CORPUS CHRISTI COLLEGE

SEQUERE DOMINUM

YEAR 12 ATAR PHYSICS
UNIT 3 and 4
SEMESTER TWO EXAMINATION 2018

Teacher: W O'CALLAGHAN / K ROURKE
(Circle)

Student Number: In figures

In words Solns

Time allowed for this paper Reading time before commencing work: 10 minutes
Working Time: 3 hours

Materials required/recommended for this paper

To be provided by the supervisor This Question/Answer Booklet
Formulae and Constants Booklet

To be provided by the candidate
Standard items: pens, pencils, eraser, correction fluid/tape, ruler, highlighters
Special items: non-programmable calculators approved for use in the WACE examinations, drawing templates, drawing compass and a protractor

Important note to candidates
No other items may be taken into the examination room. It is **your** responsibility to ensure that you do not have any unauthorised notes or other items of a non-personal nature in the examination room. If you have any unauthorised material with you, hand it to the supervisor **before** reading any further.

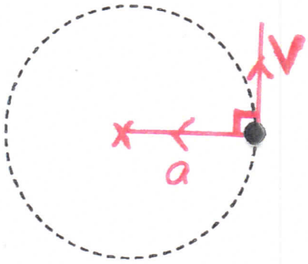
Section One: Short response **30% (60 Marks)**

This section has **11** questions. Answer **all** questions.

Suggested working time: 50 minutes.

Question 1 **(3 marks)**

(a) An object moves in a circle **in a counter-clockwise direction** with constant speed. On the diagram below draw and label the correct velocity and acceleration vectors for the object. (2 marks)



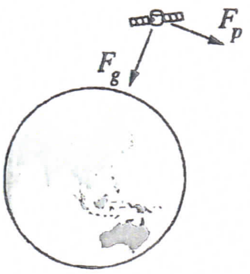
✓ centripetal acceleration towards centre

✓ tangential velocity up

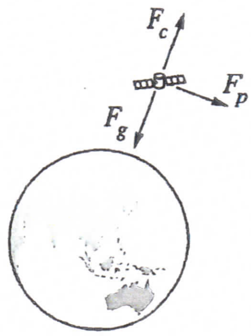
(b) Which of the following diagrams correctly represents the force(s) acting on a satellite in a stable circular orbit around Earth? Circle the correct answer. (1 mark)

F_g = gravitational force	F_p = propulsive force
F_c = centripetal force	F_r = reaction force

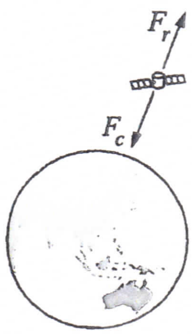
(A)



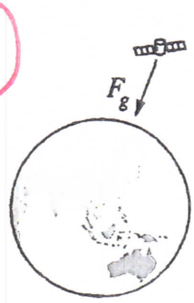
(B)



(C)



(D)



stable circular orbit, only force is gravitational attractive force, ⊥ to its motion

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Question 2 **(5 marks)**

Digital television in New Zealand can be accessed by using a satellite dish pointed at a satellite in space. The satellite used to transmit the signals appears to stay still above the equator.

The satellite, with a mass of 300 kg, is actually travelling around the Earth in a geostationary orbit at a radius of 4.22 x 10^7 m from the centre of the Earth.

(a) Calculate the force acting on the satellite. (2 marks)

$F_g = \frac{G M_E m_s}{r^2} = \frac{6.67\times10^{-11} \times 5.97\times10^{24} \times 300}{(4.22\times10^7)^2}$ ✓

$= 67.1$ N towards centre of orbit ✓

(b) Show that the speed of the satellite is about 3 x 10^3 m s^{-1}. (3 marks)

$F_c = \frac{mv^2}{r}$ $F_c = F_g$ ✓ correct equation

$v = \sqrt{\frac{F_c \times r}{m}} = \sqrt{\frac{67.1\times(4.22\times10^7)}{300}}$ ✓ rearrange

$= 3.07 \times 10^3$ ms^{-1}

$\sim 3\times10^3$ ms^{-1} ✓ solution

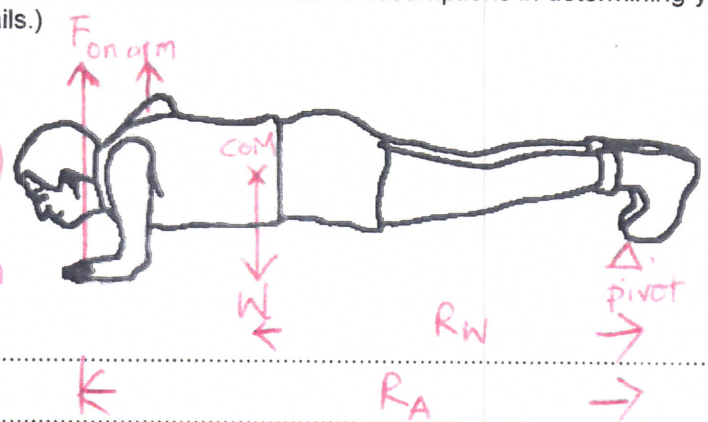
Question 3 **(5 marks)**

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.)

Mass (between 50 to 75 kg)

COM to toe = 0.85 to 1.05 m

Hand to toe = 1.25 to 1.5 m



✓✓ FBD

✓ data

Data Ranges : W = 490 to 735 N

Estimated force on each arm = 165 to 255 N ✓ 2sf

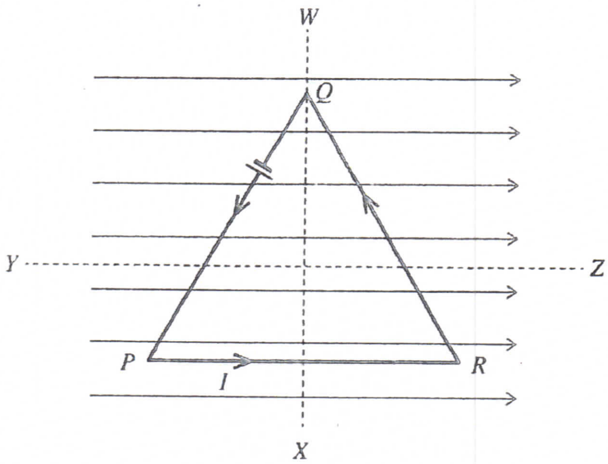
eg. At equil^m $\Sigma CM = \Sigma ACM$ ✓

$F_{arm} \times 1.25 = (50\times9.8)(0.85)$

$\therefore F_{arm} = 333.2/2 = 166.6$ N 7/10

Question 4 **(5 marks)**

(a) A triangular piece of wire is placed in a magnetic field as shown.



RHPR shows

F_{QR} ⊙

F_{QP} ⊗

$F_{PR} = 0$

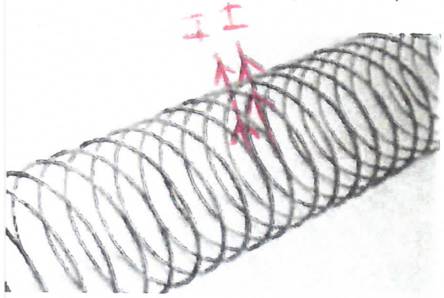
wire rotates about WX with R into page

When current I is supplied as shown, how does the wire move? Circle the correct answer.
(1 mark)

	Axis of rotation	*Direction of movement*
A	YZ	Q into page
B	YZ	Q out of page
C	WX	R into page
D	WX	R out of page

(b) A current is sent through a helical coil spring, as shown in the diagram below. When the current is flowing the spring contracts, as though it had been compressed.

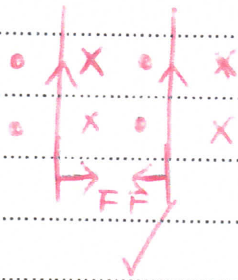
Explain why this is so. [Hint: Annotate and refer to the diagram in your answer or even draw an alternative diagram].
(4 marks)



* I in each turn of helical coil has same magnitude, flows in same direction (see right) ✓

* Each turn has a magnetic field associated with it (due to I) ✓

*



✓

* magnetic fields set up a force of attraction between resultant external magnetic field forcing turns to be closer together (or compressed) ✓

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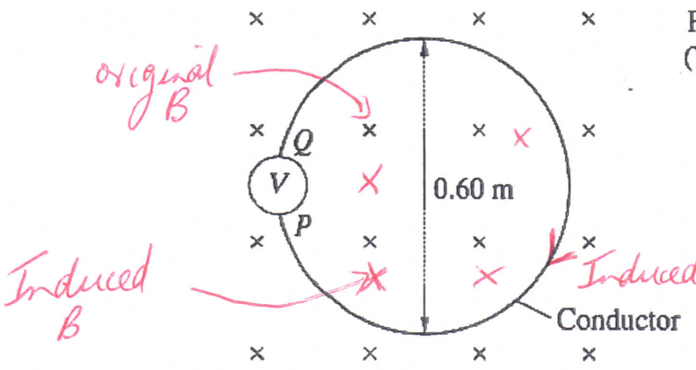
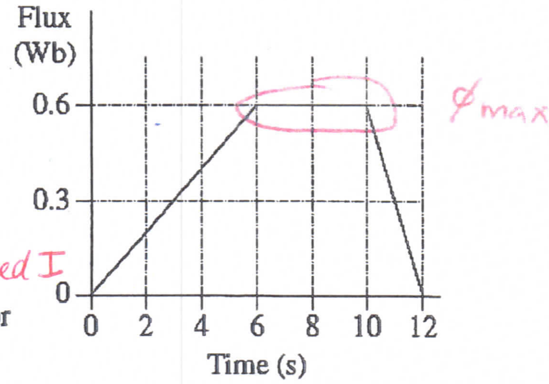
Question 5 **(5 marks)**

The diagram shows an electric circuit in a magnetic field directed into the page. The graph shows how the flux through the conductive loop changes over a period of 12 seconds.





(a) Calculate the maximum magnetic field strength within the stationary loop during the 12-second interval. (2 marks)

Max Flux ϕ occurs at $B_{max} = \frac{\phi}{A}$

$\phi = BA$

$= \frac{0.6}{\pi(0.30)^2} = 2.12\,T$ ✓ ✓

(b) Calculate the maximum voltage generated in the circuit by the changing flux. In your answer, indicate the direction of the induced current between the terminals *P* and *Q* when this occurs. (3 marks)

use Faraday's Law $\varepsilon = \frac{-\Delta flux}{time} = -\frac{\Delta\phi}{\Delta t}$ ✓

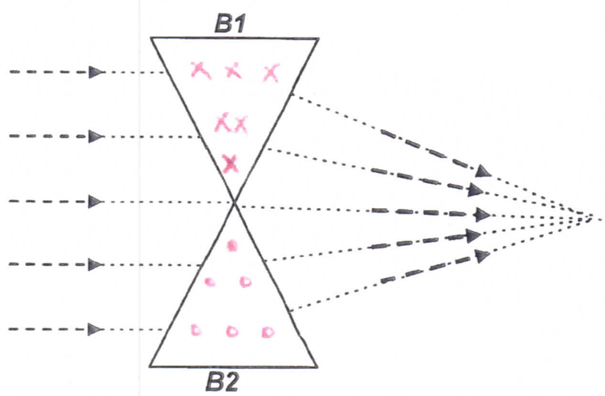
largest voltage produced by largest rate of change in flux

$\Rightarrow$ graph with steepest slope from 10 to 12 s

$\varepsilon_{induced} = \frac{-0.6}{2} = 0.3\,V$ ✓ I induced clockwise

Question 6 **(7 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.



