHz to Hz x10^6

14. Explain why light from an incandescent light bulb is not monochromatic.

An incandescent globe emits white light. White light consists of all colours/wavelengths ranging from red through to violet (ROYGBIV).

Monochromatic light consists of one colour/wavelength only. The light from an incandescent globe is not monochromatic.

(2 marks)



Source: © Noahgolan/Dreamstime.com

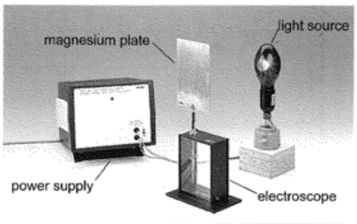
SECTION A

PART 2 (Questions 15 to 25)

(78 marks)

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

15. The photograph below shows the equipment used in an experiment to investigate the photoelectric effect:



Source: Adapted from www.phywe.com

A magnesium plate is illuminated by light of frequency 2.0×10^{15} Hz. The electroscope shows that electrons are emitted from the magnesium plate.

The work function of magnesium is $3.66\,\text{eV}$.

Calculate the maximum speed of the emitted electrons.

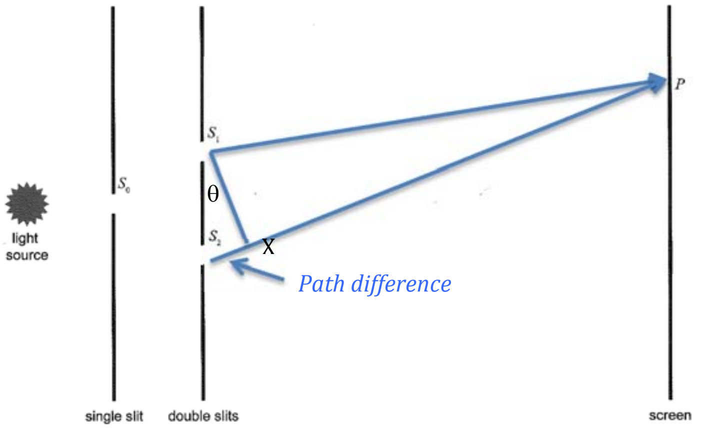
$$k_{\max} = hf - W = 6.63x10^{-34}x2x10^{15} - (3.66x1.6x10^{-19}) = 7.4x10^{-19} \quad J$$

$$K_{\max} = \frac{1}{2}mv^2 \Rightarrow v = \sqrt{\frac{2K}{m}} = \sqrt{\frac{2x7.4x10^{-19}}{9.11x10^{-31}}} = 1.3x10^6\,ms^{-1}$$

(4 marks)

HINT/COMMON ERROR
eV needs to be converted to J (x $1.6x10^{-19}$)

16. The diagram below shows a two-slit arrangement for investigating the interference of light. Monochromatic blue light passes through a single slit S_0 before illuminating two narrow slits S_1 and S_2. An interference pattern is seen on the screen.



[*This diagram is not drawn to scale.*]

(a) *On the diagram above*, draw the beams of light that travel from slits S_1 and S_2 to point P on the screen. Indicate the path difference between the two beams of light. (1 mark)

(b) Derive $d\sin\theta = m\lambda$ for two-slit interference, where d is the distance between slits S_1 and S_2 and θ is the angular position of the mth maximum.

Since the distance between the double slits and the screen is so much larger that the distance between the double slits then the angle S_1XS_2 is approximately 90°.

Using the triangle S_1XS_2 then

$$\sin\theta = \frac{path \quad difference}{d}$$

For a maxima, the path difference is $m\lambda$

$$\sin\theta = \frac{path \quad difference}{d} = \frac{m\lambda}{d}$$

It follows that

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

(3 marks)

(c) The wavelength of the monochromatic blue light is 4.70×10^{-7} m and the distance between slits S_1 and S_2 is 1.8×10^{-4} m.

Calculate the angle of the third-order maxima.

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

$$\theta = \sin^{-1}(\frac{m\lambda}{d}) = \sin^{-1}(\frac{3x4.7x10^{-7}}{1.8x10^{-4}})$$

$$\theta = \pm 0.45^0$$

(3 marks)

(d) The monochromatic blue light source is removed and replaced with a laser that produces red light.

(i) State why the single slit S_0 is not needed when the laser is used.

The laser light is coherent where as the blue light source wasn't. This means that the single slit isn't needed.

