METHODIST
LADIES'
COLLEGE

Methodist Ladies' College

Semester Two Examination, 2016

Question/Answer Booklet

PHYSICS

ATAR Year 12

Student Name: SOLUTIONS

Teacher Name: ______________________

Time allowed for this paper

Reading time before commencing work: ten minutes

Working time for paper: three hours

Materials required/recommended for this paper

To be provided by the supervisor

This Question/Answer Booklet

Physics Formulae and Data Booklet

To be provided by the candidate

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

Special items: non-programmable calculators approved for use in the WACE examinations

Important note to candidates

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

Structure of this paper

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

Instructions to candidates

1. The rules for the conduct of the Western Australian Certificate of Education ATAR course examinations are detailed in the *Year 12 Information Handbook 2016.* Sitting this examination implies that you agree to abide by these rules.

2. Write your answers in the spaces provided beneath each question in this Question/Answer booklet. The value of each question (out of 180) is shown following each question.

3. 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.

4. 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.

5. Additional working space pages at the end of this Question/Answer booklet are for planning or continuing an answer. if you use these pages, indicate at the original answer the page number it is planned/continued on and write the question number being planned/continued on the additional working space page.

6. The Formulae and Data Booklet may be removed from the booklet and used as required.

SECTION ONE: Short Response 54 marks (30%)

This section has **15** questions. Answer **ALL** questions. Write your answers in the spaces provided.

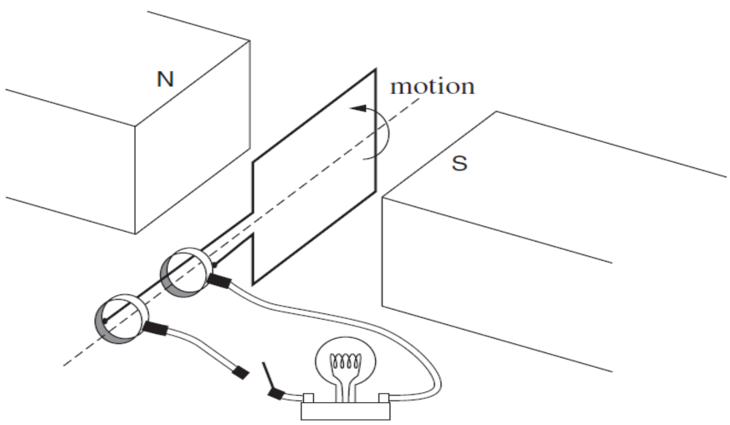
Spare pages are included at the end of this booklet. They can be used for planning your responses and/or as additional space if required to continue an answer.

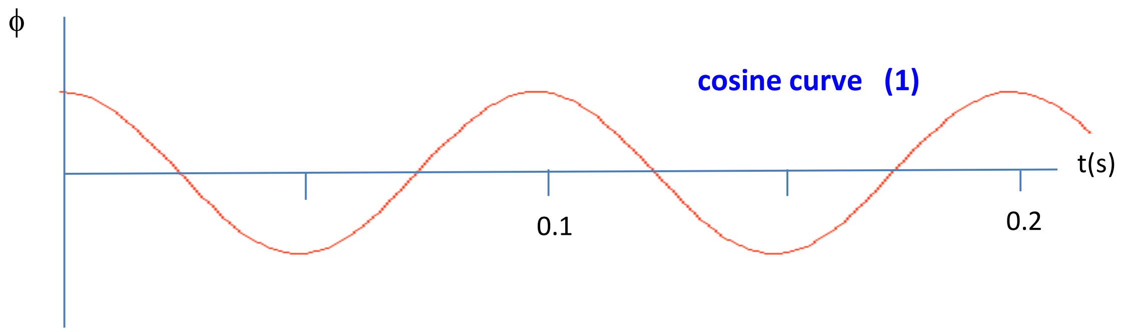
- Planning: If you use the spare pages for planning, indicate this clearly at the top of the page.
- Continuing an answer: If you need to use the space to continue an answer, indicate in the original answer space where the answer is continued, i.e. give the page number.
  Fill in the number of the question(s)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

Suggested working time for this section is **50 minutes.**

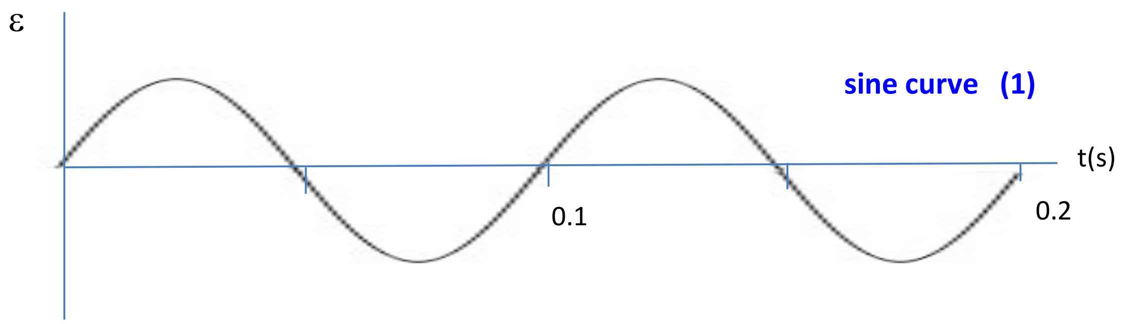
Question 1 (4 marks)

The diagram below shows a simple AC generator, rotating at a frequency of 10 Hz. On the axes provided below, sketch the magnetic flux ϕ through the coil and also the emf ε induced as the coil rotates, starting from the position shown in the diagram.





f = 10 Hz ➔ T = 0.1 s (1) ➔ 2 full cycles on each graph (1)



Question 2 **(3 marks)**

A long jumper at the Rio Olympics launches himself into the air at a speed of 11.0 m/s and an angle of 22.5° to the horizontal in an attempt to beat the world record of 8.95 metres. Show by calculation whether or not he is successful.

u_v = u sin θ = (11.0 m/s) sin 22.5° = 4.21 m/s

(1)

u_h = u cos θ = (11.0 m/s) cos 22.5° = 10.2 m/s

time in air t = $2u_v/g$ = $2(4.21\text{ m/s})/9.8\text{ m/s}^2$

(1)

= 0.859 s

horizontal displacement s_h = u_h x t

= 10.2 m/s x 0.859 s = <u>8.73 m</u> ∴ He is not successful (1)

Question 3 **(4 marks)**

The relatively nearby star Tau Ceti, which is the closest solitary G-class star like our Sun, lies 11.9 light-years from Earth, and has five exoplanets, two of which lie in the "habitable zone" — that just-right range of distances that could support the existence of liquid water on the planets' surfaces. An interstellar spaceship from Earth is travelling to Tau Ceti at 90% of the speed of light.

(a) How far away is Tau Ceti (in light-years) to the astronauts on the spaceship? (2 marks)

To the astronauts the distance to Tau Ceti is contracted due to the star moving towards the spaceship at 0.9c

$l = l_0 (1 - v^2/c^2)^{½}$ (1)

$= 11.9 (1 – 0.9^2)^{½}$

= <u>5.19 light-years</u> (1)

(b) How long will the spaceship take to reach Tau Ceti

(i) from the reference frame of observers on Earth? (1 mark)

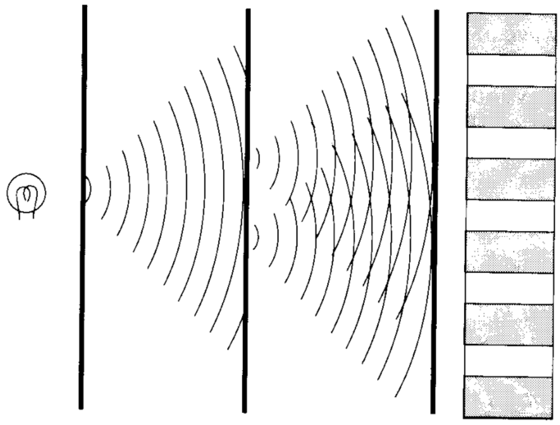
t = 11.9 lyr/ 0.9c = <u>13.2 years</u>

(ii) from the reference frame of the astronauts on the spaceship? (1 mark)

t = 5.19 lyr/ 0.9c = <u>5.76 years</u>

Question 4 **(3 marks)**

The diagram at right illustrates Young's famous double-slit experiment, which was crucial in helping us to understand the nature of light. Briefly describe how the experiment worked, and explain the insight it gave into the nature of light.