(a) Illustrate the directions of the magnetic fields *B1* and *B2* inside the triangular "magnetic" lenses (1 mark)

B1 ×

B2 • ✓

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(b) Calculate the magnitude of 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)

$F = Bqv$

$= 0.1 \times 1.6\times10^{-19} \times 1.50\times10^{6}$ ✓

$= 2.40\times10^{-14}$ N ✓

(c) (i) Calculate the de Broglie wavelength of an electron that has a velocity of 1.50×10^6 ms^{-1}. (1 mark)

$\lambda = \frac{h}{p} = \frac{h}{mv}$

$= \frac{h}{(1.6\times10^{-19} \times 1.50\times10^{6})} = 2.76\times10^{-21}$ m ✓

(ii) Use this result to explain why an electron microscope is capable of much higher magnifications and has a greater resolving power than a light microscope, allowing it to see much smaller objects in finer detail. (3 marks)

$\lambda_{electron} = 2.76\times10^{-21}$ m

$\lambda_{light,min} = 400$ nm $= 4.00\times10^{-7}$ m ✓

Any object that is $\frac{1}{2}\lambda$ of microscope's illuminatory source is not visible under that microscope ✓

$\frac{\lambda_{light}}{\lambda_{electron}} \sim 10^{14}$ | Electron microscopes able to resolve objects thousands of time smaller ✓

OR The larger the λ the greater the diffraction & hence the less detail in image

Question 7 **(12 marks)**

A beam of 35.0 keV electrons strike a molybdenum target, generating X-rays.

(a) (i) Determine the cut-off wavelength of the X rays produced. (λmin). (3 marks)

$E = \frac{hc}{\lambda}$ ✓

$\lambda_{min} = \frac{hc}{E} = \frac{6.63\times10^{-34} \times 3\times10^{8}}{35\times10^{3} \times 1.6\times10^{-19}} = 3.55\times10^{-11}$ m ✓ ✓

(ii) Are these X-rays hard or soft? Give a possible use for these X-rays. (2 marks)

From Data Sheet these X rays are in the region that overlaps with γ-rays ∴ hard X-rays.
Used for NDT, eg testing welds in pipes.

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(b) Given that the power supplied to the X-ray tube in (a) is 18 kW, estimate how many X-ray photons would be produced in a 5.0 ms period of usage. (5 marks)

$E_{Xray\ photon} = hf = \frac{hc}{\lambda} = \frac{6.63\times10^{-34} \times 3\times10^{8}}{3.55\times10^{-11}}$ ✓

$= 5.60\times10^{-15}$ J

$E_{total} = 18\times10^{3} \frac{J}{s} \times 5\times10^{-3} s = 90$ J ✓ $E=Pt$

$\#\ photons = \frac{90}{(5.6\times10^{-15})} = 1.61\times10^{16}$ ✓

But only 1% efficient ∴ # photons = 1.61×10^{14} ✓

(c) Multiple Choice (2 marks)

(i) The main advantage of using X-rays produced by a synchrotron rather than X-rays produced in a conventional X-ray tube in an X-ray machine is that

A X-rays from an X-ray machine cannot be tuned using a monochromator.

B X-rays from an X-ray machine can only be used to investigate biological materials.

C the beamline of a synchrotron can produce an intense single-wavelength X-ray beam. ✓

D radiation from a synchrotron will scatter more readily than the conventionally produced X-rays.

(ii) In the Australian Synchrotron, electrons are accelerated in several stages and their final speed approaches the speed of light.

Which of the following best describes the order in which the various components accelerate the electrons?

	First	Second	Third
A.	linac	electron gun	booster ring
B.	linac	booster ring	electron gun
C.	electron gun	linac	booster ring
D.	electron gun	booster ring	linac

✓

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Question 8 **(3 marks)**

The wavelength of the H_β line in the spectrum of the star Megrez in the constellation Ursa Major (the Great Bear) is 486.112 nm. Laboratory measurements demonstrate that the normal wavelength of this spectral line is 486.133 nm. Is the star coming towards us or moving away from us? Justify your answer. No calculation is required. (3 marks)

* Light is blue shifted (moved towards a shorter λ)

* Therefore star is moving towards us

* Because amount of space between Megrez and us is decreasing, λ_{light} contracts to fit the space (hence shifted to blue end of spectrum)

OR Doppler Effect

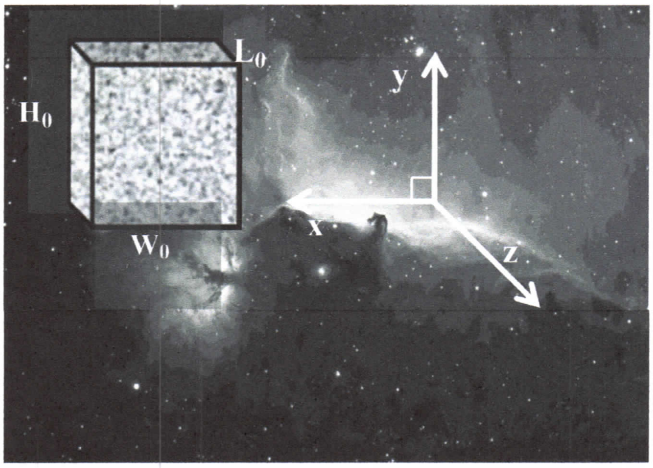
Question 9 **(3 marks)**

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

The astronaut is stationary and the view in the diagram (shown right) is what she sees from her faceplate.

A "Borg" spaceship, in the form of a cube is travelling at 20% of the speed of light (i.e. 0.2c) and is on a heading towards the astronaut *in the z direction*.

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



(a) Which of the following options best describes the dimensions (**L, W** and **H**) 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: C (1 mark)

(b) Carefully explain why you selected your answer. No calculation is required. (2 marks)

* when object travels at relativistic speeds, length contraction occurs.

* This length contraction is only in the direction of travel as seen from stationary observer

* Other dimensions not affected

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Question 10 **(5 marks)**

An alien spacecraft travelling at relativistic speed is flying overhead at a great distance as you stand in your backyard. You see its searchlight blink on for 1.20 s.

(a) The alien first officer on the spacecraft measures that the searchlight is on for 0.19 s. What is the speed of the spacecraft relative to the earth expressed as a fraction of the speed of light? (3 marks)

Time dilation : Time slows down in alien spacecraft. $t = t_0\sqrt{1 - v^2/c^2}$

$0.19 = 1.20\sqrt{1 - v^2/c^2}$

$\frac{0.19^2}{1.20} = 1 - v^2/c^2$

$0.0301 = 1 - v^2/c^2$

$v = \sqrt{1 - 0.0301}\,c = \underline{0.985c}$

$t = \frac{t_0}{\sqrt{1-\frac{v^2}{c^2}}}$

$\Rightarrow 1.20 = \frac{0.19}{\sqrt{1-\frac{v^2}{c^2}}}$

$\Rightarrow 1 - \frac{v^2}{c^2} = 2.507 \times 10^{-2}$

$\Rightarrow c^2 - v^2 = 2.507 \times 10^{-2} c^2$

$\Rightarrow v = \sqrt{0.9749c^2} = 0.987c$

(b) How does Einstein's Theory of Special Relativity explain the time difference of the blinks that we measure on Earth and what the alien measures on the spacecraft? (2 marks)

longer time interval to us compared to alien ✓
light travelling to us on earth must travel a greater distance
For speed of light to be constant ratio of space to time must remain constant & therefore time must be dilated (stretched) or slowed down. ✓

Question 11 **(7 marks)**

Towards the end of the 20th century scientists suggested that quarks were the basic building blocks of protons and neutrons. Classify the following sub-atomic particles as either Hadrons, Leptons or Neither.

(2 marks)

Proton	Hadron	Neutrino	Lepton
Muon	Lepton	Virtual photon	Neither (Boson)

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uus

(b) A member of the Σ group of particles consists of two u quarks and an s quark.

(i) What is its charge? Show your working. (2 marks)

charge $= +\frac{2}{3} + \frac{2}{3} - \frac{1}{3} = \frac{4}{3} - \frac{1}{3}$ ✓

$= +1e$ ✓

(ii) What is its Baryon Number? Show your working. (1 mark)

Baryon # $= \frac{1}{3} + \frac{1}{3} + \frac{1}{3} = 1$ ✓

(iii) Is the particle a fermion or a boson? Show your working. (1 mark)

✓ fermion (odd half integer spin)

the member is a composite particle made up of 3 quarks

(iv) Calculate its mass in terms of c. Show your working. (1 mark)

$= (2.3\times10^6 + 2.3\times10^6 + 95\times10^6)\frac{eV}{c^2} = 99.6\frac{MeV}{c^2}$ ✓

Cancelled (v) State the value of its Strangeness. -1 ✓ ~~(1 mark)~~

5

Section Two: Problem-solving **50% (98 Marks)**

This section has **eight (8)** questions. Answer **all** questions. Write your answers in the spaces provided.

Suggested working time: 90 minutes.

Question 12 **(7 marks)**

Figure 1 shows a model of a system being designed to move concrete building blocks from an upper to a lower level.

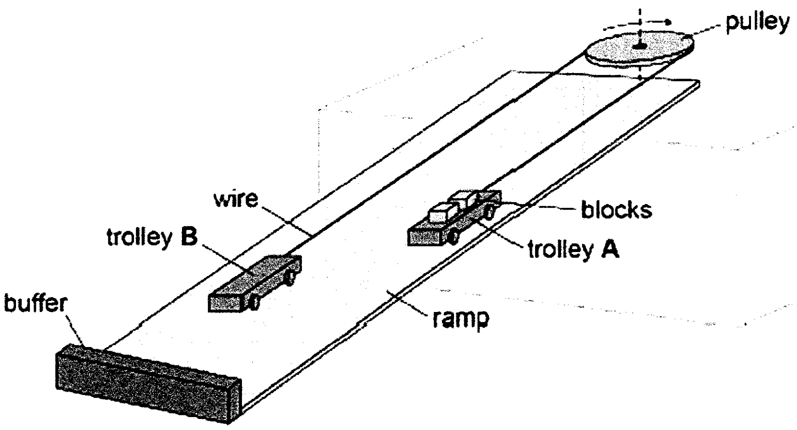


Figure 1

The model consists of two identical trolleys of mass ***M*** on a ramp which is at 35° to the horizontal. The trolleys are connected by a wire that passes around a pulley of negligible mass at the top of the ramp.

Two concrete blocks each of mass ***m*** are loaded onto trolley **A** at the top of the ramp. The trolley is released and accelerates to the bottom of the ramp where it is stopped by a flexible buffer. The blocks are unloaded from trolley **A** and two blocks are loaded onto trolley **B** that is now at the top of the ramp. The trolleys are released and the process is repeated.

Figure 2 shows the side view of trolley **A** when it is moving **down** the ramp.

