ATAR Physics Year 12

Semester Two Examination, 2018

Question/Answer Booklet

Student Name: ___**SOLUTIONS**_______________________________

Time allowed for this paper

Reading time before commencing work: 10 minutes

Working time for paper: 3 hours

Materials required/recommended for this paper

To be provided by the supervisor

This Question/Answer Booklet and the Formulae and Constants Sheet

To be provided by the candidate

Standard items: pens (blue/black preferred), pencils (including coloured), sharpener, correction tape/fluid, eraser, 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.

Structure of this paper

Section	Number of questions available	Number of questions to be answered	Suggested working time (minutes)	Marks available	**Marks Attained**
Section One: Short answers	13	13	54	54 (30%)	/54
Section Two: Problem-solving	7	7	90	90 (50%)	/90
Section Three: Comprehension	2	2	36	36 (20%)	/36
				180 (100%)	/180

Instructions to candidates

Write your answers in the spaces provided beneath each question. The value of each question (out of 180) is shown following each question.

The enclosed Physics: Formulae and Constants Sheet may be removed from the booklet and used as required.

Calculators satisfying conditions set by the Curriculum Council may be used to evaluate numerical answers.

Answers to questions involving calculations should be evaluated and given in decimal form. Give final answers to three significant figures and include appropriate units where applicable.

When calculating numerical answers, show your working or reasoning clearly. Despite an incorrect final answer, credit may be obtained for method and working, providing this is clearly and legibly set out.

Questions containing specific instructions to **show working** should be answered with a complete, logical, clear sequence of reasoning showing how the final answer was arrived at; correct answers which do not show working will not be awarded full marks.

Questions containing the instruction **estimate** may give insufficient numerical data for their solution. Students should provide appropriate figures to enable an approximate solution to be obtained. When estimating numerical answers, show your working or reasoning clearly. Give final answers to a maximum of two significant figures and include appropriate units where applicable.

SECTION ONE: Short Response 54 marks (30%)

This section has **12** questions. Answer **ALL** questions. Write your answers in the spaces provided.

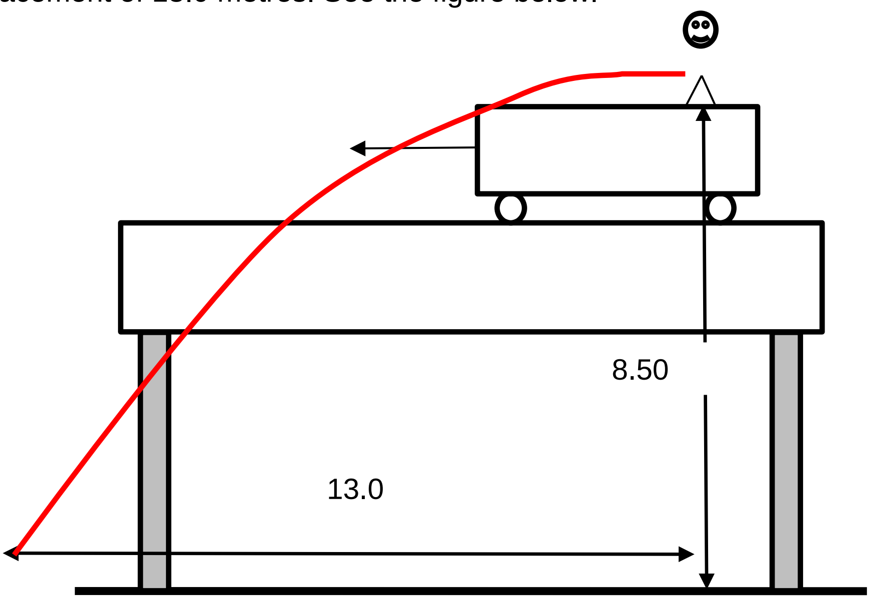
Spare pages are included at the end of this booklet. They can be used for planning your responses and/or as additional space if required to continue an answer.

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

Suggested working time for this section is **54 minutes.**

Question 1 (5 marks)

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



(a) On the diagram above, draw the path taken by the man as he descends to the water. Air resistance can be ignored. (1 mark)

Parabolic path, horizontal launch, lands 13.0 m horizontal displacement from starting position

(b) Calculate the velocity of the train. The bridge can be assumed to be horizontal. (4 marks)

$¿ \text{the vertical plane}; s = ut + \frac{1}{2}at^2;$ $8.50 = 0 \times t + \frac{1}{2} \times 9.80 \times t^2$ $t = \sqrt{\frac{8.50}{4.90}} = 1.32\, s$	1-2 marks
$¿ \text{the horizontal plane}; v = \frac{s}{t}; \therefore v = \frac{13}{1.32}$	1-2 marks

$\therefore v = 9.87\ m\,s^{-1}$	

Question 2 **(4 marks)**

A police radar gun used to measure the speed of moving vehicles operates using radio waves. An officer using the device points the radar at the oncoming vehicle and presses the trigger for

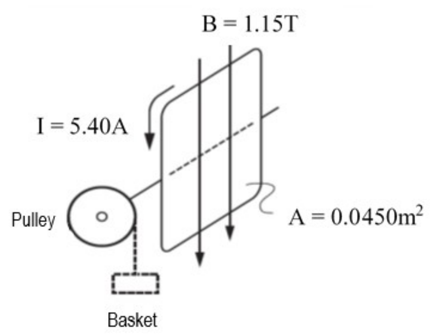
5 seconds to record a reading. If the radar has a power rating of 40.0 mW and emits a wave of frequency 27.0 GHz, calculate the number of photons produced by the device.

$E=Pt=40.0\times10^{-3}\times5=0.200\,J$ $E_{photon}=hf$ ¿$6.63\times10^{-34}\times27.0\times10^{9}$ ¿$1.79\times10^{-23}\,J$	1-3 marks
$no.\,of\ photons=\frac{E}{E_{photon}}=1.12\times10^{22}$	1 mark

Question 3 **(4 marks)**

A simplified diagram of an electric motor used to lift laundry in a laundry chute is shown at right. It consists of a flat rectangular coil of area 0.0450 m^2 in a magnetic field of strength 1.15 T, directed down as shown.

A current of 5.40 A is flowing through the coil. The axle of the coil must be connected to a pulley which has a cable attached to a 25.0 kg laundry basket as illustrated (not to scale).



(a) In which direction will the coil of the motor turn relative to the pulley? (1 mark)

Clockwise

(b) If a 750 turn motor is used, determine the diameter of the pulley required to lift the laundry basket up the laundry chute. (3 marks)

$\tau\ of\ motor=BAIN=1.15\times0.0450\times5.40\times750=209.6\,N\,m$	1
$\tau\ motor=\tau\ basket$ $209.6=mgr$ $209.6=25.0\times9.8\times r$ $r=0.855\,m$	1
$diameter=2r=1.71\,m$	1

Question 4 **(4 marks)**

A pilot is navigating their jetfighter through a giant vertical circular loop. The pilot knows that at particular points on the vertical circular path, they will feel 'weightless'. At other points they will feel so heavy that they will experience G-forces that may cause them to pass out.