Light from a source passed through a slit in a screen and was diffracted onto another screen that had two slits. The light diffracted through each of these slits (1) , forming two overlapping beams that produced a pattern of alternating bright and dark bands on a third screen. (1) This pattern was characteristic of an interference pattern, and indicated that light was wave-like in nature. (1)

Question 5 **(4 marks)**

A satellite orbits the Earth in a circular orbit at an altitude of 4000 km. Calculate

(a) the centripetal acceleration experienced by the satellite. (2 marks)

$a_c = g = GM/r^2$ (1)

$= (6.67 \times 10^{-11})(5.97 \times 10^{24}) / (6.37 \times 10^6 + 4 \times 10^6)^2$

$=$ $\underline{3.70 \text{ m/s}^2}$ (1)

(b) the orbital speed of the satellite. (2 marks)

$a_c = v^2/r$ ➔ $v^2 = a_c \times r$ (1)

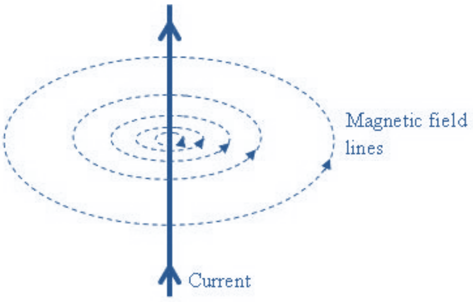
$v^2 = 3.70 \text{ m/s}^2 \times (6.37 \times 10^6 + 4 \times 10^6)$ ➔ $v =$ $\underline{6.20 \times 10^3 \text{ m/s}}$ (1)

[Or could use $v = (GM/r)^{½}$]

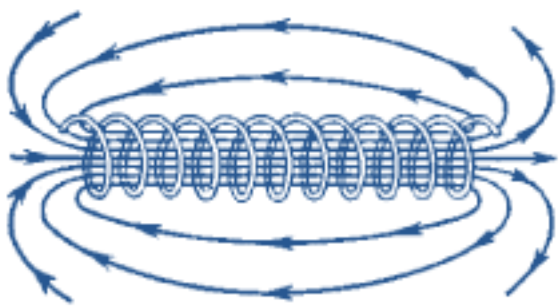
Question 6 **(5 marks)**

The diagrams below show a long straight vertical wire (diagram A) and a solenoid (diagram B). Arrows indicate the direction of the current through each of the conductors.

A



B



each diagram: shape (1) , direction (1) (-1 for each mistake)

(a) Sketch on each diagram the magnetic field produced by each conductor. (3 marks)

(b) In diagram A the magnetic field strength is found to be 45 μT at a perpendicular distance of 1.75 cm from the long straight wire. Calculate the size of the current in the wire. (2 marks)

$B = {}^{\mu_0}/_{2\pi}\ {}^{I}/_{r}$ ➔ $45 \times 10^{-6} = (2 \times 10^{-7})\ {}^{I}/_{(0.0175)}$ **(1)**

$\therefore\ I = 45 \times 10^{-6} \times {}^{(0.0175)}/_{(2 \times 10^{-7})} = \underline{3.94\ A}$ **(1)**

Question 7 **(5 marks)**

(a) Balance each of the following particle reactions by including the missing particle:

(i) $p \rightarrow n + \underline{e^+} + \nu_e$ (1 mark)

(ii) $\tau^- \rightarrow e^- + \nu_\tau + \underline{\bar{\nu}_e}$ (1 mark)

(b) Neutrinos are detected by the following reaction

$n + \nu_e \rightarrow p + e^-$

Show that three conservation laws are obeyed in this reaction. (3 marks)

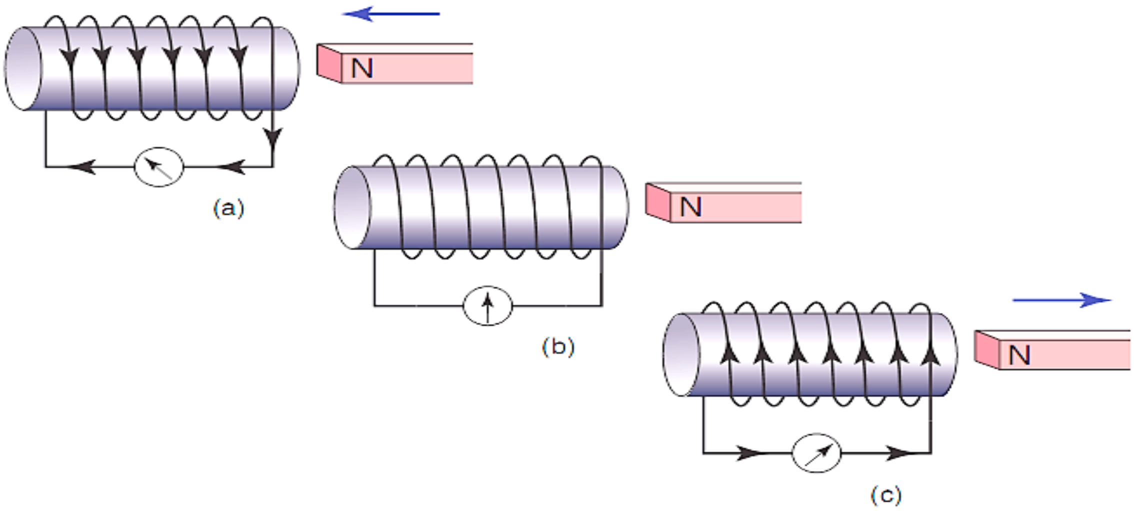
charge: 0 + 0 = (+1) + (-1) = 0 (1)

baryon number: 1 + 0 = 1 + 0 (1)

electron lepton number: 0 + 1 = 0 + 1 (1)

Question 8 **(4 marks)**

The diagrams below show the interaction between a bar magnet and a solenoid in three different situations. The needle of the galvanometer, shown below the solenoid, indicates any flow of current.



Briefly explain the following observations:

(a) No current flows (diagram b) when the magnet is held stationary near the solenoid. (1 mark)

When the magnet is held stationary near the solenoid there is no change of flux through the solenoid, and hence no emf is induced in the solenoid.

(b) The current flows in opposite directions in diagrams (a) and (c) when the magnet is pushed towards, then pulled away from the solenoid. (3 marks)

When the magnet is moved relative to the solenoid there is a change of flux through the solenoid and an emf is induced in the solenoid that causes current to flow. (1)
The induced current always flows in a direction such that its magnetic field opposes the flux change that generated it (Lenz's Law). (1) Hence the current must flow in opposite directions when the magnet is pushed towards or pulled away from the solenoid as these motions produce opposite flux changes in the solenoid. (1)

Question 9 **(5 marks)**

A photoelectric cell contains an aluminium electrode that is illuminated with ultraviolet light of wavelength 284 nm. The work function of aluminium is 4.08 eV. Calculate

(a) the energy of one of the ultraviolet photons in electron-volts. (2 marks)

$E = hc/\lambda = (6.63 \times 10^{-34})(3 \times 10^{8})/(2.84 \times 10^{-7})$ **(1)**

$= 7.00 \times 10^{-19}$ J $=$ **4.38 eV** **(1)**

(b) the velocity of the emitted photo-electrons. (3 marks)

$E_K = hf - W = 4.38 \text{ eV} - 4.08 \text{ eV} = 0.297 \text{ eV}$ **(1)**

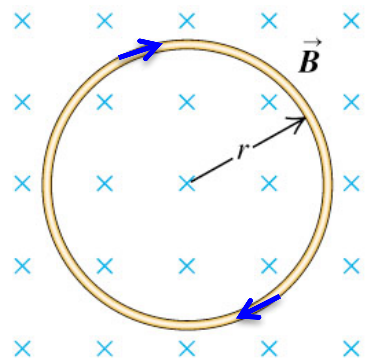
$\therefore E_K = 4.76 \times 10^{-20} \text{ J} = \frac{1}{2} mv^2$ **(1)**

$\frac{1}{2}(9.11 \times 10^{-31}) v^2 = 4.76 \times 10^{-20}$

$v = 3.23 \times 10^{5}$ m/s **(1)**

Question 10 **(3 marks)**

The diagram at right shows a ring of wire of radius r = 2.00 cm, which is fully immersed in a uniform magnetic field B = 50.0 mT. The ring is pulled quickly out of the magnetic field, taking 0.15 s to be clear of the magnetic field.



