Government of **Western Australia**
School Curriculum and Standards Authority

ATAR course examination, 2018

Question/Answer booklet

PHYSICS

Student number: In figures

In words G. Moran Solutions.

Number of additional answer booklets used (if applicable):

Time allowed for this paper

Reading time before commencing work: ten minutes
Working time: three hours

Materials required/recommended for this paper

To be provided by the supervisor

This Question/Answer booklet
Formulae and Data booklet

To be provided by the candidate

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

Special items: non-programmable calculators approved for use in this examination, 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 material. If you have any unauthorised material with you, hand it to the supervisor **before** reading any further.

Ref: 18-067

PHY

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Structure of this paper

Section	Number of questions available	Number of questions to be answered	Suggested working time (minutes)	Marks available	Percentage of examination
Section One Short response	10	10	50	55	30
Section Two Problem-solving	7	7	90	89	50
Section Three Comprehension	2	2	40	37	20
				Total	100

Instructions to candidates

1. The rules for the conduct of the Western Australian external examinations are detailed in the *Year 12 Information Handbook 2018*. Sitting this examination implies that you agree to abide by these rules.

2. Write your answers in this Question/Answer booklet preferably using a blue/black pen. Do not use erasable or gel pens.

3. You must be careful to confine your answers to the specific questions asked and to follow any instructions that are specific to a particular question.

4. When calculating or estimating answers, show all your working clearly. Your working should be in sufficient detail to allow your answers to be checked readily and for marks to be awarded for reasoning.

   In calculations, give final answers to three significant figures and include appropriate units where applicable.

   In estimates, give final answers to a maximum of two significant figures and include appropriate units where applicable.

5. Supplementary pages for planning/continuing your answers to questions are provided at the end of this Question/Answer booklet. If you use these pages to continue an answer, indicate at the original answer where the answer is continued, i.e. give the page number.

6. The Formulae and Data booklet is not to be handed in with your Question/Answer booklet.

Section One: Short response **30% (55 Marks)**

This section has **10** questions. Answer **all** questions. Write your answers in the spaces provided.

When calculating numerical answers, show your working or reasoning clearly. Give final answers to **three** significant figures and include appropriate units where applicable.

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.

Supplementary pages for planning/continuing your answers to questions are provided at the end of this Question/Answer booklet. If you use these pages to continue an answer, indicate at the original answer where the answer is continued, i.e. give the page number.

Suggested working time: 50 minutes.

Question 1 **(4 marks)**

A generator is capable of producing 3.00 × 10² kW of electricity at 415 V AC. Its output is stepped up to 11.0 kV for transmission.

(a) Determine the primary to secondary turns ratio of the step-up transformer used at the power station. (2 marks)

$P = 3.00 \times 10^5$ W

$\Delta V_1 = 415$ V

$\Delta V_2 = 11.0 \times 10^2$ V

$\frac{V_P}{V_S} = \frac{N_P}{N_S}$

$\frac{N_P}{N_S} = \frac{(415)}{(11.0 \times 10^3)}$

$\frac{N_P}{N_S} = 3.77 \times 10^{-2}$

Answer ________________

(b) Determine the current available at the output of the step-up transformer. (2 marks)

* Assume 100% efficient.

$P_{in} = P_{out}$

$P_{OUT} = \Delta V_o I_o$

$I_o = \frac{P_{out}}{\Delta V_o}$

$= \frac{(3.00 \times 10^5)}{(11.0 \times 10^3)}$

Answer ________________ A

$= 2.73 \times 10^1$ A

Question 2 **(6 marks)**

A tram is powered by four identical electric motors. Each motor has a maximum power output of 30.0 kW. The motors are connected in parallel and powered by 6.00×10^2 V DC from overhead power lines. When the motors are operating at maximum power output there is a back emf of 5.20×10^2 V with an internal resistance of 1.39 Ω.

(a) Calculate the current drawn by each motor when operating at maximum power output. (4 marks)

$P = 30.0 \times 10^3$ W

$\Delta V_{sup} = 6.00 \times 10^2$ V

$\Delta V_{back} = 5.20 \times 10^2$ V

$\Delta V_{nett} = 8.0 \times 10^1$ V

$I = \frac{P}{\Delta V_{nett}}$

$= \frac{(30.0 \times 10^3)}{(8.0 \times 10^1)}$

$I = 3.75 \times 10^2$ A

* is max power at 80 V nett potential difference?

$I = \frac{\Delta V_{nett}}{R}$

$I = 5.76 \times 10^1$ A. ?

$P = \frac{V^2}{R} =$

$P = 4.6 \times 10^3$ W

not 30 kW?

Answer ______________ A

(b) After operating for a while one of the motors becomes jammed. Describe, with a reason, what happens to the current in that motor when it becomes jammed. (2 marks)

As the back EMF results from the rotor moving the back emf will drop to zero when the motor jams. This would result in the nett emf increasing to the supplied emf value, which would increase the current flowing in the motor to 4.32×10^2 A

$I = \frac{\Delta V}{R}$

$= \frac{(6.00 \times 10^2)}{(1.39)}$

* Internal resistance of each motor or all motors in parallel?

Question 3 **(6 marks)**

Silicon is a semiconducting material commonly used to make photovoltaic cells.

Manufacturers of a solar-powered watch wanted to determine the work function of the silicon under low levels of artificial light. To test the solar-powered watch, the manufacturer used a light source which emitted photons with wavelengths of 510.6 nm and 578.2 nm.

The photoelectrons emitted were found to have a maximum kinetic energy of 5.36×10^{-20} J.

(a) State why **all** photoelectrons emitted from the silicon do not have the same kinetic energy for a given incident wavelength. (1 mark)

some photoelectrons may undergo collisions with other particles and so they may transfer some of their kinetic energy in elastic collisions.

(b) Determine the maximum energy in joules of the highest energy incident photons. (2 marks)

$\lambda = 5.106 \times 10^{-7}$ m

$c = 3.00 \times 10^{8}$ m s^{-1}

$h = 6.63 \times 10^{-34}$ J s

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

$$= \frac{(6.63 \times 10^{-34})(3.00 \times 10^{8})}{(5.106 \times 10^{-7})}$$

$$E = 3.90 \times 10^{-19} \text{ J}$$

Answer ______________ J

(c) Calculate the work function of the silicon in joules. (3 marks)

$$E_{ph} = W + E_K$$

$$W = E_{ph} - E_K$$

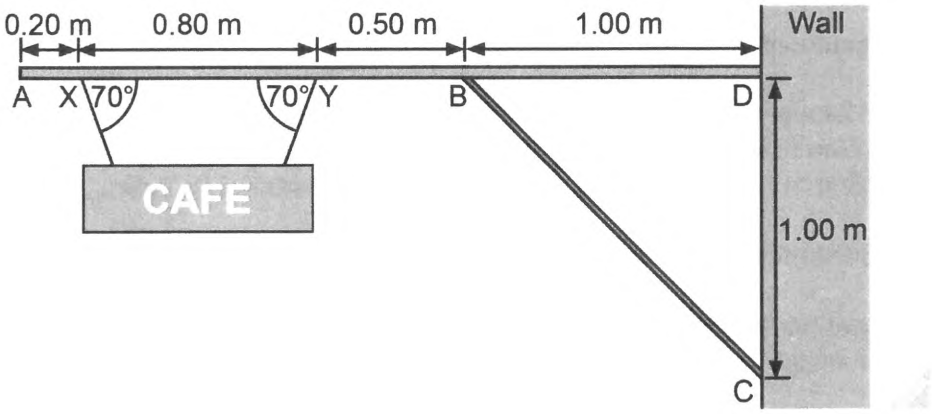
$$= (3.90 \times 10^{-19}) - (5.36 \times 10^{-20})$$

$$W = 3.36 \times 10^{-19} \text{ J}$$

* 3 marks ?

Answer ______________ J

Question 4 **(7 marks)**



A uniform horizontal 2.50 m beam AD of mass 15.0 kg is attached to the front wall of a shop. It is strengthened and supported by a steel bracket BC that is attached to the beam AD at point B, 1.00 m from end D, and to the wall at point C, 1.00 m below end D.

Beam AD supports a uniform sign of mass 4.00 kg. The sign is attached to beam AD at points X and Y using two light steel cables. They are 0.20 m and 1.00 m respectively from end A, both making angles of 70.0° to beam AD. The light steel cables are attached at equal distance from the centre of the sign as shown in the diagram above.