TOP

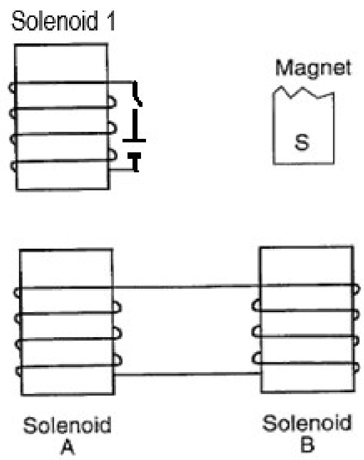
(a) At which point (TOP or BOTTOM) will the pilot feel 'heaviest'? Explain. (2 marks)

BOTTOM	1 mark
$N = \frac{mv^2}{r} + mg; \therefore N > W$ OR – the reaction force needs to counteract gravity as well as provide all of the centripetal force.	1 mark

(b) If the radius of the jetfighter's path is 1000 m, at what speed would it have to be travelling for the pilot to feel absolutely weightless. (2 marks)

Weightless when N = 0	1 mark
$At\ top,\ N = \frac{mv^2}{r} - mg;\ when\ N = 0,\ v = \sqrt{gr};$	1 mark
$\therefore v = \sqrt{9.8\,x\,1000} = 99.0\ m\,s^{-1}$	1 mark

Question 5 **(3 marks)**



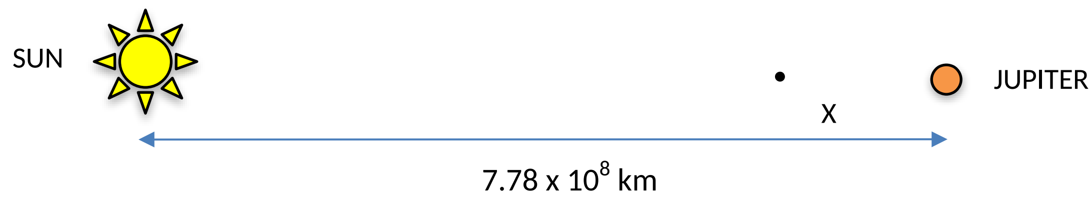
Identifies the closing of the switch causes a flux to be produced by solenoid 1 (1 mark)

Identifies a change in flux occurs in solenoid A, driving a current into B. Identifies solenoid B acts as an electromagnet, applying a force on the magnet. (1 mark)

States that when the current is constant there is no change in flux hence no current in either solenoid so force on magnet stops. (1 mark)

Question 6 **(4 marks)**

The Sun and the planet Jupiter are 778 million km apart, measured centre to centre, as shown in the sketch below. Along the line joining their centres, there is a point where the net gravitational field strength is zero. Calculate the distance that this point is from the centre of the Sun, given that the mass of Jupiter is 1.90 x 10^{27} kg.



Let X be the point between the Sun and Jupiter where net gravitational field strength is zero, and let r be the distance from the centre of the Sun to X

At X g(Sun) = g(Jupiter) in magnitude (✓)

$$\frac{G M_{Sun}}{r^2} = \frac{G M_{Jupiter}}{(7.78 \times 10^{11}\text{m} - r)^2} \quad (✓)$$

$$\frac{(7.78 \times 10^{11}\text{m} - r)^2}{r^2} = \frac{M_{Jupiter}}{M_{Sun}} = \frac{1.90 \times 10^{27}\text{kg}}{1.99 \times 10^{30}\text{kg}} = 9.55 \times 10^{-4} \quad (✓)$$

$$\frac{(7.78 \times 10^{11}\text{m} - r)}{r} = 3.09 \times 10^{-2}$$

$$(7.78 \times 10^{11}\text{m} - r) = (3.09 \times 10^{-2})\ r$$

$$7.78 \times 10^{11}\text{m} = r + (3.09 \times 10^{-2})\ r = 1.0309\ r$$

$$\text{Hence } r = \frac{7.78 \times 10^{11}\text{m}}{1.0309} = \underline{7.55 \times 10^{11}\text{m}} \quad (✓)$$

Question 7 **(5 marks)**

An earth-like planet is detected orbiting around a star 16 light-years away. A spaceship is launched towards this star that uses a radical new propulsion system that enables it to travel at the near light speed of 240 000 km/s.

(a) How long will it take for the spaceship to travel to the star from the viewpoint of observers on Earth? (2 marks)

speed v = (240 000km/s)/(300 000km/s) = 0.80c (✓)

time taken = d/v = (16 light-years)/(0.80c) = <u>20 years</u> (✓)

(b) From the reference frame of the crew on the starship the distance to the star is contracted. Calculate the distance they measure to the star, and hence calculate how long they expect to take to reach the star. (3 marks)

$$L = L_o (1 - v^2/c^2)^{½} = 16 [1 - (0.80c)^2/c^2]^{½} \quad (✓)$$

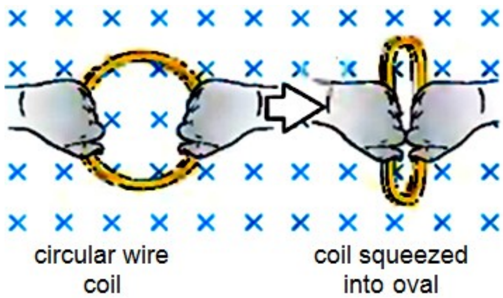
$$= 16 [1 - 0.64]^{½}$$

$$= \underline{9.6 \text{ light-years}} \quad (✓)$$

time taken = d/v = (9.6 light-years)/(0.80c) = <u>12 years</u> (✓)

Question 8 **(4 marks)**

A circular wire coil of radius 10 cm, containing 250 loops of wire, is placed in a perpendicular magnetic field of strength 90 mT, as shown at right. The coil is then rapidly squeezed down to a quarter of its original area in a time of about 0.5 s.



Calculate a value for the emf induced around the coil as it is rapidly reduced in size.

The change in flux through the coil is given by

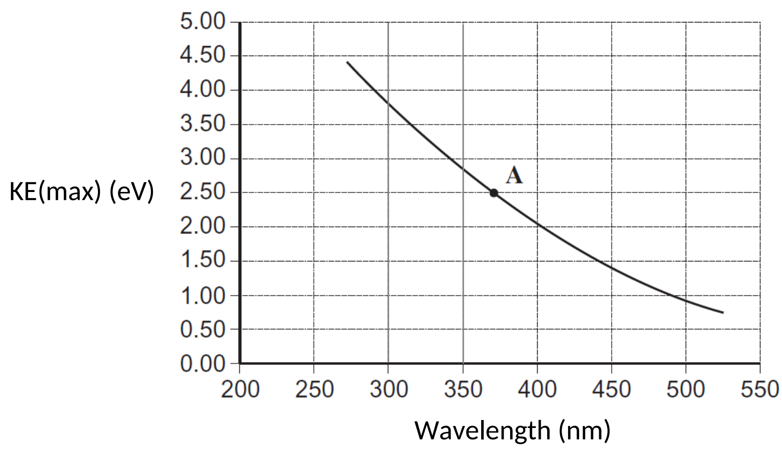
= B A = (0.090 T)(1/4 (0.1 m)^2 - (0.1 m)^2) = -2.12 x 10^{-3} Wb
(✓) (✓)

Hence the emf induced is = -N / t = -(250) (-2.12 x 10-3 Wb)/0.5s (✓)

= <u>1.06 V</u> (✓)

Question 9 **(4 marks)**

Light, of varying wavelength, is incident on the metal cathode in a photoelectric cell. The graph at right shows how the maximum kinetic energy of the emitted electrons varies with the wavelength of the incident light. Use **point A** to find the work function for this metal in eV.