(a) Indicate on the ring the direction of any induced current. (1 mark)

current is clockwise

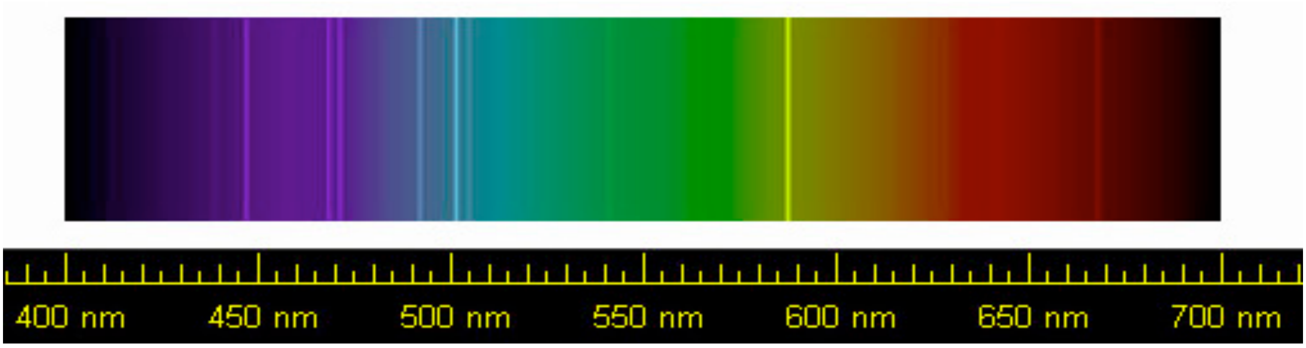
(b) If the ring has a resistance of 0.03 Ω, find the size of the average current induced as the ring is pulled clear of the magnetic field. (2 marks)

$\varepsilon = \Delta\phi/\Delta t = (0.050 \text{ T})(\pi (0.02\text{m})^2)/(0.15\text{s}) = 4.19 \times 10^{-4} \text{ V}$ **(1)**

$I = \varepsilon/R = (4.19 \times 10^{-4} \text{ V})/0.03\ \Omega = $ **0.0140 A** **(1)**

Question 11 **(5 marks)**

Observations of the luminosity of a supernova in a distant galaxy indicate that it is 50 mega parsecs away from Earth. Analysis of the helium spectrum from the supernova shows that the yellow line that usually occurs at a wavelength of 587.6 nm was measured for this galaxy to be at 595.3 nm.



(a) What has caused this change in wavelength of the yellow line in the helium spectrum for this distant galaxy? (1 mark)

The wavelength of the yellow line has increased, indicating a Doppler shift due to the distant galaxy moving away from the Earth.

(b) Calculate the recessional velocity of the galaxy from this spectral data, given $v = (\Delta\lambda/\lambda)\,c$ (2 marks)

$\Delta\lambda = 595.3 \text{ nm} - 587.6 \text{ nm} = 7.7 \text{ nm}$ **(1)**

$v = (\Delta\lambda/\lambda)\,c = (7.7 \text{ nm}/587.6 \text{ nm})\,(3 \times 10^{8} \text{ m/s}) = \underline{3.93 \times 10^{6} \text{ m/s}}$ **(1)**

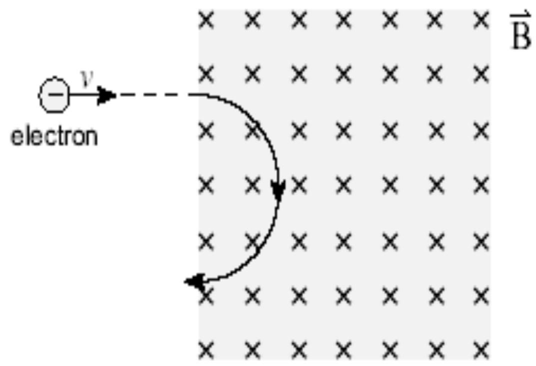
(c) Use the data from this galaxy to estimate a value for Hubble's constant H_o. (2 marks)

$v = H_o d \rightarrow H_o = v/d = (3.93 \times 10^{6} \text{ m/s})/50 \text{ Mpc}$ **(1)**

$= (3930 \text{ km/s})/50 \text{ Mpc} = \underline{79 \text{ km/s/Mpc}}$ **(1)**

Question 12 **(5 marks)**

An electron is fired into a uniform perpendicular magnetic field of strength 230 μT and follows a semi-circular path through the magnetic field of radius 350 mm, as illustrated at right.



(a) Calculate the speed needed for the electron to follow the semi-circular path. (2 marks)

$r = \frac{mv}{qB}$ $\quad v = \frac{rqB}{m}$ (1)

$\therefore\ v = \frac{(0.35\ m)(1.6 \times 10^{-19}\ C)(230 \times 10^{-6}\ T)}{(9.11 \times 10^{-31}\ kg)}$

$= \underline{1.41 \times 10^{7}\ m/s}$ (1)

(b) Determine the potential difference through which the electron was accelerated (before reaching the magnetic field) in order to have this speed. (3 marks)

$W = Vq = \Delta E_K$ (1)

$\Delta E_K = \frac{1}{2}mv^2 = \frac{1}{2}(9.11 \times 10^{-31}\ kg)(1.41 \times 10^{7}\ m/s)^2 = 9.11 \times 10^{-17}\ J$ (1)

$\therefore\ V = \frac{\Delta E_K}{q} = \frac{9.11 \times 10^{-17}\ J}{1.6 \times 10^{-19}\ C} = \underline{569\ V}$ (1)

Question 13 **(4 marks)**

There are 6 different quarks, which are shown in the table below. Quarks interact strongly with one another and exist in combination as composite particles called hadrons. There are two classes of hadrons – baryons, made of three quarks, and mesons, made of a quark-antiquark pair.

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

(a) All matter is made up of hadrons and leptons. State two characteristics of leptons that distinguish them from hadrons. (2 marks)

Leptons are distinguished from hadrons as they:

- **are typically much lighter in mass than hadrons**
- **are fundamental particles, not composite particles made of quarks**
- **do not interact by the strong nuclear force**

(any 2 points for 2 marks)

(b) Give the quark composition of each of the following hadrons: (2 marks)

(i) the baryon Σ^0 which has Q = 0, B = 1, S = -1 and c = b = t = 0

u d s

(ii) the meson K+ which has Q = +1, B = 0, S = +1 and c = b = t = 0

u $\bar{s}$

End of Section One

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

This section has **7** questions. Answer **ALL** questions. Write your answers in the spaces provided.

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

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

Suggested working time for this section is **90 minutes.**

Question 16 **(12 marks)**

Kepler-186f is one of five planets found in an extrasolar system located about 490 light-years from Earth. The newly discovered exoplanet orbits about 52.4 million kilometres from its sun. It takes Kepler-186f about 130 days to orbit its red dwarf star. Kepler-186f is the first Earth-size alien planet found in the habitable zone of its star. That means the planet, which is about 10% larger in diameter than Earth, is in the part of its star system where liquid water could exist on the planet's surface. An artist's impression of the planet's surface is pictured at right.

(a) What is the orbital speed of Kepler-186f? (2 marks)

$v = {}^{2\pi r}/_{T}$

$= 2\pi(5.24 \times 10^{10}\text{ m})/(130 \times 86400\text{ s})$ **(1)**

$= \underline{2.93 \times 10^{4}\text{ m/s}}$ **(1)**

(b) Is Kepler-186f accelerating? Explain. (2 marks)

Yes, Kepler-186f is accelerating (1) as it orbits as it is continually <u>changing direction</u> and therefore <u>continually changing velocity</u> due to the gravitational pull of its sun. (1) (although its orbital speed stays roughly constant)

(c) From the orbital data about Kepler-186f, calculate the mass of its red dwarf sun. (3 marks)

Kepler's 3rd Law states

$r^3/T^2 = GM/4\pi^2$ (1)

$(5.24 \times 10^{10}\ m)^3/(130 \times 86400\ s)^2 = (6.67 \times 10^{-11}\ Nm^2/kg^2)M/4\pi^2$ (1)

M = $\underline{6.75 \times 10^{29}\ kg}$ (1)

(d) Assuming that Kepler-186f has a similar density to Earth, estimate a value for its mass based upon the estimate of its size given above. (2 marks)

Kepler-186f has a diameter and hence radius that is 1.1 times larger than that of Earth

Since mass = density x volume = density x $4/3\pi r^3$ (1)

mass(Kepler-186f) = mass(Earth) x 1.1^3

= 6×10^{24} kg x 1.331

= $\underline{8 \times 10^{24}\ kg}$ (1) (no more than 2 sig figs)

(e) Hence find a value for the gravitational force between Kepler-186f and its sun. (3 marks)

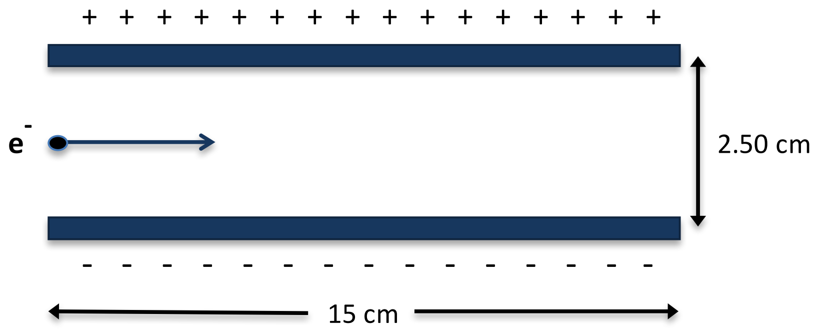
$F = G\, m_1 m_2/r^2$ (1)

$= (6.67 \times 10^{-11}\ Nm^2/kg^2)(6.75 \times 10^{29}\ kg)(8 \times 10^{24}\ kg)/(5.24 \times 10^{10}\ m)^2$ (1)

= $\underline{1.3 \times 10^{23}\ N}$ (1) (no more than 2 sig figs)

Question 17 **(13 marks)**

An electron enters the gap between two oppositely charged parallel plates while moving horizontally and parallel to the plates at a speed of 1.2 x 10^8 m/s, as shown in the diagram below. The plates are 15.0 cm long with a separation of 2.50 cm, and a potential difference of 2400 V.



