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

ATAR course examination, 2020

Question/Answer booklet

PHYSICS

Place one of your candidate identification labels in this box.
Ensure the label is straight and within the lines of this box.

WA student number: In figures | | | | | | | | |

In words Greg Moran
JTC Science

Time allowed for this paper

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

Number of additional answer booklets used (if applicable):

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: up to three calculators, which do not have the capacity to create or store programmes or text, are permitted in this ATAR course 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: 20-067
PHY
089598

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	12	12	50	53	30
Section Two Problem-solving	7	7	90	92	50
Section Three Comprehension	2	2	40	39	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 2020: Part II Examinations*. 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% (53 Marks)**

This section has **12** 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.

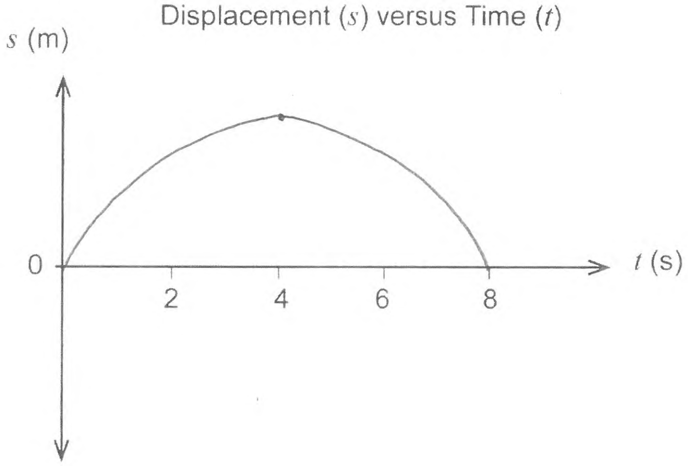
Supplementary pages for planning/continuing your answers to questions are provided at the end of this Question/Answer booklet. If you use these pages to continue an answer, indicate at the original answer where the answer is continued, i.e. give the page number.

Suggested working time: 50 minutes.

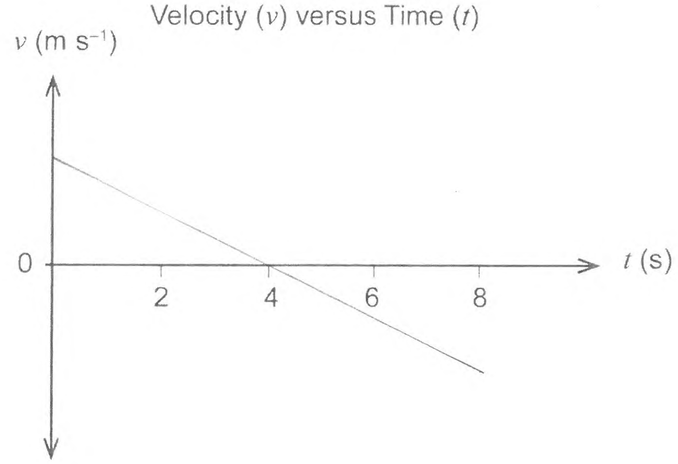
Question 1 **(3 marks)**

A ball is launched vertically into the air with an initial velocity at $t = 0$ from ground level ($s = 0$) and returns to ground level. It takes four seconds for it to reach its maximum height. Taking upwards as positive, graph the ball's displacement, velocity and acceleration versus time from take-off to landing. Ignore air resistance and do not place any values on the y-axis.

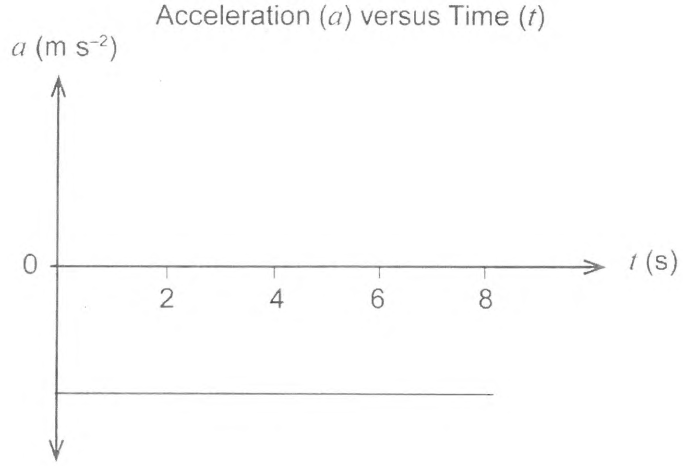
Displacement (s) versus Time (t)



Velocity (v) versus Time (t)



Acceleration (a) versus Time (t)



Question 2 **(3 marks)**

Calculate the speed of an electron with a de Broglie wavelength of 1.23 nm.

$\lambda = 1.23 \times 10^{-9}$ m
$h = 6.63 \times 10^{-34}$ Js
$m_e = 9.11 \times 10^{-31}$ kg
$v_e =$

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

$v = \frac{h}{m\lambda}$

$= \frac{(6.63 \times 10^{-34})}{(9.11 \times 10^{-31})(1.23 \times 10^{-9})}$

$v = 5.9168 \times 10^{5}$

5.92×10^{5} m s^{-1}

Question 3 **(4 marks)**

A 10.0 watt monochromatic LED radiates light with a wavelength of 525 nm. How many photons does it emit per second? Assume all the energy is converted to light.

$P = 10.0$ W
$\lambda = 525 \times 10^{-9}$ m
$N_{ph} = ?$
$t = 1$ s
$c = 3.00 \times 10^{8}$ m s^{-1}
$h = 6.63 \times 10^{-34}$ Js.

$P = \frac{E}{t} = \frac{N E_{ph}}{t}$

$N = \frac{P t}{E_{ph}} = \frac{P . t}{\frac{hc}{\lambda}}$

$= \frac{(10.0)(1)}{\frac{(6.63 \times 10^{-34})(3.00 \times 10^{8})}{(525 \times 10^{-9})}}$

$N = \frac{(10.0)}{(3.78857 \times 10^{-19})}$

$N = 2.63952 \times 10^{19}$

Answer: 2.64×10^{19} photons per second

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Question 4 * conventional current ?? **(4 marks)**

In a Physics experiment, a group of students run a DC current upwards through a 3.5 m long vertical wire.

(a) Calculate the magnetic field strength 25.1 cm from the vertical wire carrying a current of 2.78 A. (3 marks)

$r = 25.1 \times 10^{-2}$ m

$I = 2.78$ A

$\mu_0 = 4\pi \times 10^{-7}$ N A^{-2}

$B = ?$

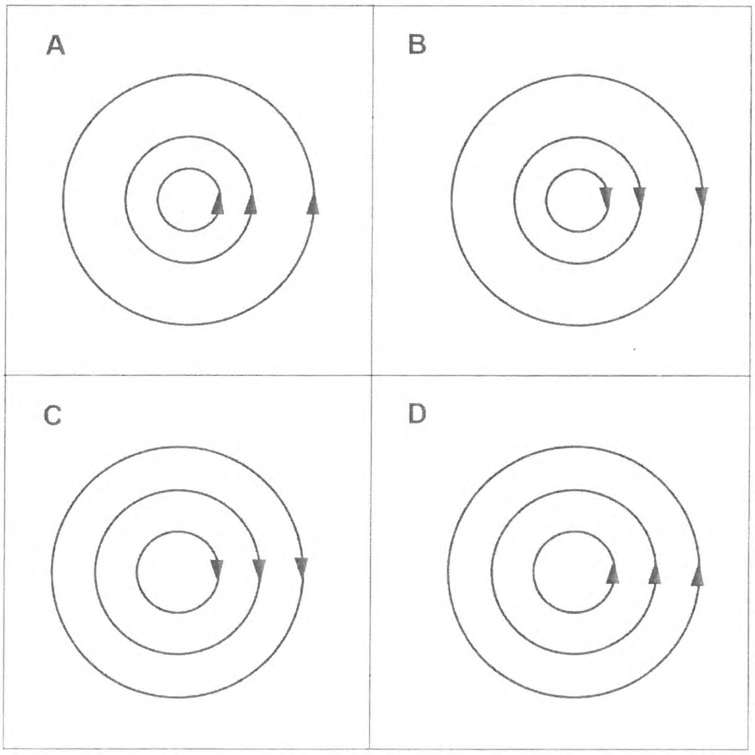
$$B = \frac{\mu_0}{2\pi} \cdot \frac{I}{r}$$

$$= \frac{(\cancel{4}^{2}\cancel{\pi} \times 10^{-7})(2.78)}{\cancel{2\pi}(25.1 \times 10^{-2})}$$

$$B = 2.21514 \times 10^{-6}$$

2.22×10^{-6} T

(b) Looking from above, which of the following diagrams shows the magnetic field around the wire correctly? (1 mark)



Answer: A

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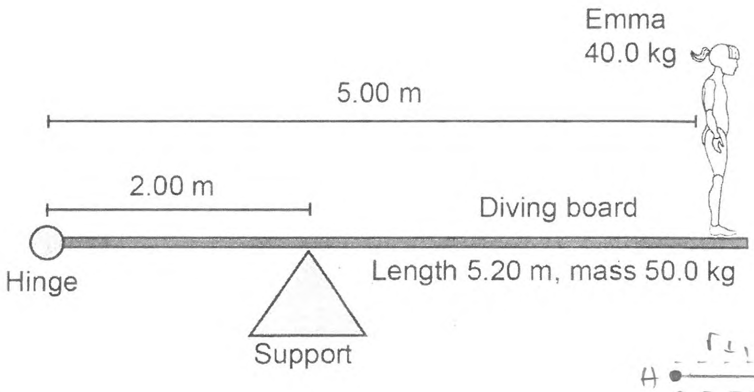
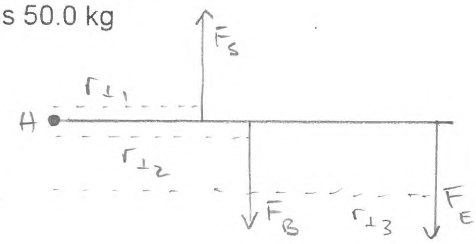
Question 5 **(4 marks)**

Emma stands 20.0 cm from the end of a 5.20 m long uniform diving board. Calculate the upwards force the support must exert on the 50.0 kg board for the system to remain in equilibrium.