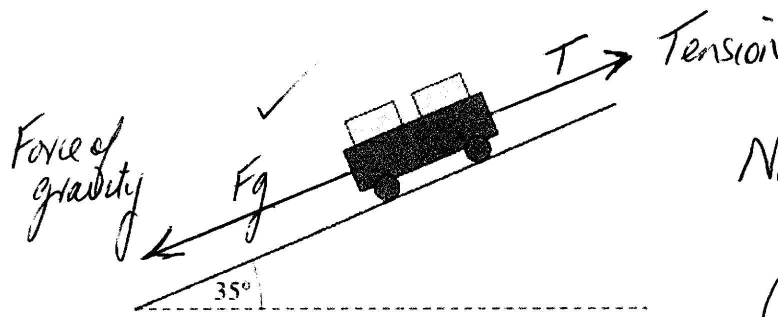


Figure 2

Note: Fg longer than T (accelerating down)

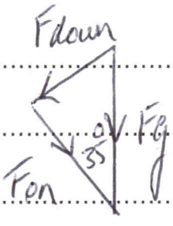
The tension in the wire when the trolleys are moving is **T**.

Assume that no friction acts at the axle of the pulley or at the axles of the trolleys or between the wheels and the ramp and that air resistance is negligible.

(a) Draw and label arrows on **Figure 2** to represent the magnitudes and directions of any forces that act on trolley **A** *parallel* to the ramp as it travels down the ramp. (2 marks)

2

(ii) Write an expression in terms of M and m for the force of gravity acting on trolley **A** *parallel* to the ramp as it travels down the ramp. (2 marks)



$F_{down} = F_g \sin 35°$ ✓

$= (M+m)(9.8) \times \sin 35°$

$= \underline{(M+m)\, g \sin 35°}$ ✓

(iii) Show that the acceleration ***a*** of trolley **A** along the ramp is given by

$$a = \frac{m\,g \sin 35°}{M+m}$$

(3 marks)

Tension in the string reducing the accel^n of Trolley A is the force due to gravity pulling Trolley B down the ramp. ie $F = T = Mg \sin 35°$ ✓

$F_{net} = F_g$ on A $- T$

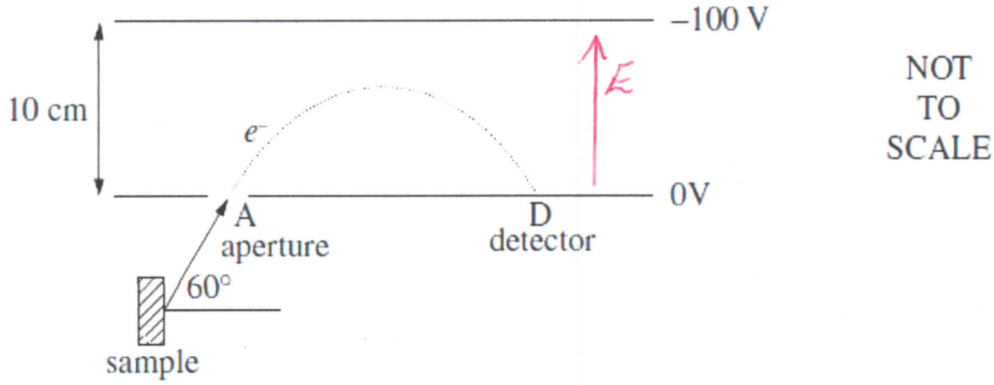
$= (M+m) g \sin 35 - Mg \sin 35°$ ✓

So $(M+m)\, a = \cancel{Mg \sin 35} + mg \sin 35 - \cancel{Mg \sin 35°}$ ✓

$\therefore \; a = \dfrac{mg \sin 35°}{M+m}$

Question 13 **(9 marks)**

An electron is emitted from a mineral sample, and travels through aperture **A** into a spectrometer at an angle of 60.0° with a speed of 6.00 x 10^6 m s^{-1}.



(a) Calculate the magnitude and direction of the force experienced by the electron inside the spectrometer. (3 marks)

$F = Eq \qquad E = \frac{V}{d} = \frac{100}{0.10} = 1000 \text{ V m}^{-1}$ ✓

$= 1000 \times 1.6 \times 10^{-19}$ ✓

$= \underline{1.60 \times 10^{-16} \text{ N}}$ ✓ Vertically down to 0V plate

causes parabolic motion

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(b) The electron experiences constant acceleration and eventually strikes the detector, D. What is the time taken for the electron to travel from **A** to **D**? (4 marks)

Perfect parabola. Only vertical vel affected by E field

$6\times10^{6}\,ms^{-1}$, 60°, y, x

$y = 6\times10^{6}\times\sin 60^\circ = 5.196\times10^{6}\,ms^{-1}$

$F = ma$

$1.60\times10^{-16} = 9.11\times10^{-31}a$

$a = 1.756\times10^{14}\,ms^{-2}$

Mid pt: $v = u + at$

$0 = 5.196\times10^{6} + at$

$t = \dfrac{5.196\times10^{6}}{1.756\times10^{14}}$

$= 2.959\times10^{-8}\,s$

$\therefore$ total time $= 5.92\times10^{-8}\,s$

Displacement: $s = ut + \frac{1}{2}at^2$

$0 = 5.196\times10^{6}t + \frac{1}{2}at^2$

$\therefore 0 = 5.196\times10^{6} - \frac{1}{2}(1.756\times10^{14})t$

$\therefore t = \dfrac{5.196\times10^{6}}{\frac{1}{2}(1.756\times10^{14})}$

$t = 5.92\times10^{-8}\,s$

(c) Calculate the distance between **A** and **D**. (2 marks)

Horizontal: $s = vt$

$V_x = 6\times10^{6}\cos 60^\circ$

$= 3\times10^{6}\,ms^{-1}$

$\therefore s = 3\times10^{6}\times5.92\times10^{-8}$

$= 1.775\times10^{-1}$

$= 0.178\,m$

Question 14 **(18 marks)**

(a) **Figure 1** shows two magnets, supported on a yoke, placed on an electronic balance.

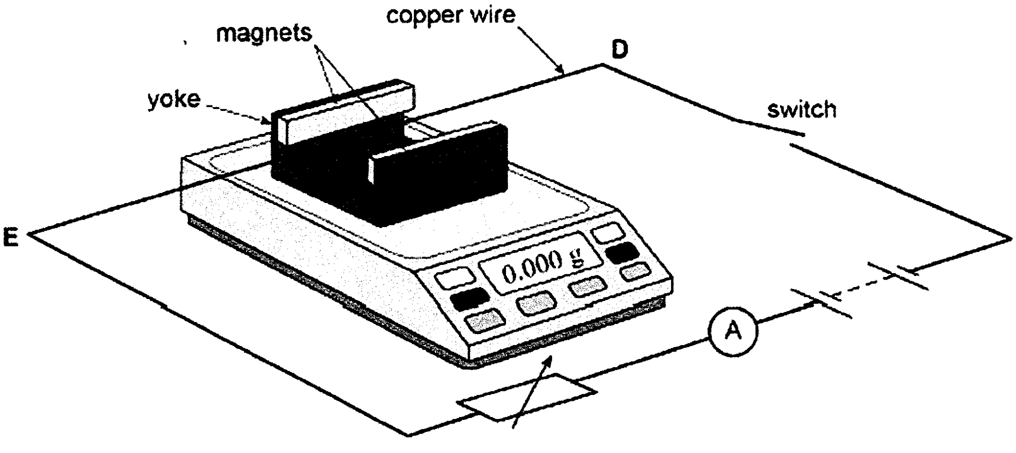

Figure 1

The magnets produce a uniform horizontal magnetic field in the region between them. A copper wire **DE** is connected in the circuit shown in **Figure 1** and is clamped horizontally at right angles to the magnetic field.

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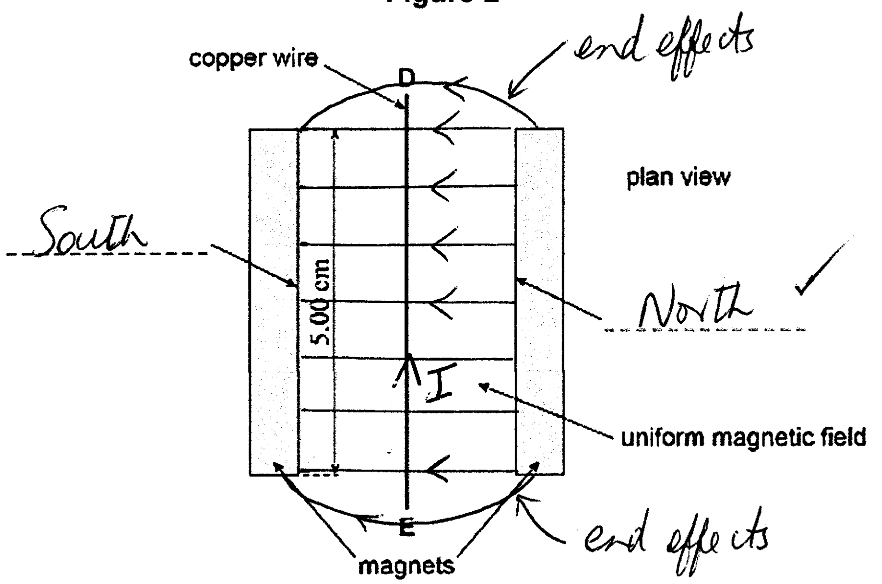
Figure 2 shows a simplified plan view of the copper wire and magnets.

Figure 2



When the apparatus is assembled with the switch open, the reading on the electronic balance is set to 0.000 g. This reading changes to a positive value when the switch is closed.

(i) Which of the following correctly describes the direction of the force acting on the wire **DE** due to the magnetic field when the switch is closed?

Tick (✓) the correct box. (1 mark)

towards the left magnet in Figure 2	
towards the right magnet in Figure 2	
vertically up	✓
vertically down	

Newtons 3rd Law: If scales are pushed down then wire is pushed up.

(ii) Label the poles of the magnets by putting **N** or **S** on each of the two dashed lines in **Figure 2**. Draw the magnetic field between the magnets. [Use a minimum of 6 lines of flux.] (2 marks)

B field evenly spaced $(\frac{1}{2})$, correct direction $(\frac{1}{2})$

(iii) Define the tesla. (2 marks)

In this context ($F = BIl$): A magnet field strength of 1 tesla produces a force 1 Newton per metre of wire carrying a current of 1 ampere (perp to wire)

(iv) The magnets are 5.00 cm long. When the current in the wire is 3.43 A the reading on the electronic balance is 0.620 g. Assume the field is uniform and is zero beyond the length of the magnets.

Calculate the magnetic flux density between the magnets. (2 marks)

$F = BIl$ ✓

$\frac{1}{2}$ mark for each conversion $(0.620 \times 10^{-3})(9.8) = B \times 3.43 \times 0.05$ ✓

$B = 3.543 \times 10^{-2} = \underline{3.54 \times 10^{-2}\ T}$ (3sf)

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(b) A cyclotron has two D-shaped regions where the magnetic flux density is constant. The D-shaped regions are separated by a small gap.

An alternating electric field between the D-shaped regions accelerates charged particles. The magnetic field causes the charged particles to follow a circular path.

Figure 3 shows the path followed by **a proton** that starts from **O**.

