ROSSMOYNE SENIOR HIGH SCHOOL

SCIENCE

MARKING GUIDE

Semester 2, Examination 2019

PHYSICS ATAR 12

Question/Answer Booklet

Student Number: In figures

In words ______________________________

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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

To be provided by the candidate

Standard items: pens, pencils, eraser, correction fluid, ruler, highlighters

Special items: nil

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.

Circle your Teacher's name: Mr. Holyoake , Mr. Patterson, Mrs. Shashikumar

Structure of this paper

Section	Number of questions available	Number of questions to be answered	Suggested working time (minutes)	Marks available	Percentage of exam
Section One: Short answer	13	13	50	54	30
Section Two: Extended answer	7	7	90	90	50
Section Three: Comprehension and data analysis	2	2	40	36	20
			Total	180	100

Instructions to candidates

1. Answer the questions in the space provided.

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

3. 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.

4. 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.

Section One: Short response 30% (54 Marks)

This section has **thirteen (13)** questions. Answer **all** questions. Write your answers in the space provided. Suggested working time for this section is 50 minutes.

Question 1 **(4 marks)**

Mars has a mass of 6.39 × 10^{23} kg and has an orbital radius around the Sun of 228 million kilometres. Calculate the weakest gravitation force that can act between Earth and Mars, assuming both Earth and Mars have circular orbits.

$F_g = \frac{GMm}{r^2}$ (1)

$F_g = \frac{6.67\times10^{-11}\times6.39\times10^{23}\times5.97\times10^{24}}{(228\times10^{6}\times10^{3}+1.50\times10^{11})^2} = 1.78\times10^{15}\ N$ (1-3)

Answer: $1.78\times10^{15}\ N$

Question 2 **(6 marks)**

A photoemissive metal plate is used as the target sample in a photoelectric effect experiment. When 320 nm light is used, a 0.685 V stopping voltage is required. When 250 nm light is used, the stopping voltage is 1.77 V.

(a) Explain why decreasing the wavelength of the light increases the stopping voltage. (3 marks)

Relates a decrease in wavelength to an increase in light energy

"The energy of a photon of light in inversely proportional to the wavelength ($E = \frac{hc}{\lambda}$) (1)

Relates the increase in light energy to more energetic electrons

"Higher energy photons can eject photoelectrons with more energy." (1)

Relates faster electrons needing a larger stopping voltage/electric field to stop the electrons

"To bring these faster electrons to a stop requires a larger stopping voltage." (1)

(b) Calculate the work function of the photoemissive metal plate. (3 marks)

$$E_k = hf - W \quad (1)$$

$$E_k = \frac{hc}{e\lambda} - W$$

$$0.685 = \frac{6.63\times10^{-34}\times3.00\times10^{8}}{1.60\times10^{-19}\times320\times10^{-9}} - W$$

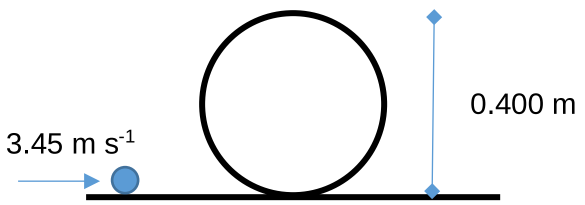
$$W = 3.20\ eV \quad (1\text{-}2)$$

Note: May also use the other pair of wavelength/stopping voltage values to obtain same answer.

Answer: $3.20\ eV$

Question 3 **(4 marks)**

A 30.0 g golf ball at a mini golf course approaches a small vertical loop obstacle at 3.45 m s^{-1}. The ball follows the track, completing the vertical loop.



Calculate the magnitude of the reaction force applied to the ball by the track when the ball is at the top of the loop.

$$E_{top} = E_{bottom}$$

$$mgh + \frac{1}{2}mv^2 = \frac{1}{2}mu^2 \quad (1)$$

$$v = \sqrt{2(\frac{1}{2}u^2 - gh)} = \sqrt{2(\frac{1}{2}(3.45)^2 - 9.8 \times 0.4)} = 2.016\ m\ s^{-1} \quad (1)$$

$$R = F_c - W \quad (1)$$

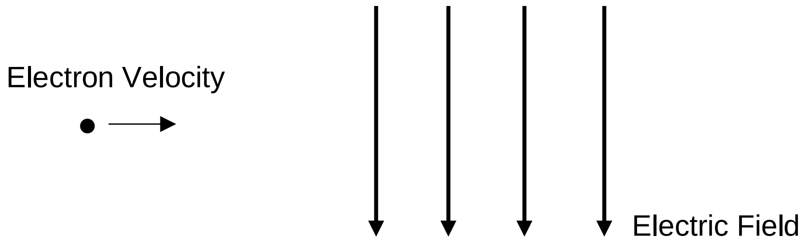
$$\text{R} = \frac{\text{mv}^2}{r} - mg$$

$$R = \frac{0.03\times2.016^2}{0.2} - 0.03 \times 9.8 = 0.316\ N \quad (1)$$

Answer: $0.316\ N$

Question 4 **(4 marks)**

The diagram below shows an electron entering a uniform 2.00 N C^{-1} electric field. There is also a magnetic field in this region (not shown on the diagram).



The electron has a constant velocity of 8540 m s^{-1} while in the presence of the two fields. State the direction of the magnetic field and calculate its strength.

Magnetic field is into the page. (1)

Field forces must balance

$F_E = F_B$ (1)

$E\cancel{q} = \cancel{q}vB$

$B = \frac{E}{v} = \frac{2.00}{8540} = 2.34 \times 10^{-4}\ T$ (1-2)

Direction: Into the page Strength: $2.34 \times 10^{-4}\ T$

Question 5 **(4 marks)**

Muon's produced in a CERN experiment are travelling at 0.920c relative to the particle accelerator. They cover a 728 km distance as measured from the reference frame of the particle accelerator before hitting their intended target. Calculate the time the muon's spend on their journey to the intended target from the reference frame of the muon.

$t = \frac{s}{v} = \frac{7.28\times10^5}{0.920\times3.00\times10^8} = 2.638 \times 10^{-3}\ s$ (1-2)

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

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

$t_0 = 2.638 \times 10^{-2} \times \sqrt{1-\frac{0.92^2c^2}{c^2}} = 1.03 \times 10^{-3}\ s$ (1-2)

Answer: $1.03 \times 10^{-3}\ s$

Question 6 **(4 marks)**

The following particle reaction is proposed by a PhD student while studying new, exotic particles of the standard model.

$$udb \rightarrow c\bar{c} + s\bar{u} + uud$$

Justify whether this reaction is possible based on baryon number and electric charge.

Baryon number

$udb \rightarrow c\bar{c} + s\bar{u} + uud$

$+1 \rightarrow 0 + 0 + 1$ (conserved, therefore possible) (1-2)

Electric charge

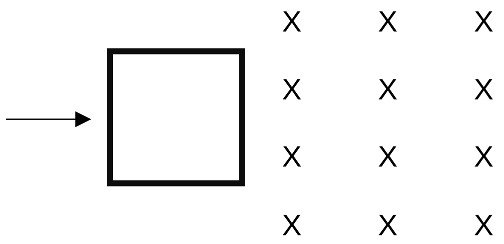
$udb \rightarrow c\bar{c} + s\bar{u} + uud$

$\left(\frac{2}{3}-\frac{1}{3}-\frac{1}{3}\right) \rightarrow \left(\frac{2}{3}-\frac{2}{3}\right)+\left(-\frac{1}{3}-\frac{2}{3}\right)+\left(\frac{2}{3}+\frac{2}{3}-\frac{1}{3}\right)$

$0 \rightarrow 0 - 1 + 1$ (conserved, therefore possible) (1-2)

Question 7 **(4 marks)**

A square coil moves into a uniform 260 mT magnetic field which is aligned perpendicular to the area of the coil. A 0.650 V emf is induced in the coil as it enters the field at 4.75 m s^{-1}. For what amount of time does the coil have an induced emf?