At point A, wavelength of the incident photons is = 370 nm, while the ejected electrons have kinetic energy KE = 2.50 eV (✓)

Incident photons have energy

E = hc/ = (6.63 x 10-34)(3 x 108)/(3.70 x 10-7) (✓)

= 5.38 x 10^{-19} J = 3.36 eV (✓)

Hence work function = E(photon) - KE = 3.36 eV - 2.50 eV = <u>0.86 eV</u> (✓)

Question 10 **(5 marks)**

A Transperth train draws its electrical power from overhead lines, which have a resistance of 3.00 Ω/km. The overhead lines are supplied by a transformer at Perth train station, which provides an output power of 500 kW. When operating at Perth station, the voltage provided by the overhead lines is 25 kV.

(a) Find the current in the overhead lines. (2 marks)

P = V I → 500 000 W = (25 000 V) I (✓)

So I = <u>20 A</u> (✓)

(b) The train reaches Midland, which is 15 km from Claisebrook. What is the voltage available to the train at Midland? (3 marks)

R = (3.00 Ω/km)(15 km) = 45 Ω (✓)

V_{drop} = I R = (20 A)(45 Ω) = 900 V (✓)

V_{train} = 25 000 V - 900 V = <u>24 100 V</u> (✓)

Question 11 **(4 marks)**

(a) Describe what is meant by *cosmic background radiation* and briefly explain how the existence of cosmic background radiation supports the Big Bang model for the beginning of the universe. (2 marks)

Cosmic background radiation is microwave radiation that is spread uniformly throughout space (✓)

It is considered to be radiation leftover from the extremely energetic early stages of the universe (the Big Bang) (✓)

(b) Briefly explain the principle of redshift and describe how this phenomena supports the Big Bang theory. (2 marks)

Light from sources moving away from us has its light shifted to lower frequencies. (1)

The increasing redshift of light from more distant galaxies indicates that the universe is expanding (✓)

Question 12 **(5 marks)**

The table below shows the 6 types of quark and lists their properties.

NAME	SYMBOL	Charge (Q)	Baryon Number (B) $\frac{+2}{3}$ e	Strangeness (S)	Charm (c)	Bottomness (b)	Topness (t)
Up	u	$\frac{+2}{3}$ e	$\frac{1}{3}$	0	0	0	0
Down	d	$\frac{-1}{3}$ e	$\frac{1}{3}$	0	0	0	0
Strange	s	$\frac{-1}{3}$ e	$\frac{1}{3}$	-1	0	0	0
Charmed	c	$\frac{+2}{3}$ e	$\frac{1}{3}$	0	+1	0	0
Bottom	b	$\frac{-1}{3}$ e	$\frac{1}{3}$	0	0	-1	0
Top	t	$\frac{+2}{3}$ e	$\frac{1}{3}$	0	0	0	+1

When a K^- meson collides with a proton, the following reaction can take place.

$$\mathbf{K^- + p \rightarrow K^0 + K^+ + X}$$

The quark structure of the mesons in the reaction is given in the table below. Note that X is a particle whose quark structure is to be determined.

particle	K^-	K^+	K^0
quark structure	$s\bar{u}$	$u\bar{s}$	$d\bar{s}$

(a) Is the K^- meson classified as a hadron, a lepton or an exchange particle (gauge boson)? Briefly explain. (2 marks)

K^- meson is a hadron (✓), as it is composed of quarks (quark-antiquark pair) (✓)

(b) A proton has S, c, b and t values that are all zero. Show that the quark structure of a proton must be uud (1 mark)

Proton can only contain up and down quarks, and must have charge = +1e

$u + u + d = +{}^{2}/_{3}e + +{}^{2}/_{3}e + -{}^{1}/_{3}e = +1e$

(c) Given that X has a baryon number of 1, deduce the quark structure of X. (2 marks)

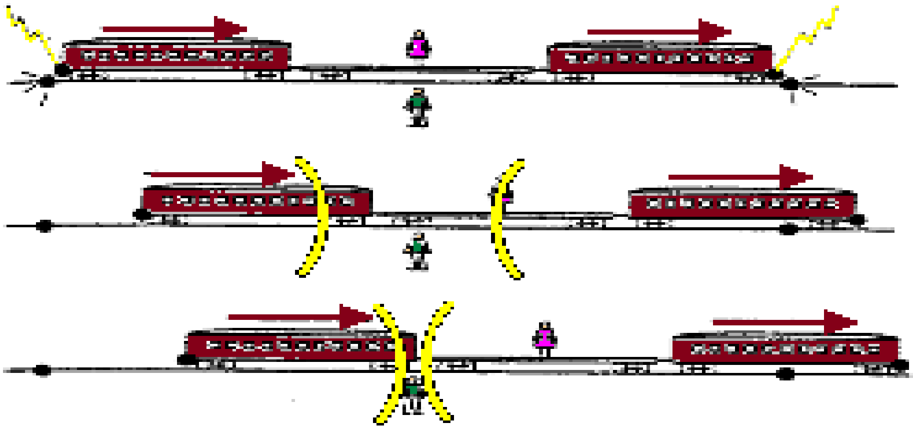
$$\mathbf{K^- + p \rightarrow K^0 + K^+ + X}$$

$s\bar{u}$ + uud → $d\bar{s}$ + $u\bar{s}$ + X (✓) (X is a baryon – made of 3 quarks)

X = sss (✓)

Question 13 **(3 marks)**

An extremely high speed train, carrying an observer on an open platform, is struck by two lightning bolts at the front and rear of the train. The observer on the open platform claims that the lightning bolt at the front of the train occurred before the lightning bolt at the rear of the train. A second observer, standing on the ground next to the train tracks as the train races past, claims that the lightning bolts occurred simultaneously.



Which observer is correct, the observer on the open platform of the train or the second observer standing on the ground? Briefly explain.

Both observers are correct (✓)

Each observer sees the light flashes from the lightning bolts travelling at the same constant speed of light in their own reference frame (✓)

Consequently, observers in different reference frames can fundamentally disagree about the temporal order of events (✓)

End of Section One

SECTION TWO: Problem-solving **90 marks (50%)**

This section has **7** questions. Answer **ALL** 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.

- Planning: If you use the spare pages for planning, indicate this clearly at the top of the page.
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Suggested working time for this section is **90 minutes.**

Question 14 **(13 marks)**

Diagram 1 below shows the lines of the emission spectrum of atomic hydrogen that are in the visible region of the electromagnetic spectrum. Diagram 2 shows the energy levels of the hydrogen atom.

Diagram 1

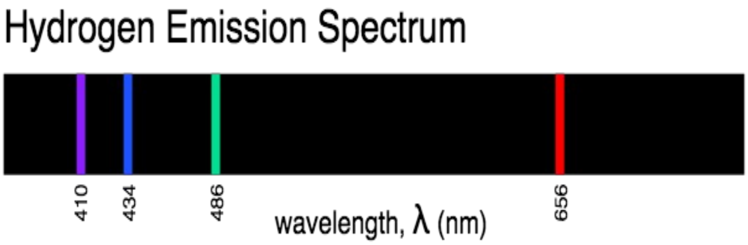
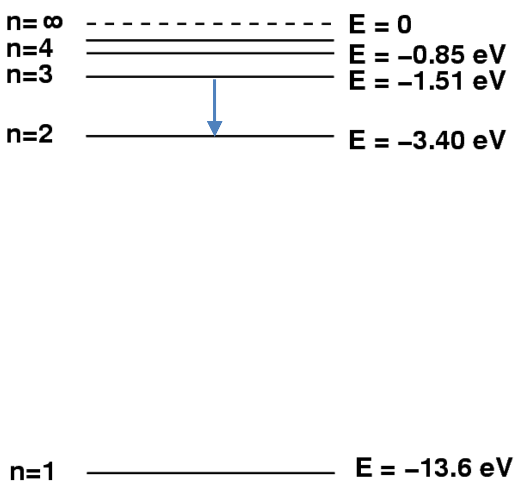


