ALL SAINTS' COLLEGE

WACE PHYSICS Stage 3
Semester 2 Examination, 2014

Question/Answer Booklet

Student Number: In figures ☐☐ ☐☐☐ ☐☐☐

In words ____

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	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. The rules for the conduct of Western Australian external examinations are detailed in the *Year 12 Information Handbook 2014.* Sitting this examination implies that you agree to abide by these rules.

2. Write answers in this Question/Answer Booklet.

3. 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.

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

5. 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 **13** questions. Answer **all** questions. Write your answers in the space provided. Suggested working time for this section is 50 minutes.

Question 1

A straight wire of length 250 mm carries a current of 4.50 A and is placed in a uniform magnetic field. The wire experiences an electromagnetic force of 5.48 x 10^{-2} N. Calculate the magnitude of flux density perpendicular to the wire.

(2)

$l = 0.250$ m $I = A$ $F = 5.48 \times 10^{-2}$ N

$F = BIl$

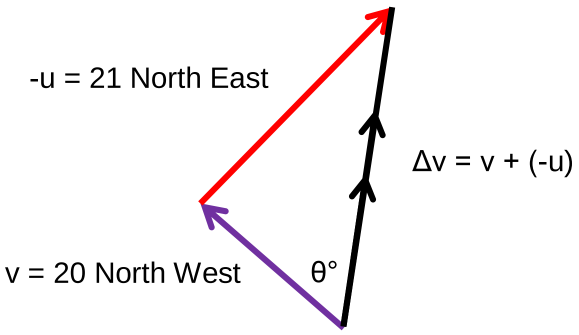
$B = F / Il = 5.48 \times 10^{-2} / (4.50 \times 0.250)$ ✓

$B = 4.87 \times 10^{-2}$ T ✓

Question 2

An ice hockey puck slides at 21.0 m s^{-1} South-West, hits a goal post and rebounds at 20.0 m s^{-1} North-West. Calculate the change in velocity of the ice hockey puck. You must refer to a vector diagram and state both magnitude and direction in your response.

(4)



$\Delta v = v + (-u)$ as shown in 2D diagram ✓

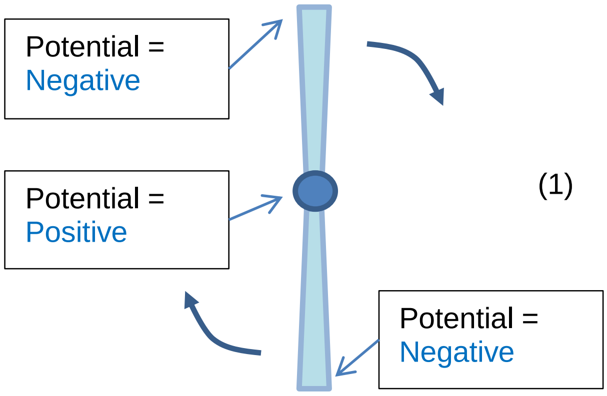
$\Delta v = \sqrt{21^2 + 20^2} = 29.0$ m s^{-1} ✓

➔ = $\tan^{-1}(21/20)$ ✓ = 46.4° = true bearing 1.40° or N 1.40° E ✓

Question 3

The metal rotor blades of a helicopter are shown in the diagram as viewed from above. The helicopter is in Perth where the Earth's magnetic field points upwards with an angle of dip of 66° to the horizon. The blades are turning clockwise.

a. Identify areas of positive or negative electric potential as indicated in the diagram.



(1)

✓

b. Explain how a potential difference is established in this situation.