Find length of single side of coil

$\varepsilon = vBl$

$l = \frac{\varepsilon}{vB} = \frac{0.650}{4.75 \times 260 \times 10^{-3}} = 0.5263\ m$ (1-2)

Find time to completely move into the field, hence time of induced emf

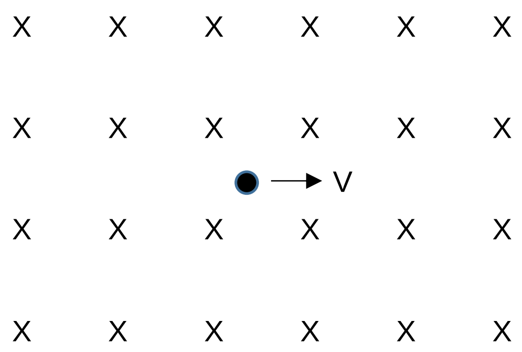
$v = \frac{s}{t}$

$t = \frac{s}{v} = \frac{0.5263}{4.75} = 0.111\ s$ (1-2)

Answer: $0.111\ s$

Question 8 **(4 marks)**

A single charged sodium ion (Na^+) is moving at 1250 m s^{-1} within a 0.866 T magnetic field as shown below. The sodium ion has a 3.82×10^{-26} kg mass.



(a) Calculate the wavelength of the sodium ion. (2 marks)

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

$\lambda = \frac{6.63\times10^{-34}}{3.82\times10^{-26}\times1250} = 1.39 \times 10^{-11}\ m$ (1-2)

Answer: $1.39 \times 10^{-11}\ m$

(b) Calculate the radius of the ion's movement. (2 marks)

$r = \frac{mv}{qB}$

$r = \frac{3.82\times10^{-26}\times1250}{1.60\times10^{-19}\times0.866} = 3.45 \times 10^{-4}\ m$ (1-2)

Answer: $3.45 \times 10^{-4}\ m$

Question 9 **(4 marks)**

Describe how an operating coloured LED and a voltmeter could be used to estimate Planck's constant. Include the measurements or data that would need to be obtained and any calculations required.

Measure the threshold voltage across the LED when it turns on (1)

Obtain the wavelength (or frequency) of the LED from manufacturer specifications (1)

Perform calculation

$E_{photon} = E_{LED}$

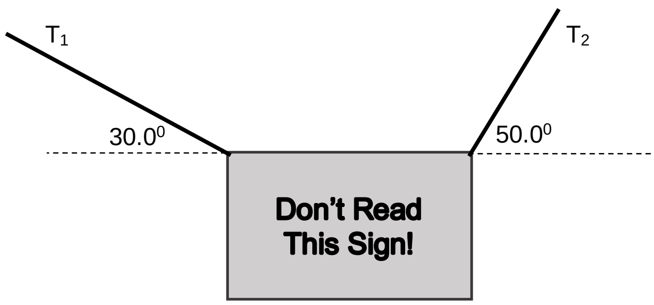
$\frac{hc}{\lambda} = Vq$

$h = \frac{Vq\lambda}{c} \quad (or\ h = \frac{Vq}{f})$ (1-2)

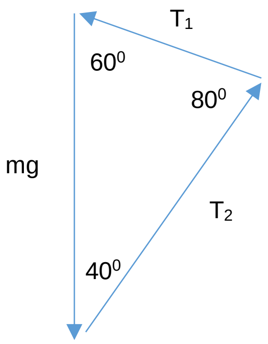
Note: using the led to power a photoelectric effect is **not** a suitable test because you would need more than the 1 LED in the question and UV is a typical threshold f – which is not emitted by the coloured LED. This is too far from the spirit of the question, just recalling facts, to be awarded marks.

Question 10 **(4 marks)**

A 25.0 kg sign is hung by connecting two wires of negligible mass, as shown in the diagram below.



Calculate the tensions T_1 and T_2 by use of a vector diagram.



1 for suitable diagram

$mg = 25.0 \times 9.8 = 245\ N$ (1)

$\frac{T_1}{sin40} = \frac{mg}{sin80}$

$T_1 = 1.60 \times 10^2\ N$ (1)

$\frac{T_2}{sin60} = \frac{mg}{sin80}$

$T_2 = 2.15 \times 10^2\ N$ (1)

Answer $\boldsymbol{T_1 = 1.60 \times 10^2\ N}$ $\boldsymbol{T_2 = 2.15 \times 10^2\ N}$

OR simultaneous equations:

$T_{1up} + T_{2up} = 245\ N$ $and\ T_{1left} = T_{2right}$ (2)

Then solve (1) (still need vector diagram)

Question 11 **(4 marks)**

An induction hotplate first converts the 50.0 Hz electrical supply, common to households in Australia, into a new frequency. By referring to physical principles, explain the benefit of the frequency change and whether the frequency is increased or decreased.

The frequency is increased (1)

Increasing the electrical frequency increases the rate at which the magnetic field fluctuates. (1)

According the Faraday's law, the induced emf is proportional the rate of change of magnetic flux (1)

A larger induced emf/induced current in a saucepan on the stove increases the rate of cooking. (1)

Question 12 **(4 marks)**

The redshift of light from galaxies not our own is supporting evidence of the Big Bang Theory. Describe what causes the increasing amount of redshift of light from galaxies further away and also describe why **only** nearby galaxies may have blue shifted light.

The redshift is caused by the expansion of space (or recessional velocity), stretching out the wavelength of light passing through space. (1)

Light from the furthest galaxies has its wavelength stretched out more due to the time/distance the light spends within the expanding space. (1)

The space between Earth and the closest galaxies experience a lower total amount of space expansion. Therefore, it is possible that these galaxies can be moving towards us through local space, causing blueshifted light.

(1-2)

Question 13 **(4 marks)**

A motorbike is using a 16.0^0 banked curve to assist with making a turn with a 35.0 m radius at 60.0 km h^{-1}. While the road supplies a normal force of 1280 N, the wheels of the motorbike supply an additional 185 N frictional force, down the slope, to assist with making the corner. Calculate the centripetal force acting on the motorbike.

$F_c = horizontal\ component\ of\ normal + horizontal\ component\ of\ friction$ (1)

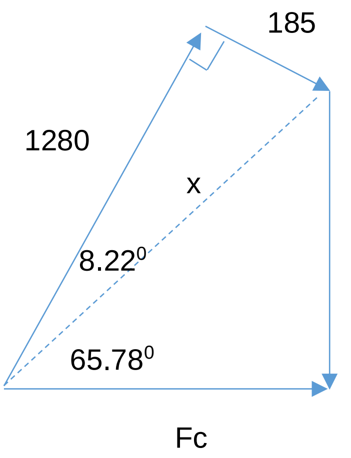
$N_h = 1280 sin16 = 352.8\ N$ (1)

$F_h = 185 cos16 = 177.8\ N$ (1)

$F_c = 352.8 + 177.8 = 531\ N$ (1)

*May also use the vector diagram with trigonometric relationships (sine rule, Pythagoras, etc.). The exact approach depends on student diagram. An example mark allocation below:

Finds important angles	1
Uses Pythagoras to find x from N and Friction	1-2
Uses $F_c = x cos(65.78)$	1



Answer: $531\ N$

NOTE: r and v in questions don't match physical requirements of F and angle.