(a) Calculate the tension in each of the light steel cables supporting the sign. (3 marks)

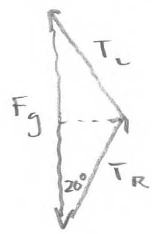
$m_s = 4.00$ kg
$g = -9.80$ m s^{-2}

$\cos 20° = \frac{\frac{1}{2} F_g}{T_R}$

$T_L = T_R = \frac{\frac{1}{2}(m \cdot g)}{\cos 20°}$

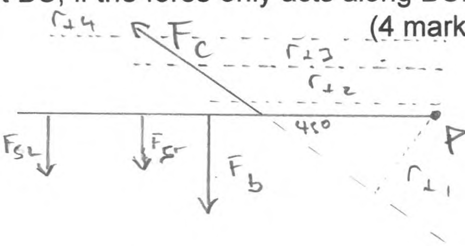
$= \frac{\frac{1}{2}(4.00 \times 9.80)}{(\cos 20°)}$

$T_L = T_R = 2.09 \times 10^1$ N



Answer ______________ N

(b) Calculate the compression force in the steel bracket BC, if the force only acts along BC. (4 marks)



$\sum M_{cw} = \sum M_{acw}$

$F_c r_{\perp 1} = F_{SL} r_{\perp 4} + F_{SR} r_{\perp 3} + F_b r_{\perp 2}$

$F_c r_{\perp 1} = (\frac{1}{2} \times 4.00 \times 9.80)(2.30) + (\frac{1}{2} \times 4.00 \times 9.80)(1.50) + (15.0 \times 9.80)(1.25)$

$r_{\perp 1} = (1.00)\sin 45°$
$r_{\perp 1} = 0.7071$ m
$r_{\perp 2} = 1.25$ m
$r_{\perp 3} = 1.50$ m
$r_{\perp 4} = 2.30$ m

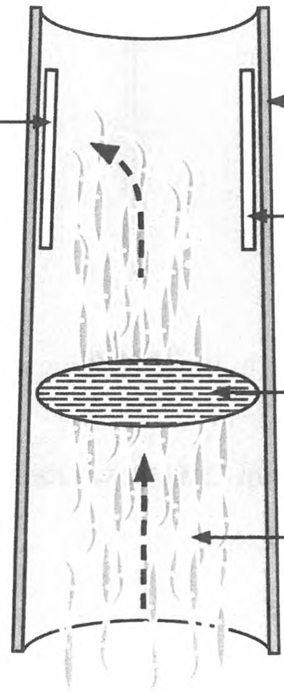
$F_c = \frac{(4.508 \times 10^1) + (2.940 \times 10^1) + (1.8375 \times 10^2)}{(0.7071)}$

$F_c = 3.65 \times 10^2$ N.

Answer ______________ N

Question 5 **(3 marks)**

Electrostatic precipitators are used inside industrial chimneys to remove smoke and dust particles from waste gases before being released into the atmosphere. As shown in the diagram below, smoke and dust particles pass through a highly negatively charged screen where the dust particles gain electrons and are charged to -1.00×10^{-8} C. They then flow upwards between two parallel vertical metal plates. One vertical metal plate has a positive potential of +50.0 kV DC and the other is earthed at zero volts.



Calculate the force exerted on one of these dust particles by the field when it is between the parallel vertical metal plates. The horizontal distance between the plates is 47.5 cm.

$\Delta V = 50.0 \times 10^3$ V
$q = -1.00 \times 10^{-8}$ C
$d = 0.475$ m
$F = ?$

$E = \frac{F}{q} = \frac{\Delta V}{d}$

$F = \frac{\Delta V q}{d}$

$= \frac{(50.0 \times 10^3)(-1.00 \times 10^{-8})}{(0.475)}$

$F = -1.05 \times 10^{-3}$ N

$F = 1.05 \times 10^{-3}$ N towards the positive plate

Answer ______________________ N

Question 6 **(6 marks)**

An experiment was conducted to investigate the nature of light. A parallel beam of monochromatic light was directed at a very small spherical object and a white screen was positioned behind the object (Diagram 1). The pattern observed on the white screen is shown in Diagram 2. (Note: diagrams not to scale.)

Diagram 1

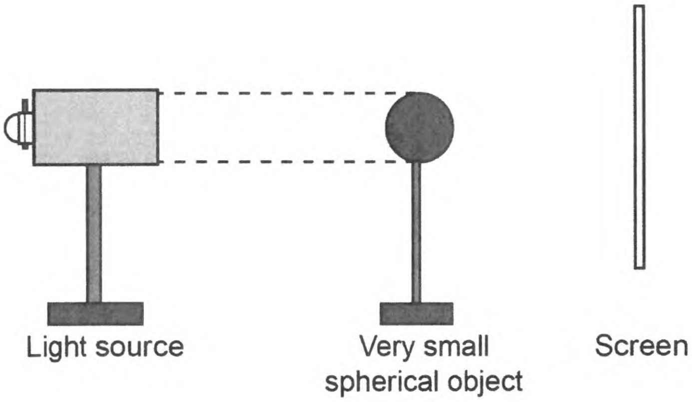
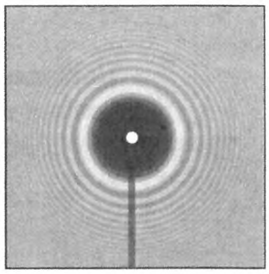


Diagram 2



Screen

(a) Discuss how the pattern in Diagram 2 was produced. (5 marks)

As the light passes by the sphere it behaves like a wave and diffracts into the shadow region. After diffracting the light waves will interfere and cause constructive and destructive interference patterns on the screen. The central bright spot is due to constructive interferance due to the equal path difference from this spot to the edge of the sphere.

(b) From this experiment, what conclusion can be made regarding the nature of light? (1 mark)

That light has wave-like properties.

Question 7 **(5 marks)**

A rectangular coil of a car alternator (AC generator) has 3.20 × 10^2 turns, a radius of 7.00 cm and a length of 6.00 cm. The coil rotates in a uniform magnetic field supplied by electromagnets. The alternator is designed to produce sufficient output voltage to recharge the car battery even when the alternator rotates at 6.00 × 10^2 rpm. The output voltage is steady at 14.5 V rms.

(a) Determine the peak voltage output of this alternator. (1 mark)

$emf_{max} = \sqrt{2}\ emf_{rms}$
$= \sqrt{2} \times (14.5)$
$emf_{max} = 2.05 \times 10^1$ V

Answer ______________ V

(b) Calculate the magnetic field strength needed to produce this peak output voltage. If you were unable to obtain an answer for part (a), use 25.0 V. (4 marks)

$emf_{max} = 2.05 \times 10^1$ V
$B = ?$
$N = 3.20 \times 10^2$ turns
$r = 7.00 \times 10^{-2}$ m
$l = 6.00 \times 10^{-2}$ m
$f = \frac{6.00 \times 10^2}{60}$
$f = 10.0$ Hz.

$emf_{max} = 2\pi NBAf$

$B = \frac{emf_{max}}{2\pi NAf}$

$= \frac{(2.05 \times 10^1)}{2\pi(3.20 \times 10^2)(7.00 \times 10^{-2} \times 6.00 \times 10^{-2})(10.0)}$

$B = \frac{(2.05 \times 10^1)}{(8.446 \times 10^1)}$

$B = 2.43 \times 10^{-1}$ T

Answer ______________ T

* should use magnetic flux density rather than strength.
* why 3 SF for number of turns, it is an absolute number.

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Question 8 **(5 marks)**

An experiment was conducted to observe changes in colour and intensity as a bar of dull grey tungsten metal was heated from room temperature.

When heated to 200 °C the tungsten is observed as remaining grey and dull. When heated to 700 °C the tungsten is observed as red and dull, and at 2700 °C the tungsten is observed as white and bright.

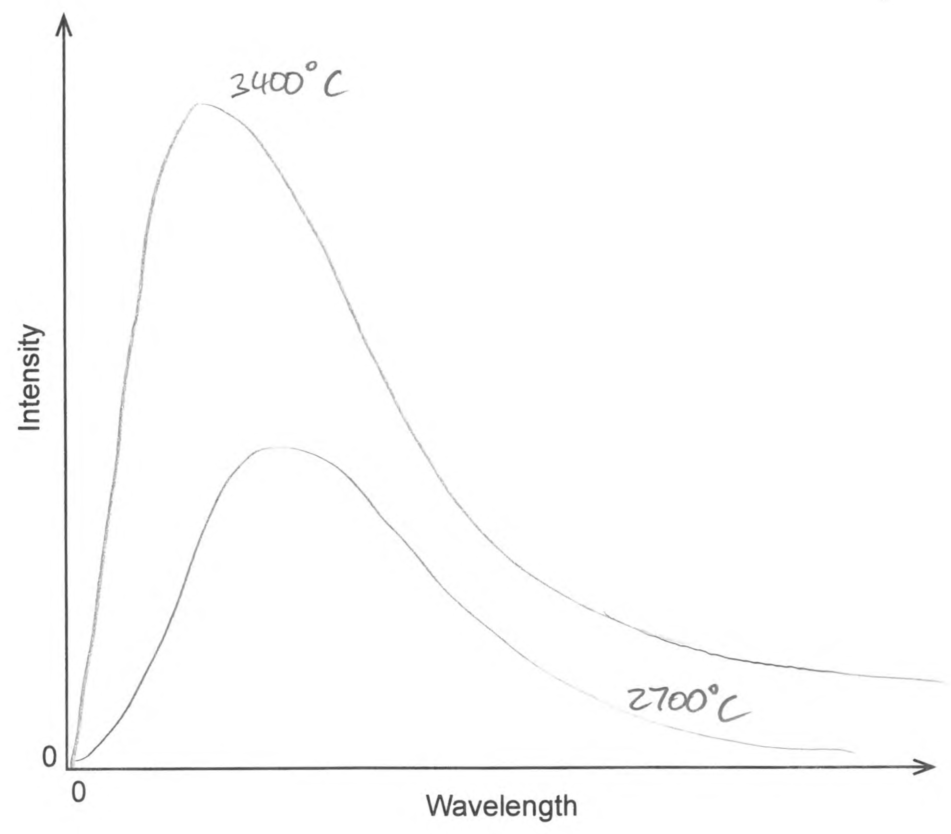
(a) Describe why the colour and intensity of the tungsten changes as it is heated. (2 marks)

