



# WACE PHYSICS Stage 3

## Semester 2 Examination, 2015

### Question/Answer Booklet

Student Number:      In figures

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In words

## Worked Solutions

### 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

Formulae and Constants Sheet

#### *To be provided by the candidate*

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

Special items:     non-programmable calculators satisfying the conditions set by the SCSA for this course.

### 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	Percentage of exam
Section One: Short answer	12	12	50	54	30
Section Two: Extended answer	8	8	90	90	50
Section Three: Comprehension and data analysis	2	2	40	36	20
<b>Total</b>				180	100

## Instructions to candidates

- The rules for the conduct of Western Australian external examinations are detailed in the *Year 12 Information Handbook 2015*. Sitting this examination implies that you agree to abide by these rules.
- Write answers in this Question/Answer Booklet.
- 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.

- You must be careful to confine your responses to the specific questions asked and follow any instructions that are specific to a particular question.
- 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.
  - 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. Refer to the question(s) where you are continuing your work.

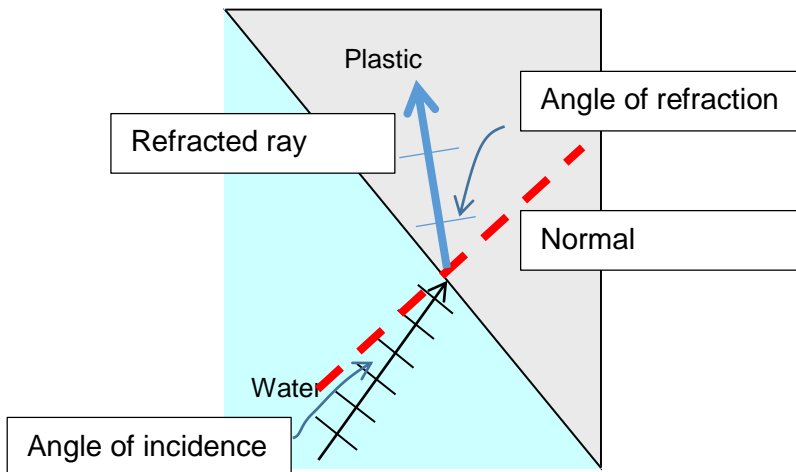
**Section One: Short response**

**30% (54 Marks)**

This section has **12** questions. Answer **all** questions. Write your answers in the space provided. Suggested working time for this section is 50 minutes.

**Question 1**

A sound wave travels through water to meet a boundary with plastic.



- a) Indicate on the diagram with an arrow, a possible path of the sound wave if it refracts into the plastic. You must also show a normal and the angles of incidence and refraction. (2)

Refracted ray ✓ Correct normal and angles ✓

- b) The wave fronts in the water are shown on the diagram. Indicate on the diagram, the general pattern of the wave fronts when the sound wave travels in the plastic. (1)

Shows greater spacing for increased speed ✓

- c) Is it possible for total internal reflection to occur as the sound wave travels through the water and meets the boundary with plastic? The sound waves can approach the boundary from any angle. Explain briefly. (2)

Yes because the wave would increase speed in the new medium and refract away from normal ✓  
Beyond an angle of refraction of  $90^\circ$  TIR can occur. ✓

### Question 2

The photographs show a rechargeable electric toothbrush and its plastic base unit charger.



(3)

The base unit charger is connected to a mains socket. When the toothbrush is placed into the base unit, as shown in the second photograph, the battery in the toothbrush can be recharged even though there is no direct electrical connection between the toothbrush and the charger. Explain how this is possible by reference to appropriate Physics principles.

This is an example of a transformer  
A primary coil in the base unit is fed with AC electricity which causes a constantly changing magnetic field ✓  
A secondary coil in the brush is placed near to the primary and the changing magnetic field will induce an emf in it (by Faraday's Law). ✓ The induced emf can drive a circuit in the brush to charge its battery. ✓ (or similar)

### Question 3

a) For the particles listed below, circle those that are composed of quarks.

Proton

Electron

Neutrino

Neutron

Photon

Positron

(1)

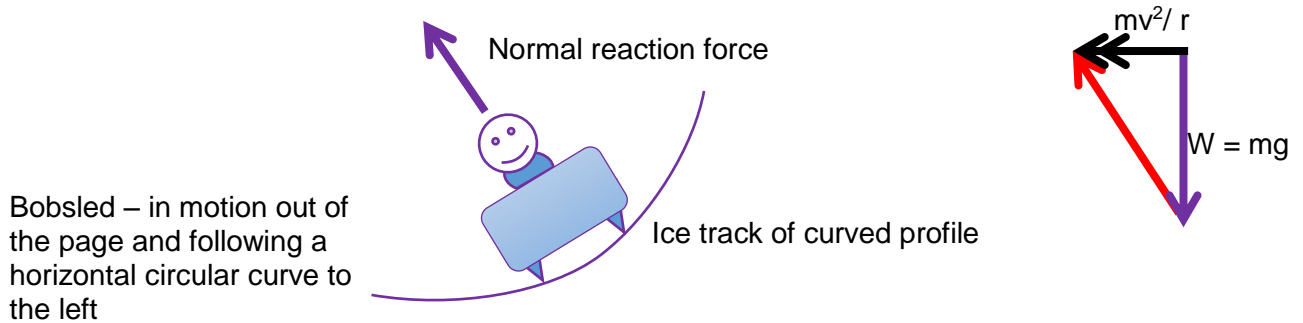
b) The existence of the neutrino was theorised by Pauli in 1930 but it was not until 1956 that they were detected. Explain, referring to two properties of the neutrino, why they were so difficult to detect.

The neutrino has nearly zero mass so is hard to detect by the effects of collision ✓  
The neutrino has no charge so has no electromagnetic interactions ✓  
Or similar

(2)

#### Question 4

The diagram shows a bobsled in motion along a frictionless ice track. When it is following the arc of a horizontal circle it tilts from an upright position as shown. The direction of the normal reaction force is shown.



- a) For a bobsled of mass  $3.50 \times 10^2$  kg calculate the magnitude of the normal reaction force required to maintain a horizontal circular path of radius 75.2 m at a speed of 86.4 km per hour. (4)

$$r = 75.2 \text{ m} \quad v = 86.4/3.6 = 24 \text{ m s}^{-1} \quad m = 350 \text{ kg} \quad \checkmark$$

By Pythagoras

$$N = \sqrt{\left(\frac{mv^2}{r}\right)^2 + (mg)^2} \quad \text{correct vector analysis} \quad \checkmark$$

$$N = \sqrt{\left(\frac{350 \times 24^2}{75.2}\right)^2 + (350 \times 9.8)^2} \quad \checkmark$$

$$N = 4353.37 = 4.35 \times 10^3 \text{ N} \quad \checkmark$$

- b) Calculate the angle ( $\theta$ ) from the vertical that that bobsled must lean in order to achieve this motion. (2)

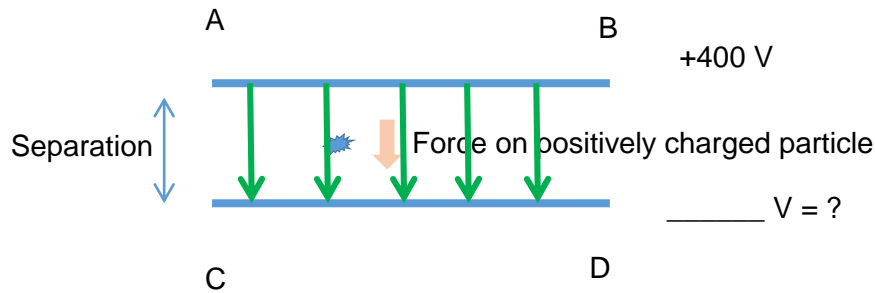
$$\theta = \tan^{-1}\left(\frac{mv^2}{r} \times \frac{1}{mg}\right)$$

$$\theta = \tan^{-1}\left(2680 \times \frac{1}{3430}\right) \quad \checkmark$$

$$\theta = 38.0^\circ \quad \checkmark$$

### Question 5

The diagram shows two parallel plates, AB and CD, which have a potential difference across them. A positively charged particle placed between them experiences a force downwards.



- a) On the diagram above, sketch a uniform electric field pattern that exists between plates AB and CD using at least 5 lines with arrowheads to indicate the field. (2)

Evenly spaced ✓ arrows directed down ✓

- b) The electric field strength between the plates is  $240 \text{ kV m}^{-1}$  and the plate separation is  $2.60 \text{ mm}$ . Plate AB is set at a voltage of  $+400 \text{ V}$ . Calculate the voltage of the bottom plate CD. (3)

$$E = 240\,000 \text{ V m}^{-1} \quad d = 2.60 \times 10^{-3} \text{ m} \quad \checkmark$$

$$E = V / d \quad V = E \times d = 240\,000 \times 2.60 \times 10^{-3}$$

$$V = 624 \text{ V} \quad \checkmark \quad (= \text{potential difference})$$

$$\text{So } V \text{ bottom plate} = 400 - 624 = -224 \text{ V} \quad \checkmark$$

- c) Calculate the electric force experienced by the particle which has a charge of  $+27.2 \text{ } \mu\text{C}$  and mass  $6.35 \times 10^{-4} \text{ kg}$ . (2)

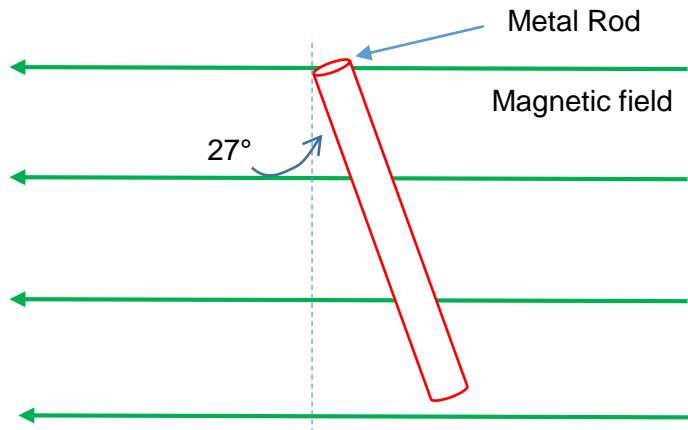
$$E = 240\,000 \text{ V m}^{-1} \quad q = +27.2 \times 10^{-6} \text{ C} \quad \checkmark$$

$$E = F / q \quad F = E \times q = 240\,000 \times 27.2 \times 10^{-6}$$

$$F = 6.53 \text{ N} \quad \checkmark$$

### Question 6

A metal rod of length 1.70 m is viewed from above and is falling through air (into the page) under the influence of gravity. The rod is in a region of magnetic field going left which has a flux density of 948 mT. The rod is at an angle of  $27^\circ$  from being perpendicular to the field lines as shown.