(a) Find the strength and direction of the electric field in the region between the charged parallel plates. (2 marks)

$E = V/d = 2400\ V / 0.025\ m$ = <u>9.6 x 10^4 V/m</u> (1)

The electric field is directed <u>downwards</u> (from positive plate to negative plate) (1)

(b) Calculate the magnitude of the electric force acting on the electron as it moves between the plates, and the size and direction of its resulting acceleration. (3 marks)

The electric force is of magnitude

F = q E = (1.6 x 10^{-19} C)(9.6 x 10^4 V/m) = <u>1.54 x 10^{-14} N</u> (1)

Hence the electron experiences acceleration

a = F/m = (1.54 x 10^{-14} N)/(9.11 x 10^{-31} kg) = <u>1.69 x 10^{16} m/s^2</u> (1)

The acceleration of the electron is <u>upwards</u> (1) (opposite to direction of electric field)

(c) Why could we ignore the weight of the electron in determining its acceleration? (1 mark)

The weight of the electron is F_w = mg = (9.11 x 10^{-31} kg)(9.8 m/s^2) ≈ 10^{-29} N , which is insignificant compared to the magnetic force of ≈ 10^{-14} N and so can be ignored for further calculations. (1)
[the acceleration due to gravity is 9.8 m/s^2, compared to the acceleration due to the electric field of 1.69 x 10^{16} m/s^2]

(d) Calculate the time it takes for the electron to move through the gap between the parallel plates. (2 marks)

$t = s_H/v_H = (0.15\text{ m})/(1.2 \times 10^8\text{ m/s})$ (1)

$= \underline{1.25 \times 10^{-9}\text{ s}}$ (1)

(e) Determine the vertical displacement of the electron as it moves through the gap between the parallel plates. (use an acceleration of $1.50 \times 10^{16}\text{ m/s}^2$ if no answer from part (b)) (2 marks)

$s_V = u_V t + \frac{1}{2} a t^2 = 0 + \frac{1}{2}(1.69 \times 10^{16}\text{ m/s}^2)(1.25 \times 10^{-9}\text{ s})^2$ (1)

$= \underline{1.31 \times 10^{-2}\text{ m}}$ (1.31 cm upwards) (1)

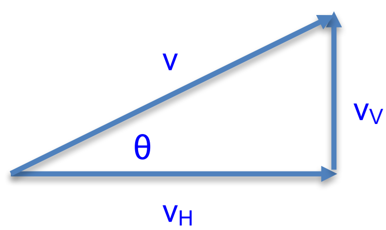
[if using $a = 1.50 \times 10^{16}\text{ m/s}^2$ then $s_V = 1.17 \times 10^{-2}\text{ m}$]

(f) Find the final velocity (magnitude and direction) of the electron as it exits the gap between the parallel plates. (3 marks)

$v_H = 1.2 \times 10^8\text{ m/s}$

$v_V = a\,t = (1.69 \times 10^{16}\text{ m/s}^2)(1.25 \times 10^{-9}\text{ s})$

$= 2.11 \times 10^7\text{ m/s}$ (1)



$v^2 = (1.2 \times 10^8\text{ m/s})^2 + (2.11 \times 10^7\text{ m/s})^2$

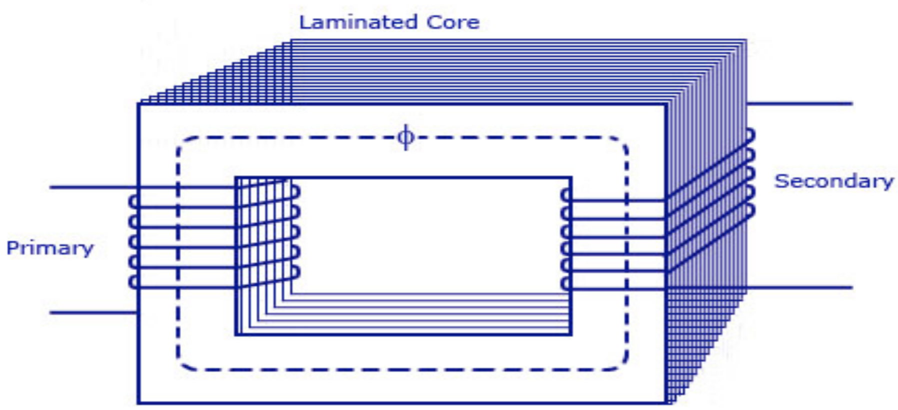
➔ $v = \underline{1.22 \times 10^8\text{ m/s}}$ (1)

$\tan\theta = (2.11 \times 10^7\text{ m/s})/(1.2 \times 10^8\text{ m/s})$ ➔ $\theta = \underline{10.0°}$ (1)

[if using $a = 1.50 \times 10^{16}\text{ m/s}^2$ then $v = \underline{1.21 \times 10^8\text{ m/s}}$ and $\theta = \underline{8.9°}$]

Question 18 **(13 marks)**

The diagram below shows an iron-cored transformer



(a) Explain how energy is transferred from the primary coil to the secondary coil, with reference to *Faraday's Law of electromagnetic induction.* (3 marks)

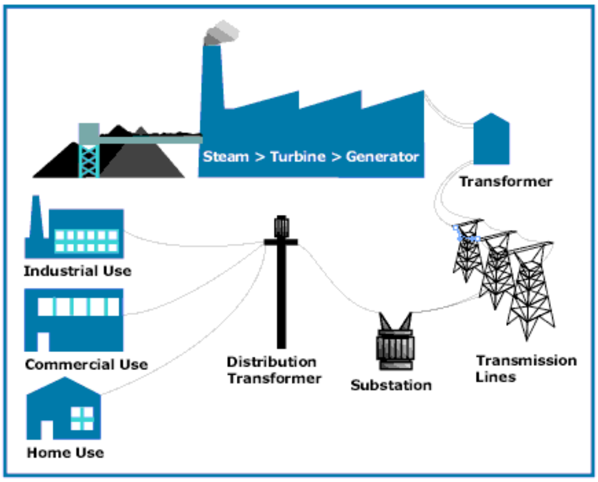
The alternating current in the primary coil produces magnetic flux that continually varies in size as well as oscillating back and forth in direction. (1)
This continually varying flux is channelled by the iron core of the transformer and directed through the secondary coil of the transformer (1) , where, by Faraday's Law of electromagnetic induction, it induces an emf in the secondary coil due to the continually varying flux, thereby transferring energy from primary coil to secondary coil. (1)

(b) What is a ***laminated*** core, and what is its purpose? (2 marks)

A laminated core is composed of thin slices of iron glued together by an electrically insulating material. (1)

Its purpose is to greatly restrict the formation of eddy currents in the iron core so as to limit loss of energy through heating of the core. (1)

In order to transmit electric power more efficiently, an electricity company uses transformers and high voltage transmission lines to transmit power at 330 kV from the power station to the city 200 km away. The average output power of its generators is 600 MW during the high demand period from 3pm to 9pm on a hot summer day. The high voltage transmission lines have a total resistance of 5.00 Ω over their 200 km length.