As the temperature increases a larger proportion of the electromagnetic radiation is emitted at shorter wavelengths causing the colour to change to include all colours, hence it looks white. The intensity increases as there are more particles vibrating with sufficient energy to emit photons in the visible region.

* space?

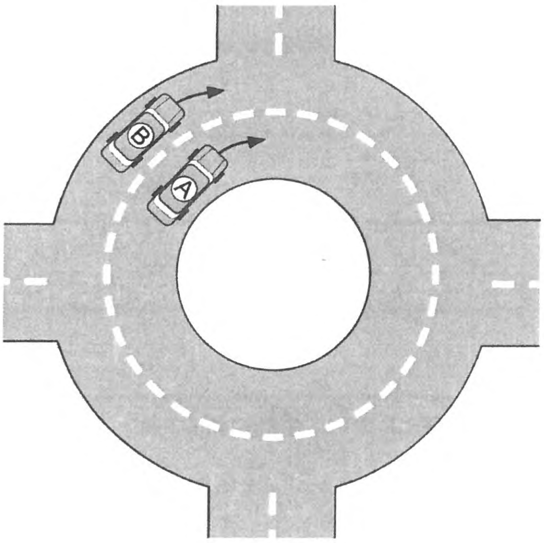
The tungsten is heated further until it starts melting at approximately 3400 °C.

(b) Use the axes below to sketch labelled graphs of intensity against wavelength for the two observed spectra at 2700 °C and 3400 °C. (3 marks)



Question 9 **(6 marks)**

Cars A and B are moving in a circle around a horizontal dual lane roundabout at a constant speed of 30 km h^{-1} as shown in the diagram below. (Note: diagram not to scale.)



(a) Compare the acceleration of cars A and B. Include an equation in your answer. (3 marks)

$a = \frac{v^2}{r}$ ∴ $v^2 = a \cdot r$ ∴ $a_A r_A = a_B r_B$ as v^2 is constant.

As the radius of B is larger than the radius of A the acceleration of B must be smaller than the acceleration of A to maintain the same speed.

The roundabout currently has a maximum speed limit of 30 km h^{-1} to enable the cars to travel safely. Engineers have been asked to redesign the roundabout so as to increase the safe speed limit to 50 km h^{-1}, while still maintaining the same inner and outer radius.

(b) How can the roundabout be redesigned to enable cars to travel safely at a higher speed? Explain your answer. Calculations are not required. (3 marks)

use a banked curve profile so that there is a component of the normal reaction force of the road on the car that acts horizontally towards the centre of the roundabout. This adds to the centripetal force due to friction to reduce the overall reliance on friction.

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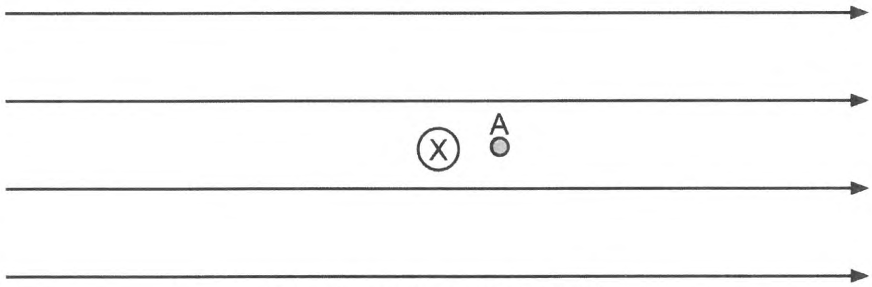
Question 10 **(7 marks)**

An experiment was conducted to determine the effect of an external magnetic field on a current carrying conductor. A DC solenoid was used to produce a constant magnetic field of 32.0 μT. A conductor carrying a direct current of 285 mA was introduced to the magnetic field. The conductor was fixed in place and carries the current directly into the page. Point A is 8.00 mm from the centre of the conductor, along a line parallel to the constant magnetic field as shown below.



Direction of magnetic field

(a) Use the information above to calculate:

(i) the magnitude of the magnetic field at point A due to the current in the conductor. (2 marks)

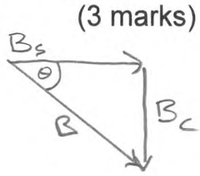
$B = \frac{\mu_0}{2\pi} \cdot \frac{I}{r}$

$B = \frac{(4\pi \times 10^{-7})}{2\pi} \cdot \frac{(285 \times 10^{-3})}{(8.00 \times 10^{-3})}$

$B = 7.13 \times 10^{-6}$ T

Answer magnitude ______________ T

(ii) the magnitude and direction of the resultant magnetic field at point A. If you were unable to obtain an answer to part (a)(i), use 6.00 × 10^{-6} T. Include a diagram in your answer. (3 marks)



$B = \sqrt{(7.13 \times 10^{-6})^2 + (32.0 \times 10^{-6})^2}$

$B = 3.28 \times 10^{-5}$ T

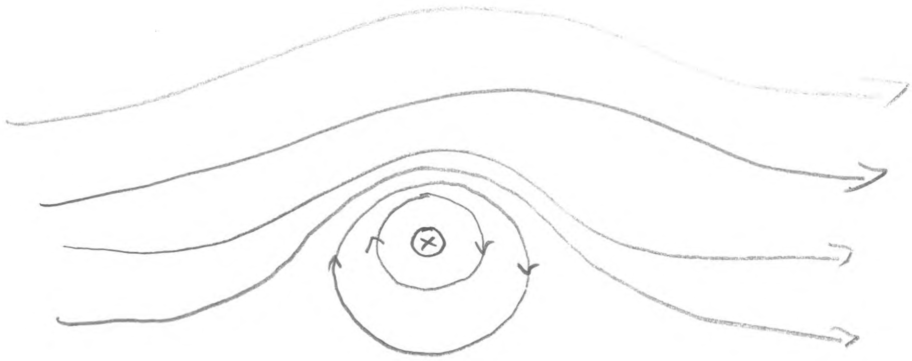
$\theta = \tan^{-1} \frac{(7.13 \times 10^{-6})}{(32.0 \times 10^{-6})}$

$\theta = 12.6°$

Answer magnitude ______________ T

Direction ______________

(b) Sketch the resultant magnetic field around the conductor. (2 marks)



End of Section One

Section Two: Problem-solving **50% (89 Marks)**

This section has **seven** questions. Answer **all** questions. Write your answers in the spaces provided.

When calculating numerical answers, show your working or reasoning clearly. Give final answers to **three** significant figures and include appropriate units where applicable.

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.

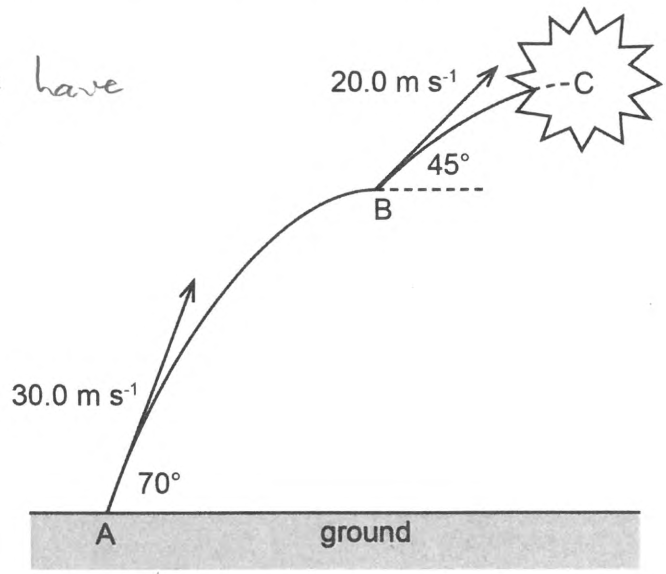
Supplementary pages for planning/continuing your answers to questions are provided at the end of this Question/Answer booklet. If you use these pages to continue an answer, indicate at the original answer where the answer is continued, i.e. give the page number.