Diagram 2



(a) Calculate the energy (in eV) of a photon associated with the largest wavelength (λ) in the emission spectrum. (3 marks)

$E = hc/\lambda = (6.63 \times 10\text{-}34)(3 \times 108)/(6.56 \times 10\text{-}7\,m) = 3.03 \times 10^{-19}$ J

(✓) (✓)

$= (3.03 \times 10\text{-}19)/(1.6 \times 10\text{-}19) =$ <u>1.90 eV</u> (✓)

(b) On diagram 2, draw an arrow to represent the electron transition that gives rise to the photon with the largest wavelength (λ). (1 mark)

(c) State two physical processes by which an electron in the ground state can move to a higher level. (2 marks)

absorption of a photon of correct energy

collision with an electron of sufficient energy

thermal agitation – collision of sufficient energy with other atoms

(any two processes)

(d) A beam of light, consisting of a continuous spectrum from infrared to ultraviolet, is shone through a cold sample of hydrogen gas. When the beam is analysed after transmission, it is found that the intensity of light of wavelength 122 nm is greatly reduced. Carefully explain this observation. (4 marks)

Light of wavelength 122 nm consists of photons of energy

$E = {}^{hc}/_{l} = {}^{(6.63 \times 10\text{-}34)(3 \times 108)}/_{(1.22 \times 10\text{-}7\text{m})(1.6 \times 10\text{-}19)} = 10.2 \text{ eV}$ **(✓)**

which matches the energy difference between levels n = 1 and n = 2 (✓)

When the continuous spectrum of light passes through the hydrogen gas, those particular photons are absorbed by hydrogen atoms and excite the atoms from level 1 to level 2 (✓)

When the excited atoms return to the ground state, they emit photons of wavelength 122 nm randomly in all directions (scattering) so the intensity of that wavelength in the original direction is greatly reduced (✓)

(e) An energetic electron collides with an atom of hydrogen gas. What is the minimum speed needed for the incident electron to be able to ionise the atom of hydrogen? (3 marks)

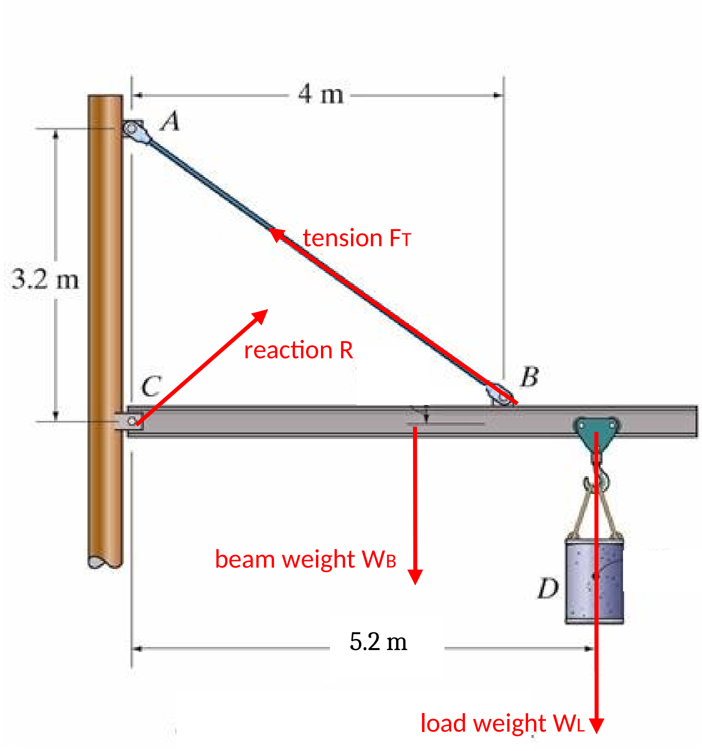
To ionise an atom of hydrogen, the colliding electron must have a kinetic energy of at least 13.6 eV = 2.18×10^{-18} J (✓)

Hence KE = $\frac{1}{2} m v^2$ = → 2.18×10^{-18} J = $\frac{1}{2}(9.11 \times 10^{-31} \text{ kg}) v^2$ (✓)

v = <u>2.19×10^6 m/s</u> (✓)

Question 15 **(14 marks)**

The diagram at right shows a uniform steel beam of mass 24.0 kg suspended horizontally from a vertical pole by a hinge at point C and a cable that connects point A on the pole to point B on the beam. The steel beam is of length 6.0 m and supports a load D of mass 45.0 kg as shown.



(a) On the diagram, show all forces acting on the steel beam as labelled vectors. (3 marks)

weight forces (✓)

tension force (✓)

reaction force (✓)

(b) Find the tension in the cable that connects point A to point B on the beam. (4 marks)

Take the pivot at point C (the hinge) to calculate torques **CW = ACW** **pivot should be clearly indicated (✓)**

tan = $^{3.2}/_{4.0}$ → = 38.7° (✓)

(24kg)(9.8m/s^2)(3.0m) + (45kg)(9.8m/s^2)(5.2m) (✓) = F_T (4m) sin(38.7°) (✓)

F_T = <u>1200 N</u>

(c) Find the size and direction of the reaction force exerted on the steel beam by the hinge at point C. (4 marks)

F_{up} = F_{down} → R_v + $F_T\sin$ = $(24kg)(9.8m/s^2)$ + $(45kg)(9.8m/s^2)$

R_v = -73.5 N (✓)

F_{left} = F_{right} → R_h = $F_T\cos$ = 937 N (✓)

R^2 = R_v^2 + R_h^2 = $(-73.5)^2$ + $(937)^2$ → R = <u>940 N</u> (✓)

tan = $^{R_v}/_{R_h}$ = $^{-73.5}/_{937}$ → = <u>4.48° below horizontal</u> (✓)

alternatively 2 for a correct triangle showing sides and angles

1 for R

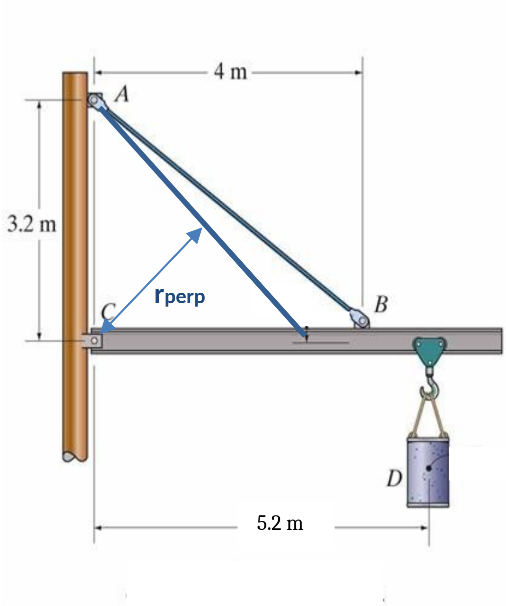
1 for angle

(d) An engineer suggests shortening the cable and attaching it to the steel beam slightly to the left of point B and closer to point C (but leaving the other end of the cable still attached at point A), so as to increase the angle between the cable and the steel beam. Explain how and why the tension in the cable would change if this suggestion is implemented. (3 marks)

Since the clockwise torque due to the weight of the beam and the load is still the same, the cable must supply the same size torque as before (✓)

However the perpendicular distance r_{perp} from the pivot to the cable (the lever arm) is smaller, as shown in the diagram at right (✓)