$r_{\perp 1} = 2.00\ m$

$r_{\perp 2} = 2.60\ m$

$r_{\perp 3} = 5.00\ m$

$m_E = 40.0\ kg$

$m_B = 50.0\ kg$

Take moments about point H

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

$F_S . r_{\perp 1} = F_B r_{\perp 2} + F_E r_{\perp 3}$

$$F_S = \frac{(50.0 \times 9.80)(2.60) + (40.0 \times 9.80)(5.00)}{(2.00)}$$

$F_S = 1.6170 \times 10^3$

1.62×10^3 N

Question 6 **(4 marks)**

Calculate the electric field strength 2.25×10^{-3} m from a point charge of 4.00×10^{-18} C.

$r = 2.25 \times 10^{-3}\ m$

$q = 4.00 \times 10^{-18}\ C$

$E = ?$

$\varepsilon_0 = 8.85 \times 10^{-12}\ F\ m^{-1}$

$$E = \frac{F}{q} = \frac{\frac{1}{4\pi\varepsilon_0} \cdot \frac{q_1 q_2}{r^2}}{q_1}$$

$$E = \frac{1\ (4.00 \times 10^{-18})}{4\pi (8.85 \times 10^{-12})(2.25 \times 10^{-3})^2}$$

$E = 7.1046 \times 10^{-3}$

7.10×10^{-3} N C^{-1}

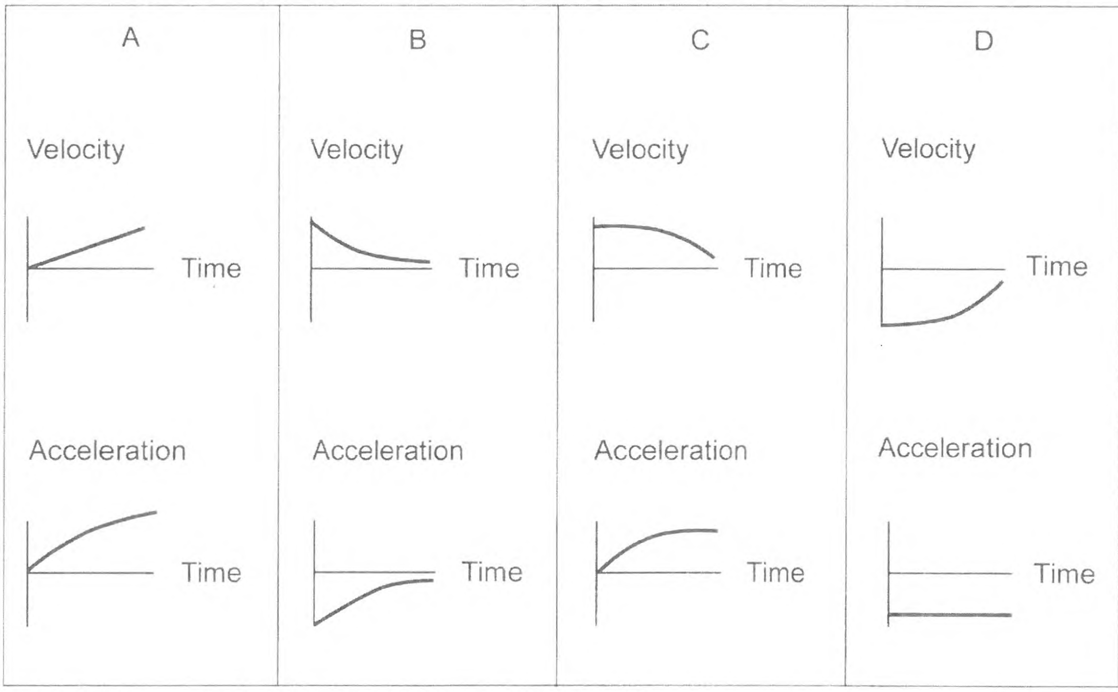
Question 7 **(5 marks)**

Students in a physics laboratory launch plastic discs across an aluminium air table. Air is blown vertically through small holes in the surface of the table, allowing the discs to float above the surface as they move. This is a nearly frictionless environment and the discs barely slow down as they cross the table. The students then attach a small but strong magnet on top of a disc and repeat the experiment. The disc slows down quite quickly, even though there is still no contact between it and the table.

(a) Explain why the disc with the magnet slows down quickly. (4 marks)

- The aluminium table is a conductor
- the moving magnet on the plastic disc causes a changing magnetic field in the conductor.
- This causes an induced current in the conductor before and after the disc with the magnet.
- Lenz's Law states that the current will flow in a direction that creates a magnetic field that opposes the change that induces the current.
- The field of the induced current will oppose the motion of the disc magnet causing it to slow quickly.

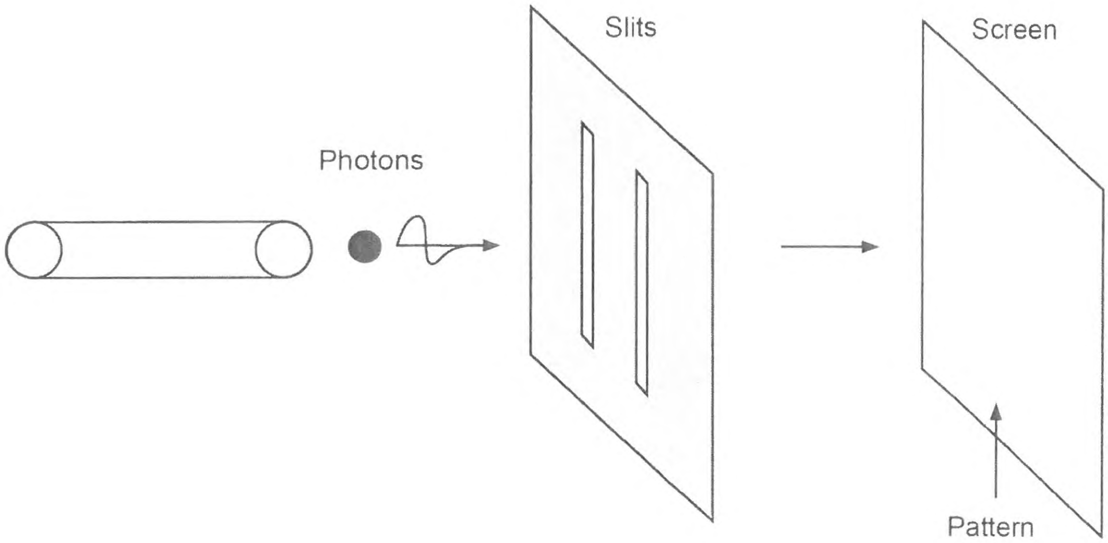
(b) The students deduce that the retarding force on the disc with the magnet is proportional to the speed of the disc. Which set of velocity and acceleration versus time graphs below best describe the motion of the disk with the magnet? (1 mark)



Answer B

See next page

Question 8 **(5 marks)**



The diagram above shows that when monochromatic coherent light is shone through two narrow slits onto a screen, light and dark fringes appear on the screen.

(a) What property of light causes this to happen? Circle your answer. (1 mark)

Wave Particle Massless

(b) Explain how **both** the light and dark fringes are formed. (4 marks)

- As light passes through the slits the light waves will diffract.
- the diffracted waves will overlap and cause constructive and destructive interference
- bright fringes occur where constructive interference occurs, so at these points the waves arrive in-phase so that the amplitudes of each wave add to cause greater intensity.
- dark fringes occur where destructive interference occurs, so at these points the waves are 180° out-of-phase, so that the amplitude of the waves add to zero to cause zero intensity.