REASONING
The purpose of the single slit is to produce two coherent light sources at the double slits.

(1 mark)

(ii) Describe, giving reasons, the effect that the change of light source has on the distance between adjacent maxima on the screen.

Since the fringe separation $\Delta y = \frac{\lambda L}{d}$, then the fringe separation (distance between adjacent maxima) is proportional to the wavelength.

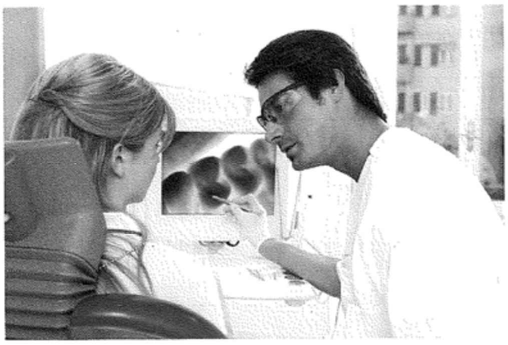
Changing the wavelength from blue to red means that the wavelength is greater.

A greater wavelength means a greater fringe separation/distance between adjacent maxima.

The colour of the bright fringes will also change from blue to red.

(3 marks)

17. Dentists can use X-rays to detect tooth decay, as shown in the photograph below:



Source: © Diego.cerv.../Dreamstime.com

(a) When taking an X-ray image, the dentist can control the settings of the filament current and of the potential difference across the X-ray tube.

Identify, giving reasons, which of these settings would be used to reduce the exposure time to the X-rays.

Increasing the filament current will reduce the exposure time.

This is because the filament current releases electrons that collide with a target metal to produce X-rays.

If more electrons are released, then more collisions occur and more X-rays are produced reducing the overall exposure time.

(3 marks)

(b) State one other way in which dentists can reduce their exposure to ionising radiation.

Exposure to ionising radiation can be reduced by wearing appropriate shielding such as a lead lined apron.

(1 mark)

18. In the Davisson–Germer experiment electrons were projected at the surface layers of a crystal lattice.

(a) Calculate the wavelength of electrons travelling at a speed of $4.36 \times 10^{6}\ \text{ms}^{-1}$.

$$\lambda = \frac{h}{p} = \frac{h}{mv} = \frac{6.63x10^{-34}}{9.11x10^{-31}x4.36x10^{6}} = 1.67x10^{-10} \quad m$$

(2 marks)

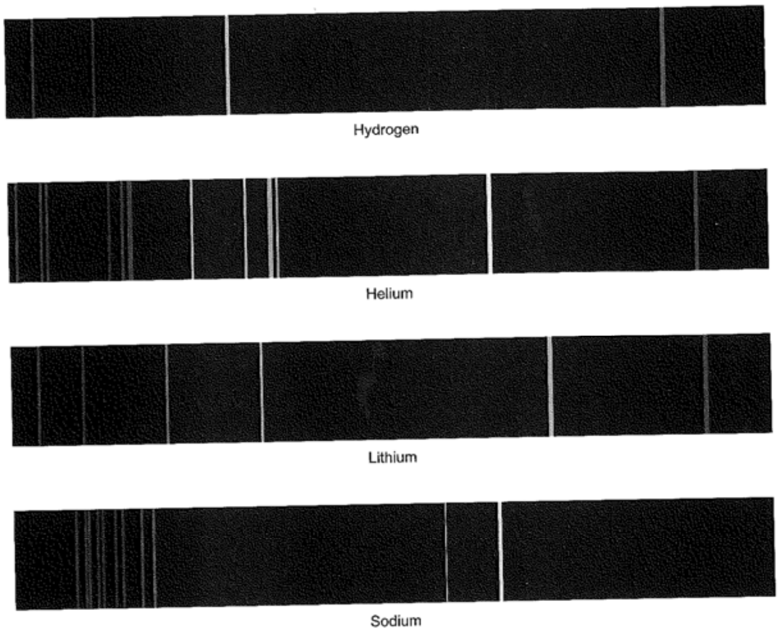
(b) Explain how the results of the Davisson–Germer experiment demonstrated the wave behaviour of low-energy electrons.

Low energy electrons were fired towards a crystal lattice and they were diffracted at preferred angles rather than being scattered randomly.