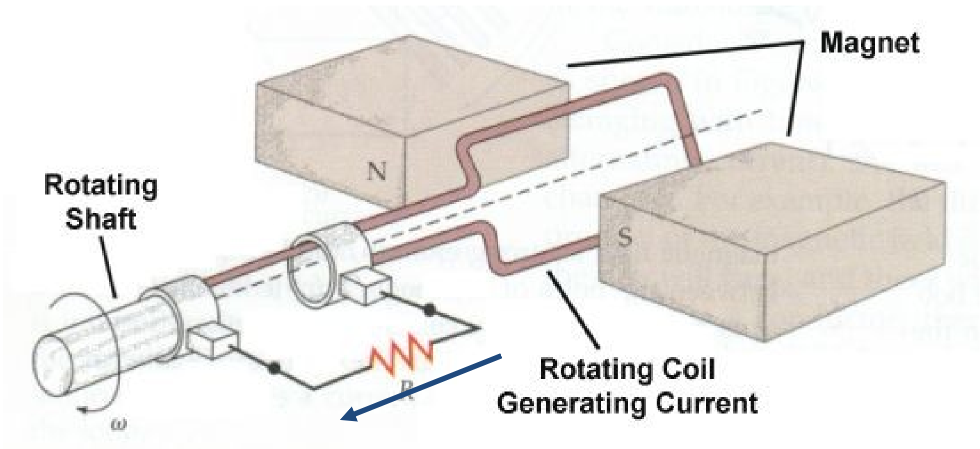
Hence the tension must be <u>larger</u> in order to create the same size torque (✓)



Paid 1 where students presented a <u>rational</u> argument about angle of force increasing so T reduced to provide same Torque

Question 16 **(14 marks)**

The diagram below shows a simple AC generator. The rectangular coil has a length of 15.0 cm and a width of 8.00 cm, and contains 500 turns of wire. The uniform magnetic field in which the coil rotates is of strength 90 mT.



(a) Show the direction of the induced current as the coil rotates as shown, at the instant depicted in the diagram, by drawing an arrow next to the resistor R. (1 mark)

(b) Explain why an electric current is produced in the coil as it rotates. (2 marks)

As the coil rotates, electrons in the two long sides of the coil move through the magnetic field and cut flux lines. (✓)

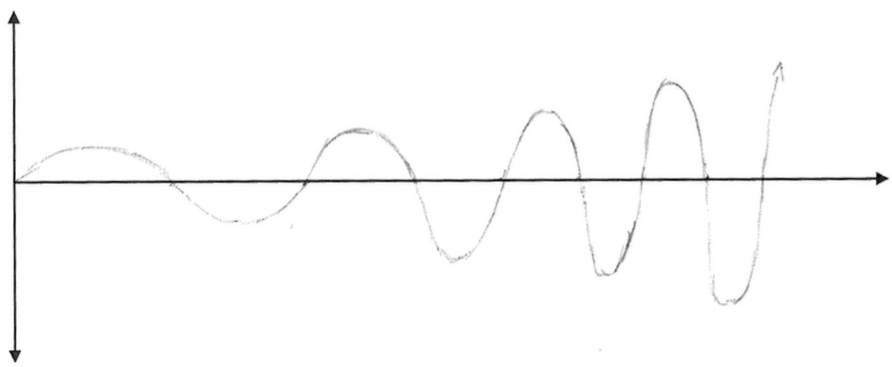
As a result, these electrons experience a magnetic force given by F = q v B which pushes them around the coil, creating an electric current. (✓)

OR

As the coil rotates, it experiences a change in flux. According to faraday's law, this will induce an emf ($\varepsilon = \Delta \varnothing / \Delta t$) (1)

The emf will drive an electric current around the coil (1)

(c) On the axes below, sketch the induced current over several rotations of the coil as the generator picks up speed. (no scales are needed on the axes) (3 marks)



sinusoidal (✓)

increasing frequency OR decreasing period (✓)

increasing amplitude (larger current) (✓)

(d) Under normal operating conditions, the coil reaches a steady rotational speed of 50.0 Hz. Calculate the value of the voltage (rms) emf induced at this rate. (2 marks)

$_{rms}$ = 1/√2 (2 BANf)

= 1/√2 (2)(0.090T)(0.15m x 0.08m)(500)(50Hz) (✓)

= <u>120 V</u> (✓)

(e) Given that the resistor R has a resistance of 25.0 , find a value for the average torque needed to keep the generator turning at this speed. (3 marks)

induced current I = $^{rms}/_{R}$ = $^{120V}/_{25}$ = 4.8 A (✓)

torque needed must balance counter torque $_{back}$ = NIAB (✓)

torque needed = (500)(4.8A)(0.15m x 0.08m)(0.090T) = <u>2.59 Nm</u> (✓)

(f) Explain, in terms of Lenz's Law, why a torque is needed to keep the generator turning at constant speed. (3 marks)

The rotating coil induces a current that flows around the coil (✓)

By Lenz's Law, this current must flow in a direction such that the magnetic field causes forces to act on the coil opposing its rotation (counter torque) (✓)

Hence an external torque is continuously needed to balance this counter torque and keep the coil rotating at a constant speed (✓)

Question 17 **(13 marks)**

Barnard's star, at a distance from us of 6 light-years, is the second closest star system to our Sun. It is a red dwarf and is much cooler than our Sun, radiating much of its energy as infrared. Barnard's star has 14.4% of our Sun's mass and a diameter that is 19.6% of our Sun's diameter.

For Barnard's star to have a planet in the "habitable zone", with liquid water at its surface, the planet would need to be quite close to the star. According to astronomers, a suitable distance would be 0.06 AU. Note one AU (astronomical unit) is the distance between the Earth and the Sun.

(a) Calculate the gravitational field strength of Barnard's star at the distance of a planet orbiting in the habitable zone. (3 marks)

$g = {}^{GM}/_{r2}$ where mass $M = 0.144 \times 1.99 \times 10^{30}$ kg

(✓)

orbital radius $r = 0.06 \times 1.50 \times 10^{11}$ m

$$g = \frac{(6.67 \times 10\text{-}11)(0.144 \times 1.99 \times 10^{30})}{(0.06 \times 1.50 \times 10^{11}\ \text{m})^2} \quad (✓)$$

$= \underline{0.236\ \text{m/s}^2}$ (✓)

No penalty for including the radius of Barnards star but not a required step

(b) Compare the gravitational field strength of Barnard's star at the distance of the planet orbiting in the habitable zone to the gravitational field strength of the Sun at the distance of the Earth. (2 marks)

$$\frac{g(\text{B's star})}{g(\text{Sun})} = \frac{G\,M_{\text{Bs star}} / r_{\text{planet}}^2}{G\,M_{\text{Sun}} / r_{\text{Earth}}^2} \quad (✓)$$

$$= \frac{(0.144)M_{\text{Sun}} / (0.06\ r_{\text{Earth}})^2}{M_{\text{Sun}} / r_{\text{Earth}}^2} = {}^{(0.144)}/_{(0.06)2} = \underline{40\ \text{times stronger}} \quad (✓)$$

Payed 2 for a correct and set out calculation of g sun without a ratio comparison.