Question 9 **(4 marks)**

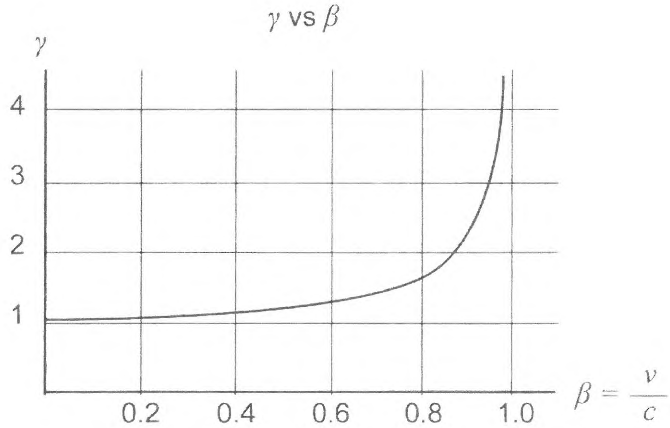
The Lorentz transformation equation for total relativistic energy states

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

This can be simplified to $E = \gamma mc^2$ where

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

With reference to the graph of γ vs β (v/c) and the equation for relativistic energy, explain why it is impossible for any particle with mass to achieve the speed of light.



- As the speed of the particle approaches the speed of light β approaches 1.0.
- As it does γ approaches infinity.
- As the total energy is directly proportional to γ then the total energy approaches infinity.
- This implies that it would require more energy than all of the energy in the Universe to reach the speed of light, which is impossible.
- This also implies that the relativistic mass of the particle would approach infinity, which is impossible.

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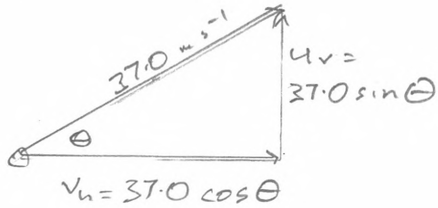
Question 10 **(6 marks)**

A golfer hits a ball at 37.0 m s^{-1} at 31.0° to the horizontal on a flat fairway. It travels 123 m. She wants to hit a target 135 m away, so she increases the angle at which she hits the ball, without changing the launch speed. Calculate the smallest increase of angle that allows her to reach the target. (Hint: $2\sin\theta\cos\theta = \sin 2\theta$)



$s_v = 0$ m

$u_v = 37.0 \sin\theta$

$v_v = -37.0 \sin\theta$

$a_v = -9.80$ m s^{-2}

$t =$

$s_h = 135$ m

v_h : $37.0 \cos\theta$

t

$v_h = \frac{s_h}{t}$

$t = \frac{s_h}{v_h}$

$t = \frac{(135)}{(37.0\cos\theta)}$

$s_v = u_v t + \frac{1}{2}at^2$

$0 = \frac{(37.0\sin\theta)(135)}{(37.0\cos\theta)} + \frac{(-9.80)(135)^2}{2(37.0\cos\theta)^2}$

$\frac{(9.80)(135)^{\cancel{2}}}{2(37.0\cos\theta)^{\cancel{2}}} = \frac{(37.0\sin\theta)\cancel{(135)}}{\cancel{(37.0\cos\theta)}}$

$2\sin\theta\cos\theta = \frac{(9.80)(135)}{(37.0)^2}$

$\sin 2\theta = 0.9663988$

$2\theta = 75.105$

$\theta = 37.5525$

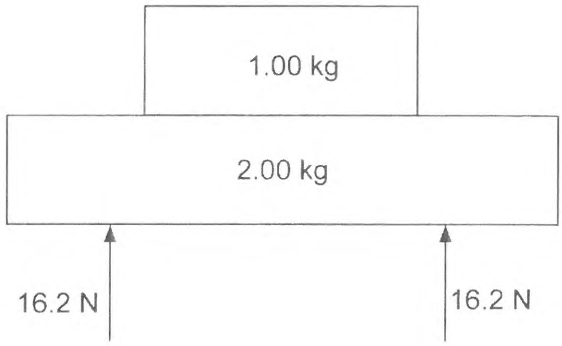
$\Delta\theta = 37.5525 - 31.0°$

$\Delta\theta = 6.5525$

increase $= 6.55°$

Question 11 **(6 marks)**

Jake is lifting two books of mass 1.00 kg and 2.00 kg respectively. The lighter book sits on top of the heavier book, and each of Jake's hands exerts a vertical force of 16.2 N on the lower book, as shown in the diagram.



(a) What is the magnitude of the acceleration of the books? (3 marks)

+↑ −↓

$F_T = F_L + F_R$

$F_T = 32.4$ N

$F_g = m \cdot g$

$= (3.00)(-9.80)$

$= -2.94 \times 10^1$ N

$F_{NETT} = F_T + F_g$

$= 3.00$ N

$m = 3.00$ kg

$F = ma$

$a = \frac{F_{NETT}}{m}$

$= \frac{(3.00)}{(3.00)}$

$= 1.00$

1.00 m s^{-2}

(b) What is the magnitude of the force that the 2.00 kg book exerts on the 1.00 kg book during this acceleration? (3 marks)

+↑ −↓

$F = ?$

$m = 1.00$ kg

$a = 1.00$ ms^{-2}

$F = ma$

$= (1.00)(1.00)$

$= 1.00$

1.00 N

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Question 12 **(5 marks)**

Exchange particles (gauge bosons) mediate interactions between elementary particles such as quarks and leptons. The gauge bosons (see the Formulae and Data Booklet) have different fundamental properties.

(a) Choose the appropriate combination of relevant fundamental force and property from the table below that corresponds to the gauge bosons listed. Place the number of your choice in the spaces provided. (4 marks)

Number	Fundamental forces	Properties
1	strong nuclear i	massless
2	strong nuclear i	has mass i
3	weak nuclear iii	massless
4	weak nuclear iii	has mass iii
5	electromagnetic ii	massless ii
6	electromagnetic ii	has mass

i. Gluon Answer: 2

ii. Photon Answer: 5

iii. Z Boson Answer: 4

iv. W Boson Answer: 4

(b) Which of the fundamental forces below has the longest range of interaction? (1 mark)

i. weak nuclear
ii. electromagnetic
iii. strong nuclear

Answer: ii electromagnetic

End of Section One

Section Two: Problem-solving 50% (92 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.

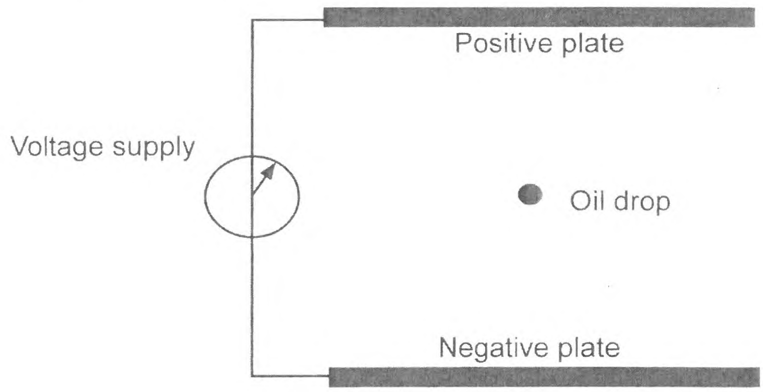
When estimating numerical answers, show your working or reasoning clearly. Give final answers to a maximum of **two** significant figures and include appropriate units where applicable.

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.

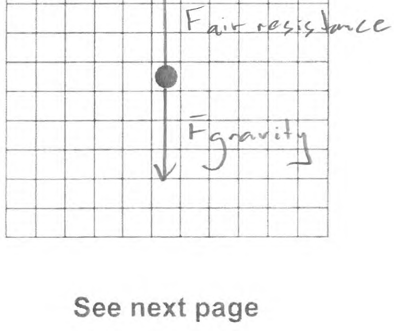
Question 13 (10 marks)

In an experiment to measure the charge of an electron, a student creates many tiny oil drops and allows some to enter the space between two horizontal plates that are connected to a variable voltage supply. A diagram of the apparatus is shown below.



Initially there is no potential difference between the plates and the student chooses an oil drop and, using a microscope, watches as it slowly falls, measuring its speed. The student determines that the speed is constant at 0.0313 mm s^{-1}.

(a) On the grid below, draw a free body diagram showing all the forces acting on the oil drop as it falls. (2 marks)



Using the speed of the oil drop and other known quantities the student calculates the mass of the oil drop as 6.88×10^{-16} kg. The oil drop is exposed briefly to radiation and it captures one or more electrons and hence becomes negatively charged.

The student turns on the voltage supply and adjusts the potential difference between the upper and lower plates until the oil drop stops moving. The potential difference at this point is 346 V.

(b) Name the **two** forces now acting on the oil drop. (2 marks)

One: gravity

Two: electromagnetic force

(c) If the plate separation is 7.71 mm, what is the electric field strength experienced by the oil drop? (2 marks)

$\Delta V = 346$ V

$d = 7.71 \times 10^{-3}$ m

$E = ?$

$E = \frac{\Delta V}{d} = \frac{(346)}{(7.71 \times 10^{-3})} = 4.48768 \times 10^{4}$

* space for answer?