Magnetic field: 0.44 T   ΔV between "D"s: 186000 V

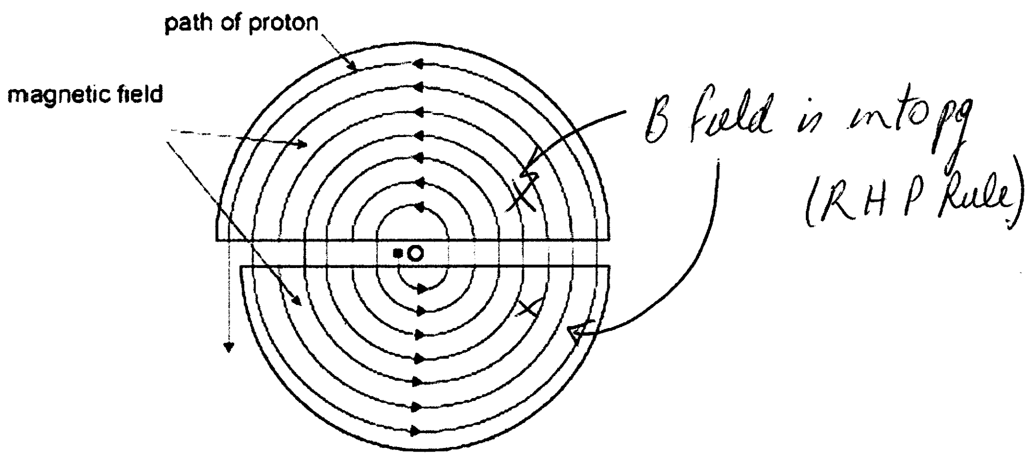


Figure 3

(i) Show clearly on Figure 3 the direction of the magnetic fields in the D-shaped regions. (1 mark)

(ii) Explain why it is **not** possible for the magnetic field to alter the speed of a proton while it is in one of the D-shaped regions. (2 marks)

$W \Leftrightarrow E_K$ and $W = Fs$. However, the force is towards the centre of O and the direction of motion ('s') is perpendicular to F. Since these are independent no work is done on the proton, so speed unaffected.

(iii) When the proton crosses the gap between the "D"s, how much energy does it gain? (2 marks)

$W \Leftrightarrow E = Vq$

$= 186000 \times 1.6 \times 10^{-19}$

$= 2.976 \times 10^{-14} = \underline{2.98 \times 10^{-14}\ J}$

5

(iv) The maximum radius of the path followed by the proton is 0.85 m and the magnetic flux density of the uniform field is 0.44 T.

Calculate the maximum speed of a proton when it leaves the cyclotron. (2 marks)

Ignore any relativistic effects.

$r = mv/Bq$

$\therefore v = \frac{rBq}{m} = \frac{0.85 \times 0.44 \times 1.6 \times 10^{-19}}{1.67 \times 10^{-27}}$ ✓

$= 3.583 \times 10^{7} = \underline{3.58 \times 10^{7}\ ms^{-1}}$ ✓

Is the assumption: "*Ignore any relativistic effects.*" reasonable? Explain briefly. (1 mark)

No $3.58 \times 10^{7} / 3 \times 10^{8} \times 100 = 11.9\%\ c$

Relativistic effects become significant at $v \geq 10\% \cdot c$

The following expression for the cyclotron frequency is independent of the radius of the path.

$$f = \frac{q\,B}{2\,\pi\,m}$$

A synchrocyclotron is a cyclotron in which the frequency of the driving electric field is varied to compensate for relativistic effects as the particles' velocity begins to approach the speed of light. This is in contrast to the classical cyclotron, where the frequency was held constant.

Assuming that the correction is necessary, calculate the cyclotron frequency. (3 marks)

Increase in mass $m = \gamma m_0$ =

$\therefore m = \frac{1.67 \times 10^{-27}}{\sqrt{1 - v^2/c^2}} = \frac{1.67 \times 10^{-27}}{\sqrt{1 - \left(\frac{0.358 \times 10^{8}}{3 \times 10^{8}}\right)^2}}$ ✓

$m = 1.682 \times 10^{-27}$ kg ✓

$\therefore f = \frac{1.60 \times 10^{-19} \times 0.44}{2\pi m} = \underline{6.66 \times 10^{6}\ Hz}$ ✓

(v) Use formulae on the Data Sheet to derive following expression for the cyclotron frequency. (2 marks)

$$f = \frac{q\,B}{2\,\pi\,m}$$

(CANCELLED) (due to Time restraint)

$F_B = F_c$

$Bq\cancel{v} = \frac{mv^{\cancel{2}}}{r}$ But $v = 2\pi r/T$

$\therefore Bq = m\left(\frac{2\pi \cancel{r}}{T}\right)\frac{1}{\cancel{r}}$ and $T = 1/f$

$\therefore Bq = 2\pi f m \therefore f = \frac{Bq}{2\pi m}$.

6

Question 15 **(16 marks)**

(a) The following makeshift device, **Figure 1**, was made to provide lighting for a stranded astronaut on Mars.

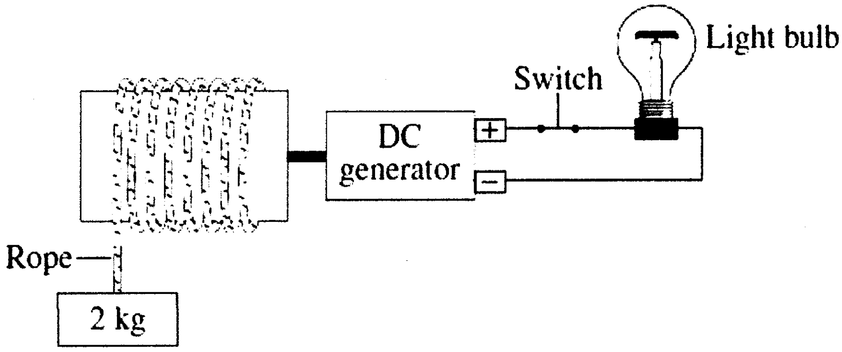


Figure 1

Explain the difference in the behaviour of the falling mass when the switch is open.

(3 marks)

When the switch is opened the mass will fall faster ✓ than when the switch is closed. With the switch closed the rotating generator will provide an induced Emf that opposes the motion caused by gravity due to Faraday's Law ✓ Lenz's Laws resp. When the switch is open there is no opposing force to gravity

(b) The alternator in **Figure 2** has a rectangular coil with sides of 0.30 m x 0.40 m and 10 turns. The coil rotates 240 times a minute in a uniform magnetic field. The magnetic flux intensity through the coil in the position shown is 0.20 T.

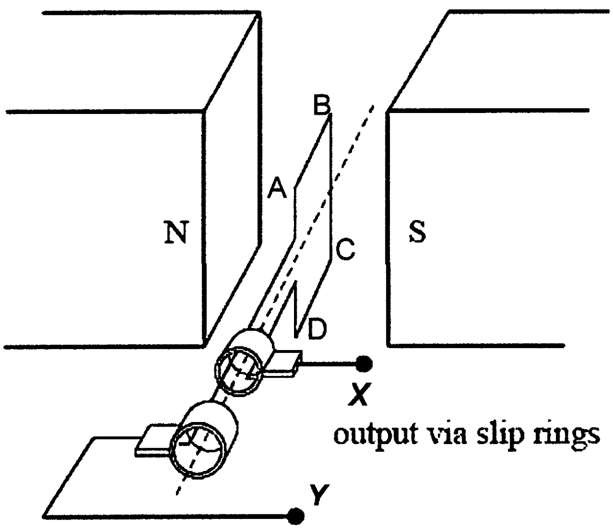


Figure 2

3

(i) Calculate the magnitude of the peak EMF ($\mathcal{E}$) generated. (2 marks)

$EMF_{max} = 2\pi BAnf$

$= 2\pi\ 0.20\ (0.30 \times 40) \times 10 \times \frac{240}{60}$

$= 30.16\ V$

$= 30.2\ V$ (3sf)

Figure 3 shows the output EMF ($\mathcal{E}$) versus time graph of the alternator for two complete cycles.

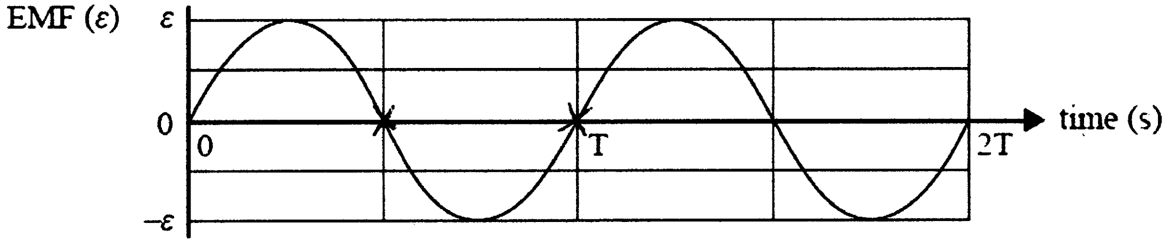
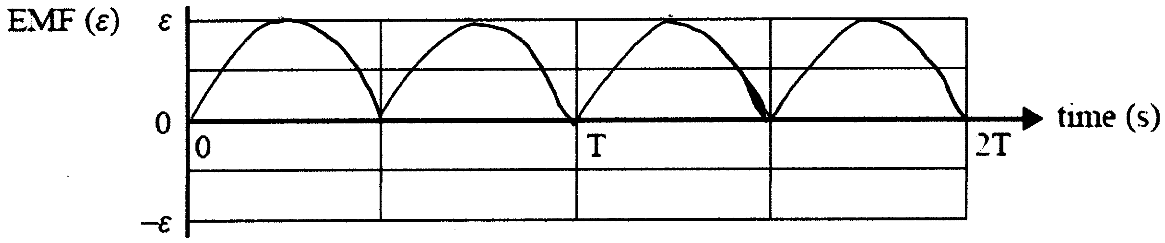


Figure 3

(ii) On **Figure 3** show a point that corresponds to the EMF at the point of rotation shown in **Figure 2.** Any pt showing EMF = 0. (1 mark)

The two slip rings in **Figure 2** are now replaced with a split-ring commutator.

(iii) On the axes provided below, sketch the EMF ($\mathcal{E}$) versus time graph of this new arrangement for two complete cycles. (2 marks)



Again refer to **Figure 2.**

(iv) Describe the orientation and movement of the coil ABCD so that the output slip ring ***X*** is + (positive) and the output slip ring **Y** is – (negative). (2 marks)

X is attached to DC, Y is attached to AB

For X to be positive current must be induced from C → D ie current must be induced A → B → C → D.

Side CD must be moving clockwise past the S pole magnet.

4

(c) (i) **Figure 4** shows lines of force for the electric field surrounding two charged objects **L** and **M**.

N is a point between **L** and **M**.

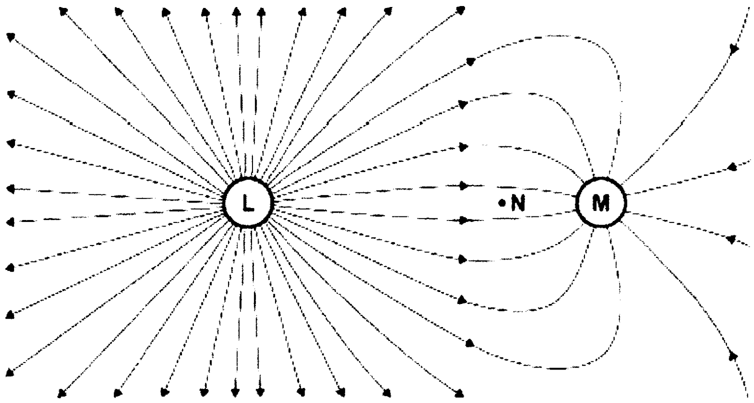


Figure 4

State which object **L** or **M** has a charge with the greater magnitude. ....L.... ($\frac{1}{2}$)

State which object **L** or **M** has a positive charge. ....L.... ($\frac{1}{2}$)

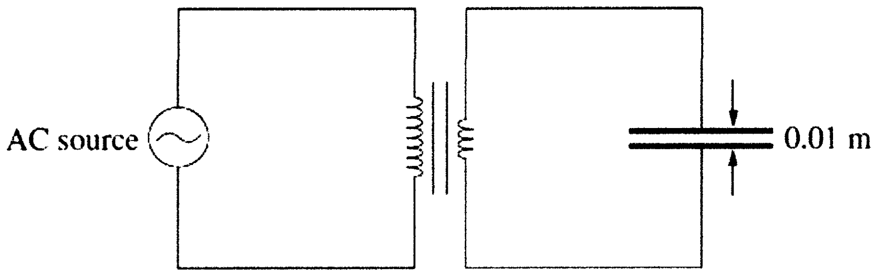
(1 mark)

Explain why the lines of force shown in **Figure 4** cannot represent a gravitational field.