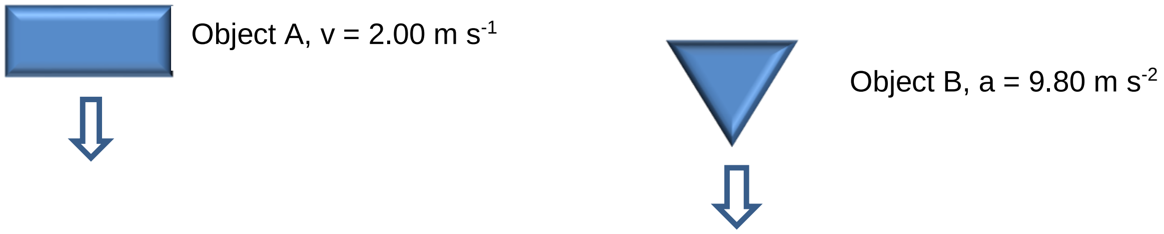
(3)

Charge within the blades is moved in the direction of the arrows through the Earth's magnetic field. ✓ In Perth the component of the field acting upwards from the ground interacts with the circular field established by the moving charges. ✓
Delocalised electrons are pushed to the rotor tips giving them a net negative charge. This leaves a net positive charge at the centre. ✓
Or similar

Question 4

The diagram shows object A falling at a constant speed of 2.00 m s^{-1} towards the ground and object B accelerating at 9.80 m s^{-2} towards the ground. What is the acceleration of object B relative to object A? Explain briefly.

(3)



In the frame of reference of the ground the acceleration of A = zero and B = 9.80 m s^{-2} down. ✓

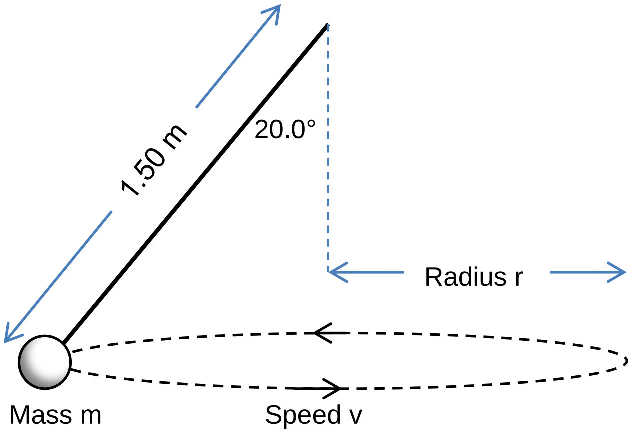
In terms of acceleration the reference frame of the ground and object A is the same. They have no acceleration in each other's reference frame. ✓

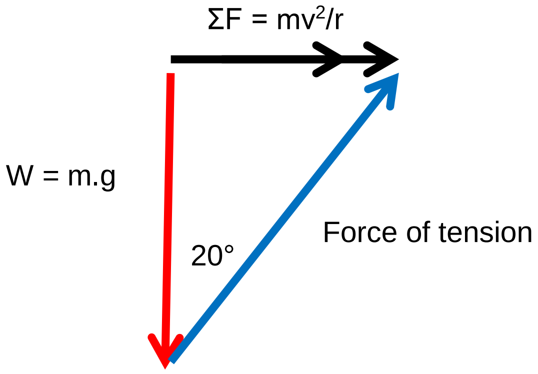
Therefore the acceleration of object B relative to A is 9.80 m s^{-2} down. ✓

Question 5

A ball of mass **m**, suspended from a ceiling moves along a horizontal circle of radius **r** at a constant speed **v**. The string connecting the mass to the ceiling makes an angle of 20.0° to the vertical. The string has a length of 1.50 metres.

Calculate the time taken for the ball to make one revolution.