If diagram shows correct addition of forces, but student uses m to find Fc, answer is 814 N and can be awarded full marks.

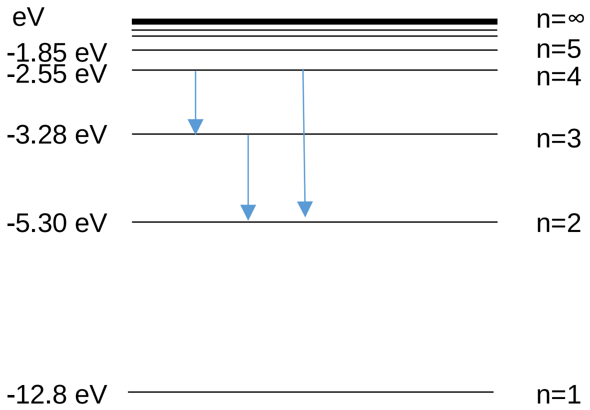
End of Section One

Section Two: Problem-solving **50% (90 Marks)**

This section has **seven (7)** questions. You must answer **all** questions. Write your answers in the space provided. Suggested working time for this section is 90 minutes.

Question 14 **(14 marks)**

Consider the energy level diagram below, with a single electron in the ground state.



(a) Calculate how much energy is required to move from the ground state to the n=2 energy level.
(1 mark)

$$-5.30 + (-)12.8 = 7.50\ eV$$

Answer: $7.50\ eV$

(b) On the energy level diagram, draw all the possible transitions an electron can make as it changes from the n=4 level to the n=2 level.
(1 mark)

All transitions shown, no extra.

(c) Calculate the largest wavelength of all possible photons produced as an electron makes a transition between n=4 and n=2. (4 marks)

Uses smallest energy transition

$E = -2.55 + (-)3.28 = 0.730\ eV$ (1)

Converts to joules
$E = 0.730 \times 1.6 \times 10^{-19} = 1.168 \times 10^{-19}\ J$ (1)

Calculates wavelength
$E = hf \text{ and } f = c/\lambda$
$E = \frac{hc}{\lambda}$
$\lambda = \frac{hc}{E} = \frac{6.63\times10^{-34}\times3.00\times10^{8}}{1.168\times10^{-19}} = 1.70 \times 10^{-6}\ m$ (1-2)

Answer: $1.70 \times 10^{-6}\ m$

Question 14 (Continued)

(d) An EMR source is used to promote an electron from the ground state to n=4. Which part of the electromagnetic spectrum does the EMR belong? Justify your answer with a calculation.
(4 marks)

Finds energy difference
$E = -2.55 + (-)12.8 = 10.25\ eV$ (1)

Converts to joules (1)
$10.25 \times 1.6 \times 10^{-19} = 1.64 \times 10^{-18}\ J$

Determines frequency (or wavelength)
$f = \frac{E}{h} = \frac{1.64\times10^{-18}}{6.63\times10^{-34}} = 2.47 \times 10^{15}\ Hz$ (1)

Matches frequency (or wavelength) to spectrum on formulae and data sheet
"Ultraviolet"

Answer: Ultraviolet

(e) "To ensure the photons from the EMR source are able to excite electrons from the ground state to n=4, we should increase the frequency of the EMR source slightly".
Comment on the suitability of this suggestion. (4 marks)

States changing the frequency increases/changes the energy (1)

"Increasing the frequency will increase the energy of the photons ($E = hf$)

Describes the energy requirements for excitation of electrons by incident photons (1-2)

"When photons are used to excite an electron, the photon energy must match the difference in energy between the levels exactly. Having more energy will result in the excitation not occurring at all.

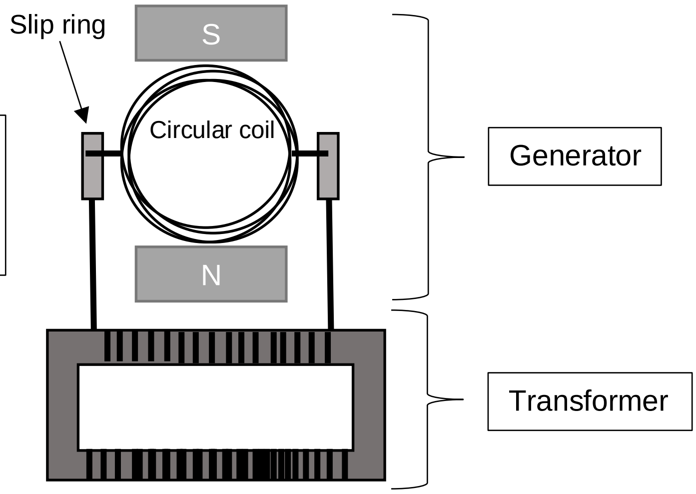
Refers back to question (1)

"Thus increasing the frequency of the EMR source is not a good idea"

Question 15 **(13 marks)**

To help students' visualise the workings of a generator, a demonstration generator is built using the design shown in the diagram below.

Generator coil number:	18
Generator coil radius:	0.0700 m
Magnetic flux density:	3.00 mT



The demonstration generator is not capable of a high voltage output. To increase the output voltage, the demonstration generator was connected to a transformer. The primary to secondary windings ratio was 1:53, resulting in an rms output voltage of the transformer of 2.36 V.

(a) Explain in detail how the rotation of the generator coil results in the generation of a sinusoidal current delivered to the transformer. (5 marks)

Rotation causes a change in flux within the coil (1-2)

"As the coil rotates, the area of the coil perpendicular to the field lines of the magnets changes, therefore changing the amount of flux in the coil."

Refers to Faraday's law, resulting in emf (1)

"The change in flux induces an emf in the coil"

Refers to a current being driven by the emf to the transformer (1)

"The emf drives a current through the slip rings to the transformer"

Describes why the current is an alternating current output

(1)

"The sinusoidal rotation of the coil results in a rate of change of flux that is also sinusoidal – resulting in alternating current

Question 15 (continued) **(13 marks)**

(b) Calculate the maximum flux that can be encased by the generator coils. (2 marks)

$A = \pi r^2$

$A = 3.1415 \times 0.07^2 = 1.539 \times 10^{-2}\ m^2$ (1)

$\Phi_B = BA$

$\Phi_B = 3 \times 10^{-3} \times 1.539 \times 10^{-2} = 4.617 \times 10^{-5} = 4.62 \times 10^{-5}\ Wb$ (1)

Answer: $\mathbf{4.62 \times 10^{-5}\ Wb}$

Note: Allowed students to multiply by N in this questions (but not ideal).

(c) Calculate the rms voltage output by the generator, when the transformer has a 1:53 turns ratio and an output voltage of 2.36 V. (2 marks)

$\frac{V_p}{V_s} = \frac{N_p}{N_s}$ (1)

$V_p = \frac{N_p}{N_s} \times V_s$

$V_p = \frac{1}{53} \times 2.36 = 4.453 \times 10^{-2} = 4.45 \times 10^{-2}\ V$ (1)

Answer: $\mathbf{4.45 \times 10^{-2}\ V}$

(d) Calculate the frequency of the rotation of the generator coils. If you could not obtain an answer to part (c), you may use a value of 4.00×10^{-2} V. (4 marks)

Find peak voltage output

$\varepsilon_{peak} = 4.453 \times 10^{-2} \times \sqrt{2} = 6.297 \times 10^{-2}\ V$ (1-2)

Find frequency

$\varepsilon = 2\pi BANf$ (taking BA from part (b), or calculating here)

$f = \frac{\varepsilon}{2\pi BAN} = \frac{6.297 \times 10^{-2}}{2\pi \times 4.62 \times 10^{-5} \times 18} = 12.1\ Hz$

(or 10.9 Hz if used assumed value) (1-2)

Answer: $\mathbf{12.1\ Hz}$

Question 16 **(12 marks)**

Claire is standing on Earth. She observes Jim passing by in a spaceship at 0.60 c. Jim observes the spaceship to be 18.0 m long. Jim is playing hyperspace pong where he hits a ball towards the front of the spaceship from the back at 0.40 c (according to Jim). The ball has a rest mass of 0.500 kg.