(c) What is the voltage at the end of the transmission lines (before the substation) after transmission along the high voltage lines? (3 marks)

Current flow needed in the lines to deliver the output power from the power station is

$I = P/V = (600 \times 10^6\ W)/(330 \times 10^3\ V) = 1820\ A$ (1)

Voltage drop along the lines is

$V = IR = 1820\ A \times 5.00\ \Omega = 9090\ V$ (1)

Hence the voltage at the end of the transmission lines is

$330\,000\ V - 9090\ V = 321\,000\ V = \underline{321\ kV}$ (1)

(d) Calculate the percentage power loss in the high voltage transmission lines. (2 marks)

Power loss in the transmission lines is

$P = I^2 R = (1820\ A)^2 (5.00\ \Omega) = 16.5\ MW$ (1)

Hence the percentage power loss in the transmission lines is

$\%P(loss) = 16.5\ MW/600\ MW \times 100\% = \underline{2.75\%}$ (1)

(e) Given that the energy content of coal is 24 MJ per kilogram, and that the process of generating electrical energy in a coal fired power station is 40% efficient, calculate the mass of coal needed to supply the electrical energy required during the high demand period from 3pm to 9pm on a hot summer day. (3 marks)

Electrical energy required during the high demand period is

$E = P \times t = (600 \times 10^6\ W) \times (6 \times 60 \times 60\ s) = 1.30 \times 10^{13}\ J$ (1)

Energy needed from coal (power station is only 40% efficient) is

$1.30 \times 10^{13}\ J/0.40 = 3.24 \times 10^{13}\ J$ (1)

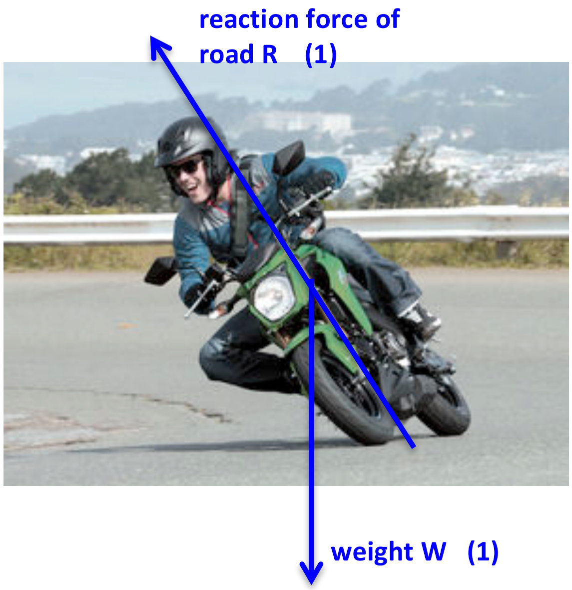
Hence the mass of coal needed is

$3.24 \times 10^{13}\ J/(24 \times 10^6\ J/kg) = \underline{1.35 \times 10^6\ kg}$ (= 1350 tonne) (1)

Question 19 **(11 marks)**

A man rides a motorcycle around a flat curve in the road at a constant speed of 54.0 km/h. The man and motorcycle have a combined mass of 185 kg and the curve has a radius of curvature of 35.0 m. The rider must lean over as he corners.

(a) Show the forces acting on the man as he rides the motorcycle around the corner. Use labelled arrows in the picture at right (2 marks)



(b) Explain why the rider has to lean over as he corners on the motorcycle. (3 marks)

In order to follow a curved path around the corner there must be a centripetal force acting on the motorcycle. (1)

By leaning inwards as he corners, the rider causes the tyres of the motorcycle to push outwards with a friction force on the road. (1)

The reaction force of the road friction pushing inwards on the tyres provides the necessary centripetal force for the motorcycle to negotiate the curve. (1)

(c) Calculate the force of friction acting on the tyres of the bike. (2 marks)

$F_{fr} = F_c = {}^{mv^2}/_{r}$ **(1)**

$= (185 \text{ kg})(15 \text{ m/s})^2/(35.0 \text{ m}) = \underline{1190 \text{ N}}$ **(1)**

(d) What is the size of the total force exerted by the road on the tyres? (2 marks)

Reaction force R exerted by the road on the tyres has two components

R_H = F_{fr} = 1190 N and R_V = W = 185 x 9.8 = 1810 N (1)

Hence R = $\sqrt{R_H{}^2 + R_V{}^2}$ = $\sqrt{1190^2 + 1810^2}$ = <u>2170 N</u> (1)

(e) What is the angle that the bike and rider make to the horizontal? (2 marks)

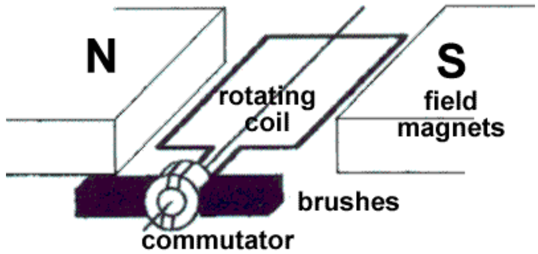
The angle θ that the bike and rider make to the horizontal is given by

tan θ = R_V/R_H = $1810/1190$ (1)

∴ θ = <u>56.7°</u> (1)

Question 20 **(14 marks)**

A typical DC electric motor is shown at right. The coil contains 250 turns and has dimensions of 8.00 cm in length by 5.00 cm in width. The field magnets produce a uniform magnetic field of strength 0.0240 T in which the coil rotates.



(a) Explain the purpose of the commutator and brushes. (2 marks)

The brushes provide a sliding electrical contact to the rotating commutator (1), while the split ring reverses the current flow every half turn of the coil so that the torque always acts in the same rotational direction. (1)

(b) Describe two ways that an *actual* electric motor would differ from the one shown in the diagram above. (1 mark)

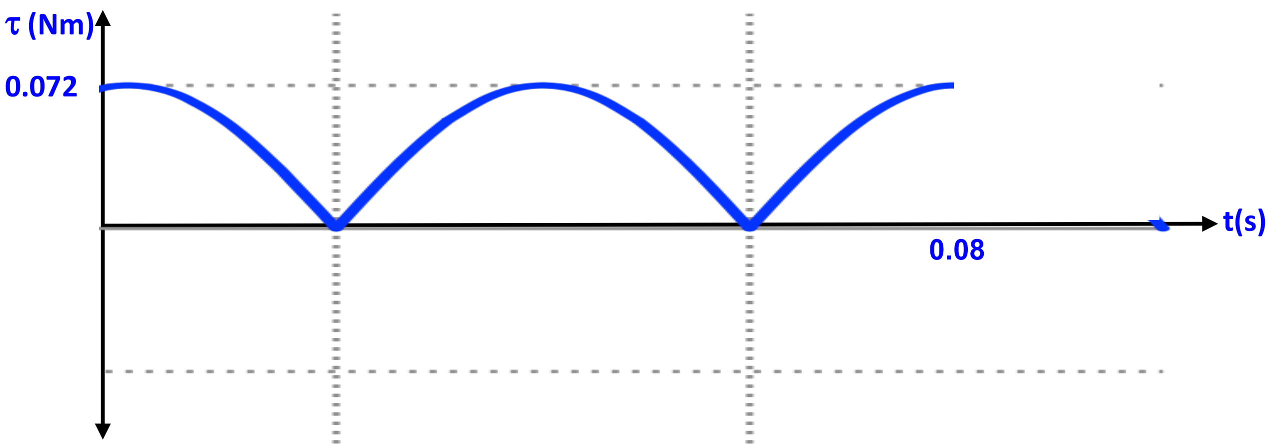
Any one of the following points

- **curved magnetic poles**
- **electromagnets for the poles (stator coils), rather than permanent magnets**
- **multiple armatures, rather than a single coil**
- **segmented commutator, rather than a split ring commutator**

(c) When in operation under load, the motor rotates at a steady rate of 750 rpm (revolutions per minute) and draws a current of 3.00 A. On the axes below, sketch the torque produced by the motor over a full rotation of the coil, starting from the position shown in the diagram above. Include appropriate scales on both axes. (4 marks)

f = 750 rpm = 12.5 Hz ➔ T = 1/f = 1/12.5 Hz = 0.08 s (1)

max τ = N I A B = (250)(3.00 A)(0.08 m x 0.05 m)(0.0240 T) = 0.072 Nm (1)



labelled, scaled axes (1) **rectified cosine curve (1)**

(d) Even when under no load at all, the motor has a maximum rotational speed that it can reach. Explain why this is so, with reference to Faraday's Law and Lenz's Law. (4 marks)

As the motor gains speed due to the torque produced by the interaction between the current and the magnetic field, the rotating coil cuts magnetic flux. (1)

According to Faraday's Law, the changing magnetic flux through the coil will induce an emf in the coil. (1)

By Lenz's Law, this induced emf will act so as to oppose the external emf that is driving the motor. (1)

As the motor speeds up the induced emf (usually called the back emf) will increase until it balances the external emf, at which point the motor will have reached its maximum rotational speed. (1)

(e) Estimate the maximum rotational speed of the motor (in rpm) when connected to a 6.00 V battery and operating under no load. (3 marks)