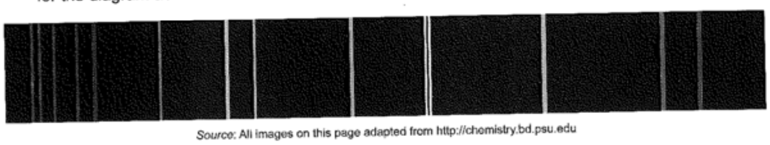
Diffraction is a wave phenomena. In addition the equation $d\sin\theta = m\lambda$ was used to calculate the wavelength of the electrons and matched that found using the de Broglie relationship $\lambda = \frac{h}{p}$.

(2 marks)

19. The diagram below shows the line emission spectra of four elements for the range 400 nm to 700 nm:



The diagram below shows the line emission spectrum of a mixture of gases for the same range as for the diagram above:



Source: All images on this page adapted from http://chemistry.bd.psu.edu

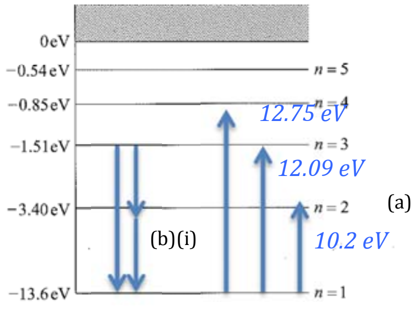
Identify, giving reasons, two elements present in the mixture of gases.

The position of lines in the spectra of hydrogen and lithium match the lines in the spectrum of the mixture.

Ie hydrogen and lithium must be present.

______________________________ (2 marks)

20. The diagram below shows some of the energy levels of hydrogen at room temperature:



[*This diagram is not drawn to scale.*]

Gaseous hydrogen is bombarded by photons of energies 12.50 eV and 12.09 eV.

(a) State why the photons of energy 12.50 eV will not be absorbed by the hydrogen.

There is no energy gap between the ground state and the higher energy levels that matches 12.50 eV. The photon will not be absorbed.

(1 mark)

(b) A photon of energy 12.09 eV collides with the electron in a hydrogen atom in its ground state. As a result of the collision the electron undergoes a transition to an excited state before it returns to the ground state.

(i) *On the diagram above*, draw all possible transitions for the electron as it returns to the ground state. (2 marks)

(ii) State the smallest-energy photon that could be emitted as the electron returns to the ground state after this excitation.

1.89 eV

(1 mark)

REASONING
The smallest jump from E_3 to E_2 will emit the smallest-energy photon.

$$E_3 - E_2 = -1.51 - -3.4 = 1.89 eV$$

21. An unstable nucleus of uranium-238 ($^{238}_{92}U$) decays to a thorium isotope via alpha decay.

(a) Balance the decay reaction below by writing the atomic and mass numbers.

$$^{238}_{92}U \rightarrow Th + \alpha$$

(3 marks)

$$^{238}_{92}U \longrightarrow ^{234}_{90}Th + ^{4}_{2}\alpha$$

(b) Explain why the alpha particles emitted by this type of radioactive decay have a range of discrete energies.

Both the nuclei (U and Th) have discrete nuclear energy levels.

When the nucleus decays to Th, it may decay to the ground state or one of the higher excited states.

It follows that as the nucleus decays the emitted alpha particles will have a range of discrete energies so that the overall (discrete) energy of this reaction is conserved.

(3 marks)

(c) A series of alpha and beta minus decays starts with uranium-238 and ends with $^{206}_{82}Pb$, a stable isotope of lead. There are eight alpha decays in this series of decays.

Determine the number of beta minus decays in the series of decays.

After 8 alpha ($8\,^{4}_{2}\alpha$) decays the atomic number of product nucleus becomes 92-16=76 and the mass number becomes 238 – 32=206.

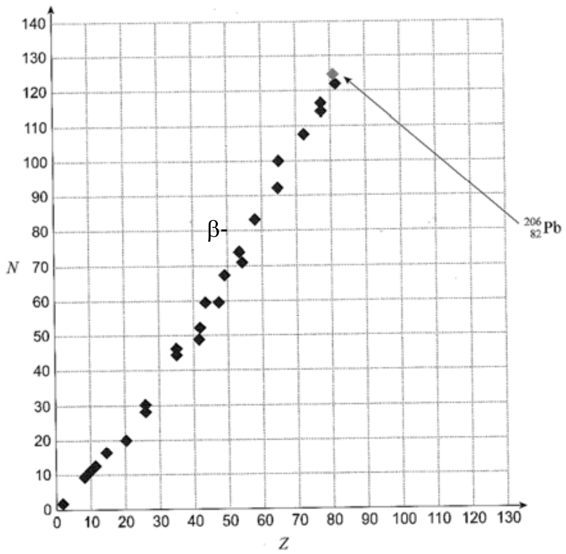
Lead (Pb) has atomic number 82.