- a) At this instant the rod has a speed of  $8.70 \text{ m s}^{-1}$  into the page. Calculate the emf induced across the rod.

$$B (\text{perp}) = 0.948 \sin (90 - 27) = 0.84467418 \text{ T } \checkmark$$

$$\text{Emf} = l.v.B = 1.70 \times 8.70 \times 0.84467418 \checkmark$$

$$\text{Emf} = 12.5 \text{ V } \checkmark$$

(3)

- b) Explain how a potential difference is established across the metal rod in this situation by identifying regions of relative charge difference.

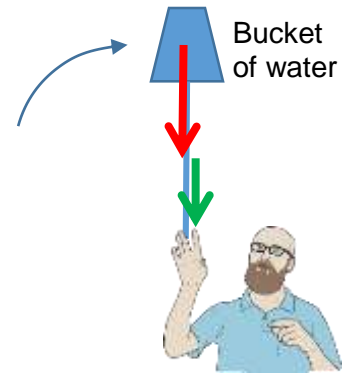
Potential difference is caused by an imbalance of charge between two locations. (or similar)  $\checkmark$

As charge in the rod is dragged through the field it experiences a force that leaves a net positive charge at the top and an excess of electrons (negative charge) at the bottom.  $\checkmark$

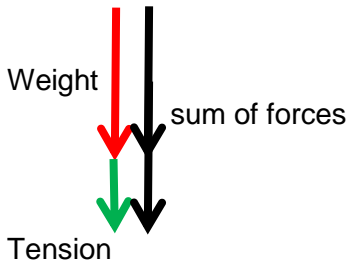
(2)

### Question 7

Steve is demonstrating that a 7.00 kg bucket full of water can undergo vertical circular motion upside down without the water falling out. He is spinning the bucket around on the end of a rope to give a radius of 1.20 m. At the top of the circle the bucket has a speed of 4.00 m s<sup>-1</sup>



a) Calculate the tension in the rope for the instant shown.



(4)

By analysing forces acting on the bucket ✓

$$\Sigma F = W + T$$

$$mv^2/r = mg + T$$

$$T = mv^2/r - mg \quad \checkmark \text{ concept}$$

$$T = (7 \times 4^2) / 1.20 - (7 \times 9.8)$$

$$T = 24.7 \text{ N}$$

b) Explain why the water does not fall out of the bucket

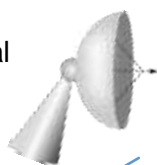
(1)

The bucket and water are in circular motion and both are being accelerated to the centre of the circle ✓  
As long as speed is high enough that an action force from mass of water is applied to base of bucket then it will not drop out of circular motion ✓ Or similar

### Question 8

In the frame of reference of the galaxy that they are situated in, a starship is moving away from a space-station at 0.4c. The space station is at rest. The space-station starts to transmit a radio signal to the starship when it is a distance of 1 million kilometres from the space-station.

Space-station  
transmits  
radio signal



1 million  
kilometres



Starship  
moving at  
0.4c



a) What is the speed of the radio signal in the frame of reference of the starship?

(1)

$$3 \times 10^8 \text{ m s}^{-1} \checkmark$$

b) Explain how time is progressing on the space-station in the reference frame of the starship

(2)

According to Einstein's special relativity in the frame of reference of the starship the space station is moving at relativistic speeds  $\checkmark$  so time will move at a slower rate on the space station  $\checkmark$

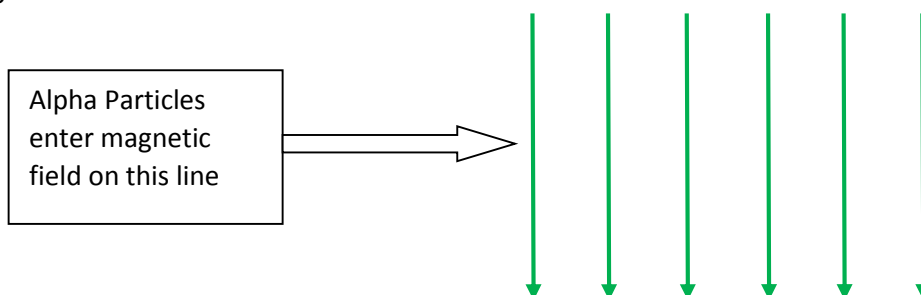
c) The occupants of the starship state that the distance they have travelled from the space-station to this location is less than one million kilometres while observers on the space station describe the distance as one million kilometres. Explain who is correct and why?

(2)

According to Einstein's special relativity in the frame of reference of the starship their path through space is moving at relativistic speeds so this distance will be contracted  $\checkmark$   
Both are correct in their own frame of reference.  $\checkmark$

### Question 9

A source of radiation emits alpha particles ( $\text{He}^{2+}$ ) which are fed into a uniform magnetic field as indicated in the diagram below. They enter with a speed of  $2.80 \times 10^7 \text{ m s}^{-1}$  and experience a magnetic force of  $6.54 \times 10^{-12} \text{ N}$ .



a) Calculate the magnetic flux density of the magnetic field.

(3)

$$v = 2.80 \times 10^7 \quad F = 6.54 \times 10^{-12} \text{ N}, q = 3.20 \times 10^{-19} \text{ C} \checkmark$$

$$F = q.v.B$$

$$B = F / q.v = 6.54 \times 10^{-12} / (3.20 \times 10^{-19} \times 2.80 \times 10^7) \checkmark$$

$$B = 0.730 \text{ T} \checkmark$$

b) State the direction of force on the alpha particles as they enter the field. Circle a response

(1)

Up

Down

Left

Right

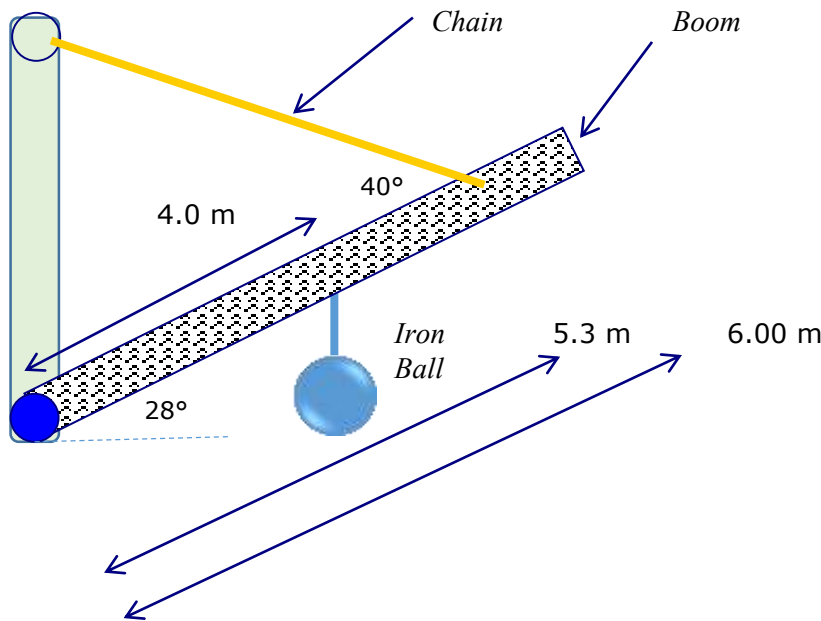
Into page

Out of page

### Question 10

The boom of a crane is lifting an iron ball.

- The boom has a mass of 190 kg distributed uniformly along its length of 6.00 m.
- An iron ball is suspended 4.00 m from the pivot point on the boom.
- A chain is attached 5.30 m from the pivot point and transmits a tension force of 3886 N.
- The chain makes an angle of  $40^\circ$  with the boom.
- The boom has been raised to  $28^\circ$  above the horizontal.



Calculate that the mass of the iron ball.