Suggested working time: 90 minutes.

Question 11 **(13 marks)**

A firework rocket was launched into the air from the ground at point A with an initial velocity of 30.0 m s^{-1} at an angle of 70.0° to the horizontal. When the firework rocket reached its initial maximum height at point B, there was a second explosion that further propelled the upper part of the firework rocket with a new velocity of 20.0 m s^{-1} at an angle of 45.0° to the horizontal. This upper part of the firework rocket was propelled to a new maximum height at point C where the firework rocket exploded. Ignore all effects due to air resistance.

* firework rockets have engines!! not projectiles!



(a) Determine the initial vertical velocity of the firework rocket. (2 marks)

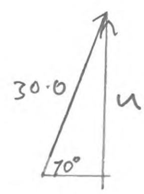
$\sin\theta = \frac{u_v}{30.0}$

$u_v = (30.0)(\sin 70°)$

$= 2.819 \times 10^1 \text{ m s}^{-1}$

$= 3 \times 10^1 \text{ m s}^{-1}$

$= 2.82 \times 10^1 \text{ m s}^{-1}$



Answer ______________________ m s^{-1}

* sig figs? = 1?
* if 3 SF is required give the data to 3 SF.

See next page

(b) Calculate the height of point B. (3 marks)

+↑ −↓ assume projectile motion.

$s = ?$
$u = 2.82 \times 10^1 \text{ ms}^{-1}$
$v = 0 \text{ ms}^{-1}$
$a = -9.80 \text{ ms}^{-2}$
$\Delta t =$

$v^2 = u^2 + 2as$

$s = \frac{v^2 - u^2}{2a}$

$= \frac{(0)^2 - (2.82 \times 10^1)^2}{2(-9.80)}$

$s = 4.0547 \times 10^1$

$s = 4.05 \times 10^1 \text{ m}.$

Answer ______________________ m

(c) Calculate the total time it takes for the firework rocket to reach point C where it explodes. (5 marks)

+↑ −↓ A − B: time.

$s = 4.0547 \times 10^1 \text{ m}$
$u = 2.82 \times 10^1 \text{ ms}^{-1}$
$v = 0 \text{ ms}^{-1}$
$a = -9.80 \text{ ms}^{-2}$
$\Delta t = ?$

$a = \frac{v - u}{\Delta t}$

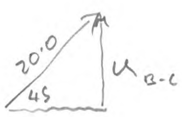
$\Delta t = \frac{v - u}{a}$

$= \frac{(0) - (2.82 \times 10^1)}{(-9.80)}$

$\Delta t_{AB} = 2.8765 \text{ s}.$

↕ B − C : time

$s =$
$u = 20.0 \sin 45°$
$u_v = 1.4142 \times 10^1 \text{ ms}^{-1}$
$v = 0$
$a = -9.8 \text{ ms}^{-2}$
$\Delta t = ?$



$a = \frac{v - u}{\Delta t}$

$\Delta t_{B-C} = \frac{v - u}{a}$

$= \frac{(0) - (1.4142 \times 10^1)}{(-9.80)}$

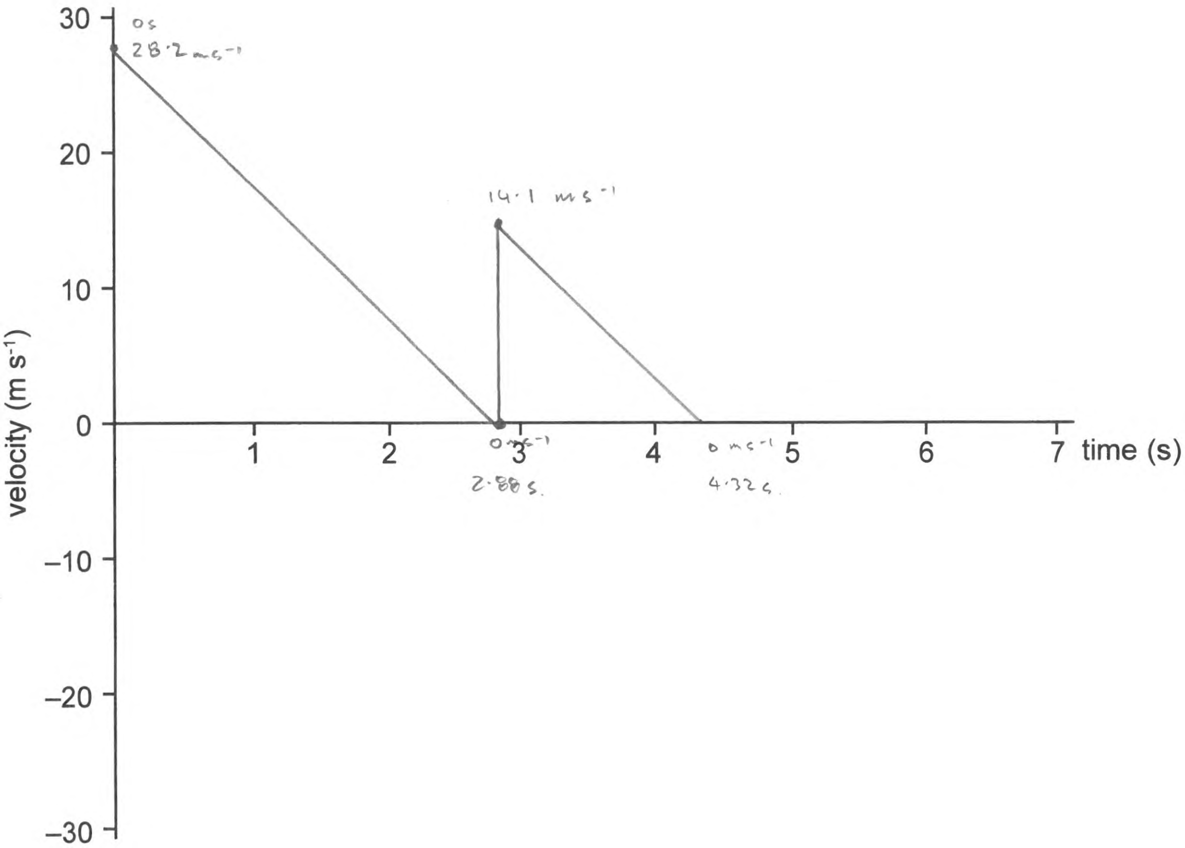
$\Delta t_{B-C} = 1.4431 \text{ s}.$

total $\Delta t = 4.32 \text{ s}.$

Answer ______________________ s

Question 11 (continued)

(d) Use the axes below to sketch a graph of vertical velocity against time of the firework from immediately after it is launched at point A until it reaches point C. Use appropriate values and ignore all effects due to air resistance. (3 marks)



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Question 12 **(8 marks)**

It is imagined that solar sails made from highly reflective thin sheets of metal might propel spacecraft on solar winds without the need for a propulsion system.

A space agency conducted an experiment to determine the possibility of propelling a spacecraft using a solar sail. To simulate the contribution of photons in solar wind they used a highly collimated (focused) beam of light. This beam of light contained 2.50×10^{18} photons, with each photon having a wavelength of 487 nm. A highly-reflective mirror of mass 3.00 μg was used to simulate the solar sail. The collimated beam is fired at 90.0° to the surface of the highly-reflective mirror in a vacuum.

(a) Calculate the magnitude of the momentum of each photon. (2 marks)

$h = 6.63 \times 10^{-34}$ Js
$\lambda = 487 \times 10^{-9}$ m
$p = ?$

$\lambda = \frac{h}{p}$
$p = \frac{h}{\lambda}$
$= \frac{(6.63 \times 10^{-34})}{(487 \times 10^{-9})}$
$p = 1.36 \times 10^{-27}$ kg ms^{-1}

Answer ____________ N s

When the photon beam collides with the mirror, momentum (equal to the product of mass and velocity) is conserved and the mirror moves.

(b) Calculate the recoil velocity of the mirror when the beam of light reflects from it. (4 marks)

$- \longleftrightarrow +$

$p_{iph.} = 1.36 \times 10^{-27}$ kg ms^{-1}
$p_{im} = 0$
$p_{fph} = -1.36 \times 10^{-27}$
$p_{fm} = ?$
$m_m = 3.00 \times 10^{-9}$ kg
$N = 2.50 \times 10^{18}$

$\Sigma p_i = \Sigma p_f$
$N p_{iph} + p_{im} = N p_{fph} + p_{fm}$
$(2.50 \times 10^{18})(1.36 \times 10^{-27}) + (0) = (-1.36 \times 10^{-27})(2.50 \times 10^{18}) + mv$
$v = \frac{(3.40 \times 10^{-9}) + (3.40 \times 10^{-9})}{(3.00 \times 10^{-9})}$
$v = 2.27$ m s^{-1}

Answer ____________ m s^{-1}

(c) Outline **two** possible limitations of using solar sail technology to propel a spacecraft. (2 marks)

One: can only accelerate away from a light source

Two: as you get further from the light source the intensity decreases at an inverse squared rate. and so the acceleration decreases rapidly.