Using the law of conservation of charge, it follows that 6 beta minus decays must occur.

$$^{238}_{92}U \longrightarrow ^{206}_{82}X + 6\,^{0}_{-1}e + 8\,^{4}_{2}\alpha + 6\,^{0}_{0}\overline{\upsilon}$$

(3 marks)

(d) The diagram below shows a graph of N (the number of neutrons) against Z (atomic number) for some stable nuclei:



(i) *On the graph above*, write the symbol $\beta-$ to indicate the position of an unstable nucleus that is likely to undergo a beta minus decay. (1 mark)

(ii) The position of the nucleus $^{206}_{82}Pb$ is indicated on the diagram.

Explain how it is possible to have stable nuclei despite the strong repulsive electrostatic force between the 82 protons in this nucleus.

There exists a strong nuclear force between the nucleons (protons and neutrons) in the nucleus that is attractive and stronger than the repulsive electrostatic forces between the 82 protons.

This force acts over short distances and quickly becomes negligible at separations of more than a few nucleon diameters. This is how the nucleons (which are very close) can be held together in a stable nucleus.

(2 marks)

22. The radioisotope oxygen-15 $\left({}^{15}\mathrm{O}\right)$ is used in positron emission tomography (PET) scans because it undergoes a beta plus decay in which a positron is emitted.

(a) State the other particle emitted in the beta plus decay of oxygen-15.

neutrino

(1 mark)

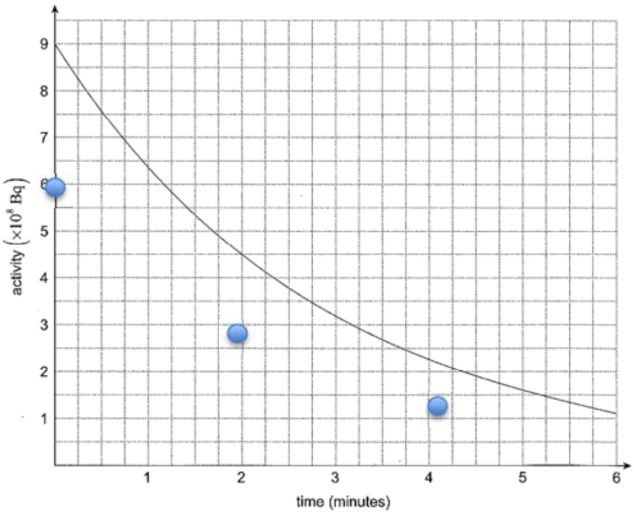
(b) Explain how the emission of a positron by oxygen-15 can lead to the production of gamma rays.

The emitted positron can collide with a nearby electron and annihilate.

The mass is converted into energy in the form of two identical photons that travel in opposite directions so that momentum is conserved.

(2 marks)

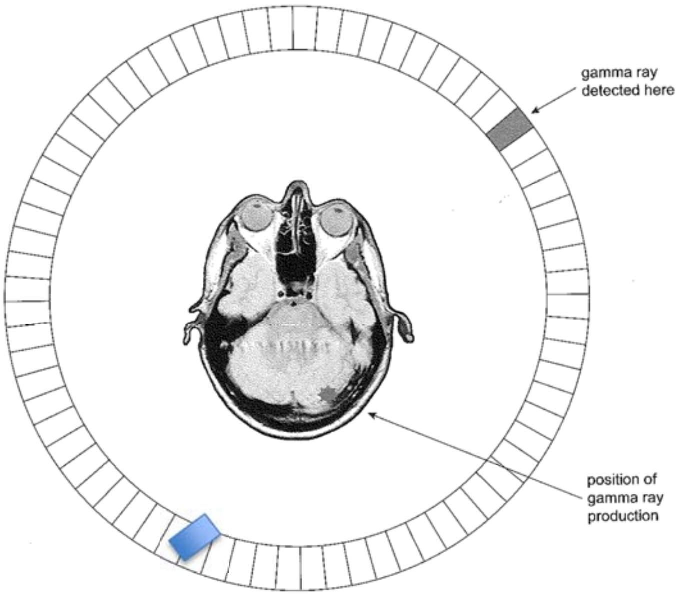
(c) The graph below shows changes over 6 minutes in the activity of ^{15}O-labelled water given to a patient undergoing a PET scan:



On the graph above, show how the activity of ^{15}O-labelled water with an initial activity of 6.0×10^8 Bq would change over 6 minutes. (3 marks)

HINT
The half life is 2 days. This is constant.