(a) What time does Jim observe the ball take to reach the front of the spaceship?

(2 marks)

$t = \frac{s}{v} = \frac{18.0}{0.40 \times 3.00 \times 10^8} = 1.50 \times 10^{-7}\ s$ (1-2)

Answer: $1.50 \times 10^{-7}\ s$

(b) As the ball completes the journey towards the front of the spaceship, does Jim observe the proper length of the ball's journey or the proper time for the ball's journey or both? Justify your choice.

(2 marks)

Proper length / not proper time (1)

Describes the proper length condition:

"Jim observes the start and end points of the journey being at rest with his frame" (1)

Note: Arguing "not proper time, therefore proper length" does not suffice, as an observer like Claire has neither proper time nor proper length.

(c) How long is the spaceship as measured by Claire? (2 marks)

$l = l_0\sqrt{1 - \frac{v^2}{c^2}} = 18.0\ \sqrt{1 - 0.60^2} = 14.4\ m$ (1-2)

Answer: 14.4 m

Question 16 (continued)

(d) What is the velocity of the ball as measured by Claire? Give your answer as a fraction of the speed of light. (2 marks)

$$u = \frac{u\prime + v}{1 + \frac{u\prime v}{c^2}} \quad (1)$$

$$u = \frac{0.40c + 0.60c}{1 + \frac{0.40c \times 0.60c}{c^2}} = 0.806\ c \quad (1)$$

Answer: $\mathbf{0.806\ c}$

(e) Calculate the energy of the ball as measured by Jim. (2 marks)

$$E = mc^2 = \frac{m_0 c^2}{\sqrt{1 - v^2/c^2}} \quad (1)$$

$$E = \frac{0.500 \times (3.00 \times 10^8)^2}{\sqrt{1 - 0.40^2}} = 4.91 \times 10^{16}\ J \quad (1)$$

Answer: $\mathbf{4.91 \times 10^{16}\ J}$

(f) Calculate the momentum of the ball as measured by Claire. (2 marks)

$$p = \frac{m_0 v}{\sqrt{1 - \frac{v^2}{c^2}}} = \frac{0.500 \times 0.806 \times 3.00 \times 10^8}{\sqrt{1 - 0.806^2}} = 2.04 \times 10^8\ kg\ m\ s^{-1} \quad (1\text{-}2)$$

Answer: $2.04 \times 10^8\ kg\ m\ s^{-1}$

Question 17 **(12 marks)**

A trebuchet is a siege weapon that flings boulders from a great distance. Consider the arrangement of a trebuchet and a castle shown below.

(a) The boulder lands at the same height it was launched from, was fired at 45.0[0] above the horizontal and was airborne for 8.16 s. Complete the following questions:

i. Calculate the launch velocity of the boulder. (3 marks)

$u_h = \frac{s_h}{t}$ (1)

$u_h = \frac{326}{8.16} = 39.95\ m\ s^{-1}$ (1)

$u = \frac{u_h}{cos\theta} = \frac{39.95}{cos45} = 56.5\ m\ s^{-1}$ (1)

Answer: $56.5\ m\ s^{-1}$

ii. Calculate the maximum height the boulder achieved above its launch point. (3 marks)

$u_v = usin\theta$

$u_v = 56.5\ sin45 = 39.95\ m\ s^{-1}$ (1)

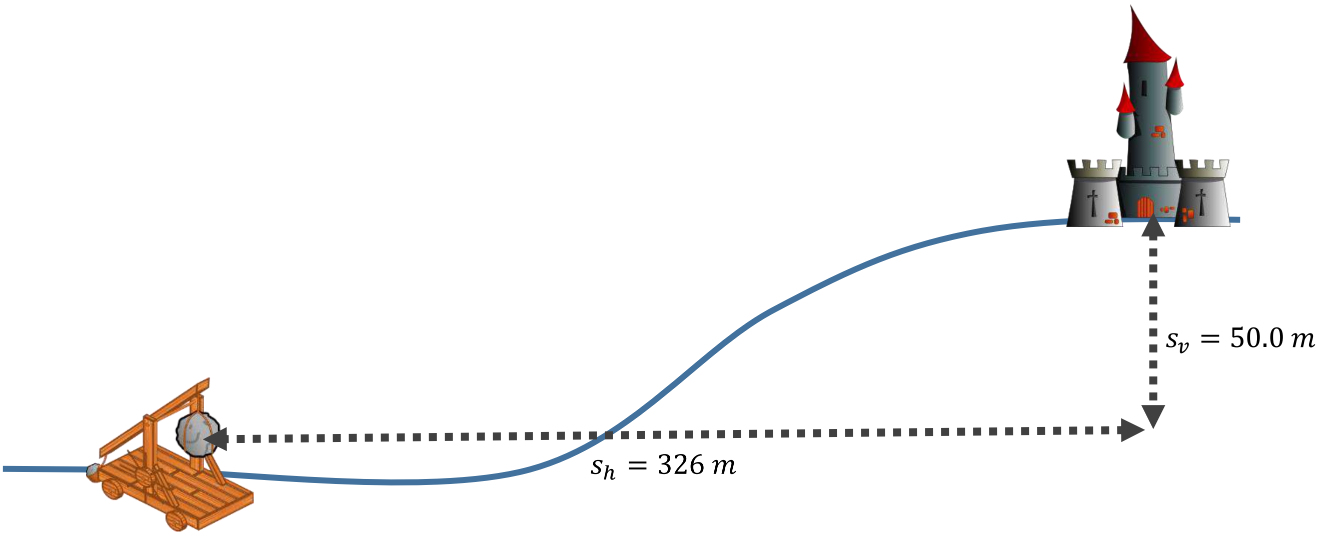
$v_v^2 = u_v^2 + 2as_v$

$s_v = \frac{v_v^2 - u_v^2}{2a} = \frac{0 - 39.95^2}{2 \times (-9.8)} = 81.4\ m$ (1-2)

Answer: $81.4\ m$

Question 17 (continued)

Medieval castles were often built at higher elevations to give an advantage to those under siege.



(b) A launched boulder is in the air for 4.80 s. The distances, s_h and s_v above indicate how far the boulder travelled to hit the castle. Determine both the speed and angle above the horizon the boulder was launched at. You may make use of the trigonometric identity $tan\theta = \frac{sin\theta}{cos\theta}$ and air resistance can be ignored. (6 marks)

Vertical

$s_v = usin(\theta)t + \frac{1}{2}at^2$

$usin(\theta) = \frac{s_v - \frac{1}{2}at^2}{t} = \frac{50.0 - \frac{1}{2}\times(-9.8)\times 4.80^2}{4.80} = 33.94\ m\,s^{-1}$ (1-2)

Horizontal

$ucos(\theta) = \frac{s_h}{t} = \frac{326}{4.80} = 67.92\ m\,s^{-1}$ (1)

$\frac{usin\theta}{ucos\theta} = tan\theta\ and\ \frac{usin\theta}{ucos\theta} = \frac{33.94}{67.92}$

$\therefore tan\theta = 0.4997$

$\theta = \tan^{-1} 0.4997 = 26.6^0$ (1-2)

Use either horizontal or vertical equations to find speed

$ucos(26.6) = 67.92\ m\,s^{-1}$

$u = 76.0\ m\,s^{-1}$ (1)

Speed: $76.0\ m\,s^{-1}$ Angle: 26.6^0

Question 18 **(10 marks)**

Transmission of radio waves by an antenna is intrinsically polarised. An AC voltage is supplied to the antenna which generates the radio waves, with a polarisation matching the orientation of the conducting metal of the antenna. Receiving antennae, like those on the roofs of most homes, must have the same orientation to receive a strong signal – the wrong orientation won't pick up the radio wave.