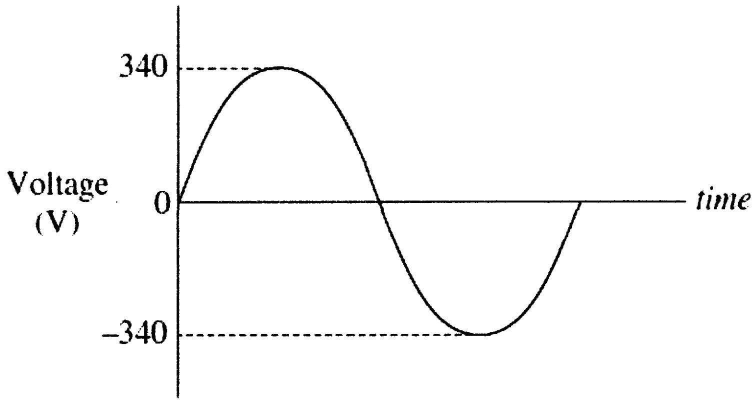
(2 marks)

A gravitational field only attracts objects. Hence the lines representing the field are always directed towards an object. Lines directed away from L not possible.

(ii) An AC source is connected to a transformer having a primary winding of 900 turns. Connected to the secondary winding of 450 turns is a pair of parallel plates 0.010 m apart.



The AC input is shown in the graph.



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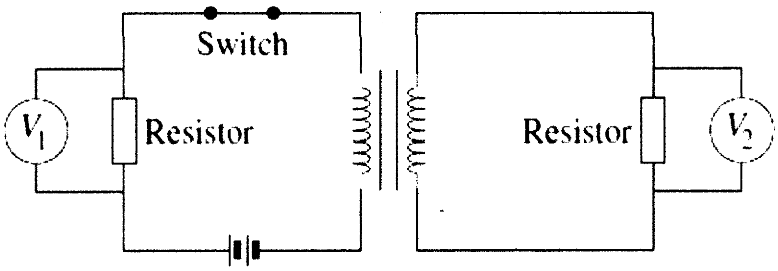
What is the maximum field strength (in V m^{-1}) produced between the plates? (2 marks)

$\frac{N_s}{N_p} = \frac{V_s}{V_p}$ $\quad \frac{450}{900} = \frac{V_s}{340}$ $\quad \therefore V_s = 170V$

$E = \frac{V}{d} = \frac{170}{0.010} = 17000\,V = 1.70 \times 10^4\,V$ (3sf)

(iii) The diagram shows a DC circuit containing a transformer.

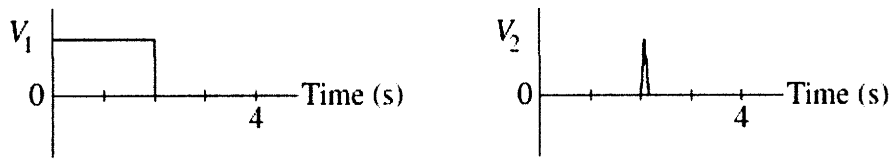


The potential differences V_1 and V_2 are measured continuously for 4 s.

The switch is initially closed. At t = 2 s, the switch is opened. → Voltage drops.

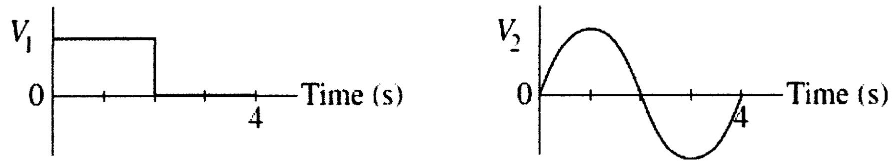
Which pair of graphs shows how the potential differences V_1 and V_2 vary with time over the 4-second interval? Circle the correct answer. (1 mark)

A.

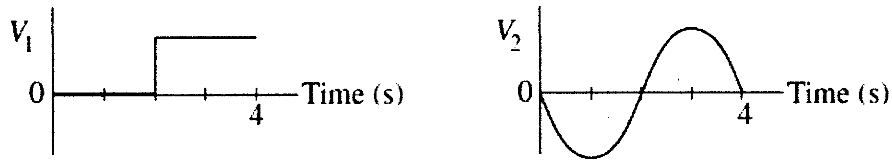


Faraday's Law!

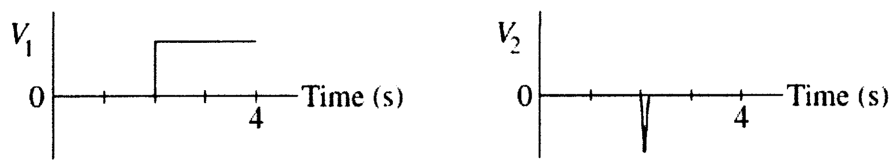
B.



C.



D.



3

Question 16 **(14 marks)**

(a) An aurora is the appearance of brilliant coloured 'curtains' of light in the sky near the north and south poles.

Particles discharged from the sun, known as the Solar Wind, travel toward Earth before they are drawn irresistibly toward the magnetic north and south poles. As the particles pass through the Earth's magnetic shield, they mingle with atoms and molecules of oxygen, nitrogen and other elements that result in the dazzling display of lights in the sky.

Typically, when the particles collide with oxygen, yellow and green are produced. Interactions with nitrogen produce red, violet, and occasionally blue colours.

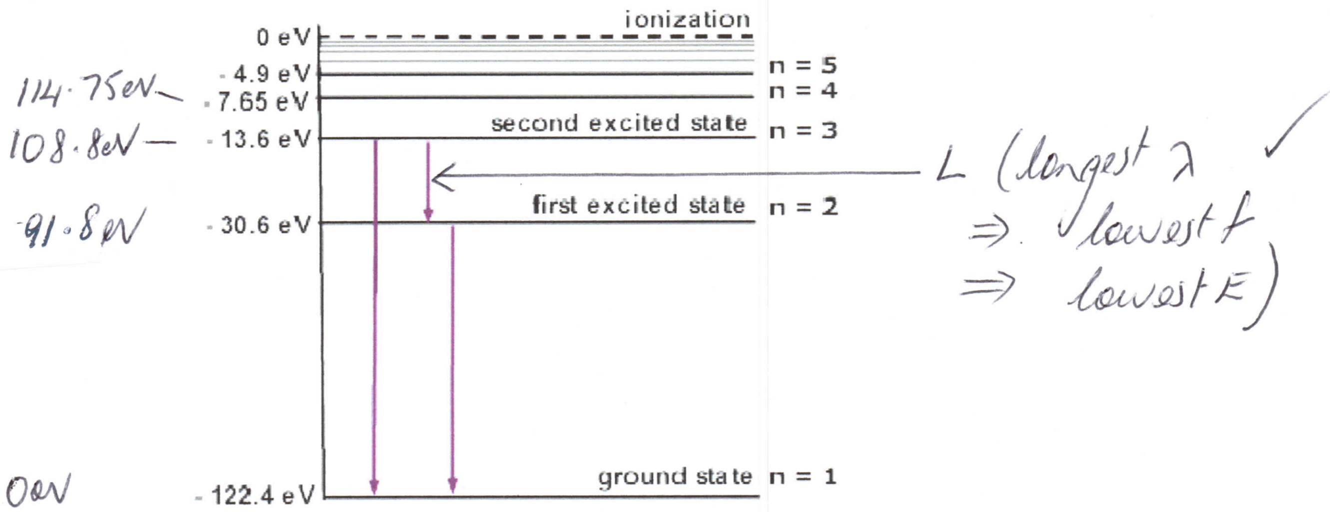
Carefully explain, using physics principles, how and why auroras occur and the reason for the different colours. (4 marks)

✓ Particle bombardment of atoms/molecules of O_2 & N_2 cause the atoms of these gases become excited.

Electrons in these gases can only exist in certain ✓ possible energy levels & hence can only aborb energy corresponding to the difference between these energy levels.

When the $\bar{e}$ return to the ground state they ✓ emit EMR photons corresponding the difference in energy levels. Since O_2 & N_2 atoms have unique ✓ energy levels the photons emitted will have different energies & hence different colours, as mentioned

(b) Consider some of the energy levels for Neon given below.



4

(i) Consider the 3 transitions shown.

Would these transitions shown be part of an *absorption* or *emission* spectrum? Circle the correct answer. (1 mark)

Indicate on the diagram the transition with the longest wavelength using the letter ***L***.

Calculate this wavelength.

Is this a photon of visible light? (4 marks)

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

$-13.6-(-30.6) = 17\,eV$

$-13.6-(-30.6) \times 1.6\times10^{-19} = \frac{6.63\times10^{-34}\times3\times10^{8}}{\lambda}$

$\therefore \lambda = hc/2.72\times10^{-18} = 7.31\times10^{-8}\,m$ (3sf)

No, U.V. region (not 400nm → 750nm)

(ii) State what would emerge from a sample of neon gas when it is bombarded by the following photons or particles. (5 marks)

Bombarding particles	Emerging particles (eV) or photons
Photons of 114.75 eV $n=4 \rightarrow n=1$	photons of 114.75eV, 5.95eV, 108.8eV $\left({}^4C_2 = \frac{4\times3}{2\times1} = 6\right)$ 22.95eV, 91.8eV, 17.0eV
Electrons of 110 eV $n=3 \rightarrow n=1$	e^- of 110 eV (elastic collision) e^- of 1.2eV, photons of 108.8eV, 17.0eV, 91.8eV. e^- of 18.2eV, photons of 91.8eV. (repeat unnecessary)

$\left(-\frac{1}{2}\right)$ commission

$/10$

Question 17 **(11 marks)**

In an experiment, blue light of frequency 6.25 x 10^{14} Hz is shone onto the sodium cathode of a photocell. The apparatus is shown in Figure 1 below.