Maximum rotational speed occurs when the back emf reaches 6.00 V

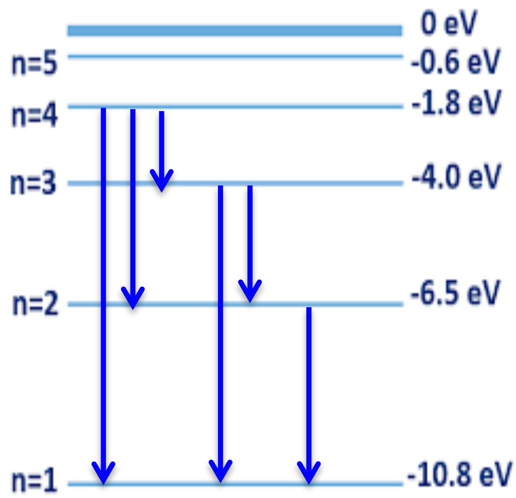
$$\varepsilon_{rms} = \frac{2\pi BANf}{\sqrt{2}} = 6.00 \text{ V} \quad (1)$$

$$\frac{2\pi(0.024\ T)(0.08\ m\ x\ 0.05\ m)(250)f}{\sqrt{2}} = 6.00 \text{ V} \quad (1)$$

f = 56.3 Hz = <u>3380 rpm</u> (1)

Question 21 **(12 marks)**

The figure at right illustrates some of the valence electron energy levels in a gaseous atom of a particular element. The energies of the levels are given in electron volts (eV).



(a) The valence electron of the atom is in the lowest energy level shown. What is the ionisation energy of the atom in joules? (2 marks)

Ionisation energy = 10.8 eV (1)

= 10.8 x 1.6 x 10^{-19} J

= <u>1.73 x 10^{-18} J</u> (1)

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

Any two of the following points

- **absorption of a photon of energy exactly equal to the energy level difference**
- **bombardment by an electron with sufficient KE to excite the atom**
- **thermal excitation whereby if the sample of gas is hot enough then atomic collisions may be energetic enough to excite atoms**

A cold gaseous sample of the element is bombarded by electrons of energy 9.5 eV and observed to emit electromagnetic radiation.

(c) Show on the diagram above the energy level transitions that cause this emission of electromagnetic radiation. (2 marks)

9.5 eV can excite atoms up to level n = 4 (1) ➔ 6 emission lines (1)

(d) Calculate the longest wavelength of the emitted electromagnetic radiation. (3 marks)

Longest wavelength of radiation = smallest energy = 2.2 eV (n = 4 to 3) (1)

$E = hc/\lambda$ ➔ $\lambda = hc/E$ = $(6.63 \times 10^{-34})(3 \times 10^{8})/(2.2 \times 1.6 \times 10^{-19})$ (1)

= <u>5.65 x 10^{-7} m</u> (1)

Invisible ultraviolet light of photon energy 6.8 eV is shone through a cold gaseous sample of the element, which is then observed to glow with a turquoise-blue light.

(e) What is the name given to this phenomenon? (1 mark)

fluorescence (1)

(f) Calculate the frequency of the turquoise-blue light. (2 marks)

6.8 eV excites atoms to level n= 3

n = 3 to n = 2 releases photon with <u>2.5 eV</u> ➔ visible light (1)

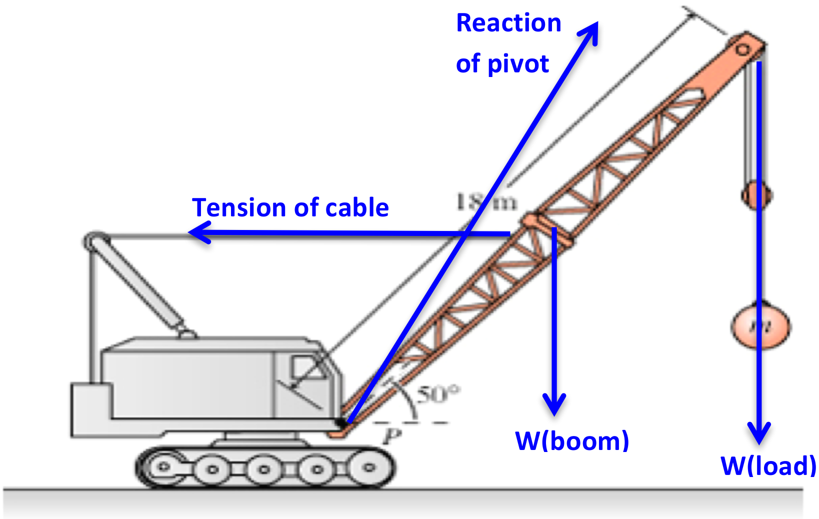
(n = 2 to n = 1 releases photon with 4.3 eV ➔ ultraviolet light)

$E = hf \rightarrow f = E/h = (2.5 \times 1.6 \times 10^{-19}\ J)/(6.63 \times 10^{-34}\ Js)$

$= \underline{6.03 \times 10^{14}\ Hz}$ **(1)**

Question 22 **(15 marks)**

A mobile crane is used to lift a load m of mass 1600 kg, as shown in the diagram below. The 18 m long boom (crane arm) has a mass of 850 kg, centred halfway along its length, and can pivot about point P at its base.



(a) Clearly show all forces acting on the boom as labelled arrows on the diagram. (3 marks)

Tension (1) **Reaction of pivot (1)** **Weight forces (1)**

(b) A horizontal steel cable connects to the boom 8.00 m from the pivot P. Find the tension in the cable needed to hold the boom stationary. (4 marks)

Take moments about the pivot at point P ➔ $\Sigma \tau_{CW} = \Sigma \tau_{ACW}$ **(1)**

$(850 \times 9.8)(9)\sin 40° + (1600 \times 9.8)(18)\sin 40° = F_T (8)\sin 50°$ **(2)**

230000 Nm = F_T (8 m) sin50°

∴ F_T = <u>37500 N</u> **(1)**

(c) Determine the magnitude and direction of the reaction force provided by the pivot P on the boom. (4 marks)

horizontal: $R_H = F_T = 37500$ N (1)

vertical: R_V = W(boom) + W(load) = 8330 N + 15680 N = 24000 N (1)

$R = (R_H{}^2 + R_V{}^2)^{1/2} = (37500^2 + 24000^2)^{1/2} = \underline{44500 \text{ N}}$ (1)

$\tan\theta = R_V / R_H = 24000 / 37500 \rightarrow \theta = \underline{32.7°}$ (1)

(d) Describe how and explain why the tension in the steel cable must change as the boom is lifted to a more vertical position:

(i) at the instant the boom is first moved upwards from the position shown in the diagram above. (2 marks)

the tension in the cable will <u>increase</u> (1) in order to accelerate the combined mass of the boom and load from their stationary positions (1)

(ii) when the boom is held stationary again in a new more vertical position. (2 marks)

the tension in the cable will <u>decrease</u> (1) as the clockwise torque due to the weight forces of the boom and load decreases as their perpendicular distances from the pivot decrease (1)
(also, the cable connects to the boom at an angle closer to 90°)

End of Section Two

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

This section has 2 questions. You must answer both questions. Write your answers in the spaces provided.

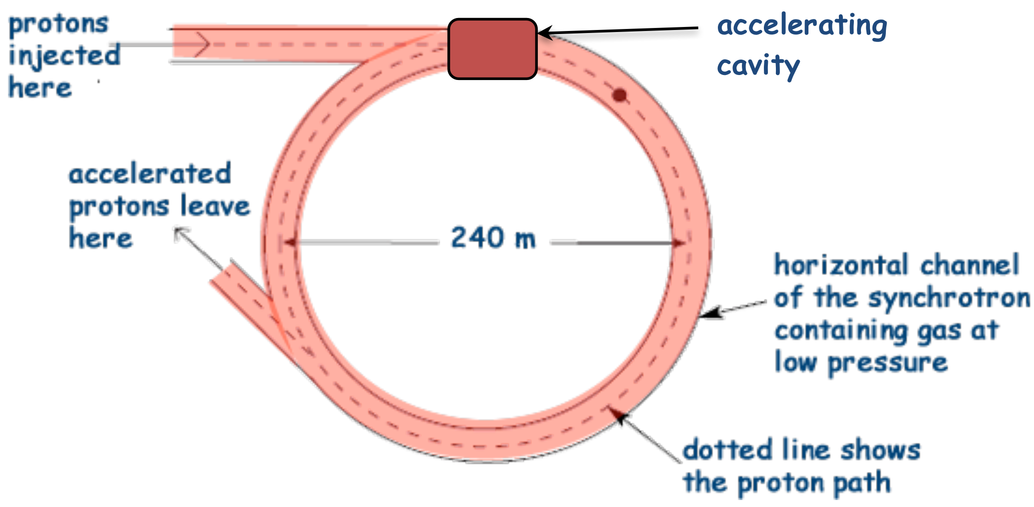
Spare pages are included at the end of this booklet. They can be used for planning your responses and/or as additional space if required to continue an answer.