4.49×10^{4} V m^{-1}

(d) Calculate the electric charge of the oil drop. (3 marks)

* use a value of.... if you couldn't answer (c) *

+↑ −↓

$m = 6.88 \times 10^{-16}$ kg

$g = -9.80$ m s^{-2}

$-F_g = F_E$

$-mg = Eq$

$q = -\frac{(6.88 \times 10^{-16})(-9.80)}{(4.48768 \times 10^{4})}$

$= 1.50242 \times 10^{-19}$

1.50×10^{-19} C

The student repeats this procedure several times for different oil drops (possibly carrying different numbers of electrons), and calculates the charge for each drop.

Trial number	Charge ($\times 10^{-19}$ C)
1	5.99 ~ 6
2	2.99 ~ 3
3	4.49 ~ 4.5
4	7.53 ~ 7.5
5	3.01 ~ 3
6	7.50 ~ 7.5

smallest difference $= 1.5 \times 10^{-19}$

and all are multiples of 1.5×10^{-19}

(e) Solely on the basis of this data, what does the student estimate the electron charge is most likely to be? (1 mark)

Answer: 1.50×10^{-19} C

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Question 14 **(15 marks)**

Muons and anti-muons are unstable, with the decay process producing three particles. When an anti-muon ($\bar{\mu}$) decays, one of these particles is an electron neutrino (ν_e).

(a) Complete the table below and use your answers to identify the missing particle X. (3 marks)

$$\bar{\mu} = X + \nu_e + \bar{\nu}_\mu$$

Reaction	$\bar{\mu}$	=	X	ν_e	$\bar{\nu}_\mu$
Conservation of electron charge	+1	=	+1	0	0
Conservation of Lepton number	−1	=	−1	+1	−1

Particle X: e^+ or β^+

Muons created in the upper atmosphere (approximately 10 km above the Earth's surface) are secondary products from highly-energetic cosmic ray interactions with nuclei of atmospheric particles. In their own frame, muons have a mean lifetime of 2.20 x 10^{-6} s, with some lasting for up to 3.0 x 10^{-6} s.

The speed of muons from cosmic rays entering the Earth's atmosphere moving in the direction of the observer on the Earth is in the range of 2.960 x 10^8 – 2.997 x 10^8 m s^{-1}.
(Ignore the effect of the Earth's magnetic field on the muons when answering the following questions.)

(b) Use non-relativistic physics to calculate the mean distance muons moving at 2.991 x 10^8 m s^{-1} could travel. (2 marks)

$\Delta t_{av} = 2.60 \times 10^{-6}$ s

$V_{av} = 2.9785 \times 10^8$ m s^{-1}

$S_{av} = ?$

$S_{av} = V_{av} t_{av}$

$= (2.9785 \times 10^8)(2.60 \times 10^{-6})$

$= 7.7441 \times 10^2$ m

7.74×10^2 m

(c) (i) Calculate the mean lifetime of muons travelling at 0.997c as observed from the Earth. (2 marks)

$t_o = 2.60 \times 10^{-6}$ s

$V = 0.997c$

$t_{av} = ?$

$$t_{av} = \frac{t_o}{\sqrt{1 - \frac{v^2}{c^2}}}$$

$$t_{av} = \frac{(2.60 \times 10^{-6})}{\sqrt{1 - 0.997^2}}$$

$t_{av} = 3.35911 \times 10^{-5}$

3.36×10^{-5} s

(ii) What is the actual mean distance travelled by such muons through the atmosphere as observed from the Earth? (2 marks)

$t_{av} = 3.35911 \times 10^{-5}$ s

$V = 0.997\ c$

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

$S_{av} =$

$S_{av} = v\, t_{av}$

$= (0.997 \times 3 \times 10^8)(3.35911 \times 10^{-5})$

$= 1.0047 \times 10^4$

$= 1.0047 \times 10^1$

1.00×10^1 km

See next page

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(d) Using information from the question, explain why a small number of muons reach the Earth. (2 marks)

· due to the relativistic velocity of the muons the mean lifetime of the muons is greater than the proper lifetime.

· as the moving muon lives longer, on average, they will travel further.

· the average distance the muons travel is 10.0 km so there will be some muons that live longer and travel further than the mean and so they can reach the Earth.

(e) With the use of a calculation, explain why these muons reach the Earth from the perspective of the muons. (4 marks)

$L_0 = 10 \times 10^3$ m

$L = ?$

$v = 0.997c$

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

$L = L_0 \sqrt{1 - \frac{v^2}{c^2}}$

$L = (10 \times 10^3) \sqrt{1 - 0.997^2}$

$L = 7.7401 \times 10^2$ m

$v_{av} = \frac{s_{av}}{t_{av}}$

$t_{av} = \frac{(7.7401 \times 10^2)}{(0.997 \times 3 \times 10^8)}$

$= 2.5878 \times 10^{-6}$

$= 2.59 \times 10^{-6}$ s.

this is slightly less time than the mean lifetime of the muon. So during this time the muon can travel the contracted distance to the surface of the Earth.

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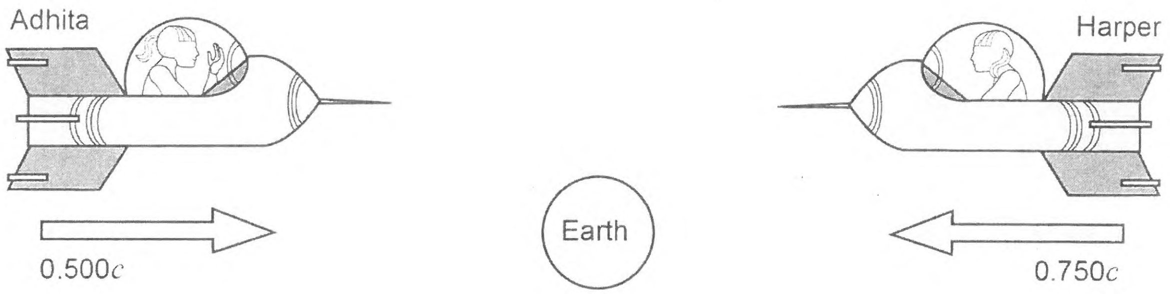
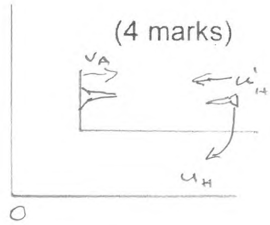
Question 15 **(12 marks)**

Two spaceships, captained by Adhita and Harper, are travelling toward each other. They are observed by a person on the Earth to be travelling at the velocities shown in the diagram. Take all velocities to the left as positive.



(a) Calculate the velocity of Harper as measured by Adhita. (4 marks)



$\overset{-\quad +}{\longleftrightarrow}$

$v_A = 0.500c$

$u_H = -0.750c$

$u'_H = ?$

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

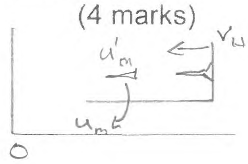
$$= \frac{(-0.750c) - (0.500c)}{(1 - (0.500)(-0.750))}$$

$$= \frac{(-1.250c)}{(1.375)}$$

$$= -0.90909$$

-0.909 c

(b) Harper fires a missile with a velocity of 0.600c with respect to her in the direction of Adhita. Calculate the velocity of the missile as measured by an observer on the Earth. (4 marks)



$\overset{-\quad +}{\longleftrightarrow}$

$V_H = -0.750c$

$u'_m = -0.600c$

$u_m = ?$

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

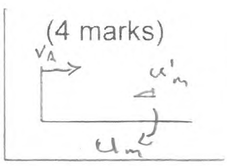
$$= \frac{(-0.750c) + (0.600c)}{(1 + (-0.750)(-0.600))}$$

$$= \frac{-1.350c}{1.450}$$

$$= -0.93103$$

-0.931 c

(c) Calculate the velocity of the missile as measured by Adhita. (4 marks)



$\overset{-\quad +}{\longleftrightarrow}$

$V_A = 0.500c$

$u_m = -0.93103c$

$u'_m =$

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

$$= \frac{(-0.93103c) - (0.500c)}{(1 - (-0.93103)(0.500))}$$

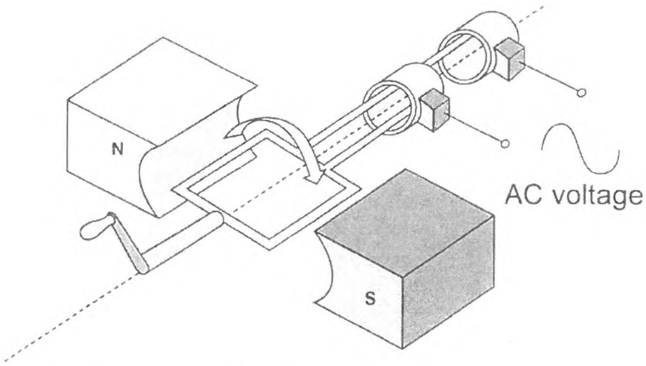
$$= \frac{-1.431c}{1.4655}$$

$$= -0.97647$$

-0.976 c

Question 16 **(12 marks)**

A group of physics students made a simple AC generator in class. It had 150 turns of wire in the 6.00 cm wide square coil and was placed in a magnetic field of strength 1.85 x 10^2 mT. They connected the handle to a motor which rotated it at 240 rpm and used the electricity produced to power a light globe.