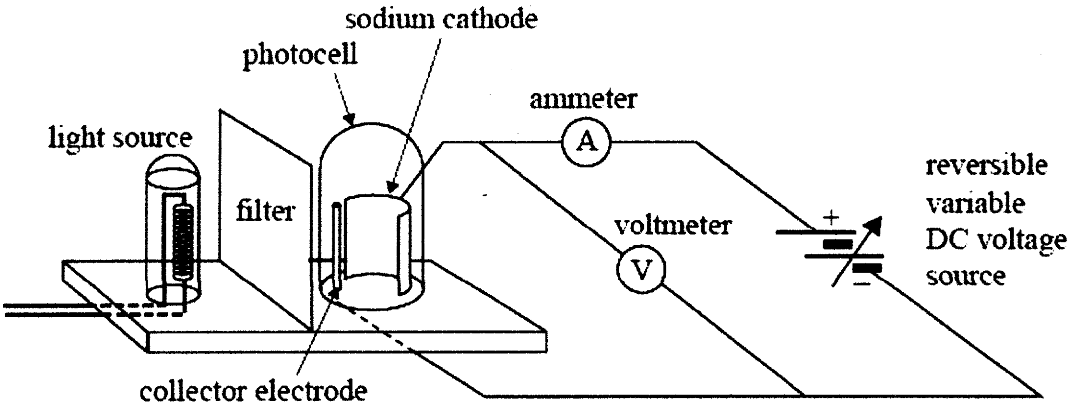
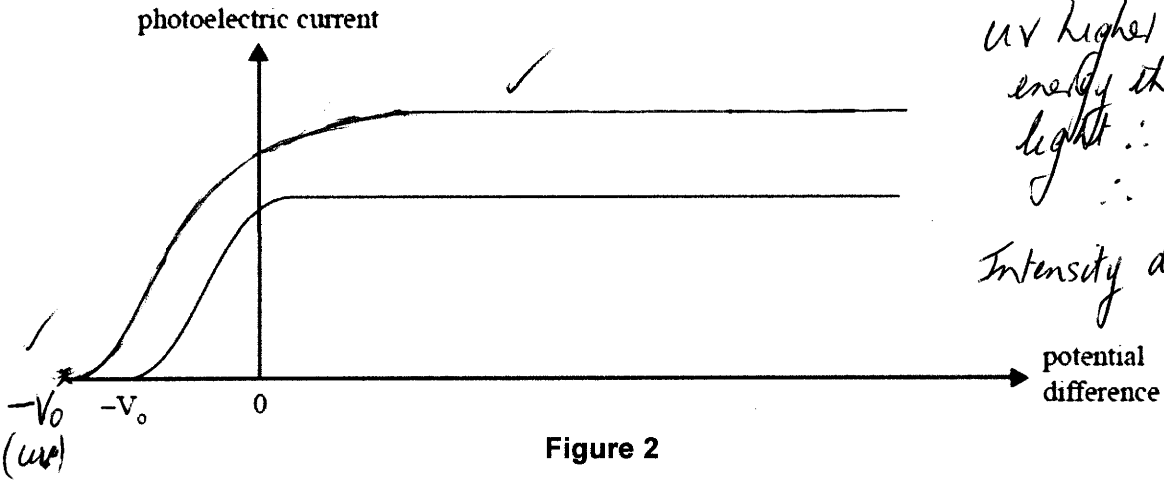


Figure 1

The graph of photoelectric current versus potential difference across the photocell is shown in Figure 2.



UV higher in energy than blue light ∴ $E_K \uparrow$ ∴ $V_0 \uparrow$

Intensity determines I.

Figure 2

The threshold frequency for sodium is 5.50 x 10^{14} Hz.

(a) Determine the maximum speed of the ejected electrons. (3 marks)

$E_{in} = E_0 + E_K$

$hf = hf_0 + E_K$

$6.63 \times 10^{-34} \times 6.25 \times 10^{14} = 6.63 \times 10^{-34} \times 5.50 \times 10^{14} + E_K$

$E_K = 4.973 \times 10^{-20}$ J

So $\frac{1}{2} m v^2 = 4.973 \times 10^{-20}$

$\frac{1}{2}(9.11 \times 10^{-31}) v^2 = 4.973 \times 10^{-20}$

$v = \sqrt{1.092 \times 10^{11}}$

$= 3.304 \times 10^5 \text{ ms}^{-1} = \underline{3.30 \times 10^5 \text{ ms}^{-1}}$

/3

(b) What is the cut-off potential, Vo, when blue light of frequency 6.25×10^{14} Hz is shone onto the sodium cathode of the photocell referred to in Figures 1 and 2? (2 marks)

$E_K = W = V_s q$

$4.973 \times 10^{-20} = V_0 \times 1.6 \times 10^{-19}$ ✓

$V_0 = 0.3108\,V = 0.311\,V$ ✓

Cut-off potential $= -0.311\,V$ (no penalty for missing -ve sign)

(c) On the graph of photoelectric current versus potential difference shown in Figure 2, sketch the curve expected if the light is changed to **ultraviolet** with a **higher intensity** than the original blue light. (2 marks)

$f_{uv} > f_{blue\ light}$.

(d) The results of photoelectric effect experiments in general provide strong evidence for the particle-like nature of light.

Outline **two** aspects of these results that provide the strong evidence that is not explained by the wave model of light, and explain why. (4 marks)

Students were required to identify two of the following:

- Negligible time delay – The wave model predicts that if the intensity of light is low enough then there will be a measurable delay between initiating the illumination of the metal and the observation of a photocurrent. The actual observation is that regardless of the intensity of the illumination, the photocurrent is observed to flow as soon as the metal is illuminated.
- The existence of a threshold frequency – The wave model predicts that all light, regardless of frequency, should produce a photocurrent since the measure of its energy is its amplitude. The actual observation is that frequencies below a certain value (the threshold frequency) will not produce a photocurrent regardless of the intensity (amplitude) of the wave.
- The independence of stopping voltage from intensity – The wave model predicts that increasing the intensity of the light source will increase the amount of energy delivered to the metal per unit of time. This will result in more photoelectrons being released and a greater range of kinetic energies of the photoelectrons as indicated by an increased stopping voltage. The actual observation is that increasing the intensity increases the photocurrent but has no effect on the stopping voltage.

/8

Question 18 **(15 marks)**

(a) Tests of relativistic time dilation have been made by observing the decay of short-lived particles. A muon, travelling from the edge of the atmosphere to the surface of Earth, is an example of such a particle.
To model this in the laboratory, another elementary particle with a shorter half-life is produced in a particle accelerator. It is travelling at 0.99875*c*. Scientists observe that this particle travels 9.14×10^{-5} m in a straight line from the point where it is made to the point where it decays into other particles. It is not accelerating.

(i) Calculate the lifetime of the particle in the scientists' frame of reference. (2 marks)

$s = vt$

$9.14 \times 10^{-5} = 0.99875c \times t$ ✓

$t = \dfrac{9.14 \times 10^{-5}}{0.99875 \times 3 \times 10^{8}} = \underline{3.05 \times 10^{-13}\ s}$ ✓

(ii) Calculate the distance that the particle travels in the laboratory, as measured in the particle's frame of reference. (2 marks)

length contraction: $l = l_0 \sqrt{1 - v^2/c^2}$

$= 9.14 \times 10^{-5} \times \sqrt{1 - (0.99875\cancel{c}/\cancel{c})^2}$ ✓

$= 4.569 \times 10^{-6}\ m$ ✓

$= \underline{4.57 \times 10^{-6}\ m}$ (3sf)

(iii) Explain why the scientists would observe more particles at the end of the laboratory measuring range than classical physics would expect. (2 marks)

($\frac{1}{2}$)

In the particles' frame of reference the distance to the detector is reduced ($\frac{1}{2}$). Hence more particles will be able to reach the detector before ✓ decaying, so more particles will be detected.

OR In the scientists' frame of reference ($\frac{1}{2}$), due to time dilation, the lifetime of the particles will increase. ($\frac{1}{2}$)
Hence ...

(b) A space probe speeding towards the nearest star moves at 0.250c and sends radio information at a broadcast frequency of 1.00 GHz.

(i) At what speed is the radio signal received on the Earth? Explain briefly. (2 marks)

Speed is c. ✓

This is due to Einstein's postulate. The speed of light is an absolute constant. It is the same regardless of movement of source or observer.

/8

(ii) What frequency is received on the Earth? (2 marks)

OR Time dilation

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

$= \frac{1}{1\times10^{9}}$

$= 1\times10^{-9}\ s$

$t = t_0\sqrt{1-\left(\frac{0.25c}{c}\right)^2}$

$= 1\times10^{-9}\times 0.9682$

$= 0.9682\times10^{-9}$

$\therefore f = \frac{1}{T} = 1.03\ GHz$

$v = f\lambda$ λ contracted

$3\times10^{8} = 1\times10^{9}\times\lambda$

$\lambda = 3\times10^{-1}\ m$

$l = l_0\sqrt{1-v^2/c^2}$

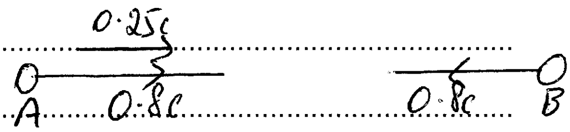
$= 3\times10^{-1}\sqrt{1-(0.25\cancel{c}/\cancel{c})^2} = 3\times10^{-1}\times 0.9682$

$= 2.905\times10^{-1}\ m$

$\therefore f = \frac{v}{\lambda} = \frac{3\times10^{8}}{2.905\times10^{-1}} = \underline{1.033\times10^{9}} = \underline{1.03\ GHz}$

(c) If two spaceships A and B are heading directly towards each other at 0.80c. A canister is shot from the first ship A at 0.25c, as measured in A's frame of reference.

(i) How fast will an external stationary observer see the projectile travelling? (2 marks)



$u = \frac{v + u'}{1 + \frac{vu'}{c^2}}$

$= \frac{0.8c + 0.25c}{1 + (0.8\cancel{c})(0.25\cancel{c})/\cancel{c^2}}$

$= \frac{1.05c}{1+0.2} = \underline{0.875c}$

(ii) How fast will B see the projectile approaching? (2 marks)

$u' = \frac{u - v}{1 - uv/c^2}$

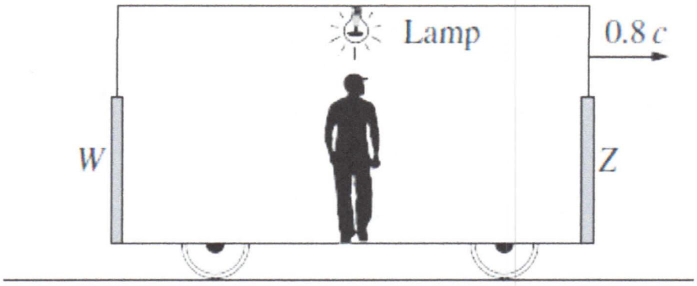
$= \frac{0.8c - (-0.875c)}{1 - (0.8\cancel{c})(-0.875\cancel{c})/\cancel{c^2}}$

$= \frac{1.675c}{1+0.7}$

$= \frac{1.675c}{1.7} = 0.9853c = \underline{0.985c}$

6

(d) In a thought experiment, a train is moving at a constant speed of $0.8c$. A lamp is located at the midpoint of a carriage. There are doors *W* and *Z* at each end of the carriage which open automatically when light from the lamp reaches them.



The passenger standing at the midpoint of the carriage switches on the lamp.
Which statement best explains what the passenger observes about the doors? (1 mark)

(A) *Z* opens before *W* because the lamp is moving towards *Z*.
(B) *W* opens before *Z* because *W* is moving towards the lamp.
(C) *W* and *Z* open simultaneously because the lamp is placed at an equal distance from both.
(D) *W* and *Z* open simultaneously because the distance from the lamp to each door has contracted by the same amount.