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

Suggested working time: **40 minutes**.

Question 23 **RELATIVITY AND MOTION** **20 marks**

(a) A synchrotron uses a perpendicular magnetic field to contain protons as they circulate around a hollow ring; the protons pass around the ring and through the accelerating cavity thousands of times before finally leaving the ring at speeds approaching that of light.



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

(i) the momentum of the proton. (3 marks)

$p = \frac{m_0 v}{(1 - v^2/c^2)^{½}}$ (1)

$= \frac{(1.67 \times 10^{-27})(0.95 \times 3 \times 10^8 \text{ m/s})}{(1 - 0.95^2)^{½}}$ (1)

$=$ <u>1.52×10^{-18} kgm/s</u> (1)

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

$\lambda = \frac{h}{p}$ (1)

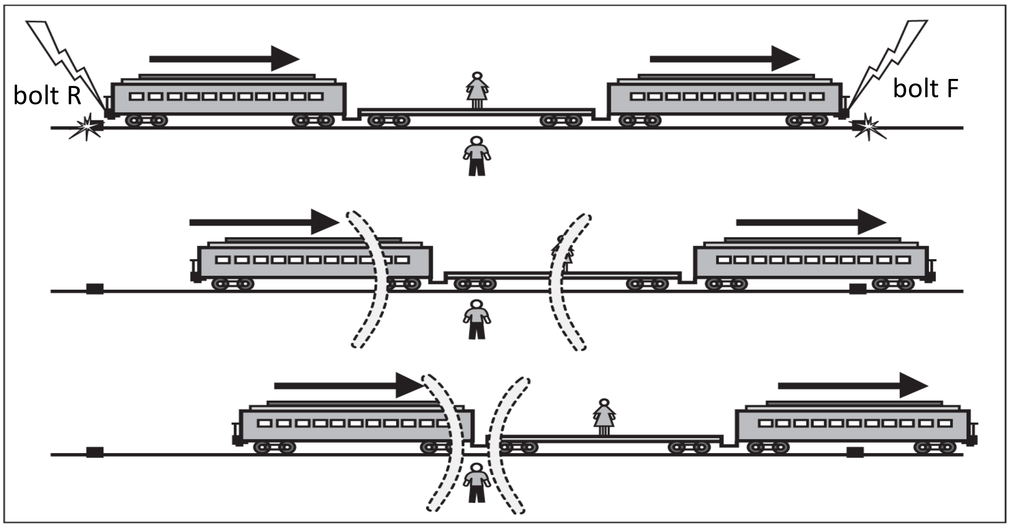
$= \frac{6.63 \times 10^{-34}}{1.52 \times 10^{-18}} =$ <u>4.35×10^{-16} m</u> (1)

(iii) the strength of the magnetic field needed to maintain its circular motion. (2 marks)

$r = {}^{mv}/_{qB}$ ➔ $B = {}^{mv}/_{qr}$ = $(1.52 \times 10^{-18}$ kgm/s$) / (1.6 \times 10^{-19}$C$)(120$m$)$ (1)

= <u>0.0794 T</u> (1)

(b) The series of diagrams below show a very fast train, with a woman standing on an open carriage, speeding at a relativistic velocity past a man standing on the ground next to the train tracks. Just as the train passes the man, two bolts of lightning strike the front (F) and rear (R) of the train.



(i) What is the order in time of the two lightning strikes according to

The man standing on the ground? (1 mark)

The wavefronts from the two bolts of lightning reach the man standing on the ground at the same instant, so he will interpret that they occurred <u>simultaneously</u>

The woman standing on the train carriage? (1 mark)

The wavefront from lightning bolt F reaches the woman first, so she will interpret that the <u>lightning bolt F occurred before lightning bolt R</u>

(ii) Whose interpretation of events is correct, the man's or the woman's? Briefly explain. (2 marks)

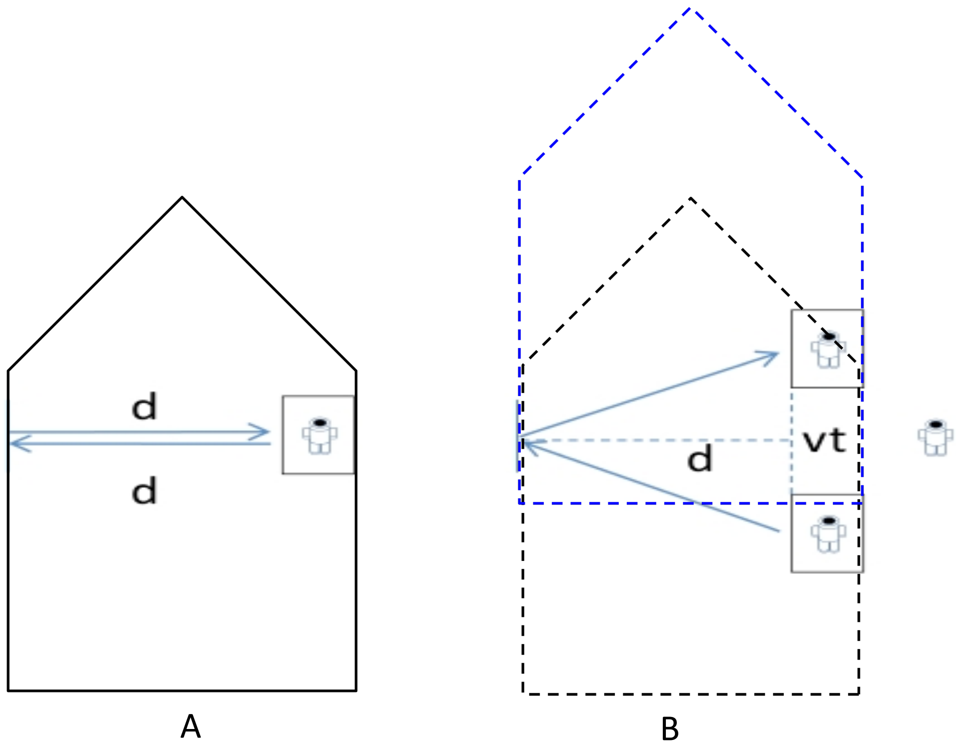
Both interpretations are <u>equally correct</u> (1) as each person is moving in their own inertial frame of reference, and <u>no inertial frame is preferred to any other</u> (1) (each person in their own frame can use their interpretation of events to explain why the other person interprets the time order of the events differently)

(iii) How does the woman explain the man's interpretation of events? (2 marks)

In the woman's frame of reference bolt F occurs first, followed a short time later by bolt R. As the man is moving rapidly towards the rear of the train from her reference frame (1) , she understands that he is moving away from the earlier bolt F and towards the later bolt R (1) , and so for him they will appear to be simultaneous.

(c) In a futuristic scenario, an astronaut aboard a relativistic spacecraft conducts a simple experiment (diagram A), by shining a beam of light onto a mirror that is a distance d away, and timing how long the reflection takes to return to her. Her value for the time taken by the light to travel to the mirror and back is

$t_0 = {}^{2d}/_{c}$ (equation 1)



While she conducts this simple experiment, a second astronaut observes the experiment from a space station (diagram B) as the relativistic spacecraft speeds past at velocity v. He sees the beam of light follow the path shown in diagram B due to the motion of the spacecraft.