(a) Calculate the maximum EMF produced by the generator. (5 marks)

$N = 150$
$L = 6.00 \times 10^{-2}$ m
$w = 6.00 \times 10^{-2}$ m
$B = 1.85 \times 10^{-1}$ T
$f = 240$ rpm
$f = 4.00$ Hz

$$\varepsilon_{max} = 2\pi NBA_{\perp}f$$
$$= 2\pi(150)(1.85\times10^{-1})(6.00\times10^{-2})^2(4.00)$$
$$= 2.51076$$

2.51 V

(b) Calculate the RMS voltage produced. (1 mark)

$$\varepsilon_{rms} = \frac{\varepsilon_{max}}{\sqrt{2}}$$
$$= \frac{(2.51076)}{\sqrt{2}}$$
$$= 1.77538$$

1.78 V

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Question 16 (continued)

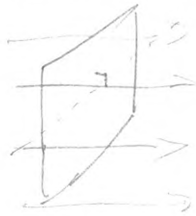
The students removed the motor and turned the handle themselves, maintaining a constant speed of rotation. They noticed that the force required to turn it varied as the coil rotated. They also noticed that the light bulb glowed brightest when the force required was greatest and went out when the force required was virtually zero.

(c) (i) Explain why the force required varied as the handle went through one rotation. (3 marks)

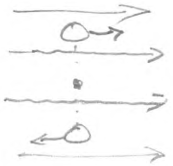
- maximum emf, and therefore maximum current, occurs when the conductor is moving perpendicular to the field of the external magnet.
- Lenz's Law states that this current will flow in a direction that creates a force opposing the motion that causes the induced current.
- Therefore when maximum current is induced, and the globe is brightest, the student feels a greater opposing force. When virtually zero current is induced the globe is "out" and virtually zero resistive force is felt.

(ii) In what position was the plane of the rotating coil relative to the field when the light bulb went out? Explain why it went out. (3 marks)

plane ⊥ to field



- the plane of the rotating coil would be perpendicular to the external magnetic field, when the light went out.
- At this point the conductor wires in the coil that are always perpendicular to the magnetic field would be moving parallel to the external field.
- As no field is being cut by the conductors no emf is induced and therefore no current flows through the light bulb.



wires move parallel to field.

Question 17 **(10 marks)**

A satellite is orbiting the Earth 4.00 x 10^3 km above its surface.

(a) Calculate the period of the satellite. (5 marks)

$r = r_E + h$

$= (6.37 \times 10^6 + 4.00 \times 10^6)$

$= 1.037 \times 10^7$ m

$G = 6.67 \times 10^{-11}$ N m^2 kg^{-2}

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

$T = ?$

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

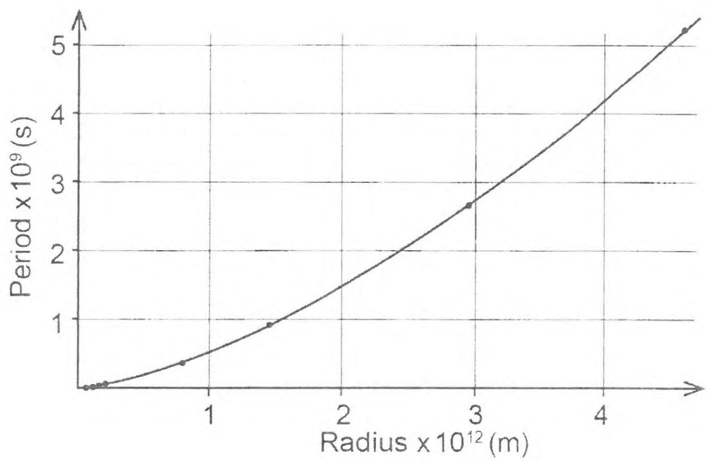
$= \sqrt{\frac{4\pi^2 (1.037 \times 10^7)^3}{(6.67 \times 10^{-11})(5.97 \times 10^{24})}}$

$= \sqrt{1.10559 \times 10^8}$

$T = \frac{(1.05147 \times 10^4)\text{s}}{(3600)\ \text{s h}^{-1}}$

$T = 2.92076$

2.92 hours



The graph shows the relationship between the period (T) and the orbiting radius (r) of all the planets in our solar system.

(b) (i) With reference to Kepler's Third Law, describe how a straight line graph could be generated using the same two variables. (Do not refer to logarithms.) (2 marks)

if $T^2 = \frac{4\pi^2}{GM} \cdot r^3 + 0$ Kepler's 3rd Law

and $y = m \quad x + c$ Linear equation.

then a graph of Period^2 (T^2) vs Radius^3 (R^3) will result in a straight-line graph with a slope of $\frac{4\pi^2}{GM}$, passing through the origin.

Question 17 (b) (continued)

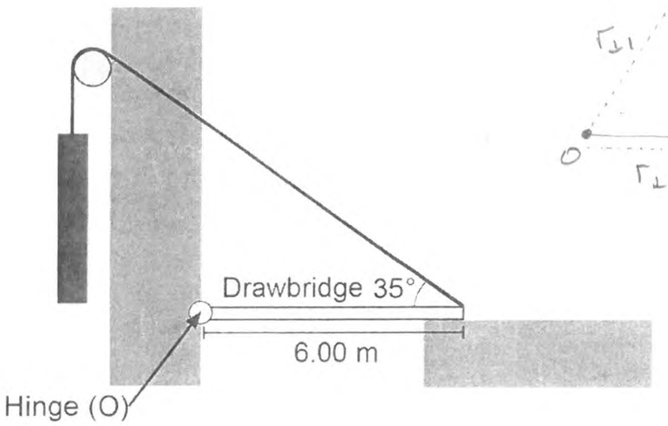
(ii) Explain how you could use the gradient of this straight line and Kepler's Third Law to estimate the magnitude of the Newtonian constant of gravitation (G). (Do not try to calculate G from the graph.) (3 marks)

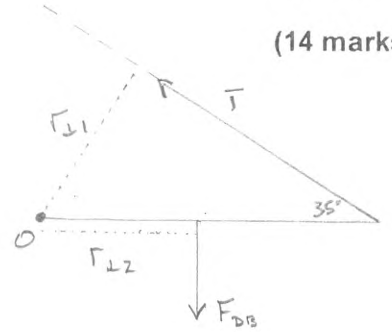
- The gradient (m) of the graph of T^2 vs R^3 gives us a value for $\frac{4\pi^2}{GM}$.
- M in this case is the central mass around which the planets orbit, in this case the sun.
- rearranging this relationship gives

$$G = \frac{4\pi^2}{M_s \times \text{slope}}$$

- hence G can be calculated, if the mass of the sun is known, from the slope of the linear graph.

Question 18 (14 marks)





A castle has a 6.00 m long drawbridge with a mass of 500 kg over its moat. It is attached to a winch by an extremely strong rope at an angle 35.0° to the horizontal.

(a) Calculate the tension in the rope when the drawbridge is just lifted off the rest on the other side of the moat. (4 marks)

$r_{\perp 1} = 6.00 \sin 35°$
$= 3.44146$ m

$r_{\perp 2} = 3.00$ m

$m_{DB} = 500$ kg

$g = 9.80$ m s^{-2}

Take moments about point O.

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

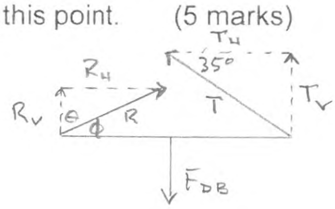
$T r_{\perp 1} = F_{DB} r_{\perp 2}$

$T = \dfrac{(500)(9.80)(3.00)}{(3.44146)}$

$T = 4.27144 \times 10^{3}$

4.27×10^{3} N

(b) Calculate the reaction force of the hinge (O) on the drawbridge at this point. (5 marks)



+↑ −↓

$T_V = (4.27144 \times 10^3)(\sin 35°)$

$T_V = 2.4500 \times 10^3$ N.

$F_{DB} = -4.9000 \times 10^3$ N

$\sum F_{\uparrow\downarrow} = 0$

$F_{DB} + T_V + R_V = 0$

$R_V = -(-4.9000 \times 10^3) - (2.4500 \times 10^3)$

$R_V = 2.4500 \times 10^3$ up

$\rightleftarrows^{+}$ $\sum F_{\leftrightarrow} = 0$

$R_H = -T_H$

$R_H = -(-4.27144 \times 10^3)(\cos 35°)$

$R_H = 3.49896 \times 10^3$ N

$R = \sqrt{(2.4500 \times 10^3)^2 + (3.49896 \times 10^3)^2}$

$R = 4.27144 \times 10^3$ N

4.27×10^3 N at 35.0 ° to the horizontal.