(4)

Select base as pivot point and take moments such that  $\Sigma M = 0$

$\Sigma cwm = \Sigma acwm$  correct concept

$$(4 \times F_B \times \sin 62) + (3 \times 190 \times 9.8 \times \sin 62) \checkmark = (5.3 \times 3886 \times \sin 40) \checkmark$$

$$(4 \times F_B \times \sin 62) = 13238.725 - 4932.1455$$

$$F_B = 8306.58 / (4 \times \sin 62) = 2351.946 \checkmark$$

$$m (\text{ball}) = 2351.946 / 9.8 = 240 \text{ kg} \checkmark$$

### Question 11

The equation that follows is a mathematical statement of Hubble's Law. Briefly explain what Hubble's Law is and how information is gathered to test the relationship in the equation.

$$v = H_0 \cdot d$$

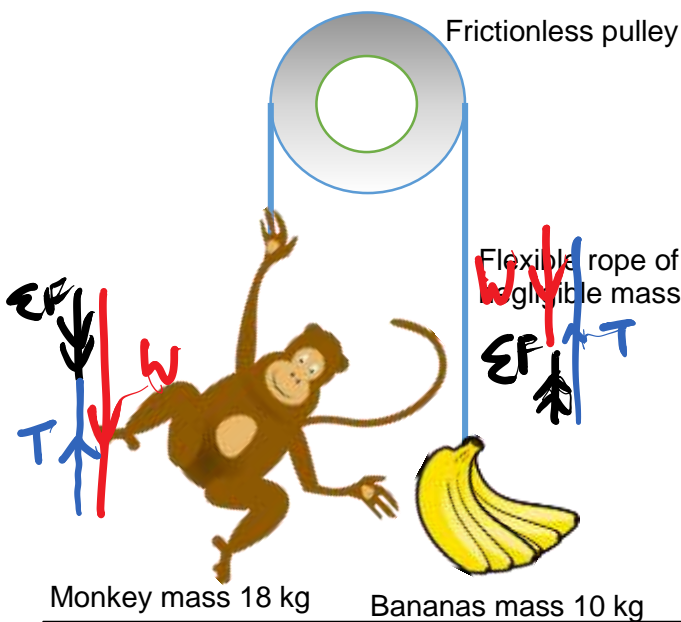
(3)

Hubble's Law states that the distance to galaxies is directly proportional to their recessional speed ✓  
Distances to galaxies are determined by analysis of the luminosity within that galaxy ✓ (of standard candles such as Cepheid variables)  
Recessional speed is determined by spectral analysis of light from stars in the galaxy to determine the amount of redshift. ✓  
Or similar.

### Question 12

A monkey of mass 18.0 kg and a bunch of bananas of mass 10.0 kg are suspended from either end of a flexible rope of negligible mass. The rope is free to move around a frictionless pulley as shown in the diagram. Calculate the tension in the rope as the monkey descends and the bananas rise.

(4)



Net weight force acting to accelerate the system

$$= W_{\text{monkey}} - W_{\text{bananas}}$$

$$\text{Net weight} = (18 - 10) \times 9.8 \text{ N}$$

$$\text{Net weight} = 8 \times 9.8 = 78.4 \text{ N} \checkmark$$

$$\text{Acceleration of system} = W/m$$

$$a = 78.4 / 28 = 2.8 \text{ m s}^{-2} \checkmark$$

Consider forces acting on the monkey (Reference frame down = positive)

$$\text{Net force acting on the monkey} = m \cdot a = 18 \times 2.8 = 50.4 \text{ N down} \checkmark$$

$$\text{Net force} = m_{\text{monkey}} \cdot g - \text{Tension}$$

$$\text{Tension} = m_{\text{monkey}} \cdot g - \text{net force} = (18 \times 9.8) - 50.4 = 126 \text{ N up} \checkmark$$

Alternatively net force on bananas =  $ma = 10 \times 2.8 = 28 \text{ N up}$  (Reference frame up = positive)

$$\text{Net force} = \text{Tension} - m_b \cdot g$$

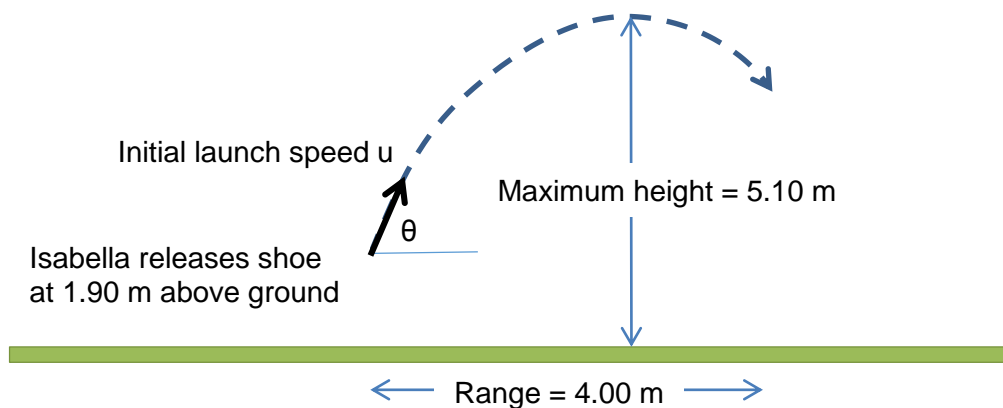
$$\text{Tension} = \text{net force} + m_b \cdot g = 28 + (10 \times 9.8) = 126 \text{ N up}$$

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

This section has **eight (8)** questions. You must answer **all** questions. Write your answers in the space provided. Suggested working time for this section is 90 minutes.

**Question 13 (12 marks)**

Isabella has got her football stuck in a tree. She throws her shoe at the tree to try and dislodge the football. The shoe is launched at an angle  $\theta$  to the horizontal. The shoe reaches its maximum height of 5.10 m above the ground, continues and then gets stuck in the tree at a horizontal distance of 4.00 m in front of her. The flight time from the launch position to arriving at the tree was 0.950 s.



- a) Calculate the initial velocity of the shoe. Note that this is a vector quantity.

(5)

Let up be positive (or alternative defined reference frame)

$$u \text{ (vertical)} = u \cdot \sin \theta \text{ (up)}$$

$$\text{at max height } s_v = 5.10 - 1.90 = +3.20 \text{ m above launch}$$

$$v^2 = u_v^2 + 2as_v$$

$$0 = u_v^2 - (19.6 \times 3.20) \quad \checkmark$$

$$u_v = +7.92 \text{ m s}^{-1} \quad \checkmark$$

$$\text{Consider horizontal } t = 0.95 \text{ s} \quad s_h = +4.00 \text{ m}$$

$$u_h = s_h / t = 4 / 0.95 = 4.21 \text{ m s}^{-1} \text{ right} \quad \checkmark$$

$$\text{By Pythagoras } u = (u_v^2 + u_h^2)^{0.5} = (7.92^2 + 4.21^2)^{0.5} = 8.97 \text{ m s}^{-1} \quad \checkmark$$

$$\text{Elevation Angle} = \tan^{-1} (u_v / u_h) = \tan^{-1} (7.92 / 4.21) = 62.0^\circ \quad \checkmark$$

- b) Calculate the height above ground of the shoe when it became stuck in the tree. If you could not solve for the initial velocity  $u$  then use a value of  $8.97 \text{ m s}^{-1}$  at  $62.0^\circ$  above the horizontal.

$$u \text{ (vertical)} = u \cdot \sin \theta \text{ (up)} = 8.97 \times \sin 62 = +7.92 \text{ m s}^{-1}$$

$$t \text{ (flight)} = 0.950 \text{ s} \quad a = -9.80 \text{ m s}^{-2}$$

$$s = ut + \frac{1}{2} at^2$$

$$s = (7.92 \times 0.95) - (4.9 \times 0.95^2) \checkmark$$

$$s = +3.10 \text{ m} \checkmark$$

$$\text{Height of shoe} = 1.90 + 3.10 = 5.00 \text{ m} \checkmark$$

(3)

- c) The kinetic energy of the shoe after 0.450 seconds of flight was 9.57 J. Calculate the mass of the shoe.

$$u \text{ (horizontal)} = 8.97 \times \cos 62 = 4.21 \text{ m s}^{-1} \text{ right} \quad t = 0.45 \text{ s}$$

$$v \text{ (vertical)} = u + at$$

$$v = 7.92 + (-9.80 \times 0.45) = 3.51 \text{ m s}^{-1} \text{ up} \checkmark$$

$$\text{speed after 3 seconds} = \sqrt{3.51^2 + 4.21^2} = 5.482 \text{ m s}^{-1} \checkmark$$

$$KE = \frac{1}{2} m v^2$$

$$9.57 = \frac{1}{2} \times m \times 5.482^2 \checkmark$$

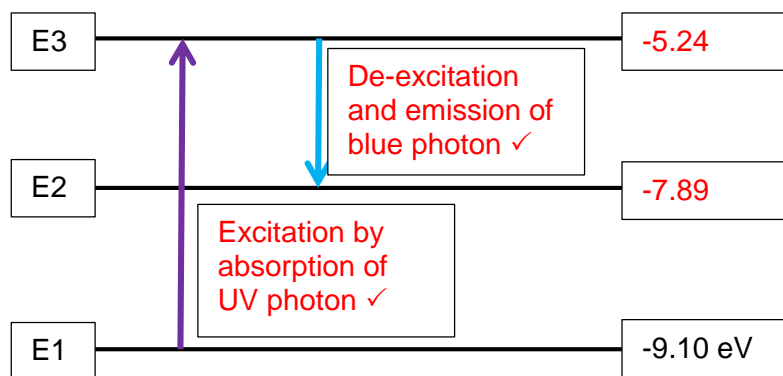
$$m = 0.637 \text{ kg} \checkmark$$

(4)

**Question 14 (10 marks)**

Tonic water contains quinine and is a clear liquid under normal lighting conditions. When UV light shines onto tonic water it starts to glow with a distinct blue colour. This is because of the process of fluorescence. One of the atoms in quinine has a ground state energy level value of -9.10 eV. It is excited to Energy Level 3 (E3) by a UV photon of wavelength 322 nm. A blue photon of wavelength 469 nm is emitted in a de-excitation from E3 to E2.

- a) On the diagram below show and label the electron transitions taking place that give rise to the observed phenomenon. (2)



- b) Calculate the value of Energy Levels 2 and 3 (eV) and show them on the diagram. Show your working in the space below.