Each television network sends out a channel's picture and sound data via radio waves. A television has electronic components that can isolate the data from a single frequency of radio wave. Each television station has **one** frequency they transmit at.

(a) Describe how an AC voltage applied to a conductor can produce electromagnetic waves. Describe why an equivalent DC voltage could not. (3 marks)

An AC voltage causes an oscillating current/ oscillating charges in the conductor (1)

Oscillating charges create electromagnetic waves, such as radio waves (1)

A DC voltage keeps current/charge flowing in one direction – no oscillation means no electromagnetic wave (1)

(b) What is polarised light? (1 mark)

Polarised light electric fields oscillate in only a single plane/orientation (1)

(c) Some satellite television networks will transmit two different channels over the same frequency. To achieve this, both the television network transmission antenna and the household receiving antenna must have a conductor with a horizontal orientation and another with a vertical orientation

(i) By referring to physical behaviour of waves, describe why it would generally be an issue if a frequency of radio wave had more than a single channel broadcast on it. (3 marks)

Waves can interfere with each other (1)

The TV/antenna needs to isolate the signal by focussing on a single frequency or radio wave/ received emr waves will be the superposition of any wave matching the transmitted frequency (1)

With multiple signals all on the same frequency, it won't be possible to have a strong, clear signal. (1)

Question 18 (continued)

(ii) Explain how two channels of a satellite television network can be on the same frequency without the issue of part (i) being a concern. (3 marks)

The horizontal antenna transmits a horizontal polarised wave which is received clearly by the horizontal receiving antenna (1)

The vertical antenna transmits a vertical polarised wave which is received clearly by the vertical receiving antenna (1)

It is possible for each polarised wave to transmit and be received without strongly interfering with the same channel on the other polarising plane. (1)

Question 19 **(11 marks)**

The Large Hadron Collider is the largest synchrotron in the world, with a total circumference of 26.7 km. While capable of accelerating protons up to 6.50 TeV, first operations in 2013 were run at the relatively lower 3.50 TeV. The Large Hadron Collider has multiple stages of particle accelerators, starting with a simple linear accelerator and eventually confining the proton beam in the main ring. Very powerful, expensive magnets, powered and cooled to near absolute zero are required to confine the beam.

(a) Describe how a magnetic field can help keep protons confined within the ring of a synchrotron. (3 marks)

When a charged particle has a velocity perpendicular to a magnetic field it experiences a force perpendicular to both field and velocity, given by $F = qvB$ (1-2)

This causes a deflection of the charged particle, keeping it moving in a circular path (1)

(b) Explain why the protons in the Large Hadron Collider must first be accelerated in a straight line, with a linear accelerator, rather than starting in a ring like in the synchrotron. (2 marks)

In order to perform a circular path around the main ring, the protons require a velocity to feel a magnetic force (1)

The linear accelerator is required to give the protons their initial velocity to start deflecting around the ring (1)

Question 19 (continued)

(c) What percentage of the energy of the proton beam used in 2013 is due to the rest mass of the proton? (3 marks)

$E_0 = m_0c^2 = 1.67 \times 10^{-27} \times (3.00 \times 10^8)^2 = 1.503 \times 10^{-10}\ J$ (1)

$E = \ 3.50\ TeV = 3.50 \times 10^{12} \times 1.60 \times 10^{-19}\ J$
$E = 5.60 \times 10^{-7}\ J$ (1)

$\%\ E\ due\ to\ rest\ mass = \frac{1.503\times10^{-10}}{5.60\times10^{-7}} \times 100 = 0.0268\ \%$ (1)

(d) Explain a benefit of making the confinement ring so large. (3 marks)

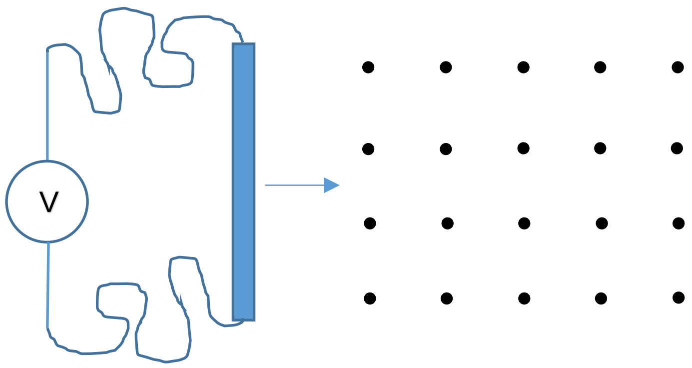
The charged particles deflect around the ring according to $r = \frac{mv}{Bq}$ (or similar) (1)

Increasing the radius of the ring allows the magnetic flux density to be smaller (1)
.

This lessens the burden of having expensive/powerful magnets
(1)

Question 20 **(18 marks)**

A pair of students entering a STEM competition proposed a method of determining the magnetic flux density of a uniform magnetic field. The students took a 30.0 cm long, straight conductor and attached either end to a voltmeter. The conductor was pushed into a uniform field while the voltmeter remained in place.



(a) Explain why a voltage is measured as the conductor moves through the field. (2 marks)

As the conductor moves across the field, it cuts through lines of flux/ the flux within the loop made with the voltmeter increases (1)

According to Faraday's law, this induces an emf which is measured by the voltmeter (1)

The velocity of the conductor was carefully controlled just prior to the conductor entering the field and the accompanying voltmeter reading was recorded over multiple trials. The students estimated their velocity measurements had a ±10% uncertainty while the voltage measurements had negligible uncertainty.