(4)

From vector diagram of forces: $\Sigma F = mv^2 / r$ $W = m.g$

By substitution of $v = 2\pi r / T$ $\Sigma F = m.4.\pi^2.r / T^2$

$\tan 20° = 0 / A = (m.4.\pi^2.r / T^2) \times (1 / m.g) = (4.\pi^2.r) / (T^2.g)$ ✓

From triangle of displacements:
$\sin 20° = O/H = r / 1.5$ so $r = 1.50 \times \sin 20°$ ✓

$\tan 20 = (4.\pi^2.r) / (T^2.g) = (4.\pi^2 \text{ x } 1.50 \text{ x } \sin 20°) / (T^2 \text{ x } 9.80)$

$T^2 = (4.\pi^2 \text{ x } 1.50 \text{ x } \sin 20°) / (\tan 20° \times 9.80)$ ✓

$T^2 = 5.6782$

$T = 2.38$ seconds ✓

(or similar)

Question 6

A battery supplies current to a DC electric motor in an electric drill. When the motor is allowed to spin freely the revolutions per second are high and the current measured is very low. When the motor in the drill is put under load by drilling a hole, the revolutions per second decrease and the current in the motor increases. Explain why the current is different in each situation.

(3)

When the motor is spinning it is also acting as a generator. The flux within the coil is changing so according to Faraday's Law an emf is established. (back emf)✓

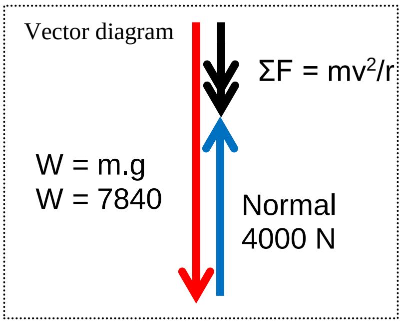
A high rate of rotation = more back emf = less current in coil. ✓

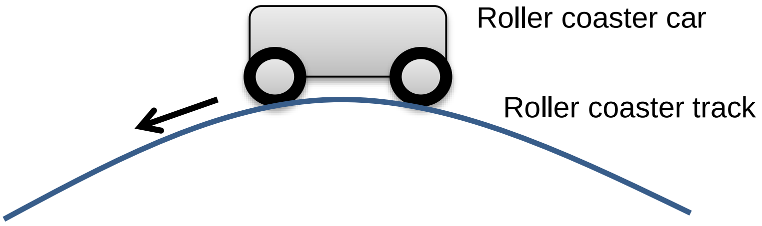
When the rate of rotation of the coil is reduced by drilling a hole, the back emf reduces and the net current increases. ✓

Or similar

Question 7

A roller coaster car of mass 800 kg is going over the apex of a circular section of track. The car has a speed of 6.00 m s^{-1}. Calculate the radius of the curve for the car to experience a normal reaction force of 4000 N from the track. You must refer to a vector diagram in your answer.





(4)

Vector diagram ✓

W = 800 x 9.8 = 7840 N down

From vector diagram $\Sigma F = 7840 - 4000 = 3840$ N to centre ✓

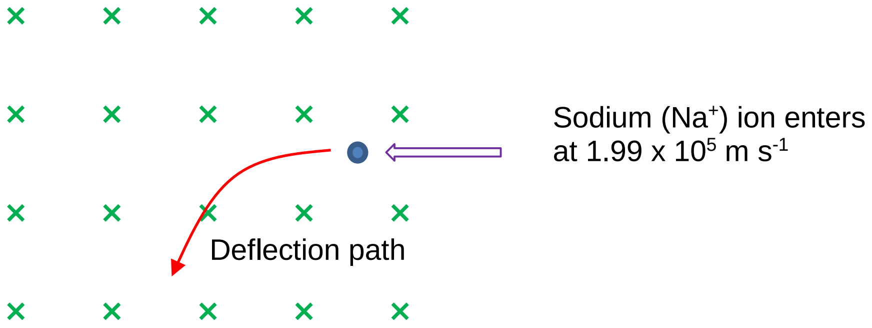
$\Sigma F = mv^2 / r = 3840$ N

$r = mv^2 / 3840$ $r = 800 \times 6^2 / 3840$ ✓ = 7.50 m ✓

(Or similar alternative derivations)

Question 8

A sodium ion with a single positive charge and a mass of mass 3.82 x 10^{-26} kg enters a uniform magnetic field of flux density 0.258 T at a speed of 1.99 x 10^5 m s^{-1} as shown in the diagram below.



a. Calculate the magnetic force acting on the sodium ion.