Consider UV photon

$$E = h.f = h.c / \lambda = 6.63 \times 10^{-34} \times 3 \times 10^8 / 322 \times 10^{-9}$$

$$E = 6.177 \times 10^{-19} \text{ J} = 6.177 \times 10^{-19} / 1.60 \times 10^{-19} = 3.86 \text{ eV} \checkmark$$

$$E3 = -9.10 + 3.86 = -5.24 \text{ eV} \checkmark$$

Consider blue photon

$$E = h.f = h.c / \lambda = 6.63 \times 10^{-34} \times 3 \times 10^8 / 469 \times 10^{-9}$$

$$E = 4.24 \times 10^{-19} \text{ J} = 4.24 \times 10^{-19} / 1.60 \times 10^{-19} = 2.65 \text{ eV} \checkmark$$

$$E2 = -5.24 - 2.65 = -7.89 \text{ eV} \checkmark$$

- c) Determine the wavelength (nm) of the other photon that can be emitted in this fluorescence process by a transition from E2 and state whether it is visible or not. (refer to the data sheet to justify your answer) (4)

$$E2 \text{ to } E1 = -9.10 - (-7.89) = 1.21 \text{ eV} \checkmark$$

Consider photon

$$E = 1.21 \times 1.60 \times 10^{-19} = 1.936 \times 10^{-19} \text{ J} \checkmark$$

$$\lambda = h.c/E = 6.63 \times 10^{-34} \times 3 \times 10^8 / 1.936 \times 10^{-19}$$

$$\lambda = 1.027 \times 10^{-6} = 1027 \text{ nm} \checkmark$$

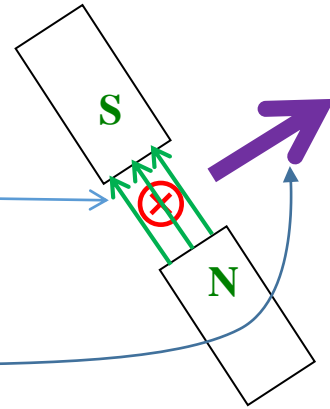
With reference to data sheet = Infra Red ✓ not visible

**Question 15 (11 marks)**

a) The diagram shows the cross section of a single conducting wire placed between 2 magnetic poles

i. Sketch three field lines to show the magnetic field between the magnetic poles. (1)

ii. Place an arrow on the diagram to indicate the direction of magnetic force experienced by the wire and label it 'force' (1)



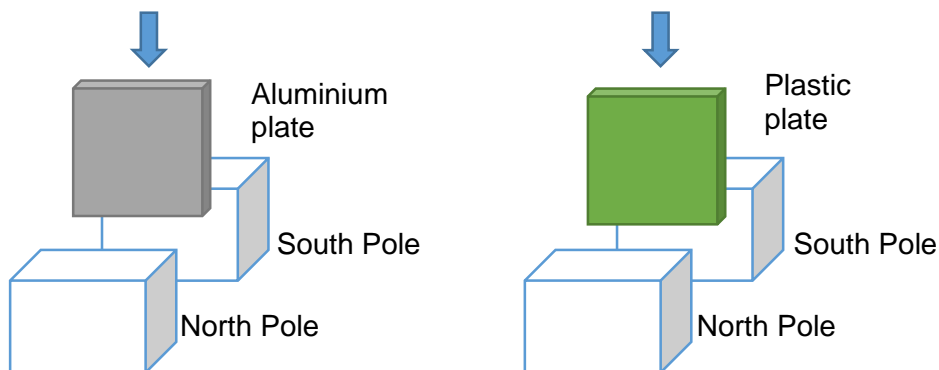
iii. The length of wire in the magnetic field is 8.00 cm. The wire is part of a series loop of resistance 4.00 Ω and has a potential difference of 12.0 V across it. It experiences a force of 18.0 mN. Calculate the magnetic flux density in the region around the wire. (3)

$$I = V / R = 12 / 4 = 3.00 \text{ A} \quad \checkmark$$

$$F = B I l$$

$$18.0 \times 10^{-3} = B \times 3.00 \times 0.08 \quad \checkmark$$

$$B = 0.0750 \text{ T} \quad \checkmark$$



b) When an aluminium plate is dropped through a magnetic field in a vacuum, its rate of descent is less compared to an identically shaped plastic plate. Explain why this is so. (3)

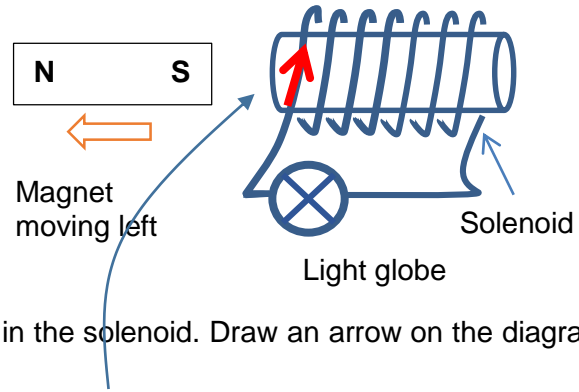
Formation of Eddy Currents can only occur within a conductor ✓

A current is established such that the magnetic fields formed by the Eddy Currents oppose the change in flux that caused them. ✓

This leads to repulsion which slows down the rate of descent. ✓ Or similar

**Question 15 continued**

- c) The diagram shows a magnet being pulled away from a solenoid that is connected to a light globe.



- i. Indicate the direction of induced current in the solenoid. Draw an arrow on the diagram and label it 'current'. (1)

- ii. Briefly explain why a current flows at this instant. (2)

By Faradays law an emf will be induced as a response to the change of flux within the coil ✓  
 A current is established such that the magnetic fields formed oppose the change in flux that caused them. ✓  
 (In this case replacing the lost field), or similar

**Question 16 (10 marks)**

New Horizons is a NASA space probe that was launched to study Pluto. It was closest to the dwarf planet in July 2015. One theoretical circular orbit proposed by NASA put the distance between the centre of Pluto and the centre of New Horizons at 3,340 km with an orbital period of 11 hours and 24 minutes. The mass of the New Horizons craft is 478 kg. Pluto has a radius of 1185 km.

- a) Calculate the centripetal force acting on New Horizons in this proposed orbit. (3)

$$v = 2\pi r / T \quad T = (11 \times 60 + 24) \times 60 = 41040 \text{ s}$$

$$r = 3,340 \times 10^3 \text{ m} \quad m = 478 \text{ kg} \quad \checkmark$$

$$F = mv^2 / r = m 4 \pi^2 r / T^2$$

$$F = (478 \times 4 \times \pi^2 \times 3340000) / 41040^2 \quad \checkmark$$

$$F = 37.4 \text{ N} \quad \checkmark \text{ (towards Pluto)}$$



b) Calculate the mass of Pluto based on this data.

(4)

Orbital radius =  $3,340 \times 10^3 \text{ m}$       Orbital period =  $41040 \text{ s}$   
 $F = 37.4 \text{ N} \checkmark$

centripetal force =  $mv^2 / r = \text{gravitational force} = GmM / r^2$

$M = ((F_{\text{centripetal}}) \times r^2) / Gm \checkmark$

$M = (37.421345 \times (3,340 \times 10^3)^2) / ((6.67 \times 10^{-11}) \times 478) \checkmark$

$M = 1.31 \times 10^{22} \text{ kg} \checkmark$

Alternatively

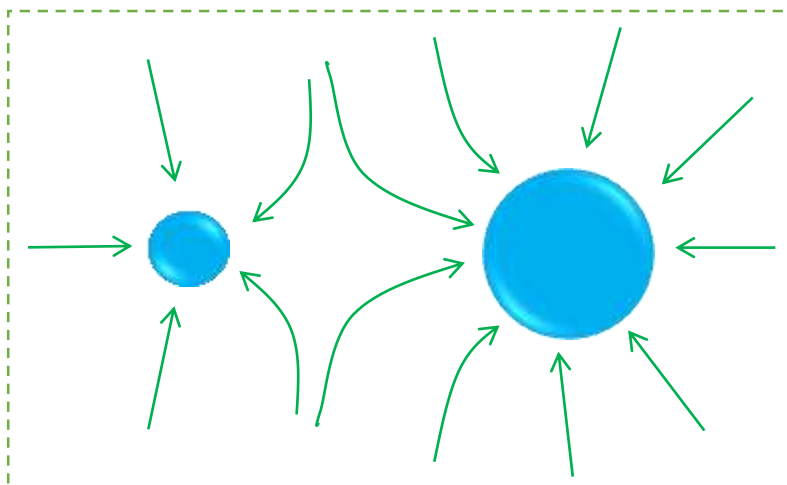
derive  $r^3 = (G.M.T^2) / 4\pi^2$

$M = (r^3 \times 4\pi^2) / (6.67 \times 10^{-11} \times T^2)$

$M = 1.31 \times 10^{22} \text{ kg}$

c) Two planets of equal density are shown in the box below. Sketch at least 12 field lines within the box to represent the net gravitational field around each planet and between them.

(3)



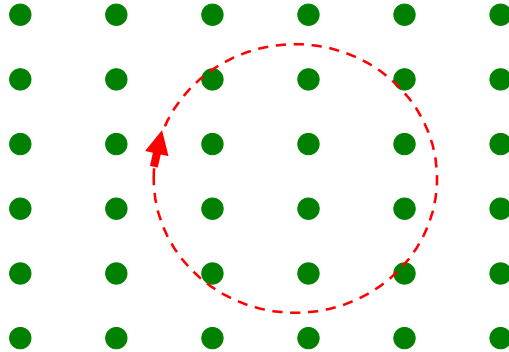
At least 12  $\checkmark$

General net field shape  $\checkmark$

Directed towards the centre of masses  $\checkmark$

**Question 17 (11 marks)**

- a) A particle of charge  $q$  and mass  $m$  has gone into clockwise circular motion in a uniform magnetic field  $B$  within a vacuum chamber. It is moving at speed  $v$  with a radius  $r$ . The situation is shown in the diagram below.



- i. State whether the particle has a positive or negative charge.

Positive ✓

(1)

- ii. Show by clear algebraic steps and with reference to equations on the data sheet, that the following relationship for the period of circular motion is true.