$\theta = \tan^{-1} \dfrac{(3.49896 \times 10^3)}{(2.4500 \times 10^3)}$

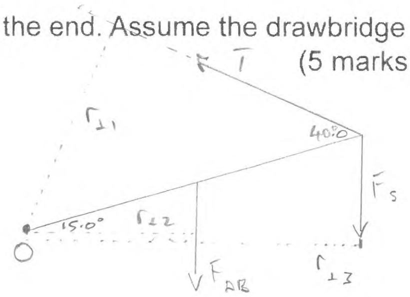
$\theta = 54.999$

$\phi = 35.000$

Question 18 (continued)

The castle comes under attack. The people inside the castle begin to raise the drawbridge. When it is at an angle of 15.0° above horizontal, the angle between the drawbridge and the rope is 40.0°. At this moment, a 95.0 kg soldier being chased by the enemy jumps onto the very end of the drawbridge.

(c) Calculate the new tension in the rope as he hangs from the end. Assume the drawbridge is stationary at this time. (5 marks)



$r_{\perp 1} = 6.00 \sin 40.0°$
$= 3.85673$ m

$r_{\perp 2} = 3.00 \cos 15.0°$
$= 2.89778$ m

$r_{\perp 3} = 6.00 \cos 15.0°$
$= 5.79556$ m

$F_{DB} = 4.900 \times 10^3$ N

$F_s = 9.3100 \times 10^2$ N

$T = ?$

take moments about point O.

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

$T \cdot r_{\perp 1} = F_s r_{\perp 3} + F_{DB} r_{\perp 2}$

$$T = \frac{(9.3100 \times 10^2)(5.79556) + (4.900 \times 10^3)(2.89778)}{(3.85673)}$$

$$= \frac{(1.95948 \times 10^4)}{(3.85673)}$$

$= 5.08068 \times 10^3$

5.08×10^3 N

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Question 19 **(19 marks)**

Hubble's law states:

'The red shifts in the spectra of distant galaxies (and hence their speeds of recession) are proportional to their distance.'

From this law comes Hubble's equation:

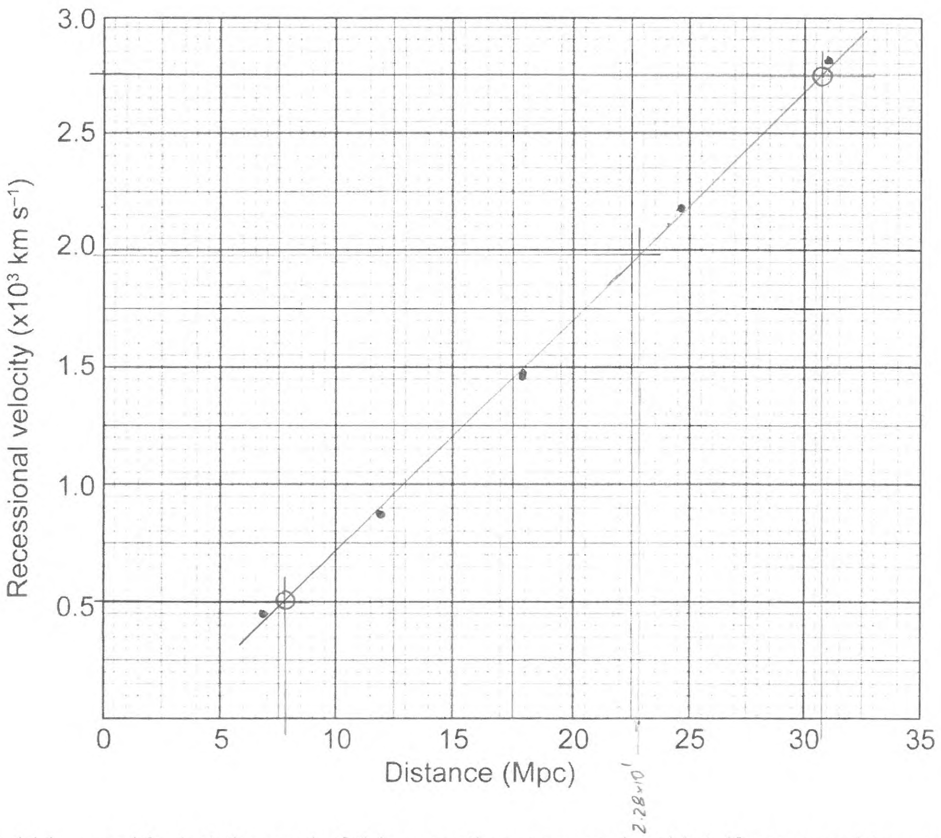
$$v = H_0 d$$

where v = recessional velocity
d = distance from the Earth
H_0 = Hubble's constant.

Below is some data Hubble used to graphically determine his constant.

Galaxy	Distance (Mpc)	Velocity ($\times 10^3$ km s^{-1})
NGC 1357	24.7	2.19
NGC 1832	31.0	2.82
NGC 2775	17.9	1.46
NGC 2903	6.96	0.45
NGC 3368	11.9	0.88

(a) Graph the recessional velocity versus distance on the set of axes provided below and draw a line of best fit. Do not take your line through the origin. (3 marks)



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

See next page

(b) Use two **non-data** points on your line of best fit to calculate Hubble's constant. Circle the two points you used and give your answer to two significant figures. (4 marks)

if $v = H_0 d + 0$ slope $= \dfrac{(2.75 - 0.50)}{(30.8 - 7.8)}$

$y = mx + c$

$\therefore m = H_0$ $H_0 = 9.7826 \times 10^{-2}$

9.8×10^{-2} 10^3 km s^{-1} Mpc^{-1}

Hubble measured the red shift of the galaxies to calculate their recessional velocities. The equation for the Doppler effect is shown below:

$$\frac{\Delta\lambda}{\lambda_0} = \frac{v}{c}$$

$\Delta\lambda$ = wavelength shift
λ_0 = wavelength of source not moving
v = velocity of source – line of sight
c = speed of light.

(c) (i) The galaxy NGC 2013 is 7.42 x 10^7 ly away from the Earth. Convert this distance into megaparsecs (Mpc). (2 marks)

$d = \dfrac{(7.42 \times 10^7)}{(3.26 \times 10^6)}$

$= 2.27607 \times 10^1$

2.28×10^1 Mpc

(ii) Using your line of best fit and the value from part (c)(i), calculate the observed red-shifted wavelength emitted from NGC 2013 if λ_0 is 840.0 nm. (6 marks)

• From the LOBF when $d = 2.28 \times 10^1$ Mpc, $v = 1.98 \times 10^3$ km s^{-1}

$v = 1.98 \times 10^6$ m s^{-1}

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

$\lambda_0 = 840.0$ nm

$\Delta\lambda =$

$\Delta\lambda = \dfrac{v\,\lambda_0}{c}$

$= \dfrac{(1.98 \times 10^6)(840.0)}{(3.00 \times 10^8)}$

$= 5.544$

$\lambda_{\text{red shifted}} = \lambda_0 + \Delta\lambda$

$= (840.0) + (5.544)$

$= 8.455 \times 10^2$ nm

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Question 19 (continued)

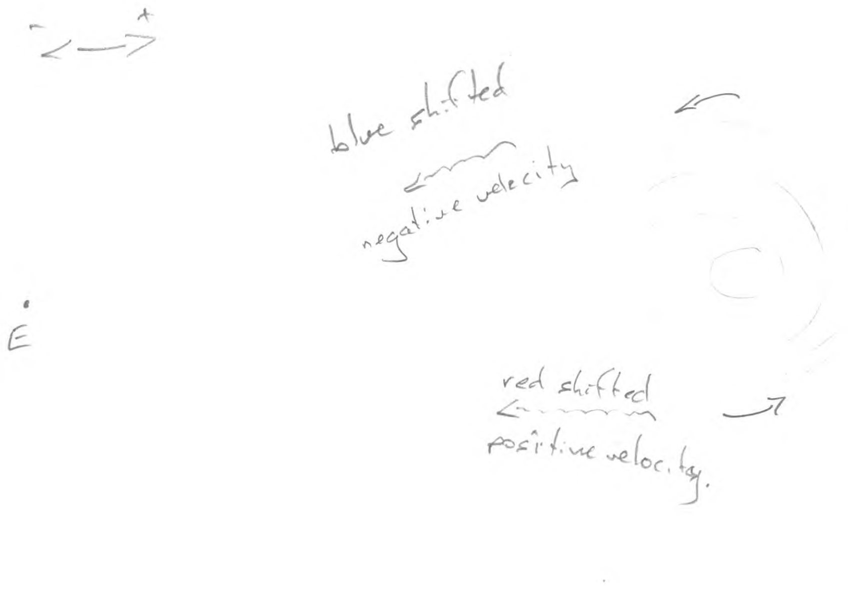
(d) In Hubble's early data, he noticed that one particular spiral galaxy close to the Earth, seen edge on, had two values of v at its extremes. One was positive and one was negative. Assuming this was not an instrumental or human error, explain how this could occur. (4 marks)

· with galaxies close to the Earth the expansion of the Universe has less affect on the relative motion than galaxies further away.