No marks if no statement about the factor of one g to another

(c) Determine the time, in weeks, that it would take the planet in the habitable zone to orbit Barnard's Star. (4 marks)

mass M = 0.144 x 1.99 x 10^{30} kg = 2.87 x 10^{29} kg

orbital radius r = 0.06 x 1.50 x 10^{11} m = 9.00 x 10^{9} m **(✓)**

T^2 = 4 2r3/GM = 4 2(9.00 x 109 m)3/(6.67 x 10-11)(2.87 x 1029 kg) **(✓)**

= 1.51 x 10^{12}

So T = 1.23 x 10^{6} s (✓) = 1.23 x 10^{6} s / (3600)(24)(7) = 2.03 weeks (✓)

(d) What effect would doubling the orbital distance have on the time it takes the planet to orbit Barnard's Star? Clearly explain your reasoning. (2 marks)

According to Kepler's 3rd law, $T^2 = \frac{4\pi}{GM} r^3$ (1)

If r is doubled, $T^2 = \frac{4\pi}{GM}(2r)^3 = 8\frac{4\pi}{GM} r^3$

$T = \sqrt{8} \times Original\,time \vee T\,is\,2.83 \times larger$ (1)

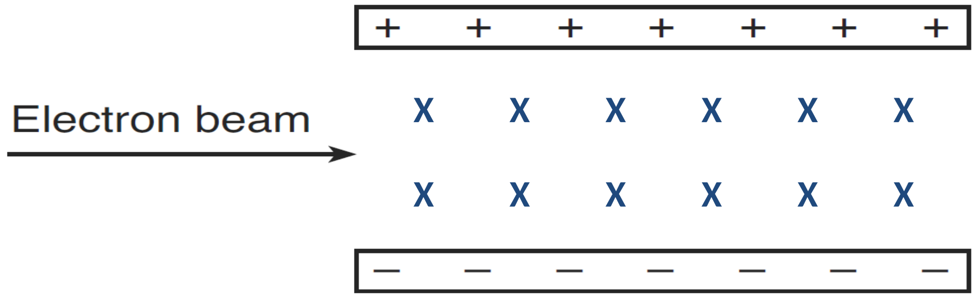
(e) What effect would doubling the mass of the planet have on the time it takes the planet to orbit Barnard's Star? Clearly explain your reasoning. (2 marks)

No effect (1)

The orbital period of a satellite is not governed by the mass of the satellite (1)

Question 18 **(13 marks)**

A beam of electrons moving in a vacuum enters the region of electric field between two oppositely charged parallel plates. The electrons enter the electric field moving at a speed of 1.50×10^7 m/s, parallel to and equidistant between the charged plates, as shown in the diagram below. The potential difference between the charged plates is 130 V. The plates are of length L = 12.0 cm and are a distance d = 4.00 cm apart from one another.



(a) Calculate the strength of the electric field between the two parallel plates. (2 marks)

$E = {}^{V}/_{d} = {}^{130V}/_{0.04m} = \underline{3250\ V/m}$ (✓) units (✓)

(b) Find the acceleration of the electrons as they move through the electric field between the two parallel plates. (4 marks)

$F = m\,a = q\,E$ → $a = {}^{q\,E}/_{m}$ (✓)

$a = {}^{q\,E}/_{m} = {}^{(1.6 \times 10\text{-}19)(3250)}/_{(9.11 \times 10\text{-}31)}$ (✓)

$= \underline{5.71 \times 10^{14}\ m/s^2\ \text{upwards}}$ (✓) direction(✓)

(c) Does the electron beam manage to pass between the parallel plates, or does it strike the positively charged plate? Support your answer with appropriate calculations. (5 marks)

$s_H = u_H t \rightarrow 0.120 \text{ m} = (1.50 \times 10^7 \text{ m/s})\ t$ (✓)

$t = 8.00 \times 10^{-9} \text{ s}$ (✓)

$s_V = u_V t + \frac{1}{2} a t^2 = 0 + \frac{1}{2} (5.71 \times 10^{14} \text{ m/s}^2)(8.00 \times 10^{-9} \text{ s})^2$ (✓)

$= 0.0183 \text{ m} = \underline{1.83 \text{ cm}}$ (✓)

Since the electrons start equidistant from the two plates, and 1.83 cm < 2.00 cm, the electrons manage to pass between the plates without striking the positive plate. (✓)

(d) A perpendicular magnetic field of the correct strength and orientation can be used to prevent the electron beam from deflecting as it passes between the parallel plates.

(i) Sketch the perpendicular magnetic field on the diagram (page 20), showing the correct direction to prevent the electron beam from deflecting. (1 mark)

Into the page (shown on diagram)

(ii) Calculate the strength of the magnetic field needed to prevent the electron beam from deflecting. (2 marks)

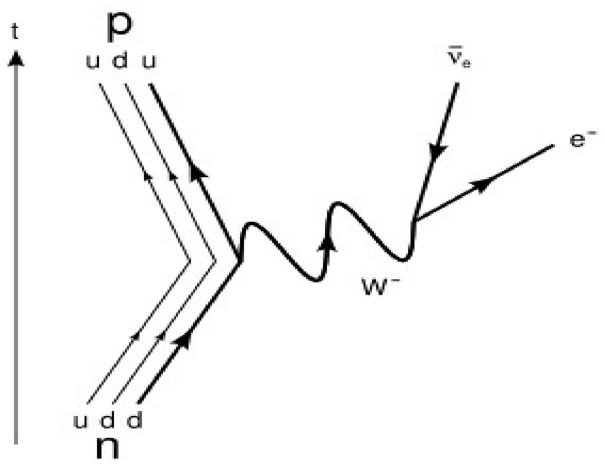
$F_e = F_m \qquad qE = qvB$ (✓)

$B = E/v = (3250 \text{ V/m})/(1.50 \times 107 \text{ m/s}) = \underline{2.17 \times 10^{-4} \text{ T}}$ (✓)

NB for using r = mv/Bq = 0 marks

Question 19 **(12 marks)**

Neutron decay is shown in the particle interaction diagram below.



(a) Neutron decay is an example of which of the following fundamental interactions? (circle your choice for the correct answer) (1 mark)

strong **weak** **electromagnetic**

(b) When the neutron decays, it produces a proton, electron and an antielectron neutrino. Write an equation for the overall neutron decay reaction shown above.

(1 mark)

n → p + e + $\bar{\nu}_e$ **(✓)**

(c) Show that each of the quantities of charge, baryon number and lepton number is conserved during neutron decay. (3 marks)

	n	**→ p + e +** $\bar{\nu}_e$	
Charge:	**0**	**= (+1) + (-1) + 0**	**(✓)**
Baryon Number:	**(+1)**	**= (+1) + 0 + 0**	**(✓)**
Lepton Number:	**0**	**= 0 + (+1) + (-1)**	**(✓)**

MUST show values of all particles (including ‘0’ values) to get mark.