(3)

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

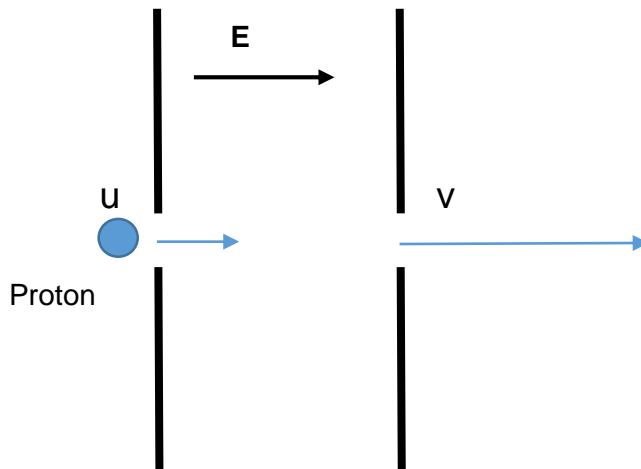
$$\begin{aligned}
 &F_{\text{centripetal}} = F_{\text{magnetic}} \\
 \frac{mv^2}{r} = q \cdot v \cdot B \quad \checkmark & \quad \frac{mv}{r} = q \cdot B \quad \checkmark & \quad \text{substitute } v = \frac{2\pi r}{T} \quad \checkmark \\
 &\frac{m2\pi r}{Tr} = q \cdot B \\
 T = \frac{2\pi m}{qB} \quad \checkmark
 \end{aligned}$$

- iii. The particle has a mass of  $4.14 \times 10^{-12}$  kg and a charge of 5.80 nC. The magnetic field has a flux density of 95.0 mT. Calculate how many times the particle goes around in a circle in a time of 4.00 seconds.

(3)

$$\begin{aligned}
 T &= \frac{2\pi m}{qB} = \frac{2 \times \pi \times 4.14 \times 10^{-12}}{5.80 \times 10^{-9} \times 0.095} \quad \checkmark = 4.72 \times 10^{-2} \text{ s} \quad \checkmark \\
 \text{Number of periods in 4 seconds} &= 4 / 0.0472 = 84.7 \quad \checkmark
 \end{aligned}$$

- b) A proton moving with an initial velocity  $u$ , has an initial kinetic energy  $KE_{\text{initial}}$ . It enters a uniform electric field with field strength  $\mathbf{E}$ , as shown in the diagram below. The proton's final kinetic energy  $KE_{\text{final}}$  is equal to  $4KE_{\text{initial}}$ .



The electric field is now tripled (it becomes  $3\mathbf{E}$ ). If another proton, having an initial kinetic energy  $KE_{\text{initial}}$  enters the field, determine this proton's final kinetic energy in terms of  $KE_{\text{initial}}$ .

You should ignore the effects of gravity.

(4)

Work is done by the electric force field ( $F_E = E \times q$ )

In case 1 work done  $W = F_e \times s = KE_{\text{final}} - KE_{\text{initial}}$  ✓ (or implied understanding)

$$W = 4KE_{\text{initial}} - KE_{\text{initial}} = 3 \times KE_{\text{initial}} \quad \checkmark$$

In case 2 If electric field is tripled the Force doing work is tripled across the same displacement so Work done is tripled

$$W = 9 \times KE_{\text{initial}} = KE_{\text{final}} - KE_{\text{initial}} \quad \checkmark$$

$$KE_{\text{final}} = 10 KE_{\text{initial}} \quad \checkmark$$

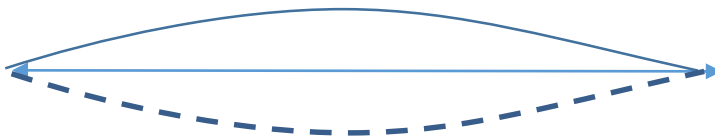
**Question 18 (14 marks)**

A Viola has a string length of 42 cm. At a certain tension the string wave speed is  $269 \text{ m s}^{-1}$



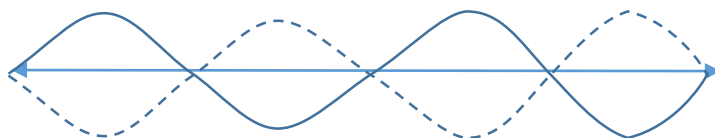
For a given note played on a musical instrument, the dominant frequency heard is called the fundamental frequency or the first harmonic. The sequence of harmonic frequencies above the fundamental frequency, that are actually present, are known as overtones. So those harmonics above the fundamental are known as the first overtone, the second overtone etc.

- a) Determine the fundamental frequency of this string and sketch the wave envelope below (3)



$$\frac{\lambda}{2} = 0.42 \text{ m} \quad \lambda = 0.84 \text{ m} \quad \checkmark$$
$$f = \frac{v}{\lambda} = \frac{269}{0.84} = 320 \text{ Hz} \quad \checkmark$$

- b) Determine the frequency of the 3<sup>rd</sup> overtone and sketch the wave envelope below. (2)



Sketch as above  $\checkmark$

$$f_4 = 4 \times f_1 = 4 \times 320 = 1.28 \times 10^3 \text{ Hz} \quad \checkmark$$

- c) How many particle displacement nodes are present on the 3<sup>rd</sup> overtone? (1)

5  $\checkmark$

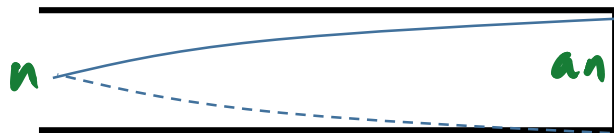
A church organ pipe can be considered to be an air column closed at one end. When the organ pipe resonates standing waves form.



- d) Draw simple sketches to show the standing wave envelope for **pressure variation** for the **fundamental** and **first overtone**. Indicate nodes and antinodes on the sketches.

Pressure variation

*Fundamental frequency*



Nodes / Antinodes ✓

Shapes ✓

*First overtone*



(2)

- e) A pipe that plays the lowest note has a fundamental frequency of 28 Hz. Calculate the effective length of the pipe so that it can resonate at this frequency when the speed of sound is 346 m s<sup>-1</sup>.

(3)

$$\lambda = \frac{v}{f} = \frac{346}{28} = 12.357 \text{ m} \quad \checkmark$$

The pipe contains one quarter of a wavelength at the fundamental frequency

the length required is  $12.357 / 4 \checkmark = 3.09 \text{ m} \checkmark$

- f) Briefly explain why an open pipe of the same length cannot resonate with a standing wave of frequency 28 Hz in this situation.

(3)

An open pipe contains one half of a wavelength at the fundamental frequency ✓

It cannot support standing waves with a lower frequency (longer wavelength) than the fundamental so an open pipe of length 3.09 m has a fundamental frequency of 56 Hz and no less at this speed of sound. ✓ Or similar

### Question 19 (15 marks)

A capillary wave is a wave that travels along the surface of a liquid. Its dynamics are mainly influenced by the effects of surface tension. They are often seen in nature, and are often referred to as ripples. The wavelength of capillary waves on the surface of water is typically less than a few centimetres.

Richard Feynman once stated that water waves are easily observed by everyone and are often used as examples of waves in school science despite the fact that the mathematics that governs their properties is highly complex.

A group of Physics students noted that the wave speed of a ripple is affected by its wavelength. This is unlike the contexts they studied for sound and light. The equation that they found was as follows:

$$v_{\text{ripple}} = \sqrt{\frac{2\pi\sigma}{\rho\lambda}}$$

$v_{\text{ripple}}$  = ripple speed ( $\text{m s}^{-1}$ )

$\sigma$  = surface tension ( $\text{N m}^{-1}$ )

$\rho$  = density ( $\text{kg m}^{-3}$ )

$\lambda$  = wavelength (m)

The students decided to investigate to see how the speed of the ripples was affected by their wavelength. Using a ripple tank and a video camera they obtained the following data. The students decided to recognise the uncertainty of their ripple speed measurements with a value of  $\pm 5\%$  for each reading.

Wavelength (m)	$\frac{1}{\text{wavelength}}$ ( $\text{m}^{-1}$ )	$v_{\text{ripple}}$ Ripple speed ( $\text{m s}^{-1}$ )	$v_{\text{ripple}}^2$ ( $\text{m}^2 \text{s}^{-2}$ )
0.0155	64.5	$0.174 \pm 0.0087$	$0.0303 \pm 0.0030$
0.0205	48.8	$0.149 \pm 0.0075$	$0.0221 \pm 0.0022$
0.0250	40.0	$0.133 \pm 0.0067$	$0.0177 \pm 0.0018$
0.0300	33.3	$0.123 \pm 0.0062$	$0.0151 \pm 0.0015$
0.0350	28.6	$0.116 \pm 0.0058$	$0.0135 \pm 0.0014$
0.0400	25.0	$0.107 \pm 0.0054$	$0.0114 \pm 0.0011$

In order to linearise this data and get a straight line of best fit they squared the above expression and then plotted  $v_{\text{ripple}}^2$  versus  $\frac{1}{\text{wavelength}}$ .