(d) The diagram below shows the ring of photon detectors used in a PET scan, with the position of gamma ray production indicated. The diagram also shows the position at which one gamma ray is detected.



Source: Image adapted from www.giblip.org

On the diagram above, indicate the position at which another gamma ray should be detected.
(1 mark)

REASONING
The photons travel in opposite directions.

23. Uranium found in nature consists primarily of two isotopes: uranium-235 and uranium-238. Naturally occurring uranium contains approximately 0.7% of the uranium-235 isotope.

(a) Explain why the uranium fuel for a fission power reactor needs to be enriched.

Uranium-238 does not readily undergo induced fission where as uranium-235 does.

Enriching the source means that a larger percentage of uranium-235 is added to the fuel. This ensures that enough of the nuclei undergo induced fission and a chain reaction can occur.

(2 marks)

(b) One method of enriching uranium fuel involves using a laser to ionise uranium-235 atoms.

Calculate the energy given to a uranium-235 atom by a laser photon with a wavelength of 502 nm.

$$E = hf = \frac{hc}{\lambda} = \frac{6.63x10^{-34}x3x10^{8}}{502x10^{-9}} = 3.96x10^{-19}J$$

(3 marks)

COMMON ERROR
Wavelength needs to be in SI units
nm to m multiply by 10^{-9}

24. Scientists believe that, in some massive stars, two carbon nuclei can undergo fusion reactions. One possible reaction is shown below:

$$^{12}_{6}C + ^{12}_{6}C \rightarrow ^{23}_{12}Mg + ^{1}_{0}n$$

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

$$^{12}_{6}C = 1.9921\times10^{-26}\,kg$$

$$^{23}_{12}Mg = 3.8172\times10^{-26}\,kg$$

$$^{1}_{0}n = 1.6749\times10^{-27}\,kg.$$

Determine whether energy is absorbed or released in this reaction, and calculate the amount of energy that is absorbed or released.

Mass of products $m_{cMg} + m_n$ = 3.8172x10^{-26} + 1.6749x10^{-27} = 3.98469x10^{-26} kg
Mass of reactant $2m_C$ = 2x1.9921x10^{-26} = 3.9842x10^{-26} kg

The mass of the products is greater than the mass of the reactants – energy is absorbed.

$$\Delta m = m_{products} - m_{reactants} = 3.98469x10^{-26} - 3.9842x10^{-26} = 4.9x10^{-30}\quad kg$$

$$E = \Delta mc^2 = 4.9x10^{-30}x(3x10^8)^2 = 4.41x10^{-13}\quad J$$

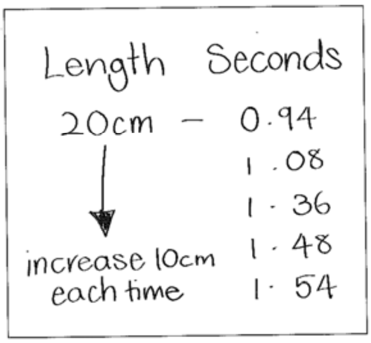
(5 marks)

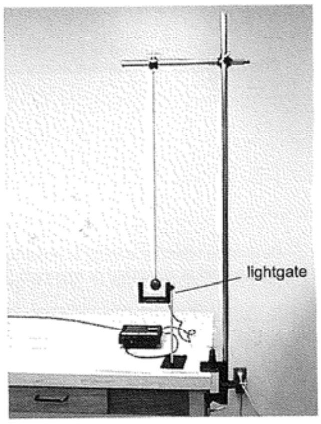
25. Students conduct an experiment in which the period of a pendulum is used to determine the acceleration of gravity.

A simple pendulum is set up with different lengths of string L. The pendulum is set swinging with a small displacement and the period T is recorded by using a lightgate connected to a computer.

The photograph (right) shows the equipment used in the experiment.