(d) The mass of a neutron, expressed as its energy equivalence in MeV, is 939.57 MeV, while the mass of a proton is 938.27 MeV. Use values from the Physics Formula and Data booklet to calculate the energy left over as kinetic energy following neutron decay. (3 marks)

From the Physics Formula and Data booklet we find that

m(e) = 0.511 MeV **m($\bar{\nu}_e$) = 2.2 x 10^{-6} MeV** **(✓)**

Since **n → p + e +** $\bar{\nu}_e$

KE = 939.57 MeV - (938.27 MeV + 0.511 MeV + 0.0000022 MeV) **(✓)**

= <u>0.789 MeV</u> **(✓)**

(e) The mass of a neutron is larger than the sum of the masses of its constituent quarks. Use values from the Physics Formula and Data booklet to calculate what fraction of the mass of a neutron is due to its constituent quarks. (2 marks)

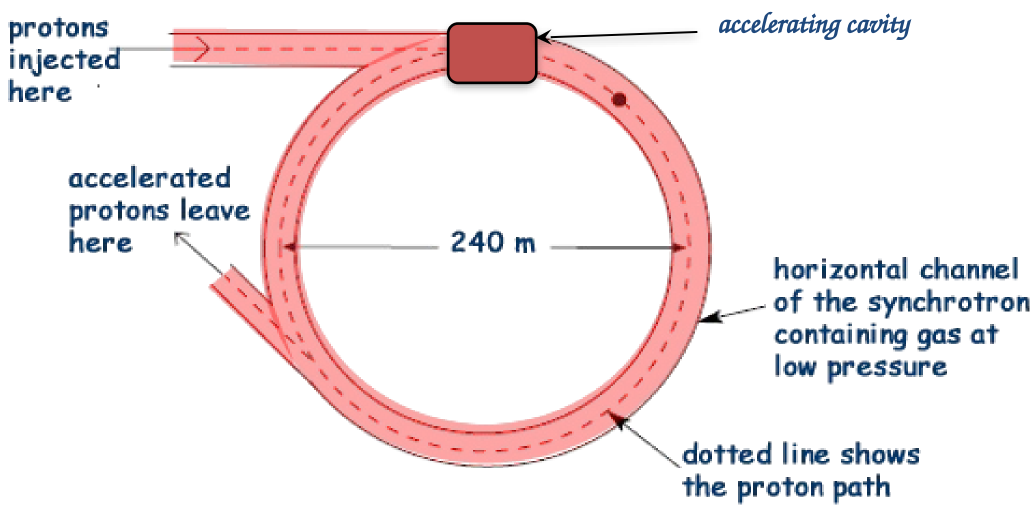
From the Physics Formula and Data booklet we find that

m(up) = 2.3 MeV **m(down) = 4.8 MeV** **(✓)**

$$\frac{m(udd)}{m(n)} = \frac{(2.3 + 4.8 + 4.8)}{(939.57)} = \underline{0.0127} \quad (= 1.27\%)$$ **(✓)**

Question 20 **(11 marks)**

A synchrotron uses a perpendicular magnetic field to contain protons as they circulate around a hollow ring; the protons pass around the ring and through the accelerating cavity thousands of times before finally leaving the ring at speeds approaching that of light. When passing through the accelerating cavity, the protons experience an effective potential difference of 24 kV each time.



(a) Calculate the gain in kinetic energy of the protons each time they pass through the accelerating cavity (2 marks)

KE = W = q V = (1.6 x 10^{-19} C)(24000 V) (✓)

= <u>3.84 x 10^{-15} J</u> (✓)

(b) Explain how the protons can continue to gain in kinetic energy every time they pass through the accelerating cavity, yet their speed can never exceed the speed of light. (2 marks)

As a proton's speed approaches the speed of light its mass increases rapidly (✓)
(by the factor = $^1/_{(1 - v2/c2)½}$)

This rapid increase in mass as v → c means that kinetic energy keeps increasing even though the speed v only increases incrementally (✓)

(c) A proton is accelerated in the synchrotron to 95.0% of the speed of light. Calculate

(i) the momentum of the proton. (2 marks)

$p = {}^{m\,v}/_{(1 - v2/c2)½} = {}^{(1.67 \times 10\text{-}27)(0.95 \times 3 \times 108)}/_{(1 - (0.95)2)½}$ (✓)

$= \underline{1.52 \times 10^{-18}\ \text{kgm/s}}$ (✓)

(ii) the wavelength of the proton. (2 marks)

$= {}^{h}/_{p} = {}^{6.63 \times 10\text{-}34}/_{1.52 \times 10\text{-}18}$ (✓)

$= \underline{4.35 \times 10^{-16}\ \text{m}}$ (✓)

(d) Find the strength of the magnetic field needed to contain the protons when they circulate around the ring at 95.0% of the speed of light. (3 marks)

$r = {}^{m\,v}/_{q\,B} \rightarrow B = {}^{m\,v}/_{q\,r}$ (✓)

$= {}^{1.52 \times 10\text{-}18}/_{(1.6 \times 10\text{-}19)(120\text{m})}$ (✓)

$= \underline{0.0794\ \text{T}}$ (✓)

End of Section Two

SECTION THREE: Comprehension and data analysis 36 marks (20%)

This section has 2 questions. You must answer both 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.

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

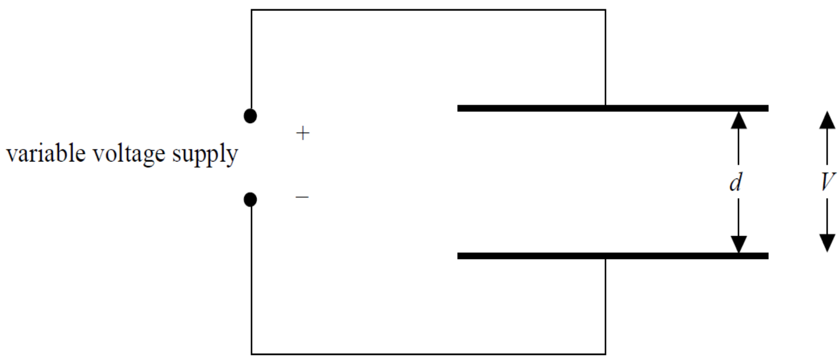
Suggested working time: **36 minutes**.

Question 21 THE PERMITTIVITY OF FREE SPACE 20 marks

The permittivity of a substance relates to how well it establishes an electric field when a potential difference is applied across it. A substance with a high permittivity tends to impede an electric field. For a vacuum, the permittivity is low and referred to as the **permittivity of free space**.

The permittivity of free space has the symbol: ε_0

The diagram at right shows two parallel conducting metal plates connected to a variable voltage supply.