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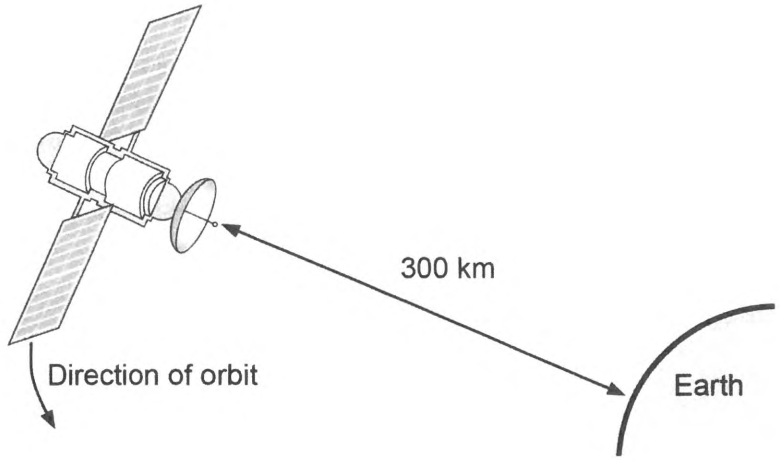
Question 13 **(10 marks)**

A 200 kg satellite is put into a low Earth orbit at an altitude of 300 km.



(a) Calculate the orbital speed of the satellite. (3 marks)

$m_s = 200$ kg

$M_E = 5.97 \times 10^{24}$ kg

$G = 6.67 \times 10^{-11}$

$r_E = 6.37 \times 10^6$ m

$h = 300 \times 10^3$ m

$g = a_c$

$\frac{GM_E}{r^2} = \frac{v^2}{r}$

$v = \sqrt{\frac{GM_E}{r}}$

$= \sqrt{\frac{(6.67 \times 10^{-11})(5.97 \times 10^{24})}{(6.37 \times 10^6 + 300 \times 10^3)}}$

$v = 7.73 \times 10^3$ m s^{-1}

Answer ______________ m s^{-1}

(b) Calculate the orbital period of the satellite. (2 marks)

$v = 7.73 \times 10^3$ m s^{-1}

$r = (6.37 \times 10^6 + 300 \times 10^3)$

$r = 6.67 \times 10^6$ m.

$T = ?$

$v = \frac{2\pi r}{T}$

$T = \frac{2\pi r}{v}$

$= \frac{2\pi(6.67 \times 10^6)}{(7.73 \times 10^3)}$

$T = 5.42 \times 10^3$ s

Answer ______________ s

(c) Calculate the gravitational acceleration experienced by the satellite in orbit. (2 marks)

$$g = \frac{GM_E}{r^2}$$

$$= \frac{(6.67 \times 10^{-11})(5.97 \times 10^{24})}{(6.67 \times 10^6)^2}$$

$$g = 8.95 \text{ m s}^{-2}$$

Answer ____________________ m s^{-2}

An amateur astronomer on Earth measures the orbital period of the international space station in the night sky at 94.7 minutes.

(d) Calculate the altitude of the international space station based on an orbital period of 94.7 minutes. (3 marks)

$T_s = 5.42 \times 10^3$ s

$T_{ss} = 94.7$ min

$r_s = 6.67 \times 10^6$ m

$r_{ss} = ?$

$$T^2 = \frac{4\pi^2}{GM_E} r^3$$

$$\frac{T^2}{r^3} = \frac{4\pi^2}{GM_E} = \text{constant.}$$

$$\therefore \frac{T_{ss}^2}{r_{ss}^3} = \frac{T_s^2}{r_s^3}$$

$$r_{ss} = \sqrt[3]{\frac{(94.7 \times 60)^2 (6.67 \times 10^6)^3}{(5.42 \times 10^3)^2}}$$

$$r_{ss} = \sqrt[3]{3.261 \times 10^{20}}$$

$$r_{ss} = 6.88 \times 10^6$$

$$h = r_{ss} - r_E$$

$$= (6.88 \times 10^6) - (6.37 \times 10^6)$$

$$h = 5.13 \times 10^5 \text{ m}$$

Answer ____________________ m

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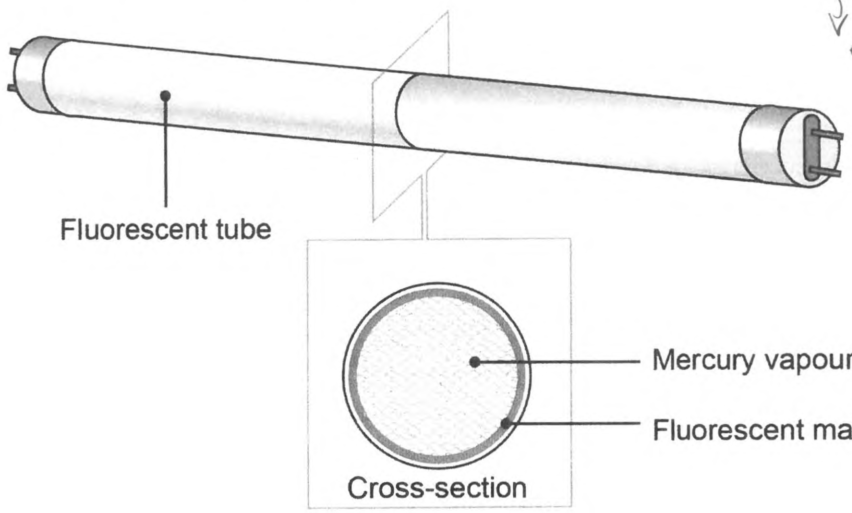
Question 14 **(13 marks)**

A fluorescent light contains mercury vapour which is excited by an electric discharge from end to end inside the tube. This excitation causes some of the mercury atoms to ionise or produce high energy photons. These high energy photons then interact with the fluorescent material coating the inside of the tube to produce visible light.

either . . .



Some of the energy levels below the ionisation level for a mercury atom are shown in the energy level diagram below.

Ionisation level	
n = 4	-4.38×10^{-19} J
n = 3	-6.02×10^{-19} J
n = 2	-9.25×10^{-19} J
n = 1	-16.7×10^{-19} J

* should this be electron?

A photon with energy of 17.9×10^{-19} J collides with an electron in the ground state of a vaporised mercury atom.

(a) Calculate the velocity of any electron emitted from the ground state mercury atom. (3 marks)

$E_{ph} = E_{ionisation} + E_K$

$E_K = (17.9 \times 10^{-19}) - (16.7 \times 10^{-19})$

$E_K = 1.20 \times 10^{-19}$ J.

$E_K = \frac{1}{2}mv^2$

$v = \sqrt{\frac{2E_K}{m}}$

$v = \sqrt{\frac{2(1.20 \times 10^{-19})}{(9.11 \times 10^{-31})}}$

$v = 5.13 \times 10^{5}$ m s^{-1}

Answer ______________ m s^{-1}

See next page

(b) Describe why some of the mercury atoms in the tube need to be ionised. (2 marks)

?

An electron with energy of 10.5×10^{-19} J collides with a ground state electron in a mercury atom.

(c) Calculate the possible energies the incident electron can have after this collision. (3 marks)

* scattered electron

* shouldn't be lines!

$E_e = (10.5 \times 10^{-19}) - (16.7 \times 10^{-19} - 9.25 \times 10^{-19})$

$E_e = 3.05 \times 10^{-19}$ J

or E_e 10.5×10^{-19} J.

(d) Determine the part of the spectrum to which the lowest energy emitted photons belong when subject to an incident electron with energy 10.5×10^{-19} J. (2 marks)

$E_{ph} = (16.7 \times 10^{-19}) - (9.25 \times 10^{-19}) = 3.05 \times 10^{-19}$ J.

$f = \frac{E}{h}$

$= \frac{(3.05 \times 10^{-19})}{(6.63 \times 10^{-34})}$

$f = 4.60 \times 10^{14}$ Hz.

this is in the visible region (just).

* borderline with I.R.

* not the photons from (d)!

The photons emitted from the electron transition of the mercury atom then interact with the fluorescent material coating the inside of the tube.

**

(e) Explain how the emitted photons produced by the mercury atoms produce visible light in the fluorescent material. (3 marks)

** this could confuse students reading this as a flow on from the previous two qns

high energy ultra-violet photons will ~~be absorbed~~ by the fluorescent material if they have the exact energy required to cause an electron transition from the ground state to a higher level in the atom above n=2. As the electron transitions back to the ground state it may do so in smaller jumps to produce photons of lower energy and frequency that would correlate to visible photons.