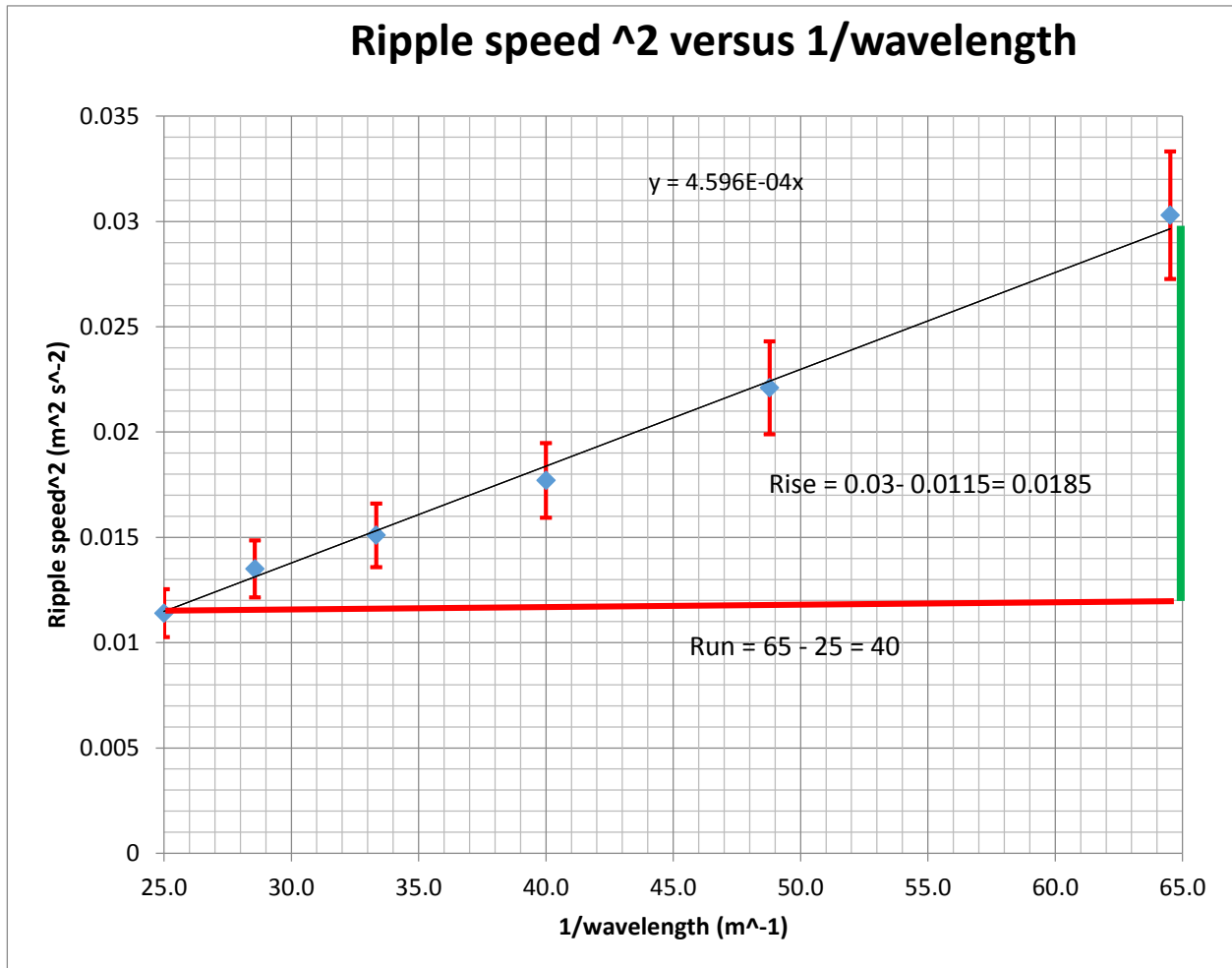
The water that they used had a density of  $997 \text{ kg m}^{-3}$ . They also wanted to determine the surface tension of the water from this experiment.

- Complete the second column of the table for  $\frac{1}{\text{wavelength}}$ , one value has been done for you.  
As above ✓ (1)
- Complete the fourth column of the table for ripple speed squared and include the appropriate uncertainty range. Two values have been done for you.  
As above ✓✓ (2)

- c. Plot a graph of  $V_{\text{ripple}}^2$  on the vertical axis versus  $\frac{1}{\text{wavelength}}$  on the horizontal axis. You must include a line of best fit and error bars.

If you need to make a second attempt, spare graph paper is at the end of this question. Indicate clearly if you have used the second graph and cancel the working on the first graph.

(6)



Axes labels ✓      Axes units ✓      Axes Scaling ✓      Accurate plotting ✓  
 Line of best fit ✓      Error bars ✓

- d. Calculate the gradient of your line of best fit from your graph showing all working.

Clearly show rise and run construction lines on the graph ✓

(3)

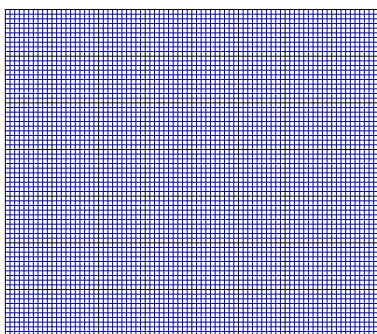
$$\text{gradient} = 0.0185/40 \quad \checkmark = 4.63 \times 10^{-4} \quad \checkmark$$

- e. Determine the surface tension  $\sigma$  from the value of the gradient that you obtained. (If you could not determine the gradient use the numerical value  $4.60 \times 10^{-4}$ ).

(3)

$$\text{gradient} = \frac{2\pi\sigma}{\rho} \quad \checkmark$$
$$4.60 \times 10^{-4} = \frac{2\pi\sigma}{997} \quad \checkmark$$
$$\sigma = 0.0730 \text{ N m}^{-1} \quad \checkmark$$

Spare graph paper

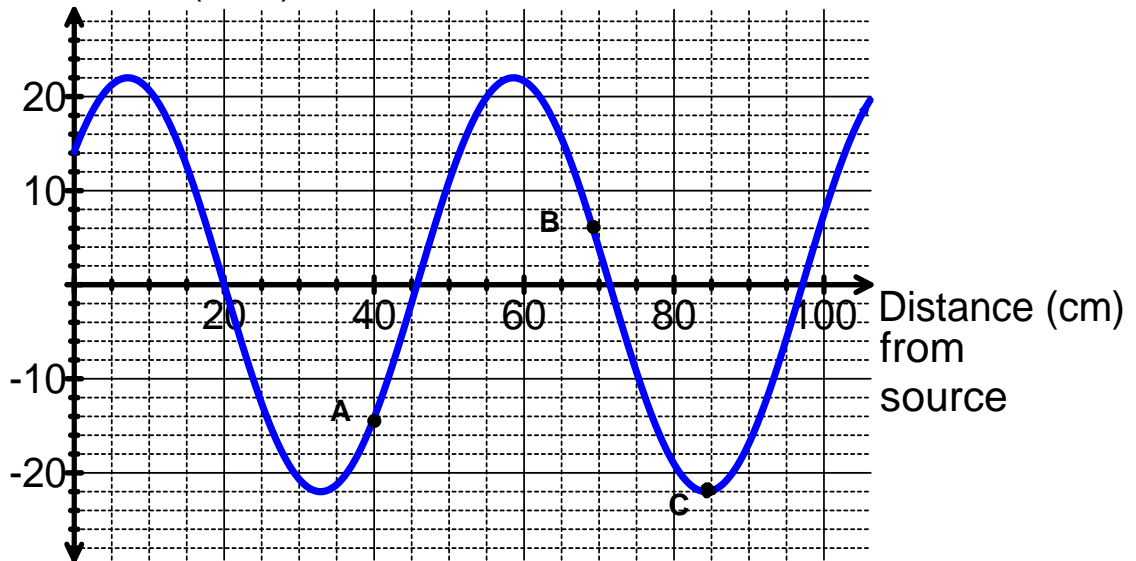




**Question 20 (7 marks)**

The pressure-distance graph below represents a longitudinal sound wave in air. The wave is not being reflected. The wave is moving from left to right at  $342 \text{ m s}^{-1}$ .

Pressure variation (HPa)



- a. Determine the wavelength of this wave:

$$0.772 - 20 = 52 = 0.52 \text{ m } \checkmark$$

(1)

- b. Calculate how many compressions pass a fixed point in **3 seconds**

$$f = \frac{v}{\lambda} = \frac{342}{0.52} \checkmark = 657 \checkmark,$$

therefore  $3f = 1.97 \times 10^3 \text{ waves } \checkmark$

(3)

- c. Calculate the time it takes for **five** complete waves to pass a fixed point.

$$T = \frac{1}{f} = \frac{1}{657.6923} = 1.52 \times 10^{-3} \checkmark$$

so  $5T = 7.60 \times 10^{-3} \text{ s } \checkmark$

Ans: \_\_\_\_\_

(2)

- d. At the instant shown in the graph, state the how pressure is changing at the following locations. Your response will be "increasing", "decreasing" or "no change"

(1)

A: *decreasing*

B: *increasing*

C: *no change*

*All correct for 1 mark ✓*

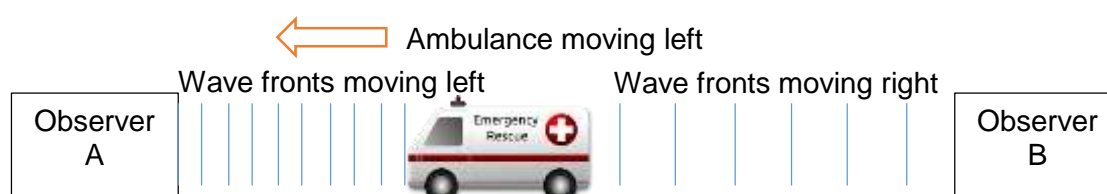
### Section Three: Comprehension 20% (36 Marks)

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

#### Question 21 (18 marks) The Doppler Effect

Most people have heard the Doppler Effect even if they did not realise it at the time. Consider a police car racing towards you with its siren sounding. As it approaches you hear a particular frequency of sound but once it has passed and is moving away, the frequency of sound is lower.

The relative motion between a sound source and an observer is responsible for the Doppler Effect. Consider the following example. An ambulance is sounding a siren at a constant frequency. It emits longitudinal pressure waves that travel outwards along spherical wave fronts. If the ambulance and observers in front and behind are all at rest relative to each other the frequency heard by the observers is the same as the frequency emitted by the ambulance.



Consider the ambulance moving left, as shown above, and emitting the same frequency of sound. The source is moving towards observer A and releases a wave. The next wave will be released one period later during which time the source has moved forwards. Because the speed of sound is constant this means that the wavelength has been shortened and the frequency heard by observer A has increased. For observer B the reverse is true and the frequency heard is lower.