The data recorded by the students conducting the experiment are shown below:


Length Seconds
20cm – 0.94
1.08
1.36
1.48
1.54
increase 10cm each time



Source: Adapted from www.phys.ufl.edu/demo/3

(a) *In the space below*, display the students' data in a table, including a column of T^2 values.

Length of pendulum/string L (cm)	**Period T (s)**	**T^2 (s^2)**
20	0.94	0.88
30	1.08	1.17
40	1.36	1.85
50	1.48	2.19
60	1.54	2.37

(3 marks)

(b) Identify the independent variable in the experiment.

The length of the pendulum/string.

(1 mark)

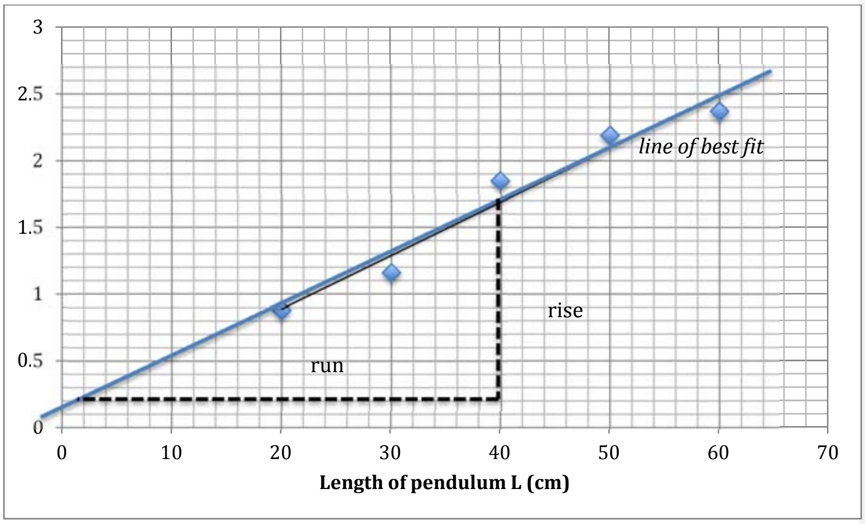
(c) *On the page opposite*, plot a graph showing the relationship between L and T^2. Include a line of best fit.

(6 marks)

REASONING:
The independent variable is the variable intentionally changed by the experimenter.

The relationship between period squared (T^2) and length of the pendulum.

T^2(s^2)



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

$$gradient = \frac{rise}{run} = \frac{1.7-0.2}{40-2} = 0.039 \quad s^2cm^{-1}$$

(3 marks)

(e) The period T of a pendulum of length L is given by:

$$T = 2\pi\sqrt{\frac{L}{g}}.$$

Using the gradient of your line of best fit, determine the acceleration due to gravity g.

$$T^2 = 4\pi^2\frac{L}{g}$$

Since the straight line has an equation $T^2=0.039L$

It follows that the slope $0.039=\frac{4\pi^2}{g}$

$$g = \frac{4\pi^2}{0.039} = 1010 \quad cms^{-2} = 10.1ms^{-2}$$

(3 marks)

(f) Suggest, giving reasons:

- one improvement that would increase the accuracy of the experiment
- one improvement that would increase the precision of the experiment.

Accuracy is how close the experimental value is to the actual value and can be improved by reducing systematic errors. An example of this would be to check that the light gate is correctly calibrated by repeating the experiment with a different light gate.

Precision is how much scatter there is in the data collected. This can be reduced, by reducing any random errors in the experiment. An example of this would be to repeat the measurements of period for each length at least three times.

(4 marks)

SECTION B (Questions 26 and 27)

(30 marks)

*Questions 26 and 27 are extended-response questions. Answer **both** questions.*

Write your answers in this question booklet:

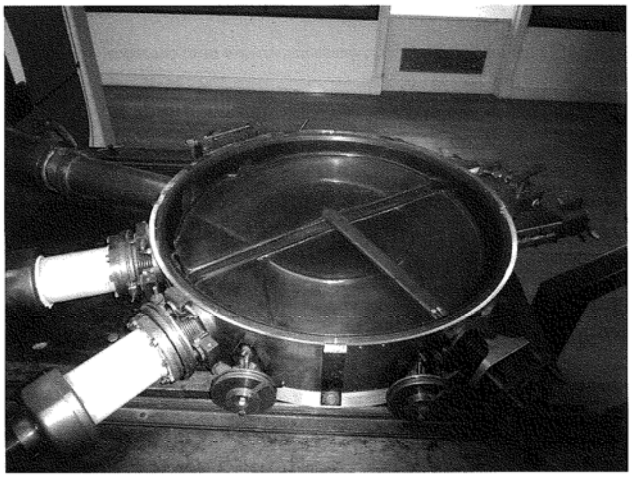
- Question 26, on pages 4 and 5, is worth 14 marks.
- Question 27, on pages 6 and 7, is worth 16 marks.