0087174

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Question 15 **(19 marks)**

An experiment was conducted to determine a value for Planck's constant. The experiment involved setting up five individual, single frequency light emitting diodes (LEDs). Each LED only emits one frequency of light when a turn on voltage (voltage above a certain threshold value) is applied across its terminals.

The relationship between the frequency of the emitted light and the voltage is given by the equation below.

$E = hf = q_e(V_0 + k)$ where
- h is Planck's constant
- f is the frequency of light emitted by the diode
- q_e is the charge on an electron
- V_0 is the turn on voltage
- k is the threshold voltage (constant dependent on the material)

The experiment produced the following results.

LED colour	Maximum wavelength (λ) (nm)	Turn on voltage (V_0)	1/λ (m^{-1})
Blue	450	2.53	2.22×10^6
Green	550	2.04	1.82×10^6
Yellow	570	1.88	1.75×10^6
Red	690	1.37	1.45×10^6
Infra-red	890	0.88	1.12×10^6

(a) Complete the table above for values of 1/λ. (2 marks)

* turn on voltage

(b) Plot a graph of voltage against 1/λ, with voltage on the y-axis, and draw a line of best fit. Error bars are not required. (5 marks)

(c) Use the graph to calculate the gradient of the line of best fit. Show construction lines. (3 marks)

$$\text{slope} = \frac{\Delta y}{\Delta x}$$

$$= \frac{(2.50 - 0.25)}{(2.16 \times 10^6 - 0.68 \times 10^6)}$$

$$\text{slope} = 1.52 \times 10^{-6} \text{ V m}.$$

Answer ______________________ V m

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(d) Use the gradient from part (c) and the provided equation to calculate a value for Planck's constant. (3 marks)

$hf = q_e(V_0 + k)$

$V_0 = \frac{hc}{q_e\lambda} - k$

$V_0 = \frac{hc}{q_e} \cdot \frac{1}{\lambda} - k$

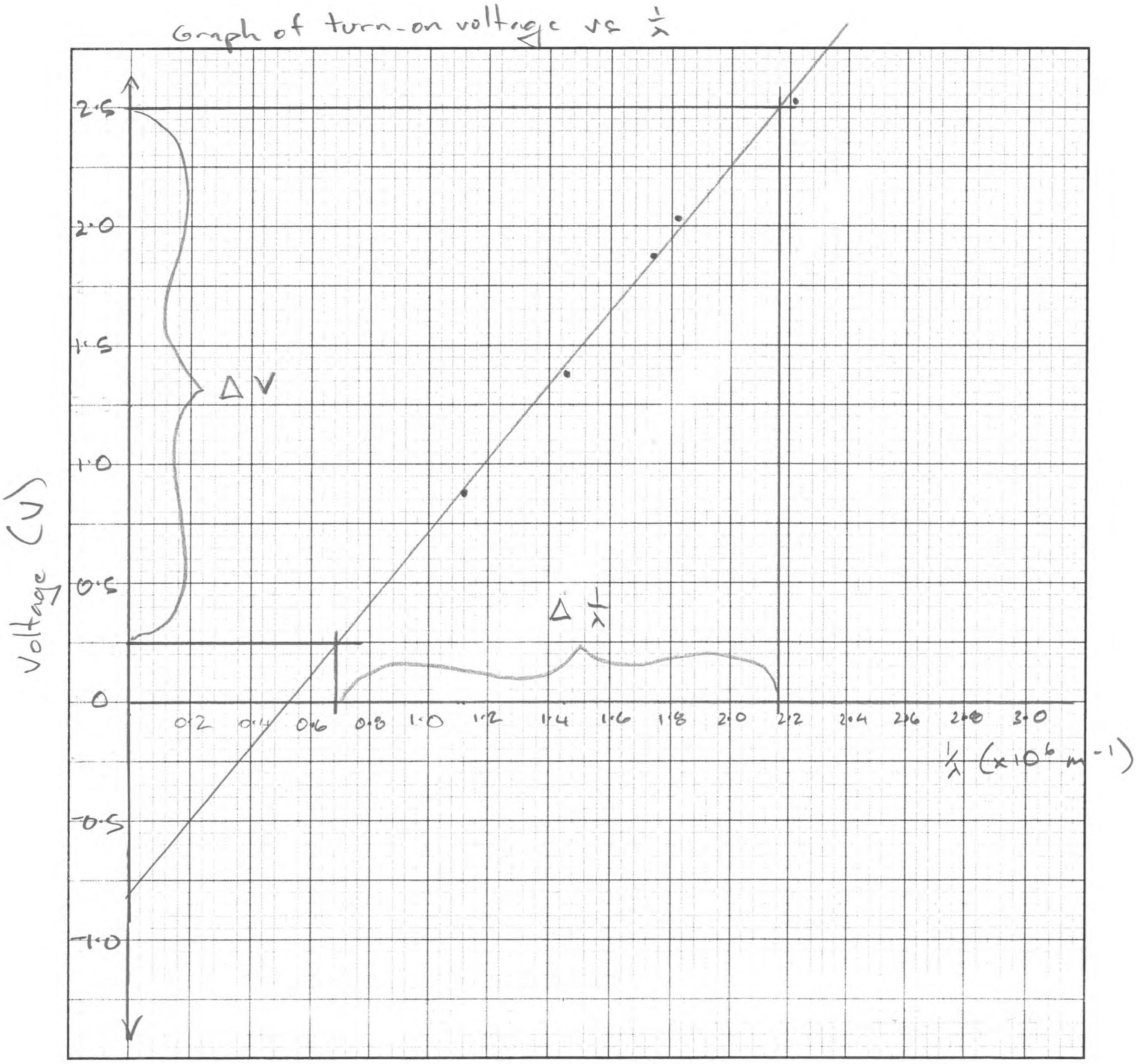
$y = m x + c$

$\therefore m = \frac{hc}{q_e}$

$h = \frac{m \cdot q_e}{c}$

$= \frac{(1.52\times10^{-6})(1.60\times10^{-19})}{(3.00\times10^{8})}$

Answer $h = 8.11\times10^{-34}$ J s



A spare grid is provided at the end of this Question/Answer booklet. If you need to use it, cross out this attempt and clearly indicate that you have redrawn it on the spare page.

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Question 15 (continued)

(e) From your graph, determine the value for k in this experiment. (2 marks)

y-intercept $c = -k$

$-k = -0{\cdot}56$

$k = 5{\cdot}6 \times 10^{-1}$ V.

Answer ______________ V

(f) Describe **two** possible sources of experimental error in the performance of this experiment and how they might be modified to produce a more accurate result. (4 marks)

One: errors in the measurement of wavelength, the values indicate that the instrument used has a limit of reading of 100 nm, a more finely scaled instrument would result in a more accurate result.

Two: errors in only one trial for each LED. Taking multiple measurements of the turn-on voltage for each LED and then averaging the trials would reduce random errors and produce a more accurate result.

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Question 16 **(12 marks)**

In the future it is possible that humans may travel to distant places like Alpha Centauri that is 4.13×10^{13} km from Earth. Imagine you are on a spacecraft travelling past Earth towards Alpha Centauri at $0.720c$ relative to Earth. On your journey you pass another spacecraft travelling parallel and in the opposite direction to you. You measure the relative velocity of the other spacecraft as $0.695c$.

(a) Calculate the velocity of the other spacecraft relative to Earth. (3 marks)

$v = 0.720c$

$u' = -0.695c$

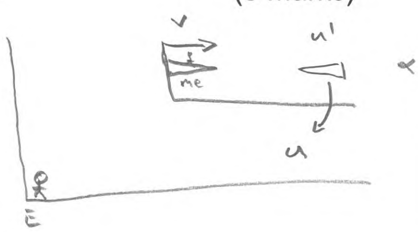
$u = ?$

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

$$= \frac{(0.720c) + (-0.695c)}{1 + \frac{(0.720c)(-0.695c)}{c^2}}$$

$$= \frac{(2.50 \times 10^{-2}c)}{(4.996 \times 10^{-1})}$$

$u = 0.0500c$



Answer ____________________ c

(b) Calculate the number of years for your spacecraft to journey from Earth to Alpha Centauri as measured by an observer on Earth. (3 marks)

$s = 4.13 \times 10^{16}$ m

$v = 0.720c$

$t =$

$$t = \frac{s}{v} = \frac{(4.13 \times 10^{16})}{(0.720 \times 3 \times 10^{8})}$$

$t = 1.912 \times 10^{8}$

$$t = \frac{(1.912 \times 10^{8})}{(365.25 \times 24 \times 60 \times 60)}$$

$t = 6.06$ y

Answer ____________________ years

(c) Calculate the number of years the journey will take as measured by those on the spacecraft travelling at $0.720c$ relative to Earth. (3 marks)

$t_0 = ?$

$t = 6.0589$ y

$v = 0.720c$

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

$$= (6.0589)\sqrt{\left(1 - \frac{(0.720c)^2}{c^2}\right)}$$

$$= (6.0589)\sqrt{4.816 \times 10^{-1}}$$

$t_0 = 4.20$ y

Answer ____________________ years

(d) For those on the spacecraft travelling to Alpha Centauri at 0.720c relative to Earth, calculate the time they would have observed to have elapsed on Earth during the journey from Earth to Alpha Centauri. (3 marks)

$t_o = ?$

$t = 4.20 y$

$v = -0.720c$

$t_o = t \times \sqrt{\left(1 - \frac{v^2}{c^2}\right)}$

$= (4.20)\sqrt{\left(1 - \frac{(0.720c)^2}{c^2}\right)}$

$= (4.20)\sqrt{4.816 \times 10^{-1}}$

$t_o = 2.91 y.$

Answer ______________ years

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Question 17 **(14 marks)**

Positron emission topography (PET) is a high resolution gamma ray medical imaging technique and is useful for scanning soft tissue of the human body.