If an observer is moving through the sound waves emitted by a stationary source, the wavelength is unchanged. If we assume that the medium is at rest then a change in frequency is a result of a change in wave speed in the frame of reference of the observer.

The following equation summarises the general relationship between velocity and frequency for the Doppler Effect:

$$\frac{f_s}{V - v_s} = \frac{f_o}{V - v_o}$$

$f_s$  = frequency emitted by the source (Hz)  
 $f_o$  = frequency received by the observer (Hz)  
 $V$  = wave speed in medium ( $\text{m s}^{-1}$ )  
 $v_s$  = velocity of source ( $\text{m s}^{-1}$ ) - (positive value if source approaches observer, negative if source recedes)  
 $v_o$  = velocity of observer ( $\text{m s}^{-1}$ ) - (negative value if observer approaches source, positive if observer recedes)

Electromagnetic waves such as light are also governed by the Doppler Effect. Einstein's theory of Special Relativity tells us that the speed of electromagnetic radiation is always fixed no matter what the relative speed of sources and observers in inertial frames of reference. In a vacuum there is no material medium to consider so it is just a matter of the waves being extended or contracted as a result of the relative motion between source and observer.

Hubble discovered that light from distant galaxies is mostly 'red-shifted' which led to the conclusion that all galaxies are receding from Earth and the Universe is expanding. **Current scientific thinking** states that space itself is expanding and light becomes 'stretched' due to the expansion rather than the motion of galaxies 'through' space.

The above equation applies for electromagnetic waves in a vacuum if the speeds are much less than the speed of light. In this case the observer is always set to be at rest and the relative speed is applied to the source. If the speed is a significant fraction of the speed of light then relativistic effects must also be accounted for. Because of time dilation effects, the oscillations within atoms that emit photons from a moving source have a lower frequency compared to similar atoms at rest.

- a) With reference to the ambulance example above. Explain why observer B hears a lower frequency. You must refer to the motion of the source and address all aspects of the wave equation  $v = f \cdot \lambda$

The source is moving away from observer B and releases a wave. The next wave will be released one period later during which time the source has moved further away. ✓  
 Because the speed of sound is constant this means that the wavelength has been increased ✓ and the frequency heard by observer B has decreased. ✓ Or similar

(3)

- b) Explain what causes a change in frequency for an observer moving towards a stationary source of sound waves. You must refer to the motion of the observer and address all aspects of the wave equation  $v = f \cdot \lambda$ .

If an observer is moving towards the sound waves emitted by a stationary source, the wavelength is unchanged. ✓  
 The wave speed in the frame of reference of the observer has increased. ✓  
 This means that frequency detected by the observer increases in proportion. ✓ Or similar

(3)

- c) A police car is racing at  $90 \text{ km h}^{-1}$  towards a building that is sounding an intruder alarm. The driver of the police car hears the alarm with a frequency of  $944 \text{ Hz}$ . Calculate the frequency of the sound in the frame of reference of the intruder alarm. The speed of sound is  $346 \text{ m s}^{-1}$ .

$v_o = 90/3.6 = -25 \text{ m s}^{-1}$  (observer approaches)  
 identifies correct variables ✓

$$\frac{f_s}{V - v_s} = \frac{f_o}{V - v_o} \quad \text{inserts correct values} \quad \frac{f_s}{346 - 0} = \frac{944}{346 - (-25)} \quad \checkmark$$

$$f_s = 8.80 \times 10^2 \text{ Hz} \quad \checkmark \quad \text{Or similar}$$

(3)

- d) A distant star emits light with a frequency of  $5.00 \times 10^{14}$  Hz. When observed on Earth the light has a frequency of  $4.88 \times 10^{14}$  Hz. Calculate the velocity of the star relative to Earth.

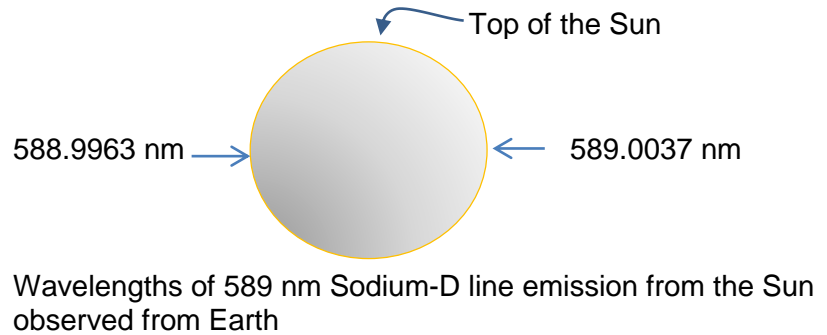
$$f_s = 5.00 \times 10^{14} \text{ Hz} \quad f_o = 4.88 \times 10^{14} \text{ Hz} \quad v_{\text{wave}} = 3 \times 10^8 \text{ m s}^{-1} \quad (3)$$

identifies correct variables ✓

$$\frac{f_s}{v - v_s} = \frac{f_o}{v - v_o} \quad \text{inserts correct values} \quad \frac{5.00 \times 10^{14}}{3.00 \times 10^8 - v_s} = \frac{4.88 \times 10^{14}}{3.00 \times 10^8 - 0} \quad \checkmark$$

$$v_s = -7.38 \times 10^6 \text{ m s}^{-1} \quad (\text{Negative} = \text{receding}) \quad \checkmark$$

Spectral analysis of light from the Sun reveals that wavelengths of light from one side of the Sun are longer compared to wavelengths from the other side of the Sun. This is shown in the diagram Application of the Doppler Effect has revealed that the Sun is rotating with a period of 27 days.



- e) With reference to the above diagram state the direction of rotation of the Sun when viewed from above. Circle one of the options below and briefly explain your response.

Clockwise      Anti-clockwise      Impossible to determine

(2)

Explain briefly

The left side is blue shifted so coming out of page. Right side is red shifted so going into page. ✓ Viewed from above this means anticlockwise ✓      Marks only awarded if explained correctly

- f) For a star moving away from an observer at close to light speeds how will relativistic effects change the observed frequency of electromagnetic radiation emitted? Circle a response and briefly explain.

Frequency increases      Frequency decreases      Frequency stays the same

(2)

Because of Special Relativity time dilation effects, the oscillations within atoms that emit photons from a moving source have a lower frequency compared to similar atoms at rest. ✓ This compounds the redshift frequency reduction as a result of recession ✓

- g) What does current scientific thinking state about the cause of "red-shift" in the universe?

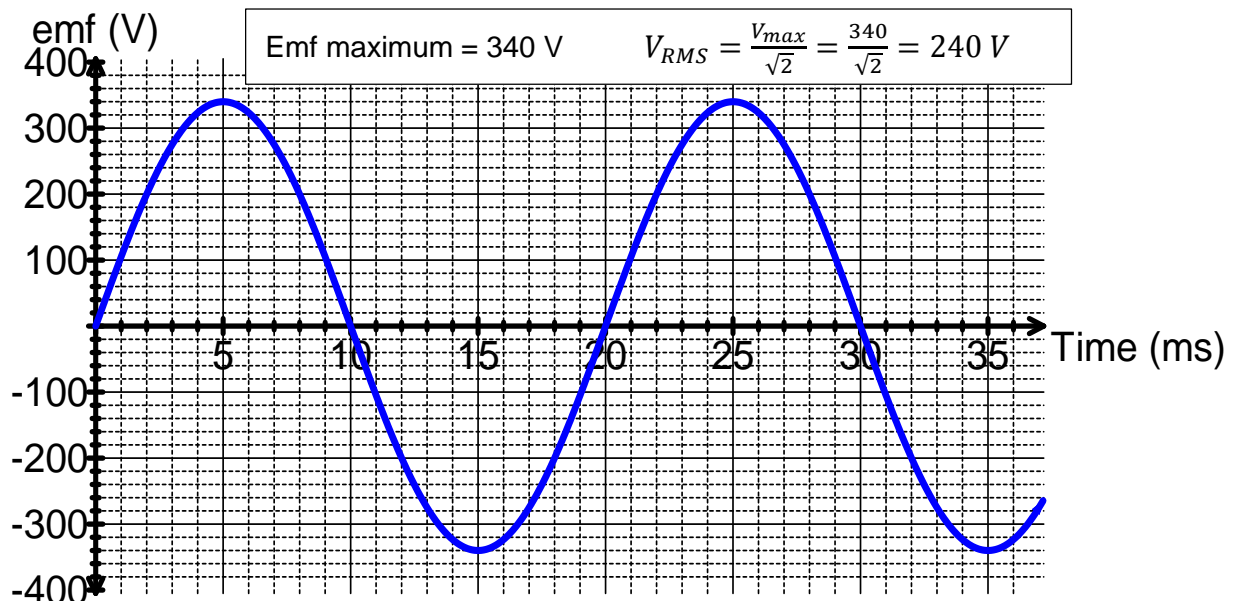
(2)

Space itself is expanding and light become 'red-shifted' due to this expansion ✓ rather than the motion of galaxies 'through' space. ✓

**Question 22      Alternating Current and RMS values****(18 marks)**

A light globe that is plugged into the mains electricity supply of an Australian house is actually switching on and off 100 times per second. This is because the mains electricity is powered by Alternating Current (AC). If current is plotted against time it is a sinusoidal wave form with a frequency of 50 Hz. The light globe will glow at its brightest when current has a maximum magnitude and will momentarily be switched off as the current changes direction.

Alternating current is driven by an alternating emf. For a simple resistance circuit, if emf is plotted against time it also has a sinusoidal form of the same frequency and is in phase with the current. Alternating emf drives charge carriers back and forth along the same piece of conducting wire.