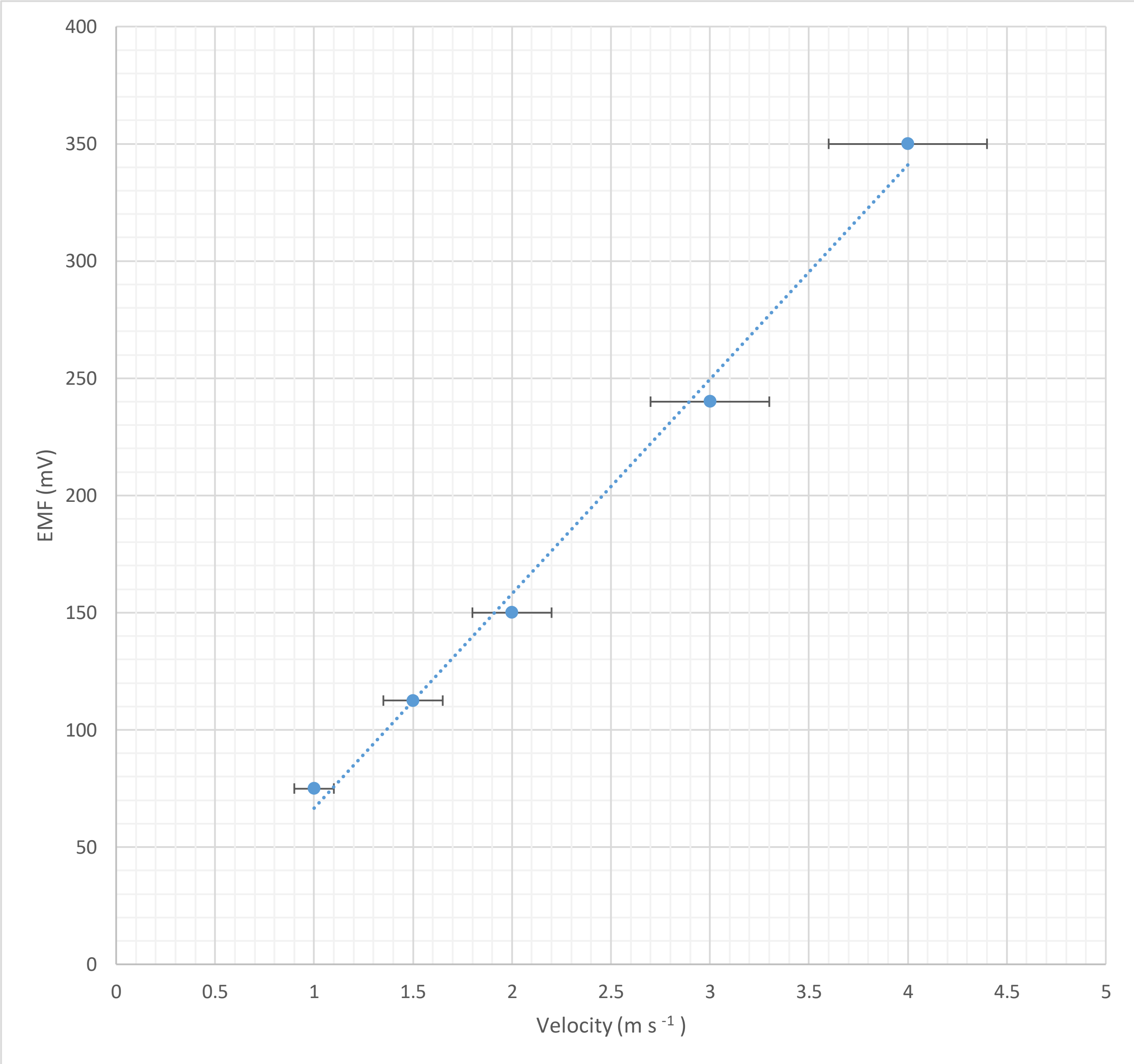
Velocity (m s^{-1})	Velocity Uncertainty (m s^{-1})	Voltage (mV)
1.00	± 0.100	75
1.50	± 0.150	110
2.00	± 0.200	150
3.00	± 0.300	240
4.00	± 0.400	350

(b) Complete the table by adding the absolute uncertainty of the velocity measurements.

(1)for values, (1)for 3 significant figures or 2sf which is correct (2 marks

Question 20 (continued)

(c) Produce a graph, using the grid provided on the next page, to show the relationship between the voltage and the velocity. The velocity needs to be placed on the horizontal axis. Include error bars and a line of best fit. (5 marks)



Labelled axes with units (1-2)

Suitable scale (1)

Error bars (1)

Line of best fit through error bars (1)

(d) Calculate the gradient of the line of best fit. (2 marks)

Uses line of best fit (not table data) to find gradient, showing clear calculation and/or work lines on graph. If plotted in mV, will need to convert to V. (1-2)

Approx. 0.09 T m

Answer: 0.09 T m

(e) Using the gradient and any other necessary data, calculate the magnetic flux density of the uniform field. (2 marks)

$gradient = \frac{\varepsilon}{v}$ and $\frac{\varepsilon}{v} = Bl$ (1)

$\therefore grad = Bl$

$B = \frac{grad}{l} = \frac{0.0900}{0.300} = 0.300\ T$ (1)

Answer: 0.300 T

(f) The students found that the voltage reading decreased the longer the bar was moving through the field – so the students recorded the voltage when the conductor was in the middle of the uniform field.

(i) In addition to air resistance and friction, explain the other cause of the change in the voltage reading. (2 marks)

The bar slows down due to the resistive force applied by Lenz's law (1)

The decrease in velocity reduces the induced emf according to $\varepsilon = vBl$ (1)

(ii) If the students had instead taken the voltage measurement soon after the conductor entered the field, how would their determination of the flux density differ from the result calculated part (e)? Justify your response. (3 marks)

The measured emf would be larger due to larger velocity (1)

Steeper gradient (1)

Larger flux density (1)

End of Section 2

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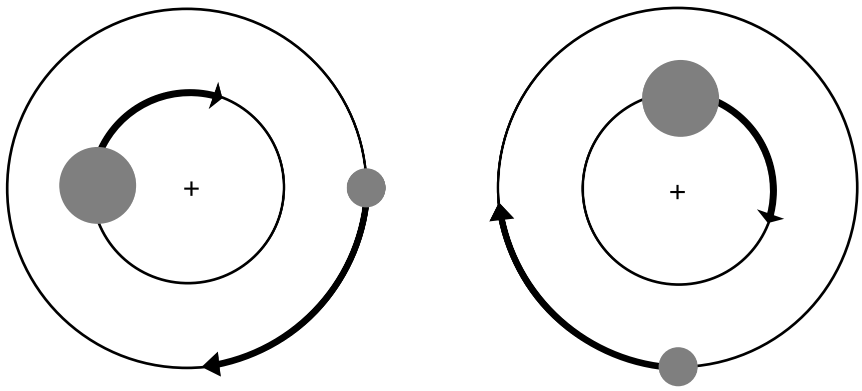
Section Three: Comprehension 20% (36 Marks)

This section contains **two (2)** questions. You must answer both questions. Write your answers in the spaces provided. Suggested working time for this section is 40 minutes.

Question 21 **(18 marks)**

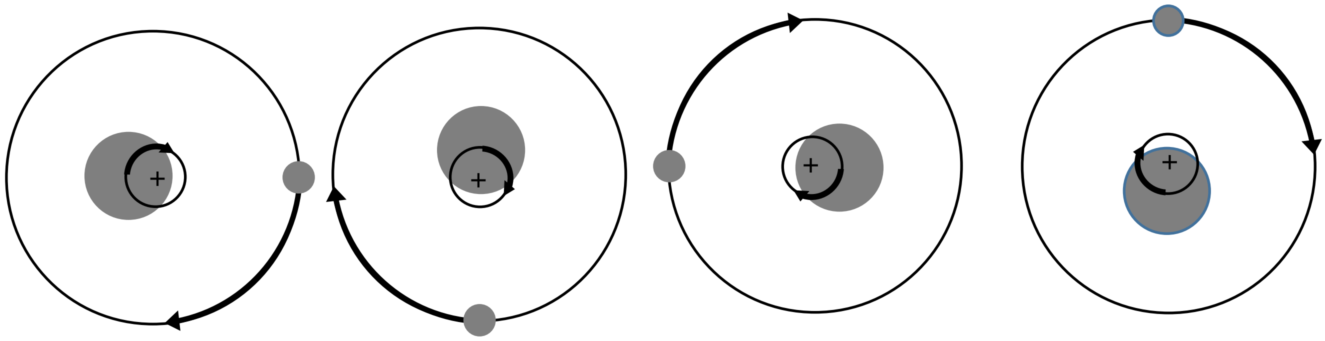
The barycentre – the true centre of a circular orbit

Physics Unit 3 covers uniform circular motion due to gravitational forces acting on a satellite. The analysis of these problems is simplified by assuming the orbital radius is the distance between the centre of mass of the two bodies (e.g. Earth and Moon). However, consider this – as the Earth pulls on the Moon to give the Moon its centripetal force, the Moon also pulls on the Earth. Wouldn't the Earth then begin to accelerate towards the Moon? In truth, it does. When any two celestial objects orbit each other, they orbit around a common central point, called the barycentre.