· This means that doppler effects are more evident in nearby galaxies.

· If a galaxy is spinning one side of the galaxy would be moving towards Earth while the opposite side would be spinning away from Earth as shown below.

· If we use the convention that towards Earth is negative velocity and away from Earth is positive.



End of Section Two

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Section Three: Comprehension **20% (39 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 20 **(19 marks)**

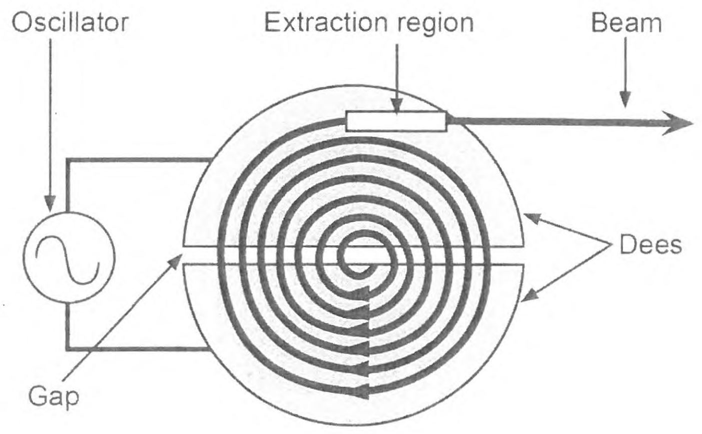
Cyclotrons

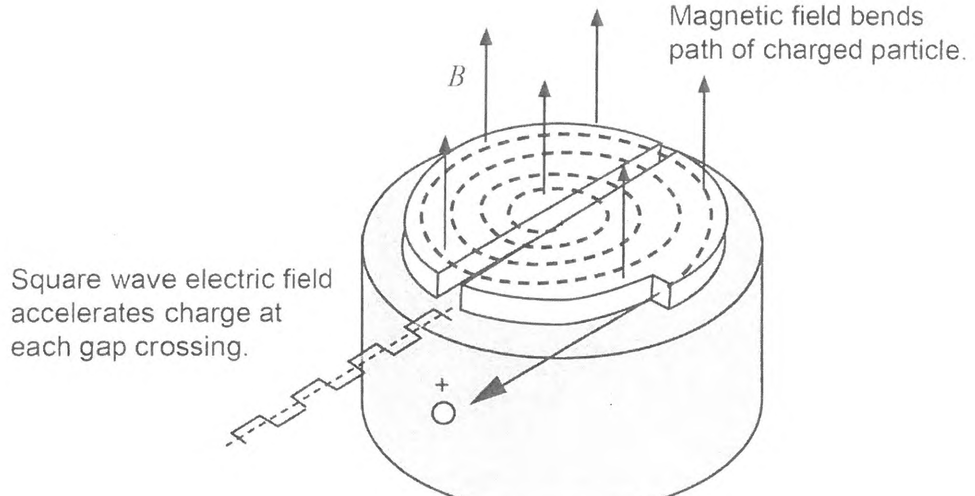
A cyclotron is a particle accelerator. It is an electrically-powered machine that produces a beam of charged particles that can be used for medical, industrial and research purposes. A cyclotron accelerates charged particles in a spiral path, which allows for a much longer path for acceleration than a straight-line accelerator.

A cyclotron consists of two semicircular charged plates in a flat vacuum chamber called 'dees' because of their shape. The chamber sits between the poles of a magnet that creates a strong and vertical magnetic field. A stream of charged particles is fed into the centre of the chamber and a high-frequency alternating voltage is applied across the plates. This voltage accelerates the charged particles across the gap every half turn. Combined with the magnetic field, this process causes the particles to spiral outwards until they exit the cyclotron.

*X

→ Then it would be better to provide an orientation to this diagram, ie Top view of cyclotron.





The cyclotron frequency (how often the electric field between the dees reverses) is independent of both the velocity of the particles and the radius of the circular path they follow.

Medical cyclotrons

Medical cyclotrons produce proton beams that are used to manufacture radioisotopes used in medical diagnosis. Radioisotopes produced in a cyclotron decay by either positron emission or electron capture. Positron emission tomography (PET) and single photon emission computed tomography (SPECT), which utilises gamma ray emission, are two imaging techniques that rely on cyclotron-produced radioisotopes.

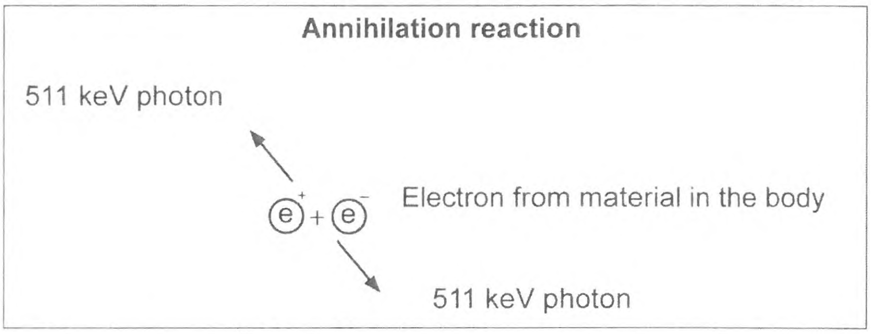
(a) The diagram above shows the acceleration of a positive particle in a cyclotron. Describe one change that would need to be made in order to use the same machine to produce a beam of negatively-charged particles exiting from the same place, and explain why.

(3 marks)

- The direction of the magnetic field will need to change to vertically down ward for negatively charged particles.
- The force on a moving charged particle in a magnetic field is always perpendicular to both the direction of motion and the magnetic field.
- It is the magnetic force that acts towards the centre of the cyclotron that provides the centripetal force.
- According to the RH palm rule a downwards magnetic field with a negatively charged particle moving clockwise as shown will experience a force towards the centre.

Question 20 (continued)

Positrons (e^+) are examples of antimatter and have the same properties as electrons (e^-) except for having a positive charge. When they collide with an electron, the following process occurs.



(b) (i) Calculate the wavelength of the photons produced in the annihilation described in the diagram above. (3 marks)

$E_{ph} = 511 \times 10^3\ eV$

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

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

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

$\lambda = \frac{(6.63\times10^{-34})(3.00\times10^{8})}{(511\times10^{3})(1.60\times10^{-19})}$

$= 2.43273 \times 10^{-12}\ m$

2.43×10^{-12} m

(ii) To which part of the electromagnetic spectrum does the photon belong? (1 mark)

higher energy X-ray or Gamma ray section

(c) Explain why increasing the strength of the magnetic field would increase the velocity of the particles leaving the cyclotron. (4 marks)

- As $F_c = F_B$ so $\frac{mv^2}{r} = qvB$ $\therefore r = \frac{mv}{qB}$
- from this we can see that an increase in the magnetic field strength (B) will result in the particle travelling with a smaller radius.
- This would enable the particle to undergo more cycles of acceleration across the "gap" before exiting the cyclotron.
- As the velocity of the particle is directly related to the number of times it is accelerated than the velocity will be greater.

(d) (i) Explain why the voltage across the dees must alternate. (2 marks)

· On one side of the Dee the particle must be accelerated by the electric field in one direction
· When the particle turns 180° the direction of the E field must swap, to once again accelerate the same charged particle in the opposite direction.

On page 31 the text states: 'The cyclotron frequency (how often the electric field between the dees reverses) is independent of both the velocity of the particles and the radius of the circular path they follow.'

* the term "how often" is a bit vague this could be interprete as time or frequency.

(ii) Derive an expression for the cyclotron frequency and use the expression to explain why this statement is correct. (Ignore relativistic effects.) (6 marks)

As $F_c = F_B$

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

then $v = \frac{rqB}{m}$ but $v = \frac{2\pi r}{T}$

so $\frac{2\pi \cancel{r}}{T} = \frac{\cancel{r}qB}{m}$

then $T = \frac{2\pi m}{qB}$

· This is the time it takes for the particle to complete one circular path in the cyclotron.
· During this time the direction of the electric field in the Dees must reverse then change back to the original direction.
· Therefore the cyclotron frequency must be half of this period, or twice the frequency.

so cyclotron frequency $= \frac{2}{T}$

$= \frac{\cancel{2}qB}{\cancel{2}\pi m}$

cyclotron $f = \frac{qB}{\pi m}$

· This expression shows that the frequency only depends on q, B and m, and not v.