Fluorine-18 is a radioisotope commonly used in PET. Fluorine-18 is produced via the proton bombardment of the stable isotope oxygen-18 in a cyclotron.

The unstable fluorine-18 used in PET decays back to oxygen-18 as shown in the equation below.

$$^{18}_{9}F \rightarrow ^{18}_{8}O + ^{0}_{+1}e + \nu_e$$

(a) Use the equation above to describe how the nucleus of the fluorine-18 decays to produce oxygen-18. Name the other particles produced. (3 marks)

A proton in the fluorine-18 decays by β^+ decay into a neutron, thus converting fluorine-18 to oxygen-18. The other particles produced are a positron and an electron neutrino.

(b) Name the force and force particle that mediate the interaction described in part (a). (2 marks)

Force: Weak nuclear force

Force particle: W^+

(c) Use your knowledge of the Standard Model to prove that this emission obeys the conservation of baryon number and charge. Assume all quarks have a baryon number equal to ⅓. (4 marks)

$p^+ \rightarrow n^0 + ^{0}_{+1}e + \nu_e$

$uud \rightarrow udd + ^{0}_{+1}e + \nu_e$

B: $\frac{1}{3}+\frac{1}{3}+\frac{1}{3} \rightarrow \frac{1}{3}+\frac{1}{3}+\frac{1}{3} + 0 + 0$

overall $+1 \rightarrow +1$ ∴ baryon number is conserved.

q: $+1 \rightarrow 0 \quad +1 \quad 0$

overall $+1 \rightarrow +1$ ∴ charge is conserved

One of the products from the decay of fluorine-18 then interacts with the electrons of the human body to create two gamma rays that travel in opposite directions to each other. These gamma rays are detected and used to form images of tissues in the human body.

(d) Discuss the interactions that must occur to produce two gamma rays travelling in opposite directions to each other. (5 marks)

the positron from the decay of fluarine-18 is antimatter, When the antimatter positron strikes a matter election total annihilation occurs and the mass of the two particles is converted to energy. In order to conserve momentum two photons of equal energy (λ and frequency) are created that must travel in opposite directions. As there is a large (relatively) energy is stored as mass the two photons are usually high energy gamma photons.

End of Section Two

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Section Three: Comprehension 20% (37 Marks)

This section has **two** questions. You must answer **both** questions. Write your answers in the spaces provided.

When calculating numerical answers, show your working or reasoning clearly. Give final answers to **three** significant figures and include appropriate units where applicable.

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.

Supplementary pages for planning/continuing your answers to questions are provided at the end of this Question/Answer booklet. If you use these pages to continue an answer, indicate at the original answer where the answer is continued, i.e. give the page number.

Suggested working time: 40 minutes.

Question 18 **(16 marks)**

What matters in the universe?

In the early 1930s Fritz Zwicky observed a cluster of galaxies in the constellation of Coma. Zwicky found that these galaxies were moving much too quickly for them to be held together in a cluster, by gravity, if the only mass in the cluster was that of the galaxies themselves. This meant that the centripetal force required was greater than the gravitational force available.

Zwicky could not find any evidence of extra mass in the Coma cluster, from the visible light detected by the telescopes he used. He thought that there must be a lot of extra matter that is also present in the cluster, but this matter did not emit visible light and was therefore 'dark'.

In the early 1970s, diffuse X-ray emission from the Coma cluster of galaxies was observed. These diffuse X-rays indicated the presence of a lot of mass that was different to the matter already observed from the visible light of the galaxies. This matter was in the form of plasma and did not emit visible light, but it did emit X-rays as it was very hot. This observation was further evidence that Zwicky had been correct in his ideas forty years previously.

Also in the 1970s, Kent Ford and Vera Rubin analysed the rotational velocity of several galaxies. Astronomers knew that Hubble's law meant that galaxies were moving further apart and were rotating due to the Doppler shift. Hubble's cosmological red shift provided evidence of an increasing distance between galaxies, while the Doppler shift explained why rotating galaxies appeared blue-shifted on one edge while the light from the other edge appeared red-shifted.

A more detailed observation of the stars at the edge of the galaxy revealed that the stars were travelling at a high velocity, but did not leave the rotating system as earlier thought.

Ford and Rubin concluded that for the stars on the edge of the galaxy to be bound together and be part of the rotating galaxy, more mass was required. This mass had to be greater than could be accounted for from the mass of the stars, plasma, gas and dust of the known galaxy. This provided further evidence for the existence of matter that was 'dark'.

It is now theorised that 80% of all matter in the universe is dark matter. This theory considers two types of dark matter; 'hot, non-baryonic dark matter' and 'cold, non-baryonic dark matter'. Hot, non-baryonic dark matter, like fast-moving neutrinos, has mass and reacts with other matter only via gravity (and the weak force). For now, cold, non-baryonic dark matter is also hypothesised to exist.

(a) Use mathematical reasoning to explain why scientists might have believed that the stars at the outer edges would leave the rotating galaxy. (5 marks)

$$F_g = \frac{G M_g m_s}{r^2} \qquad F_c = \frac{m_s v^2}{r}$$

for stable orbit: $F_g = F_c$

$$\frac{G M_g m_s}{r^2} = \frac{m_s v^2}{r} \quad \text{so} \quad v_{stable} = \sqrt{\frac{G M_g}{r}}$$

for escape velocity: $E_K = E_P$

$$\frac{1}{2} m v^2 = m g h$$

$$\text{so} \quad v_{esc} = \sqrt{\frac{2 G M_g}{r}} \qquad \therefore v_{esc} = \sqrt{2} \times v_{stable}$$

if the velocity of the outer stars is $\sqrt{2}$ or 1.41 times the velocity for stable orbit then they will escape the galaxy.

(b) What hypothesis was made to account for the observation that stars on the outer edge did not leave the rotating galaxy? (2 marks)

that the mass of the galaxy was larger than the value determined by observing visible matter. hence the gravitational force must be larger than previously calculated.

(c) Describe how red shift and blue shift are produced and how this informs astronomers on Earth that galaxies are rotating. (5 marks)

when light emitting sources are moving towards an observer the distance between subsequent wave-fronts is reduced by the distance that the source moves during the period in which the wave-fronts form. This reduces the wavelength thus light is shifted towards the blue end of the spectrum. The opposite occurs for light sources moving away from an observer. the wavelength is greater, which results in the light shifting towards the red end of the spectrum.

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Question 18 (continued)

(d) Discuss how Hubble's Law supports the Big Bang theory. (4 marks)

Hubbles Law establishes the direct relationship between distance to a galaxy and the recessional speed of the galaxy. This means that closer galaxies move slowly and distant galaxies move faster. This implies that space itself is expanding. If this expansion is "reversed" it implies that the universe started at a singularity, hence the Big Bang theory is supported by Hubble's Law

Question 19 **(21 marks)**

European Organisation for Nuclear Research – CERN

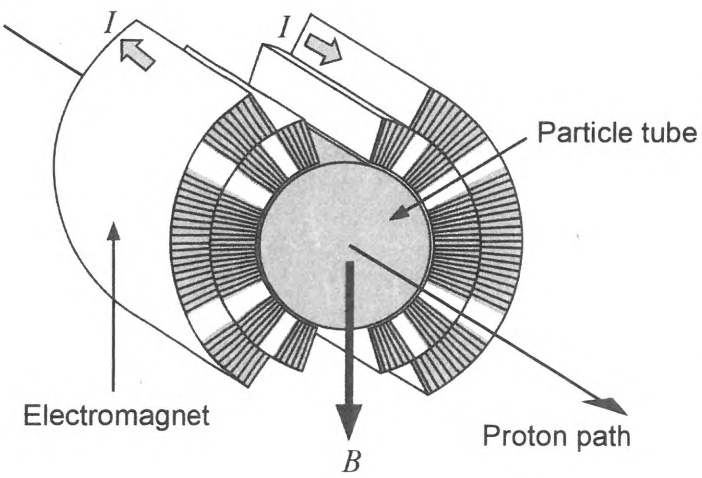
Particle accelerators are used by physicists to explore the elementary particles that might exist. In particle accelerator experiments, the particles' kinetic energy is measured in joules, often alternatively expressed in tera-electron volts (TeV).