Question 19 **(8 marks)**

(a) **Figure 1** shows how the distance to a nearby star X can be determined using trigonometric parallax. E_1 and E_2 are the positions of the Earth in its orbit around the Sun in March and September, i.e. six months apart.

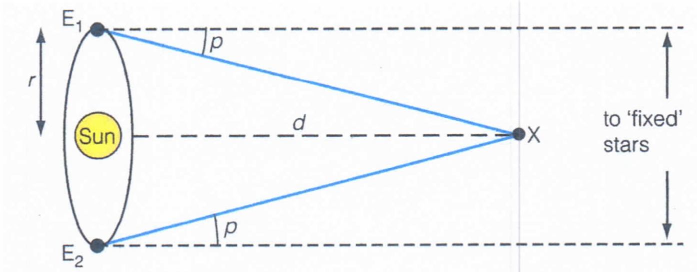


Figure 1

Taking *r* to be 1 AU, calculate the parallax angle *p* in degrees for a star that is 240 light years away. [1 year = 365.25 days.] (3 marks)

$S = 240\ ly$

$= 240 \times 3 \times 10^8 \times 365.25 \times 24 \times 60 \times 60$ ✓

$= 2.27 \times 10^{18}\ m$

$\tan\theta = \dfrac{1\ AU}{2.27 \times 10^{18}} = \dfrac{1.5 \times 10^{11}}{2.27 \times 10^{18}} = 6.602 \times 10^{-8}$ ✓

$\therefore \theta = \tan^{-1}(6.602 \times 10^{-8}) = (3.78 \times 10^{-6})^\circ$ ✓

4

(b) **Figure 2** shows a typical galaxy like the Milky Way, seen from 'the side'. The speed *v* of star S as it moves round the centre of the galaxy can be measured, as can the distance *r*.

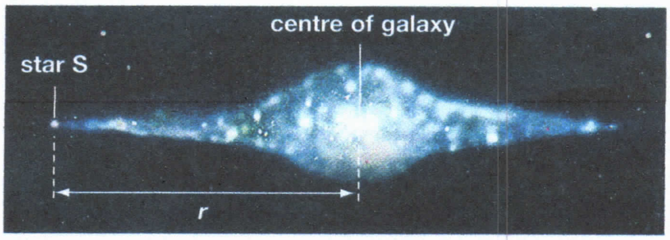


Figure 2

(i) **Figure 2** shows the stars in the galaxy detected by an optical telescope. What celestial objects would be detected by a telescope receiving EMR in the:

a) uv range?

The hottest stars (likely to be the newest stars)

b) X-ray range?

The radiation emitted by stars moving very quickly ($\approx c$) near the central black hole

(2 marks)

(ii) The mass of the galaxy can be calculated using the formula:

$$M_g = \frac{v^2 r}{G}$$

However the mass of the galaxy turns out to be much bigger than the mass expected by studying the luminosity of the galaxy. How do cosmologists explain this difference?

(3 marks)

Only about 5% of the mass of the Universe consists of atoms as we know them. The remainder of the mass is known as ($\frac{1}{2}$) dark matter & dark ($\frac{1}{2}$) energy. Some of the dark matter can be explained by "dead" ($\frac{1}{2}$) stars (now black dwarfs) and neutrinos. ($\frac{1}{2}$) Dark energy is still not understood.

/5

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

This section has two (2) questions. Write your answers in the spaces provided.

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

Suggested working time: 40 minutes.

Question 20 **(19 marks)**

An experiment is set up to investigate how the motion of a sphere on a track depends on the radius of curvature of the track.

The apparatus is set up as shown in **Figure 1**.

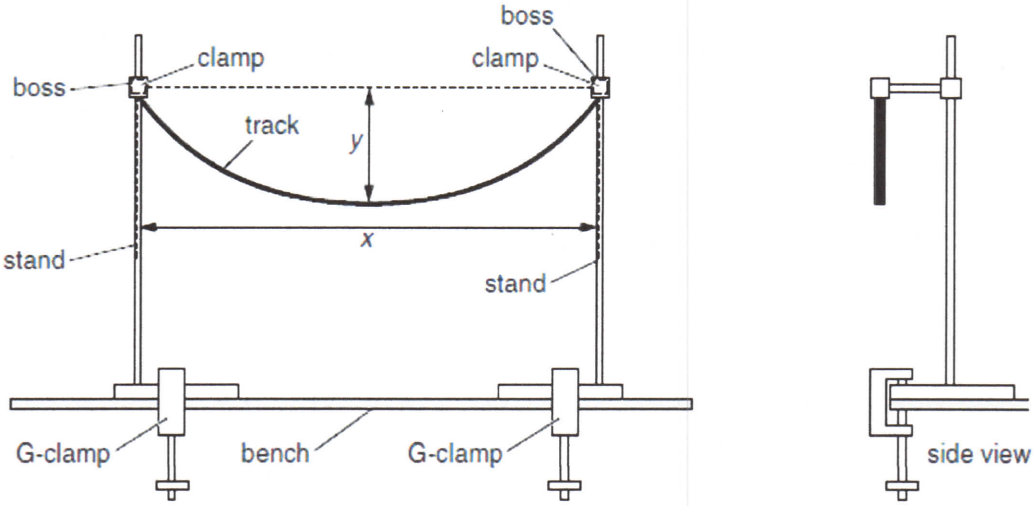


Figure 1

(a) The radius of curvature R of the track is calculated by

$$R = \frac{x^2}{8y} + \frac{y}{2}.$$

One set of data has x = 91.5 cm and y = 18 cm. Calculate the radius of curvature R, *in cm,* of the track, including the absolute error. Express your answer to the appropriate number of significant figures (4 marks)

$R = \frac{91.5^2}{8 \times 18} + \frac{18}{2}$

$= 67.14$ cm

So $R = 67.14 \pm (2.778 + 0.0546)$

$= 67.14 \pm 2.83\%$ $(\frac{1}{2})$

$= 67.14 \pm 1.902$

$= (67 \pm 2)$ cm $(\frac{1}{2})$

2sf $(\frac{1}{2})$

% error

$x = 91.5 \pm 0.05$ $(\frac{1}{2})$

$\% x = \frac{0.05}{91.5} \times 100$

$= 0.0273$ $(\frac{1}{2})$

$\therefore \% x^2 = 0.0273 \times 2$

$= 0.0546\%$ $(\frac{1}{2})$

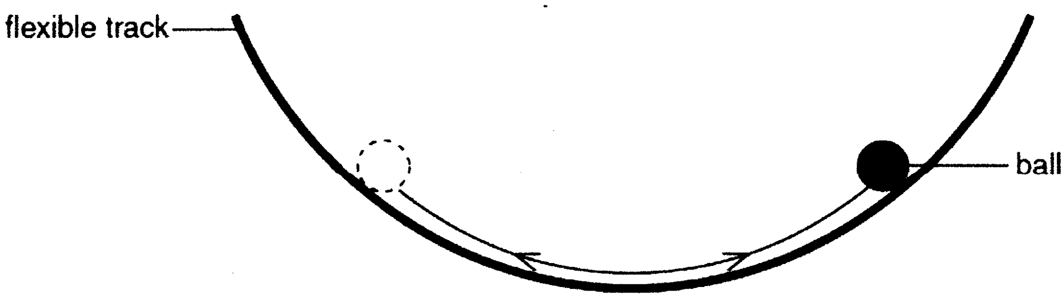
$y = 18 \pm 0.5$ cm $(\frac{1}{2})$

$\therefore \% y = \frac{0.5}{18} \times 100 = 2.778\%$

$(\frac{1}{2})$

/4

A ball rolls forwards and backwards on a curved track as shown in **Figure 2**.



It is suggested that the period ***T*** of the oscillations is related to the radius ***r*** of the ball and the radius of curvature ***R*** of the track by the relationship:

$$T^2 = \frac{28\,\pi^2}{5\,g}\,(R - r)$$

where *g* is the acceleration of free fall.

(b) The period ***T*** of the oscillations was calculated by timing 5 oscillations of the ball, repeating the trial, and averaging the results. What is the reason for each of the underlined steps? (2 marks)

Timing 5 oscillations, instead of only 1, reduces the % timing error due to reflex time.
Repeating the trial increases the reliability of the result. OR reduces random error
OR allows easier detection of outlier results.

The Table of Results is as follows:

T (s)	***R*** (cm)	***T***^{2} (s^2)
1.28 ± 10%	42	$1.28^2 \pm 20\% = 1.6384 \pm 0.3277 = 1.64 \pm 0.33$
1.55 ± 10%	53	$= 2.4025 \pm 0.4805 = 2.40 \pm 0.48$
1.61 ± 10%	58	$= 2.5921 \pm 0.5184 = 2.59 \pm 0.52$
2.09 ± 10%	83	$= 4.3681 \pm 0.8736 = 4.37 \pm 0.87$

Note 3sf + 2dec pl.

(c) Calculate the values of ***T***^{2}, including the absolute error. Record them in the Table. (4 marks)

(−1 if not 3sf)

(d) Graph ***T***^{2}, including the error bars, on the y-axis and ***R*** on the x-axis on the graph paper on the next page. Additional graph paper is supplied at the end of this question if required. (4 marks)

(e) Draw the line of best fit. (2 marks)

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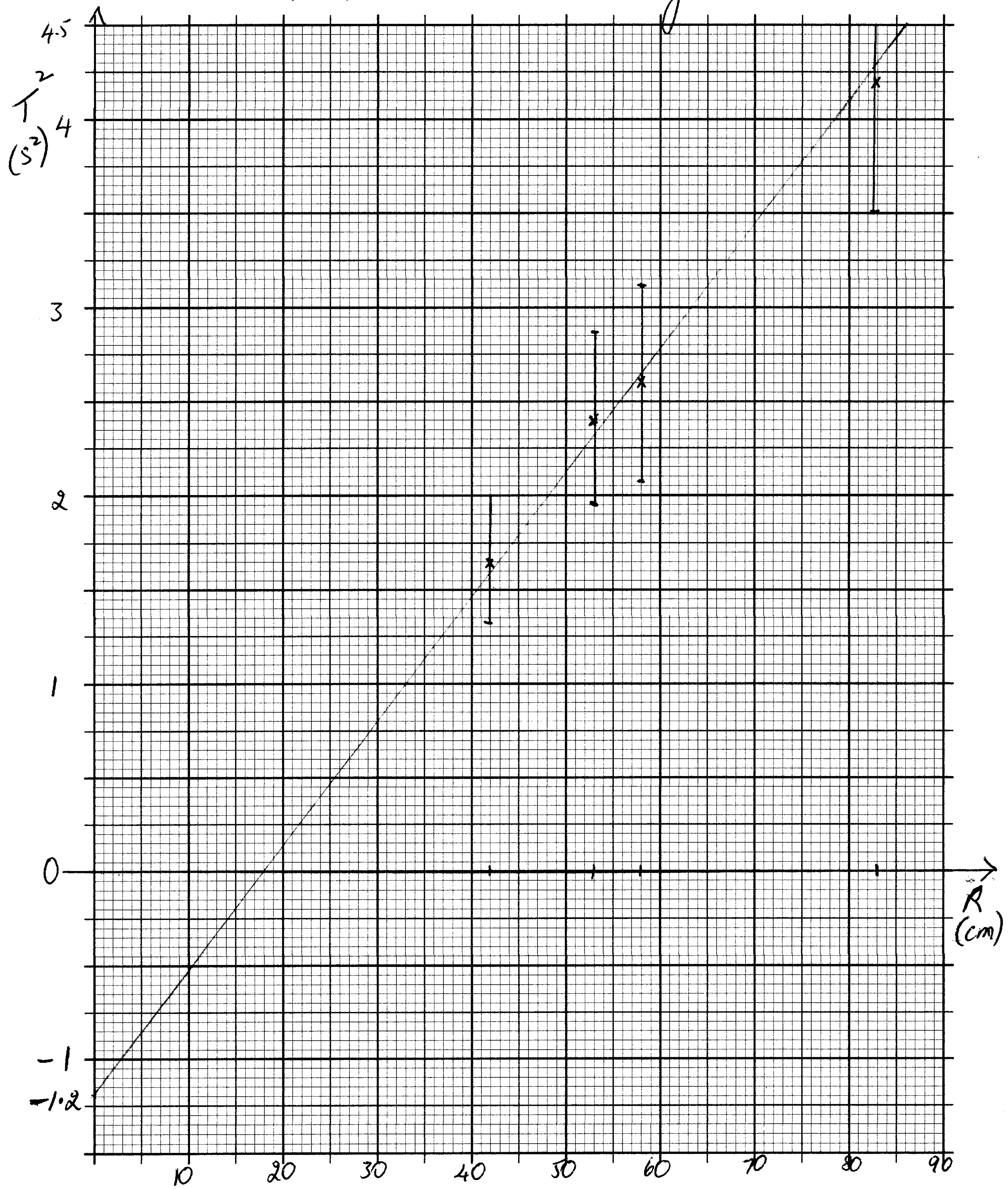
T^2 vs R for ball oscillating on curved track.