Graph 1 showing alternating emf in an Australian household mains supply

It is difficult to analyse the instantaneous power characteristics of an AC resistance circuit as the values of emf and current are constantly changing. It is more convenient to consider the average power produced over one cycle. This is done by using the Root Mean Square (RMS) values of current and emf.

The RMS equivalent current is defined as the direct current (DC) that will provide the same power in a resistor as AC does on average. The same logic applies for RMS voltages.

The equations to calculate RMS values are:  $V_{RMS} = \frac{V_{max}}{\sqrt{2}}$        $I_{RMS} = \frac{I_{max}}{\sqrt{2}}$

Use of the RMS values allows an AC circuit containing only resistors, to be analysed in the same way as a DC circuit.

An AC generator is a source of alternating emf. It can be shown that the maximum emf on the alternating cycle can be calculated using the following equation:

$$V_{max} = NAB2\pi f$$

$V_{max}$  = maximum emf (V)      N = number of turns on coil  
 A = area of coil (m<sup>2</sup>)      f = frequency of rotation (Hz)  
 B = magnetic flux density (T)

Diagram 1 shows the coil PQRS of an AC generator placed between magnetic poles.

- A uniform magnetic field of flux density 0.126 T exists between the magnetic poles.
- The dimensions of the coil are: PQ = SR = 17.0 cm and PS = QR = 9.00 cm
- The coil rotates about the axle as indicated as a torque is applied to the pulley.
- The coil has 600 turns of wire and is rotated uniformly at 840 rpm.

Diagram 1 – AC generator viewed from the top. Coil PQRS sits flat in the magnetic field between the North and South magnetic poles shown.

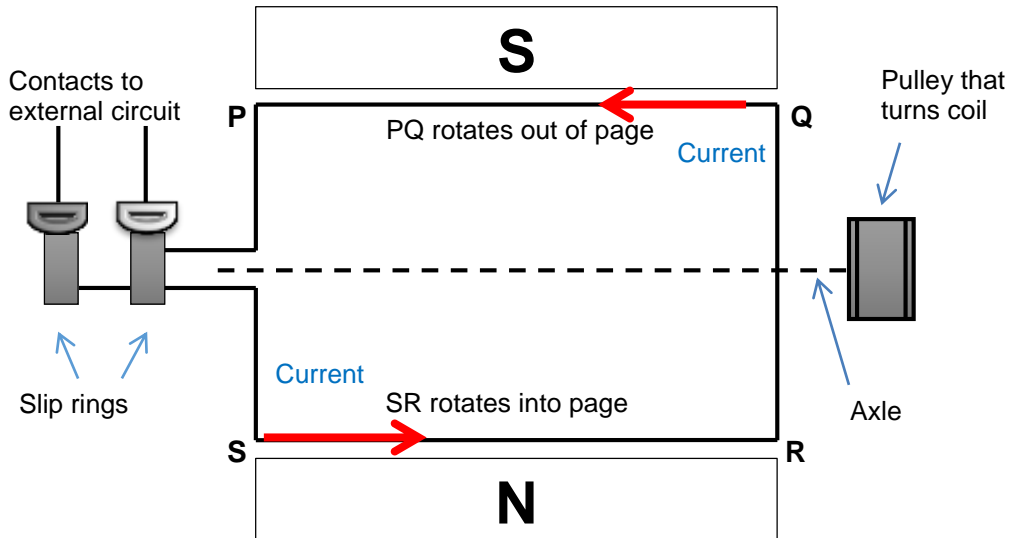
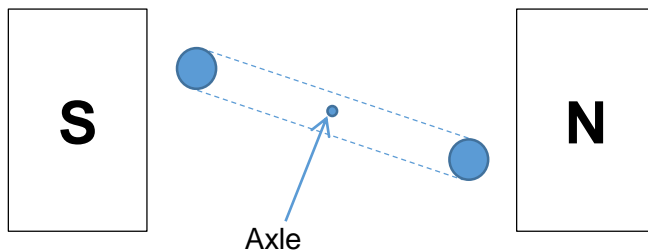


Diagram 2 – The AC generator viewed from the front (location of the slip rings) after coil PQRS has rotated by 20° from the position shown in Diagram 1.



### Questions

- a) Why does the passage state that a light globe switches on and off 100 times per second when the AC frequency is 50 Hz.

(1)

The globe is on regardless of the direction of current ✓  
 Within a cycle the current flows one way, stops and then flows the other way ✓  $2 \times 50 \text{ Hz} = 100 \text{ times per second}$ .

- b) A simple AC circuit has a resistance of  $4.00 \Omega$  and is driven by an RMS voltage of  $120 \text{ V}$ . Determine the maximum current that will flow through the resistor as part of the AC cycle. (3)

$$V_{RMS} = \frac{V_{max}}{\sqrt{2}} \quad 120 = \frac{V_{max}}{\sqrt{2}} \quad \text{so } V_{max} = 120 \times \sqrt{2} = 169.7 \text{ V } \checkmark$$

$$V_{max} = I_{max} \cdot R \quad \text{so } I_{max} = \frac{V_{max}}{R} = \frac{169.7}{4} \checkmark = 42.4 \text{ A } \checkmark$$

- c) Indicate on Diagram 1, the direction of current along PQ and SR as the coil rotates from the position shown. Use arrows and label them 'current'. (1)

- d) Briefly describe how you arrived at your answer for the previous question (1)

As the coil rotates it is gaining flux, current flows in a direction to establish a field that opposes the increase.  $\checkmark$   
Or similar

- e) At the instant shown in diagram 2, the magnitude of emf is: (circle a response) (1)  
Increasing      Zero      Decreasing      Staying Constant

- f) Explain your response to the previous question. (2)

The rate of change of flux is decreasing as the coil approaches maximum flux captured by the coil.  $\checkmark$  emf is directly proportional to the rate of change of flux.  $\checkmark$

- g) As the coil continues to rotate from the position shown in Diagram 2, the direction of emf will reverse at a certain point. Determine how many degrees from the position shown that this will occur next. (1)

$70^\circ \checkmark$

- h) Consider the lengths PQ and RS in the AC generator in Diagram 1. They can each be considered as long straight conductors and the emf generated across them is a maximum when they move in a direction perpendicular to the magnetic field lines. From the starting point of  $emf = \ell \cdot v \cdot B$  derive the equation  $V_{max} = NAB2\pi f$  showing clear logical steps.

(3)

$emf = \ell \cdot v \cdot B$  for 1 length, and  $v = \frac{2\pi r}{T} = 2\pi r f$ , so  $emf = \ell \cdot 2 \cdot \pi \cdot r \cdot f \cdot B$  ✓  
 There are 2 lengths each with N turns so,  $emf = 2 \cdot N \cdot \ell \cdot 2 \cdot \pi \cdot r \cdot f \cdot B$  ✓  
 The radius r is the distance from the axle to each length so  
 The area of the coil  $A = \ell \times 2r$ , and by substitution  
 $V_{max} = NAB2\pi f$  ✓

- i) Calculate the maximum emf ( $V_{max}$ ) for the AC generator shown in Diagrams 1 and 2.

(3)

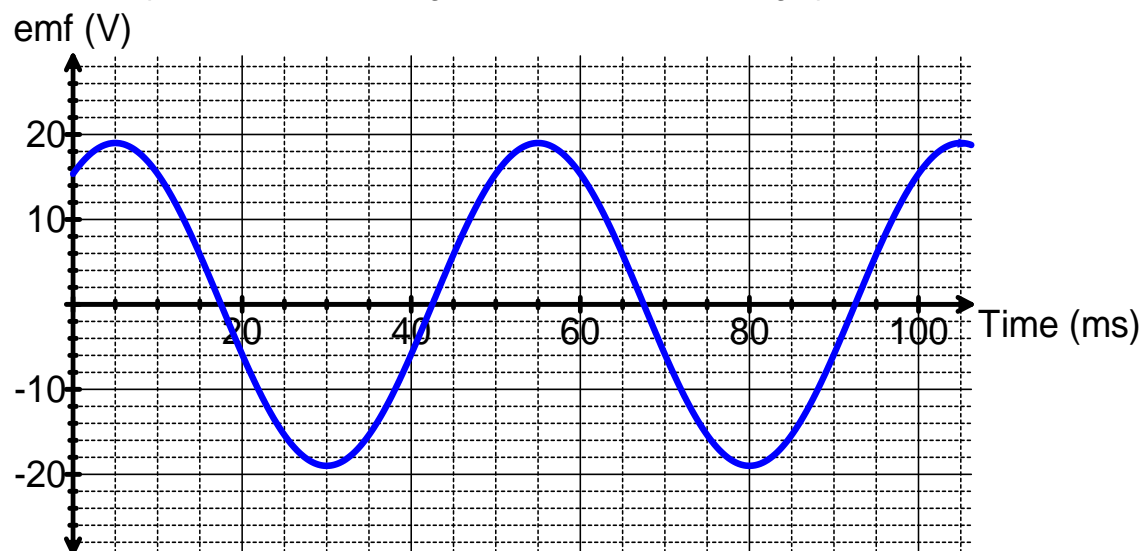
$N = 600$     $f = 840/60 = 14 \text{ Hz}$     $B = 0.126 \text{ T}$     $A = 0.17 \times 0.09 = 0.0153 \text{ m}^2$  ✓

$$V_{max} = NAB2\pi f$$

$$V_{max} = 600 \times 0.0153 \times 0.126 \times 2\pi \times 14 \quad \checkmark$$

$$V_{max} = 101.7 = 102 \text{ V} \quad \checkmark$$

The emf output of a **different** AC generator is shown on the graph below.



- j) Determine the RMS voltage of this AC generator.

(2)

Identifies that  $V_{max} = 19 \text{ V}$  from the graph ✓

$$V_{RMS} = \frac{V_{max}}{\sqrt{2}} = \frac{19}{\sqrt{2}} = 13.4 \text{ V} \quad \checkmark$$

End of questions