The world's most powerful particle accelerator is based in Europe. It is known as the Large Hadron Collider (LHC). This particle accelerator is one of several at the site and the LHC can collide protons with a combined energy of up to 14.0 TeV.

At the LHC, protons are sourced by introducing hydrogen gas into an electrified metal cylinder. A 90.0 kV electric field drives the protons to 1.40% the speed of light prior to entering four sequential radiofrequency cavities. Four steps of acceleration are experienced by the protons in these radiofrequency cavities before they are injected into the LHC. These four steps of acceleration increase the kinetic energy of the protons from 90.0 kV to 50.0 MeV, to 1.40 GeV, to 25.0 GeV and then 450 GeV. The protons are then injected into the LHC where it takes sixteen radiofrequency cavities 20.0 minutes to increase the protons' kinetic energy from 450 GeV to 6.50 TeV.

Inside the LHC, these protons form high-energy particle beams and travel in opposite directions in two separate particle tubes. They travel at close to the speed of light before being made to collide. They are guided around the horizontal accelerator ring by strong magnetic fields created by precisely arranged electromagnets that bend and tighten the path of the particles' trajectory.

The accelerator is built in a ring (large circle) with the particles completing 11 000 circuits each second. The particles can be stored in the ring for hours until they are released and used in an experiment. In the case of the LHC, the accelerator ring is 27.0 km in circumference, giving it a radius of approximately 4.30 km. The diagram below illustrates the simultaneous interactions between the electromagnets and a proton, as the proton is being accelerated towards the centre of the accelerator ring.



The magnetic field (B) is created by superconductive currents on each side of the tube in which the protons travel. The current (I) moves in opposite directions on each side of the tube.

Question 19 (continued)

The physics principle at the heart of particle accelerators is Einstein's theory on the equivalence of mass and energy. In the LHC protons (hadrons) travel in opposite directions around the ring at very high velocities and collide. When the protons collide head on, they explode and split into very hot clouds filled with many smaller particles. The greater the total energy of collision the greater is the probability of producing more massive subatomic particles. It is hoped that the energy present at the site of the collision will be sufficient to discover new particles. Hence the discovery of the Higgs Boson.

(a) Determine the kinetic energy, in joules, that each proton has on leaving the electric field prior to entering the four accelerating radio frequency chambers of the LHC. (2 marks)

$v = 1.40\% \, c$

$m = 9.11 \times 10^{-31}$ kg

$E_k = \frac{1}{2}mv^2$

$= \frac{1}{2}(1.67 \times 10^{-27})(0.0140 \times 3 \times 10^8)^2$

$= \frac{1}{2}(1.67 \times 10^{-27})(4.20 \times 10^6)^2$

$E_k = 1.47 \times 10^{-14}$ J.

* or $E_k = qV$

$= (1.60 \times 10^{-19})(90.0 \times 10^3)$

$= 1.44 \times 10^{-14}$ J

Answer ______________ J

(b) Calculate the energy per second in watts consumed per proton to increase its kinetic energy from 450 GeV to 6.50 TeV in the LHC. (4 marks)

$\Delta E = (6.50 \times 10^{12}) - (450 \times 10^9)$

$\Delta E = 6.05 \times 10^{12}$ eV.

$\Delta E = (6.05 \times 10^{12})(1.60 \times 10^{-19})$

$\Delta E = 9.68 \times 10^{-7}$ J

$\Delta t = 20$ min

$P = \frac{\Delta E}{\Delta t}$

$= \frac{(9.68 \times 10^{-7})}{(20 \times 60)}$

$P = 8.07 \times 10^{-10}$ W.

Answer ______________ W

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A proton with a kinetic energy of 6.50 TeV in the LHC has a velocity of 0.99999998c.

(c) Determine the relativistic momentum of a proton in the LHC with a velocity of 0.99999998c. (2 marks)

$m_p = 1.67 \times 10^{-27}$ kg

$p_v = \frac{m_0 v}{\sqrt{1-\frac{v^2}{c^2}}}$

$= \frac{(1.67 \times 10^{-27})(0.99999998 \times 3 \times 10^8)}{\sqrt{(1 - 0.99999998^2)}}$

Answer ______________ N s

$p_v = 2.50 \times 10^{-15}$ kg m s^{-1}

* magnetic flux density

(d) Calculate the magnetic field strength required to maintain the protons on the required path in the LHC. If you were unable to obtain an answer for part (c), use 3.50 × 10^{-15} N s. (3 marks)

$r = 4.30 \times 10^3$ m

$p_v = mv = 2.50 \times 10^{-15}$

$q_p = 1.60 \times 10^{-19}$ C

$F_B = F_c$

$qvB = \frac{mv^2}{r}$

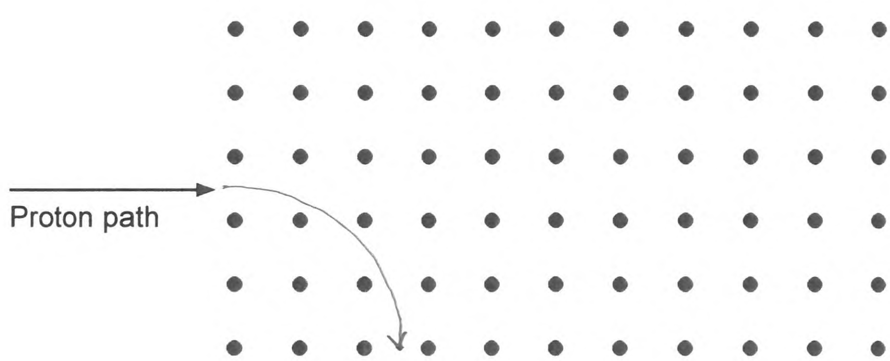
$B = \frac{mv}{rq}$

$= \frac{(2.50 \times 10^{-15})}{(4.30 \times 10^3)(1.60 \times 10^{-19})}$

Answer ______________ T

$B = 3.64$ T

(e) The diagram below represents a magnetic field directed vertically out of the page. A proton in the LHC enters this magnetic field at an angle of 90° to the direction of the field. On the diagram below, continue the path of this proton when in the magnetic field. (1 mark)



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Question 19 (continued)

(f) Describe with clear reasoning, what happens to the centripetal force on a proton in the LHC as the kinetic energy of the proton increases from 450 GeV to 4.50 TeV. (3 marks)

$F_c = \frac{mv^2}{r}$ and $E_K = \frac{1}{2}mv^2$ so $mv^2 = 2E_K$

$\therefore F_c = \frac{2E_K}{r}$

$\frac{F_{cf}}{F_{ci}} = \frac{2(450 \times 10^{12})qe}{r} \times \frac{r}{2(450 \times 10^{9})qe}$

$\frac{F_{cf}}{F_{ci}} = 10$

$F_{c\,final} = 10 \times F_{c\,initial}$. the centripetal force must increase by a factor of 10.

(g) Describe why the mass of the products after a successful collision of the two protons is greater than the rest mass of the two protons before the collision. (2 marks)

As some of the kinetic energy of the colliding particles can be converted into mass of the products, according to $E = mc^2$ and so $m = \frac{E}{c^2}$

(h) If the rest mass energy of a proton is 938 MeV, calculate the velocity the proton reaches when accelerated to a kinetic energy of 1.4 GeV. (4 marks)

$mc^2 = 938 \times 10^6$ eV

$E = 1.4 \times 10^9$ eV

$$E = \frac{mc^2}{\sqrt{1 - \frac{v^2}{c^2}}}$$

$$\sqrt{1 - \frac{v^2}{c^2}} = \frac{mc^2}{E}$$

$$1 - \frac{v^2}{c^2} = \frac{(mc^2)^2}{E^2}$$

$$\frac{v^2}{c^2} = 1 - \frac{(mc^2)^2}{E^2}$$

$$v^2 = \left[1 - \frac{(938 \times 10^6)^2}{(1.4 \times 10^9)^2}\right] \times c^2$$

$$v = 0.742\,c$$

Answer ______________ c

End of questions

Supplementary page

Question number: ______________

Supplementary page

Question number: ____________

Supplementary page

Question number: ______________

Supplementary page

Question number: ______________

Supplementary page

Question number: ______________

Supplementary page

Question number: ______________

Spare grid

ACKNOWLEDGEMENTS

Question 18 Introductory text last paragraph information from: Cayon, L., Cui, W., Lee, K., & Peterson, J. (n.d.). *Dark matter*. Retrieved April, 2018, from https://www.physics.purdue.edu/astro/darkmatter.html

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