The two-body system diagrams above show that as the two bodies orbit the barycentre, their centres of mass are always radially opposite each other – each body has the same orbital period. Each body applies a gravitational force on the other, pulling it towards the barycentre. The bigger mass is always closer to the barycentre than the smaller mass.

Since the Earth is much more massive than the Moon, the barycentre is inside of the Earth. This causes the Moon to orbit around the Earth, while the Earth appears to "wobble", as shown in the diagrams below. The Earth is still in a state of uniform circular motion about the barycentre and can be analysed as such.



For these two-body system, the barycentre can be calculated from knowledge of the masses and total distance separating the two bodies:

$$r_1 = \frac{d}{1 + \frac{m_1}{m_2}}$$

m_1 and m_2 are the masses of body 1 and body 2
r_1 is the distance from the centre of m_1 to the barycentre
d is the separation of the centre of masses of m_1 and m_2

(a) Discuss whether the following statements are physically sound for a two-body system consisting of the Earth and Moon:

(i) "Both the Earth and the Moon experience the same magnitude of gravitational force". (3 marks)

States this statement is sound (1)

"This statement is physically sound"

Provides suitable argument justifying the statement (1-2)

"According to Newton's 3rd Law, every action has an equal but opposite reaction. The same magnitude of gravitational force that the Earth pulls on the Moon will be applied to the Earth by the Moon"

(ii) "Both the Earth and Moon experience the same magnitude of centripetal acceleration." (3 marks)

States this statement is **not** sound (1)

"This statement is **not** physically sound"

Provides suitable argument that finds fault with the statement (1-2)

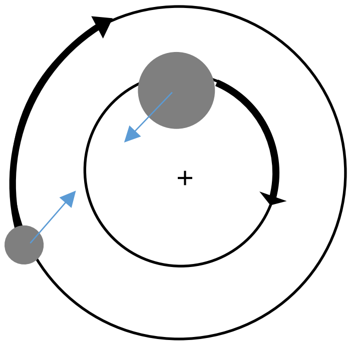
"Despite both bodies having the same forces, they have different masses on which the force is applied. According to Newton's 2nd law, acceleration is inversely proportional to mass"

OR

"Centripetal acceleration depends on radius and they have different orbital radius"

(1 mark only)

(b) By drawing gravitational forces for the two-body system shown below, explain why it is **not** possible to have the bodies in the position shown in the diagram. (3 mark)



Draws two vectors, directed from centres of mass towards other body's centre of mass. No penalty for mismatched size of vectors. (1)

Describes need for net force to be directed towards centre which doesn't occur here (1-2)

"This is not possible as for circular motion as each body needs to have a net force acting towards the (bary)centre of the orbit. Here, the gravitational forces are not acting towards the centre of the orbit."

(c) Calculate the distance from the centre of the Earth to the barycentre of the Earth Moon system. (2 marks)

Uses (1)

$d = 3.84 \times 10^8\ m$

$m_1 = 5.97 \times 10^{24}\ kg$

$m_2 = 7.35 \times 10^{22}\ kg$

$r_1 = \frac{d}{1+\frac{m_1}{m_2}}$

$r_1 = \frac{3.84\times10^8}{1+\frac{5.97\times10^{24}}{7.35\times10^{22}}} = 4.67 \times 10^6\ m$ (1)

Answer: $\mathbf{4.67 \times 10^6\ m}$

(d) Knowledge of the barycentre location allows the speed at which the Earth is orbiting the barycentre to be determined.

(i) Show that the velocity of the Earth with respect to the barycentre of the Earth-Moon system is $v = \sqrt{\frac{Gm_{moon}r_1}{d^2}}$. (2 marks)

Equates centripetal force acting on Earth to gravitational force

$F_c = F_g$

$\frac{m_E v^2}{r_1} = \frac{Gm_E m_m}{d^2}$ (1)

Cancels Earth mass and rearranges for v

$\frac{\cancel{m_E} v^2}{r_1} = \frac{G\cancel{m_E} m_m}{d^2}$

$v = \sqrt{\frac{Gm_m r_1}{\mathrm{d}^2}}$ (1)

(ii) Hence, calculate the velocity of the Earth around the barycentre of the Earth-Moon system. If you could not obtain an answer to part (c), you may use 4.60 × 10^6 m. (2 marks)

Uses correct r and r' values from part c and formula and data sheet (1-2)

$v^2 = \frac{Gm_m r_1}{d^2} = \frac{6.67\times10^{-11}\times7.35\times10^{22}\times4.67\times10^{6}}{(3.84\times10^{8})^2} = 1.553 \times 10^2$

$v = \sqrt{1.553 \times 10^2} = 12.5\ m\ s^{-1}$

Or

$12.4\ m\ s^{-1}$ if used data in question

Answer: $12.5\ m\ s^{-1}$

(e) Prove that if the two-body system is made of two bodies of identical mass, the barycentre is exactly equidistant from each body. (3 marks)

$r_1 = \frac{d}{1+\frac{m_1}{m_2}}$ $and\ m_1 = m_2$ (1)

$r_1 = \frac{d}{1+\frac{m}{m}} = \frac{d}{1+1}$

$r_1 = \frac{d}{2}$ (1)

States that the calculated 'r' applies to both bodies (or also calculates r_2)

"As m_1 and m_2 are indistinguishable/interchangeable, this is also the distance from the other body to the barycentre. Both bodies are $\frac{d}{2}$ from barycentre" (1)

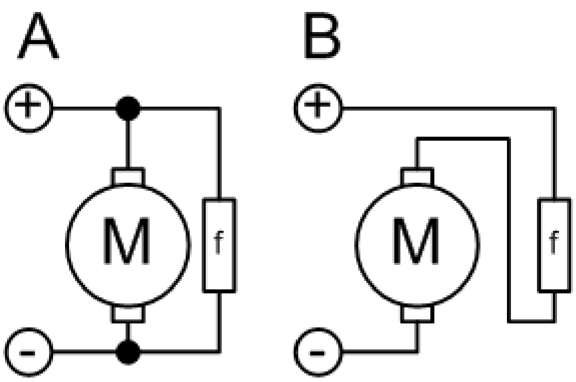
Question 22 **(18 marks)**

Brushed and Brushless DC Electric Motors

In this course you were introduced to the DC electric motor. An emf source drives a current through an armature coil, in the presence of a magnetic field, which produces a torque. Brushes and a commutator are used to ensure the direction of rotation is maintained. The motor then produces mechanical energy which is transferred to a load (the thing that we want to spin). This motor design was first used over 100 years ago but there are now many variations of motors, each with their own advantages and disadvantages.

The motor you are most familiar with from this course is referred to as a brushed DC motor. It is powered by a DC emf source and, as mentioned before, requires brushes and a commutator to operate. These motors are still used today. The smallest examples are found in toy cars and battery-operated fans. Being so small, a permanent magnet suffices to create the magnetic field required.

Larger brushed DC motors are used in printing presses. The size of these motors makes using a permanent magnet impractical. An electromagnet is used to produce the magnetic field, which can be powered by the same emf source that drives the current through the armature coil. These electromagnets are referred to as field coils – as in the coils in a motor responsible for producing the magnetic field. There are two methods by which the emf source can be connected to both the armature coils and field coils. Diagram A below is for a shunt wound DC motor and Diagram B is a series wound DC motor.