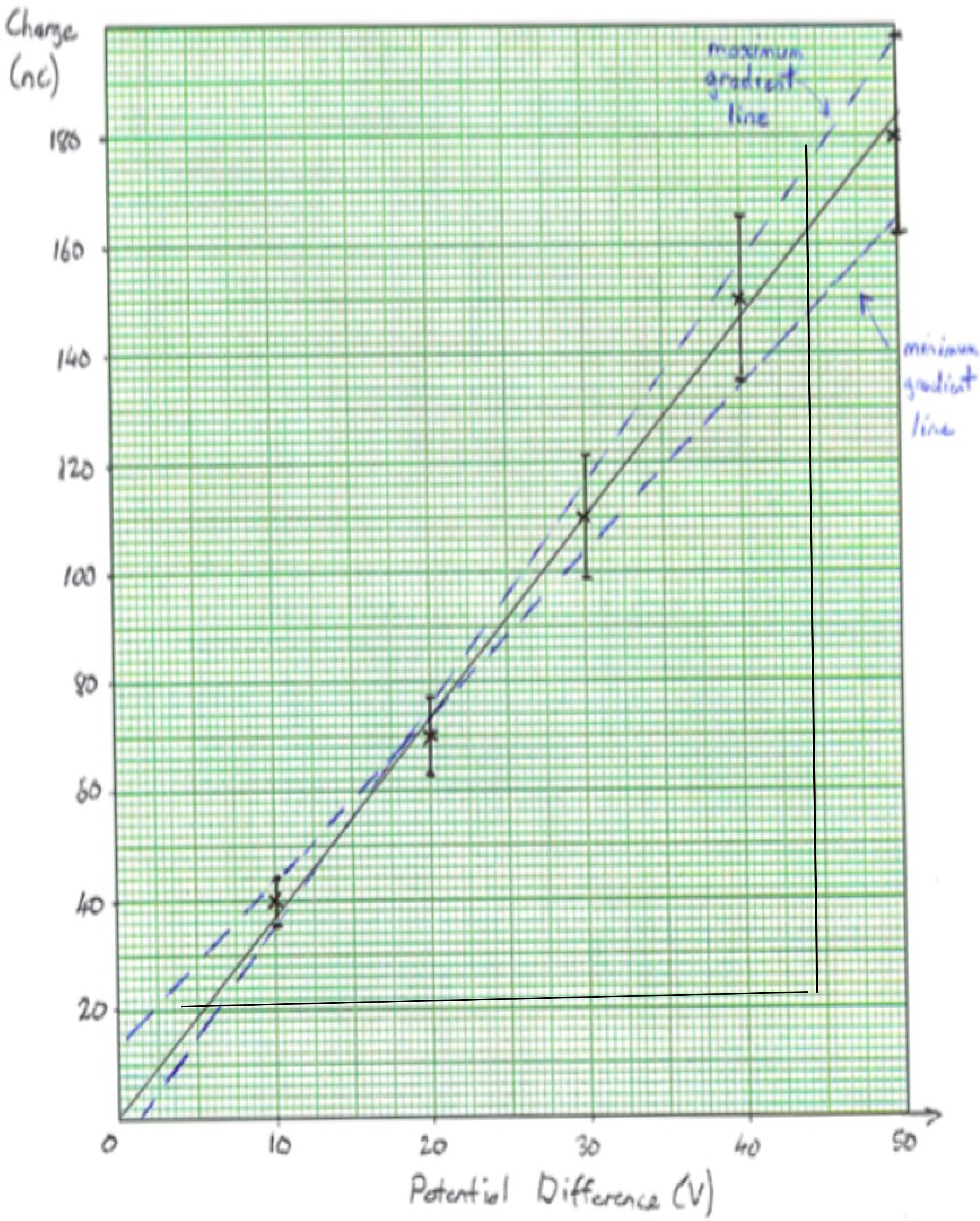
The plates are of equal area A and are a distance d apart. The area of the plates was measured to be 0.20 ± 0.005 m^2 while the distance between the plates was found to be 0.50 ± 0.01 mm.

An experiment was carried out where different values of potential difference V were applied between the plates, and the charge *Q* on each of the plates was measured for each value of potential difference V.

The values obtained are shown in the table at right. The uncertainty in the value of V is insignificant but the uncertainty in the value of *Q* is $\pm$ 10%.

V (V)	Q (nC)
10.0	40
20.0	70
30.0	110
40.0	150
50.0	180

(a) On the graph paper on the next page, plot a graph of charge *Q* (y axis) against potential difference *V* (x axis). Show appropriate error bars and draw a line of best fit. (5 marks)



Labelled axes (PD on horizontal) (✓)

Uniform scales (✓)

Plotted points (✓)

Line of best fit (✓)

Error bars (✓)

(b) The gradient of the line of best fit gives a property of the two parallel plates known as the capacitance C. Calculate the capacitance of the two parallel plates, and include the units for capacitance. (4 marks)

Capacitance = gradient = $^{\text{rise}}/_{\text{run}}$ (workings shown on graph) (✓)

= $^{(165 - 20)\text{nC}}/_{(45 - 5)\text{V}}$ = $^{145\text{nC}}/_{40\text{V}}$ (✓)

Capacitance: **3.62 x 10^{-9} (✓) C/V (✓)**

(c) On the above graph, draw lines of best fit that have the maximum and minimum permissible gradients. (2 marks)

Passes through all error bars
Accuracy – must "start high then aim low" on error bars for min grad and vice versa for max

(d) Find the values of these maximum and minimum permissible gradients and hence estimate the percentage uncertainty in the value of capacitance C. (4 marks)

Minimum gradient = $^{122\text{nC}}/_{40\text{V}}$ = 3.05 x 10^{-9} C/V (✓)

Maximum gradient = $^{162\text{nC}}/_{40\text{V}}$ = 4.05 x 10^{-9} C/V (✓)

Range of gradient values = 1.00 x 10^{-9} C/V

Uncertainty in value = ±0.50 x 10^{-9} C/V (✓)

% uncertainty in capacitance values = $\dfrac{\pm 0.50 \times 10^{-9}\ \text{C/V}}{3.62 \times 10^{-9}\ \text{C/V}}$ = ±13.8% (✓)

Did except slight variations – such as finding the largest difference between min/max and original rather than halving the difference between min and max as shown above.

Did **NOT** accept finding the % difference between the average gradient of max+min, and comparing to original as an answer as this is just an indicator of how far your gradient is from the average – not the total % uncertainty.

The relationship between charge Q and potential difference V is given by $Q = \frac{\varepsilon_0 A}{d} V$ where ***A*** is the area of the plates and $\boldsymbol{d}$ is the distance between the plates.

(e) Use your value of capacitance to find the permittivity of free space ε_0, providing an appropriate uncertainty for your calculated value. (5 marks)

Capacitance C = gradient = $\frac{\varepsilon_0 A}{d} \rightarrow \varepsilon_0 = \frac{Cd}{A}$ **(✓)**

Hence $\varepsilon_0 = \frac{Cd}{A} = \frac{(3.62 \, x \, 10^{-9} \, C/V)(0.0005 \, m)}{(0.200 \, m^2)}$ **(✓)**

= 9.06×10^{-12} **$CV^{-1}m^{-1}$**

% uncertainty in A = $^{0.005}/_{0.2}$ **= 2.5%**

(✓)

% uncertainty in d = $^{0.01}/_{0.5}$ **= 2.0%**

Hence % uncertainty in C = 13.8% + 2.5% + 2.0% = 18.3% **(✓)**

= **9.06×10^{-12} $CV^{-1}m^{-1}$ $\pm 1.66 \times 10^{-12}$** **(✓)**

If estimated uncertainty by looking at largest and lowest possible values of permittivity (based on area, distance and range of capacitance from previous question) max 3 marks.

Question 22 **THE STRONG INTERACTION** **(16 marks)**

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.

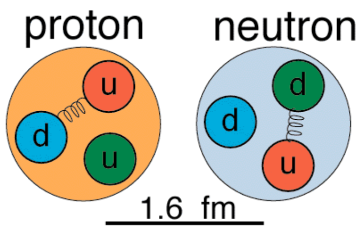
It was later discovered that protons and neutrons were not fundamental particles, but were made up of constituent particles called quarks. The strong attraction between nucleons was the side-effect of a more fundamental force that bound the quarks together into protons and neutrons. Quarks attract one 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 femtometer (1 fm = 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.

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 femtometers). 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).

(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. (✓)

Refers to data (10^{-36} x weaker) in article (✓)

(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. (✓)

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 within hadrons, between the composite quarks, (✓)

The strong force cancels within hadrons(✓), but not perfectly – causing the residual force(✓)

The residual version of the strong force binds hadrons/nucleons together. (✓)

Note: wording in the article has confused a lot of students:

"The strong nuclear force is thus a minor residuum of the **strong force that binds quarks together into protons and neutrons**" – it is the strong force that binds quarks (emphasised by placing that portion on the sentence in bold). The residual force does not bind quarks.

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

Residual strong force rapidly decreases (✓)

Electromagnetic force does not decrease as rapidly (✓)

At large nuclear radius (✓), the repulsive EM force dominates (✓) – causing instability

End of Section Three - End of Questions

Additional Working Space

Additional Working Space

Additional Graph Paper