– label + units on y axis ✓
– Title ✓
– line of best fit ✓
– plot pts carefully ✓
– error bars ✓

(f) Determine the radius *r* of the ball. Show your working clearly. (3 marks)

$$T^2 = \frac{28\pi^2}{5g}(R - r)$$

$$= \frac{28\pi^2}{5g}R - \frac{28\pi^2}{5g}r$$

$$y = m\,x + c$$

$$\therefore y \text{ intercept} = -1.20 = -\frac{28\pi^2}{5g}r$$

$$\therefore r = \frac{1.20}{28\pi^2/g} = \frac{1.20}{28.2} = \underline{0.0426\text{ m}} = \underline{4.26\text{ cm}}$$

Question 21 **(17 marks)**

THE STRONG INTERACTION

Before the 1970s, physicists were uncertain as to how the atomic nucleus was bound together. It was known that the nucleus was composed of protons and neutrons and that while neutrons were electrically neutral, protons possessed positive electric charge. Since positive charges would repel one another the positively charged protons should cause the nucleus to fly apart. A stronger attractive force was postulated to explain how the atomic nucleus was bound together. This hypothesized force was called the *strong force*, which was believed to be a fundamental force that acted on the protons and neutrons that make up the nucleus.

It was later discovered that protons and neutrons were not fundamental particles but were made up of constituent particles called quarks. The strong attraction between nucleons was the side-effect of a more fundamental force that bound the quarks together into protons and neutrons. Quarks attract one another due to the **strong interaction**, and the particle that mediates this is called the gluon.

The word *strong* is used since the strong interaction is the "strongest" of the four fundamental forces. At a distance of 1 femtometre (1fm = 10^{-15} meters) or less, its strength is around 137 times that of the electromagnetic force, some 10^6 times as great as that of the weak force, and about 10^{38} times that of gravitation.

The force carrier particle of the strong interaction is the gluon, a massless boson. Unlike the photon in electromagnetism, which is neutral, the gluon carries a colour charge (not to be confused with electrical charge). Quarks and gluons are the only fundamental particles that carry colour charge, and hence they participate in strong interactions only with each other. The strong force is the expression of the gluon interaction with other quark and gluon particles.

Unlike all other forces (electromagnetic, weak, and gravitational), the strong force between quarks does not diminish in strength with increasing distance between pairs of quarks. After a limiting distance (about the size of a hadron) has been reached, it remains at a strength of about 10,000 N no matter how much farther the distance between the quarks. As the separation between the quarks grows, the work done against this force and hence the energy required to pull the two quarks apart will create a pair of new quarks that will pair up with the original ones; hence it is impossible to create separate quarks. As a result only hadrons, not individual free quarks, can be observed. The failure of all experiments that have searched for free quarks is evidence of this phenomenon.

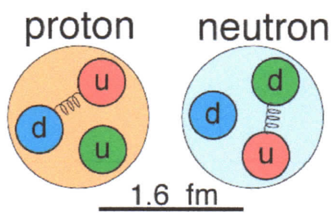


Figure 1

In hadrons, the colour-charge of the quarks essentially cancels out, and the strong force is therefore nearly absent between hadrons except that the cancellation is not quite perfect. A residual force remains, known as the **residual strong force,** or the **strong nuclear force** or simply the **nuclear force**. The strong nuclear force is thus a minor residuum of the strong force that binds quarks together into protons and neutrons. This same force is much weaker *between* neutrons and protons, because it is mostly neutralized *within* them, in the same way that electromagnetic forces between neutral atoms (van der Waals forces) are much weaker than the electromagnetic forces that hold electrons to the nucleus, forming the atoms.

This residual force *does* diminish rapidly with distance, approximately as a negative exponential power of distance, and is thus very short-range (effectively a few femtometres). The rapid decrease with distance of the attractive residual strong force, and the less-rapid decrease of the repulsive electromagnetic force acting between protons, causes the instability of larger atomic nuclei, such as all those with atomic numbers larger than 82 (the element lead).

In theoretical physics, **Feynman diagrams** are pictorial representations of the mathematical expressions describing the behaviour of subatomic particles. The scheme is named after its inventor, American physicist Richard Feynman, and was first introduced in 1948. The interaction of sub-atomic particles can be complex and difficult to understand intuitively. Feynman diagrams give a simple visualization of what would otherwise be an arcane and abstract formula.

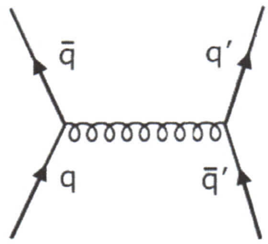


Figure 2

As David Kaiser writes, "since the middle of the 20th century, theoretical physicists have increasingly turned to this tool to help them undertake critical calculations", and so "Feynman diagrams have revolutionized nearly every aspect of theoretical physics". While the diagrams are applied primarily to quantum field theory, they can also be used in other fields, such as solid-state theory.

Questions

(a) The hydrogen atom consists of an electron bound to a proton by electromagnetic attraction. Explain why each of the following forces does not help hold a hydrogen atom together.

(i) strong interaction (2 marks)

The strong interaction only acts between quarks and composite particles made of quarks such as hadrons. (✓)

As the electron is a lepton, it does not participate in the strong interaction. (✓)

(ii) gravitation (2 marks)

The gravitational force between the proton and electron in a hydrogen atom is completely insignificant in comparison to the electromagnetic attraction. (✓)

It is of the order of 10^{-36} times weaker than the electromagnetic force (using comparative strength data from the article)

OR (✓)

It is of the order of 10^{-39} times weaker than the electromagnetic force (calculated as $F_g = G\,\frac{m(p)m(e)}{r^2}$ compared to $F_e = k\,\frac{q(p)q(e)}{r^2}$)

(b) Explain why free quarks have not been observed, and why it is thought impossible for them to be separated from one another. (4 marks)

The strong force between quarks does not weaken with increasing distance. (✓)

It remains at a constant large value of about 10 kN as quarks are separated from one another. (✓)

Hence work must be done continually against this force, and energy added to the system, as quarks are separated. (✓)

This creates new quarks that pair up with the original quarks, preventing quarks from being isolated. (✓)

(c) Describe the relationship between the strong force and the residual strong force (the strong nuclear force). (4 marks)

The strong force acts <u>within</u> hadrons, between the composite quarks, through the exchange of gluons. (✓)

It is the strongest of all the fundamental forces, being 137 times stronger than electromagnetism at the sub-atomic scale. (✓)

The residual strong force acts <u>between</u> hadrons, and exists because the colour-charge of the quarks within a hadron does not completely cancel out. (✓)

This leaves a weaker, short-range residual version of the strong force that binds hadrons together. (✓)

(d) Explain why atomic nuclei with atomic numbers larger than 82 are unstable. (4 marks)

The residual strong force between nucleons is a very short-range force which effectively only binds adjacent nucleons to each other. (✓)

The electromagnetic repulsion between protons is a weaker force but acts over the entire width of the nucleus, so each proton feels the combined repulsion of all the other protons in the nucleus. (✓)

When nuclei get larger, the cumulative effect of the electromagnetic repulsion between protons grows, while the attraction due to the residual strong force between nucleons remains roughly constant. (✓)

Hence, for nuclei with atomic numbers above 82, the electromagnetic repulsion forces can match or exceed the attraction of the residual strong force, and those nuclei are unstable. (✓)

(e) Consider **Figure 2 on page 34.** Name the exchange particle shown in the Feynman diagram.
(1 mark)

gluon (between quarks)

(f) **Figure 3** below represents the decay of a particle **X** into a particle **Y** and two other particles. The quark structure of particles **X** and **Y** are shown in the diagram.

CANCELLED

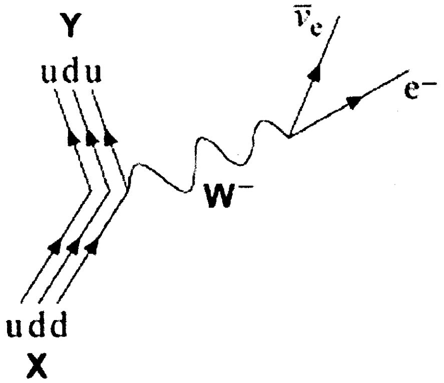


Figure 3

(i) Deduce the name of particle **X**. neutron (1 mark)

(ii) State the type of interaction that occurs in this decay. (1 mark)

weak interaction (β^- decay or change in quark)

(iii) State the class of particles to which the **W**- belongs. boson
(1 mark)

(iv) Show clearly how charge and baryon number are conserved in this interaction.
You should include reference to all the particles, including the quarks, in your answer.
(2 marks)

Q : $\left((\frac{2}{3}e)+(-\frac{1}{3}e)+(-\frac{1}{3}e)\right) \longrightarrow \left(\left((\frac{2}{3}e)+(-\frac{1}{3}e)+(\frac{1}{3}e)\right)+(-1)\right)+0$

$0 \longrightarrow +1 + (-1) + 0 = 0$ $\therefore$ conserved

B : $\left((\frac{1}{3})+(\frac{1}{3})+(\frac{1}{3})\right) \longrightarrow (\frac{1}{3})+(\frac{1}{3})+(\frac{1}{3}) + 0 + 0$

$1 \longrightarrow 1$ $\therefore$ conserved

(v) State the quark constituents of $\overline{Y}$. $\bar{u}\,\bar{d}\,\bar{u}$ (antiproton) (1 mark)

(vi) Name the only stable baryon. proton (1 mark)

(vii) A muon is an unstable particle. The incomplete decay equation is shown below.

$$\mu^- \rightarrow \nu_\mu + e^- + \bar{\nu}_e$$

State the name of the missing particle. anti electron neutrino (1 mark)

L_μ $+1\mu \rightarrow +1\mu$

L_e $0 \rightarrow +1e + (-1e)$

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