(i) Show that the time he measures for the light travelling to the mirror and back is given by

$$t = \frac{2\sqrt{d^2 + \frac{1}{4}v^2t^2}}{c}$$ (equation 2) (3 marks)

The light travels a distance 2ℓ in his reference frame at the same constant speed c, so the time the light takes is given by

$t = {}^{2\ell}/_{c}$ (1)

where ℓ is the hypotenuse of a right-angled triangle with other sides d and ½ vt

$\therefore \ \ell = (d^2 + (\frac{1}{2}vt)^2)^{\frac{1}{2}} = (d^2 + \frac{1}{4}v^2t^2)^{\frac{1}{2}}$ (1)

Hence $t = {}^{2(d^2 + \frac{1}{4}v^2t^2)^{\frac{1}{2}}}/_{c}$ (1)

(ii) By combining equations 1 and 2, derive a formula linking the two different time intervals, as measured by the astronauts, for this simple experiment. (4 marks)

Rearranging equation 2 gives $^{ct}/_{2} = (d^2 + (\frac{1}{2}vt)^2)^{\frac{1}{2}}$ (1)

Squaring both sides gives

$(\frac{1}{2}ct)^2 = d^2 + (\frac{1}{2}vt)^2 \rightarrow (\frac{1}{2}ct)^2 - (\frac{1}{2}vt)^2 = d^2$ (1)

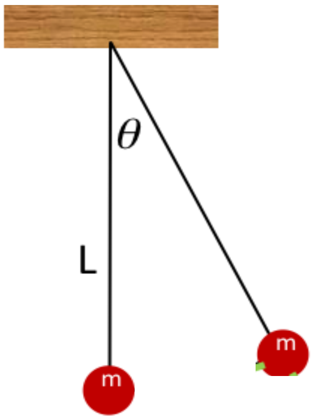
Equation 1 gives $d^2 = (\frac{1}{2}ct_0)^2$ so that

$(\frac{1}{2}ct)^2 - (\frac{1}{2}vt)^2 = (\frac{1}{2}ct_0)^2 \rightarrow c^2t^2 - v^2t^2 = c^2t_0^2$ (1)

$t^2(c^2 - v^2) = c^2t_0^2 \rightarrow t^2(c^2 - v^2)/c^2 = c^2t_0^2/c^2$

$t^2(1 - v^2/c^2) = t_0^2 \rightarrow \underline{t = t_0(1 - v^2/c^2)^{-\frac{1}{2}}}$ (1)

Question 24 **LARGE PENDULUM** **(16 marks)**



A large heavy spherical mass **m** was suspended from a wooden beam by a thin rope to form a simple pendulum. The distance **L** was measured from the point where the rope was attached to the beam to the top of the spherical mass. The mass was set swinging through a small angle θ and the time for 20 oscillations measured. Then the length **L** was reduced and the measurement of the time for 20 oscillations repeated; this was done several times to obtain the set of readings shown in the table below.

Note that the error in the measurements of distance **L** was around ± 1 cm, while the error in timing 20 oscillations was estimated to be about ± 1 s.

Distance L (m) (± 1 cm)	1.80	1.55	1.28	1.05	0.77
Time for 20 oscillations (s) (± 1 s)	55.2	51.5	47.1	43.0	37.4

This arrangement behaves as a simple pendulum of length (**L** + **r**), where **r** is the radius of the spherical mass, with the period of oscillation given by the formula

$$T = 2\pi\sqrt{\frac{(L+r)}{g}}$$

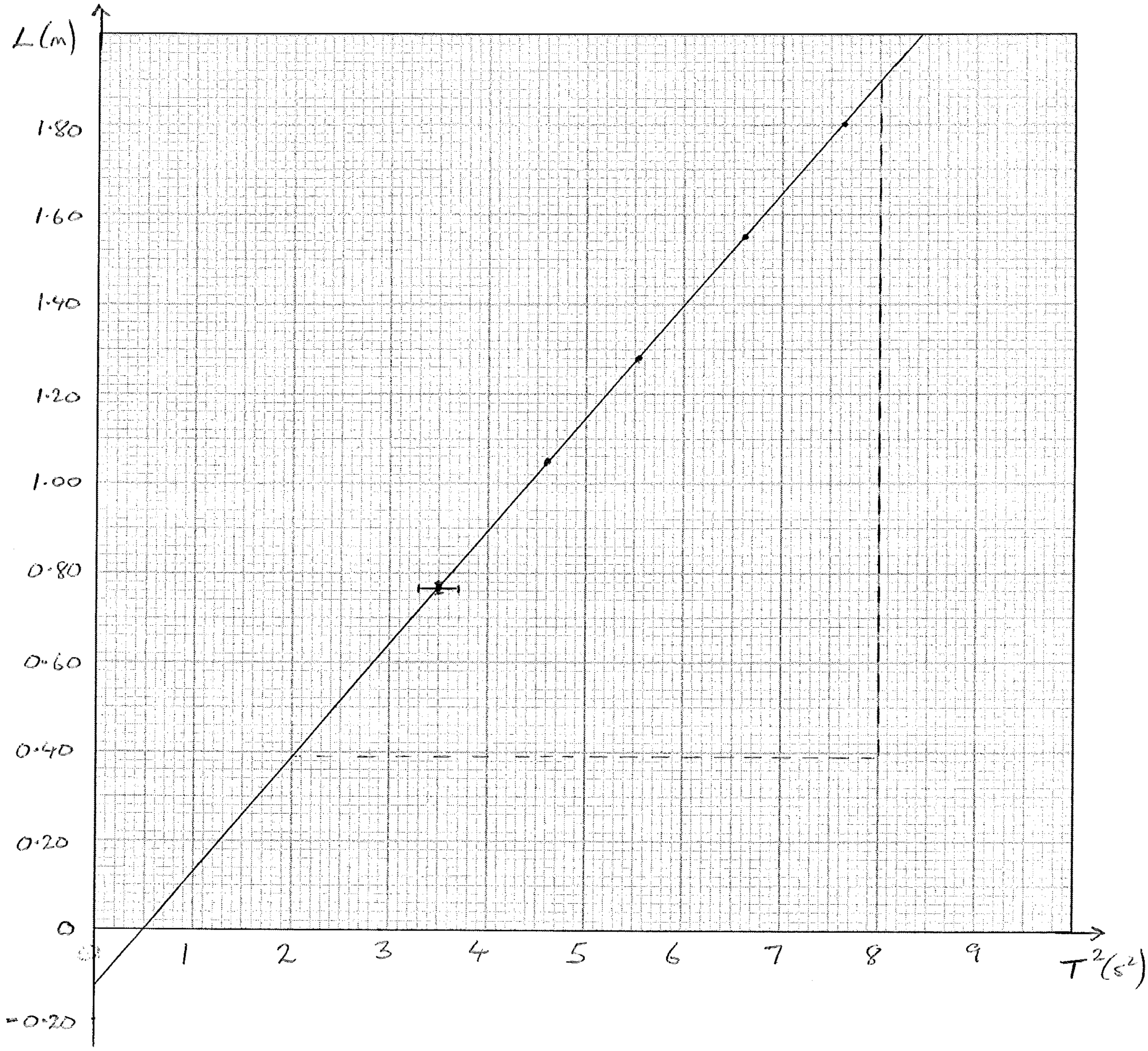
(a) Rearrange and write the formula in a form suitable for drawing a linear graph with distance **L** on the vertical axis (i.e. make **L** the subject of the formula). (1 mark)

$$\mathbf{L = (g/4\pi^2)\,T^2 - r}$$

(b) Use the table below to show the values needed to plot such a graph. (2 marks)

T (s)	**2.76**	**2.58**	**2.36**	**2.15**	**1.87**
T^2 (s^2)	**7.62**	**6.63**	**5.55**	**4.62**	**3.50**

(c) Plot the linear graph using your tabulated data on the graph paper below. (an additional copy of the graph paper is available at the back of this paper if needed) (4 marks)



(d) Show error bars on the graph for the plotted point with the smallest value of L. (2 marks)

L = 0.77 ± 0.01 m **(error bar covers one small square) (1)**

T = 1.87 s ± 2.67% ➔ T^2 = 3.50 s^2 ± 5.35% = 3.50 s^2 ± 0.19 s^2
(error bar covers four small squares) (1)

(e) Calculate the gradient of your graph. (2 marks)

gradient = rise/run = (1.89m - 0.39m)/($8s^2 - 2s^2$)

Gradient = 0.25 ms^{-2} **(0.245 to 0.255 okay)**
(1) (1)

(f) Use your gradient to obtain a value for g, the acceleration due to gravity. (2 marks)

gradient = $(g/4\pi^2)$ = 0.25 m/s^2 (1)

g = $4\pi^2$ x 0.25 m/s^2 = <u>9.87 m/s^2</u> (1)

(must show working – no marks for just giving value of g)

(g) Use your graph to estimate the radius of the spherical mass. (1 mark)

r = - (vertical intercept) = <u>0.12 m</u> (12 cm) (1)

(10 to 14 cm okay)

(h) Explain why the accuracy of the value found for g was not affected by the fact that length measurements were made only to the top of the spherical mass, and not to the centre of mass of the sphere. (2 marks)

$L = (g/4\pi^2)\,T^2 - r$ ➔ $L + r = (g/4\pi^2)\,T^2$

The radius r of the sphere appears as a constant term in the equation for length L and as the vertical intercept on the graph of L vs T^2 (1)

The value found for g is calculated from the gradient of the graph of L vs T^2, which is determined by the coefficient of the T^2 term in the equation, and is independent of the value of the vertical intercept. (1)

End of Section Three - End of Questions

Additional Working Space