In answering these questions, you should:

- communicate your knowledge clearly and concisely
- use physics terms correctly
- present information in an organised and logical sequence
- include only information that is related to the question.

You may use clearly labelled diagrams that are related to your answers.

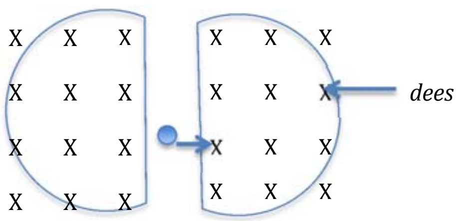
26. The photograph below shows the cyclotron in the Musée des Arts et Métiers in Paris:



Source: www.mhs-science.org.uk

The magnetic field in the dees of a cyclotron causes ions to undergo circular motion so that they cross between the dees many times. As a result the ions gain a high kinetic energy.

- Explain why the ions move with uniform circular motion each time they are in one of the dees.
- Describe the relationship between the final kinetic energy of the ions and the radius of the cyclotron. (14 marks)



As the ions enter the dees they do so at 90° to a uniform magnetic field.

A constant magnetic force always acts at 90° to the velocity of the charges.

Even though the speed remains the same, the direction of motion changes.

By definition there is a change in velocity $\Delta\vec{v} = \vec{v}_f - \vec{v}_i$ and hence acceleration given by $\vec{a} = \frac{\Delta\vec{v}}{\Delta t}$.

The magnetic force therefore provides the centripetal acceleration for uniform circular motion.

Each time the ions cross the gap between the dees, they are accelerated by a uniform electric field.

Every time the ions cross the electric field, the work done (W) by the electric field is converted into kinetic energy.

Kinetic energy each time the ions cross the gap = W = $q\Delta V = \frac{1}{2}mv^2$. The ions do not gain energy or speed while they are in the dees.

It can be shown that the final kinetic energy of the ions as they emerge from the cyclotron is given by $K = \frac{q^2B^2r^2}{2m}$ where r is the radius of the cyclotron.

It therefore follows that the final kinetic energy is directly proportional to the square of the cyclotron's radius.

This means that if the radius of the cyclotron is doubled, the kinetic energy becomes four times larger. Alternatively, if the radius is 10 times larger the kinetic energy will be 100 times larger. If the radius is 3 times smaller, the kinetic energy will be 9 times etc

HINT
$2^2 = 4$
$10^2 = 100$
$3^2 = 9$

27. In the photoelectric effect the emitted electrons have a range of energies. In the production of X-rays the X-ray photons also have a range of energies.

- Explain the range of kinetic energies of the electrons emitted in the photoelectric effect when monochromatic light is used.
- Explain the range of energies in the spectrum of X-rays when the potential difference across the X-ray tube is constant. (16 marks)

If monochromatic light is incident on a metal surface it contains a single frequency (*f*) only.

The light consists of many photons. Photons are bundles of discrete energy.

Each photon has a discrete energy given by $E = hf$ where *h* is Planck's constant (6.63×10^{-34} Js).

Electrons within the metal are bound by differing amounts of energy (depending on how deep within the metal they are positioned).

Using the law of conservation of energy, the energy of the photon is used to release and electron and any 'left over' energy is given up as the kinetic energy of the emitted electron.

This produces a range of kinetic energies up to maximum given by:

$K_{max} = hf - W$ where *W* is the work function of the metal. The work function is defined as the energy needed to release the least bound or surface electrons.

Electrons in an X-ray tube are released from a heated filament.

Each electron gains a discrete energy given by $K = q\Delta V$ as they accelerate across the potential difference ΔV.

When the electrons collide with the target metal they decelerate and lose kinetic energy.

The law of conservation of energy applies. Most of the collisions produce heat but approximately one percent of the collisions produce X-ray photons of energy equal to the energy 'lost' by the electrons during the collision.

The amount of kinetic energy lost by the colliding electrons depends on how closely they collide with the nucleus. This produces a range of X-ray photons with a range of energies.