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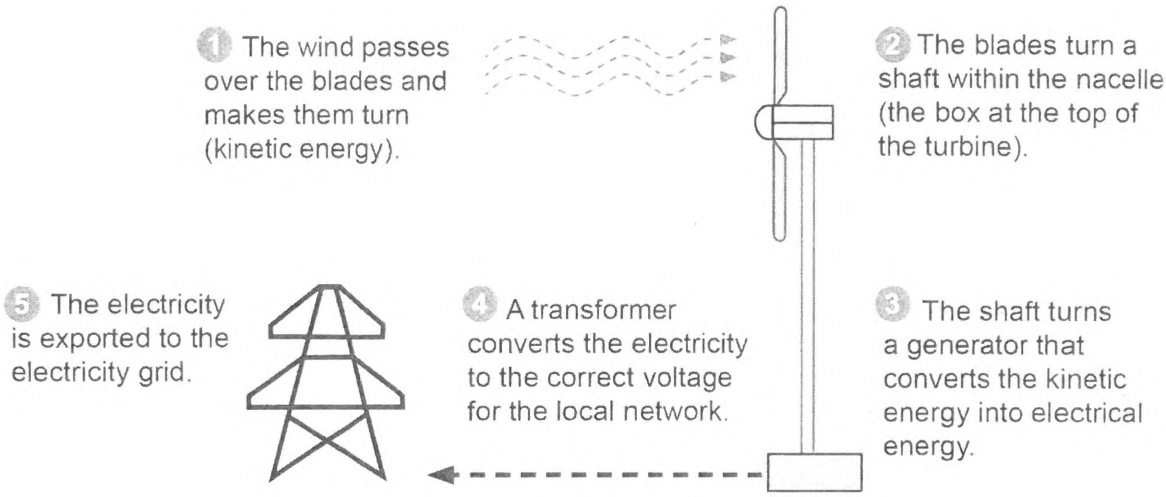
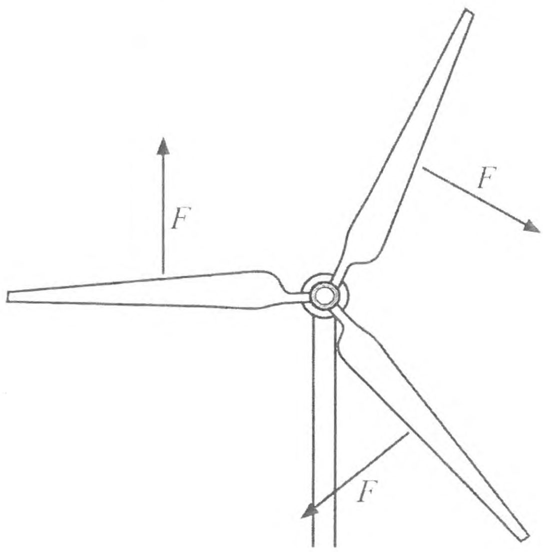
Question 21 **(20 marks)**

Wind turbines



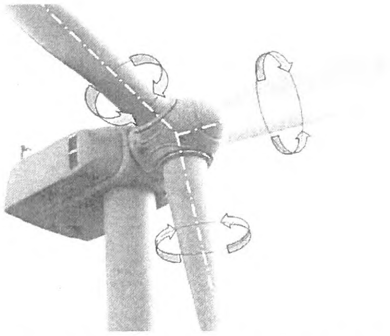
How do wind turbines work?
Wind turbine blades rotate when hit by the wind. And this doesn't have to be a strong wind, either: the blades of most turbines will start turning at a wind speed of 3 – 5 m s^{-1}, which is a gentle breeze.

It's this spinning motion that turns a shaft in the nacelle – which is the box-like structure at the top of a wind turbine. A generator built into the nacelle then converts the kinetic energy of the turning shaft into electrical energy. This then passes through a transformer, which steps up the voltage so it can be transported on the National Grid or used by a local site.



Wind turbine blades vary in length between 40 and 80 m.

A major problem with wind turbines is varying wind speed. The input power must match the output power. The output power depends entirely on rotational speed and torque so how do we keep rotational frequency constant when wind speed keeps changing? The solution is mechanical. The operators use blade pitch control which changes the angle of the blades and reduces the surface area facing the wind. This reduces the amount of energy collected by the turbine and controls the force applied to each blade.



How the pitch is altered to control the rotational speed.

Each blade experiences a gravitational torque. If the clockwise and anticlockwise gravitational torques add up to zero, the turbine is considered balanced. A symmetrical three-blade turbine is considered balanced at all times.

(a) (i) Explain why a step-up transformer is used to increase the voltage before transporting the electricity into the National Grid. Use specific equations in your answer. (4 marks)

· As power lost in an electrical circuit is equal to:

$$P_{Loss} = I^2 R$$

then by reducing the current at which the electricity flows the power loss can be reduced significantly.

· Using a step up transformer to increase the transmission voltage produces a proportional decrease in the transmission current, hence reducing power loss in the transmission wires.

(ii) Calculate the output voltage of the transformer if the turbine produces 690 V and the ratio of turns is 100 in the primary coil to 2500 in the secondary coil. (2 marks)

$V_1 = 690$ V

$N_1 = 100$

$N_2 = 2500$

$V_2 =$

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

$$V_S = \frac{(690)(2500)}{(100)}$$

$$V_S = 1.7250 \times 10^4$$

$$= 1.7250 \times 10^1$$

1.73×10^1 kV

Question 21 (continued)

(b) With specific reference to the text, explain why the pitch of the rotor blades is changed by the operators of the turbine. (4 marks)

- As stated on p34, "A major problem with wind turbines is varying wind speed".
- The method of controlling the speed of the blades is to control the blade pitch control.
- By changing the angle of the blades it changes the surface area exposed to the wind, which changes the energy collected by the turbine.
- Reducing the energy converted into kinetic energy of the turbine blades results in a decrease in the speed of the blades as:

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

(c) If the 60 m long blades on an average-sized turbine are rotating at 0.20 Hz, estimate the speed of the centre of mass of one of the blades. (4 marks)

$f = 0.20\ Hz$

$\therefore T = 5.0\ s$

assume that the blades are uniform mass $r_{com} = 30\ m$

$$v = \frac{s}{t} = \frac{2\pi r}{T} = \frac{2\pi(30)}{(5.0)} = 3.7699 \times 10^1$$

3.8×10^1 m s^{-1}

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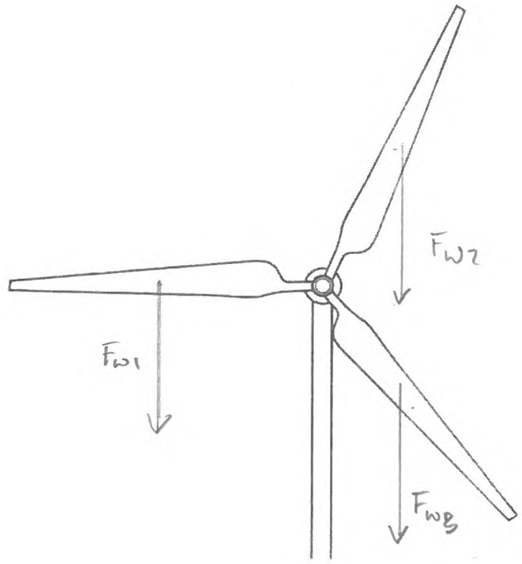
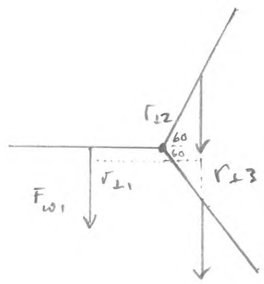
Consider the three-blade turbine in the diagram to be rotating clockwise. The blade on the left hand side is parallel to the ground. The blades are identical in size and mass.

(d) (i) Draw the weight forces acting on the blades. (2 marks)



(ii) Show mathematically that the turbine is balanced in this position. (4 marks)



$r_{\perp 1} = R$

$r_{\perp 2} = R\cos 60°$

$r_{\perp 3} = R\cos 60°$

$F_1 = F_B$

$F_2 = F_B$

$F_3 = F_B$

Take moments about axle.

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

$F_2 r_{\perp 2} + F_3 r_{\perp 3} = F_1 r_{\perp 1}$

$F_B \frac{R}{2} + F_B \frac{R}{2} = F_B R$

$F_B R = F_B R$.

$\therefore$ anticlockwise moment is equal to the clockwise moments.

End of questions

ACKNOWLEDGEMENTS

Question 8	NekoJaNekoJa. (2005). *Double-slit* [Diagram]. Retrieved May, 2020, from https://commons.wikimedia.org/wiki/File:Double-slit.PNG
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Question 20	Paragraphs 1 & 2 on cyclotrons and paragraph on medical cyclotrons adapted from: ANSTO. (n.d.). *National Research Cyclotron*. Retrieved May, 2020, from https://www.ansto.gov.au/research/facilities/national-research-cyclotron First diagram adapted from: [Schematic diagram of cyclotron]. (n.d.). Retrieved May, 2020, from https://www.chegg.com/homework-help/questions-and-answers/diagram-schematic-cyclotron-acharged-particle-starts-central-point-givenmagnetic-field-per-q116820 Second diagram adapted from: Nave, C. R. (n.d.). [Cyclotron frequency diagram]. Retrieved May, 2020, from http://hyperphysics.phy-astr.gsu.edu/hbase/magnetic/cyclot.html
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