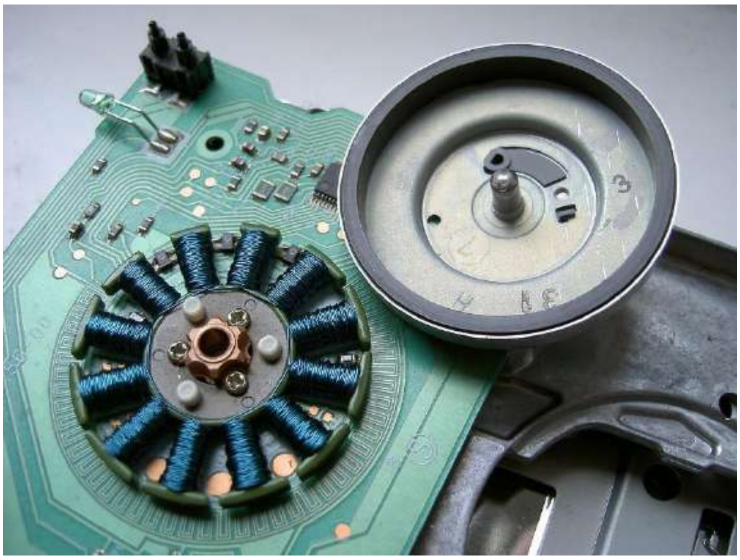


A: Shunt wound
B: Series wound
M is the armature coil, f is the field coil

A shunt wound design has the field coils in parallel with the armature coils. Both coils receive the same voltage from the emf source. When electric voltage is supplied to the shunt DC motor, due to high resistance of the shunt winding, it draws very low current. The higher number of turns of the field coil helps in generating a strong magnetic field. The armature draws a high current, thus needs thicker wires. A shunt DC motor is naturally excellent at controlling its speed. As the armature coil rotates, it generates a back emf which limits the current in the armature which also limits the torque at high speeds. When a load is attached, this reduces the rotational speed of the motor initially, but this also reduces the back emf which results in more torque that speeds the motor back up. To change the operating speed of the motor, a rheostat (variable resistor) is placed in the field coil branch - increasing the resistance here results in a decrease in field strength which speeds the motor up.

A series wound DC motor has the field coils in series with the armature coils. At all times the current in both coils will be the same. As the current is the same in both armature and field coils, and the field in a coil is proportional to the current, the torque produced is proportional to the square of the current. When first started the current through the coils is limited only by the internal resistance of the wires. So the field coils are very thick but are few in number. This can produce very large starting torques but often puts the wires at risk of overheating. An additional resistor is added during motor startup which is gradually removed as the motor picks up speed. When a load is added this slows down the motor. This reduces the back emf from the armature, resulting in a larger current. Since this current also flows through the field coils, there is an increase in magnetic flux which actually increases the back emf – so overall the net effect is that the motor will slow down whenever a load is added to it. Having large initial torque and dropping in speed as a load is added makes series DC motors ideal as starter motors, like those used in cars. A petrol-based motor in a car cannot start itself – it needs to be given a “push” by a starter motor to get things going.

Regardless whether shunt or series, when both motors are designed with brushes and commutators they suffer the same disadvantage – the relatively high wear and tear of these components. There was no avoiding this until the 1970s when semiconductor technology was developed. In a brushless DC motor, there are no brushes to achieve the necessary reversal of current/magnetic field. Electrical transistors (the semiconductor technology) perform the reversal instead.



In a brushed motor the rotor (rotating part) is the armature coil and the stator (stationary part) is the permanent magnet or field coils. A brushless motor reverses these roles. The armature coils remain stationary in the centre while a permanent magnet rotates around the outside. This reduces the inconvenience of designing a method to drive a current through a rotating armature without tangling the wires.

As the rotor rotates it triggers the transistor switches which rapidly change the direction of the current in the armature windings. Maximum speed is still reached when the back emf of the armature equals the supplied emf but speed can easily be controlled by adjusting the supplied voltage. This motor is also quieter than the brushed types because most of the noise of a motor comes from the rotation and grinding of the commutator against the brushes.

(a) State the defining components of a DC brushed motor and one place where these motors are used. (2 marks)

Has a commutator and brushes (1)

Toy cars/hand held fans/printing presses (1)

(b) State the name of the conductor windings used as an electromagnet in a large motor. (1 mark)

Field coils (1)

(c) Compare the difference in the construction of a shunt wound motor and a series wound motor. (2 marks)

Series - The field coils/electromagnet is connected in series with the armature (1)

Shunt - The field coils/electromagnet is connected in parallel with the armature (1)

(d) Explain why the components in a brushed motor have high wear and tear. (2 marks)

A brushed motor requires a commutator and carbon brushes to provide the electrical contact during high speed rotation (1)

As these parts rub against each other, frictional forces will wear them down. (1)

(e) Explain, referring to physical principles, why increasing the resistance in the field coils of a shunt wound motor results in:

(i) A decrease in the magnetic field strength. (2 marks)

Less current flows in the field coils (1)

Lower current produces a weaker magnetic field (1)

(ii) An increase in the speed of the motor. (4 marks)

Back emf is produced when motor spins (1)

Amount of back emf depends on magnetic field (which is now weaker) (1)

Motor speeds up until back emf equals supplied emf (2)

(f) By referring to formulae in the Formulae and Data Booklet and physical principles, show why torque of a series wound motor is proportional to the square of the current supplied, as suggested by the article. (Note: you are **not** required to derive a new formula) (3 marks)

The current supplied runs through the field coils, the magnetic field is proportional to the current ($B \propto I$) (1)

The current supplied runs through the armature, the force created is proportional to the field and to the current ($F \propto IB$) (1)

Therefore torque is proportional to current squared ($\tau \propto F \propto IB \propto I^2$) (1)

(g) Describe how a brushless motor overcomes the biggest disadvantage shared by all brushed motors. (2 marks)

A brushless motor uses transistors to reverse a DC current (1)

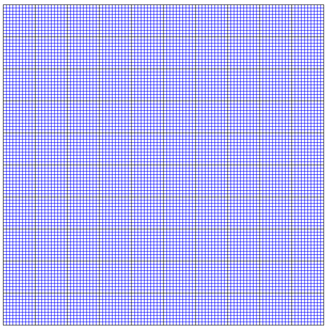
Does not need brushes/physical contact with friction (1)

OR
No major wear and tear

End of Questions

Additional working space

Spare grid for graph



End of examination

Acknowledgements

Question 17
Trebuchet Diagram
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Castle Diagram
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Question 22
Small DC motor image
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Question 22
Field and motor windings image
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https://en.wikipedia.org/wiki/Brushed_DC_electric_motor#/media/File:Serie_Shunt_Coumpound.png

Question 22
Brushless motor
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https://en.wikipedia.org/wiki/Brushless_DC_electric_motor#/media/File:Floppy_drive_spindle_motor_open.jpg

Section	**Questions**	**Marks Available**	**Your Mark**	**Section Total**	**Section as % of Exam**
1	1 **(MS)**	**4**		**/54**	
	2	**6**			
	3	**4**			
	4	**4**			
	5	**4**			
	6	**4**			
	7	**4**			
	8	**4**			
	9 **(DP)**	**4**			
	10	**4**			
	11	**4**			
	12	**4**			
	13	**4**			
2	14	**14**		**/90**	
	15	**13**			
	16	**12**			
	17	**12**			
	18 **(SH)**	**10**			
	19	**11**			
	20	**18**			
3	21	**18**		**/36**	
	22	**18**			

Total % [ ] (3SF)