(2)

$F = qvB$

$F = 1.60 \times 10^{-19} \times 1.99 \times 10^5 \times 0.258$

$F = 8.21 \times 10^{-15}$ N ✓

b. Sketch an arrow on the diagram and label it "deflection" to indicate which direction the sodium ion will be deflected.

(1)

Shows path ✓

c. Calculate the radius of the deflected path.

(3)

$qvB = mv^2 / r$ concept ✓

$r = mv / Bq$

$r = (3.82 \times 10^{-26} \times 1.99 \times 10^5) / (0.258 \times 1.60 \times 10^{-19})$ ✓

$r = 0.184$ m ✓

Question 9

An astronomer is viewing light from a star in a distant galaxy.

a. Explain how the astronomer can use the light that passed through the relatively cool outer layer of a star to predict its chemical composition.

(2)

Line absorption spectra can be identified. The lines are specific to each element and correspond to removal of photons by excitation between energy levels within that element. They can be matched with patterns from prior testing done on Earth. ✓ ✓

Or similar.

b. What is it about the spectrum of the starlight that tells the astronomer that the galaxy is receding?

(2)

The patterns are "red shifted". This means all wavelengths are slightly increased (although the pattern remains the same) because the source of em radiation is moving away from observers on Earth.

✓ ✓

Or similar.

c. When compared to a galaxy that is closer to Earth, Hubble's Law tells us that the closer galaxy is likely to be:

(Circle a response and briefly explain)

(2)

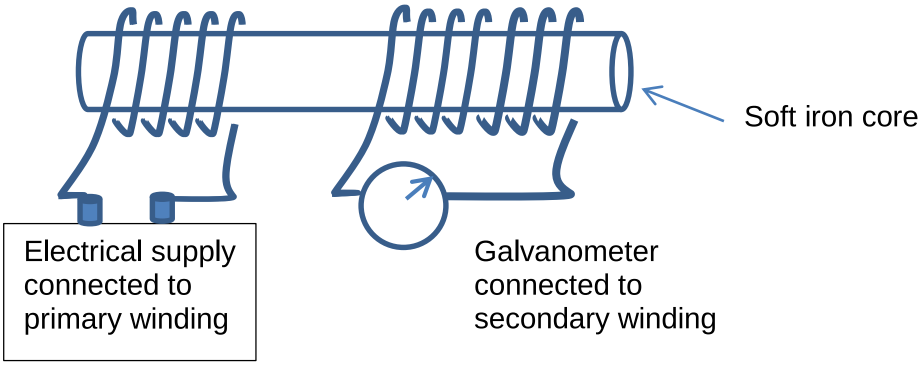
Approaching Receding at the same speed Receding faster [✓ Receding slower]

According to Hubble's Law the recession velocity of a distant galaxy is proportional to its distance from Earth. ✓

Or similar.

Question 10

A simple transformer design is shown in the diagram.



a. Explain, with reference to Faraday's Law, how emf can be established in the secondary coil. (2)

The electrical supply drives current in the primary winding. This current establishes a magnetic field in the primary winding which links into the secondary. ✓
According to Faraday's law, if this field is changing an emf will be established in the secondary winding. ✓
Or similar.

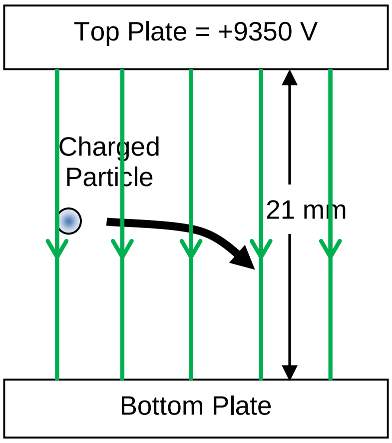
b. Explain the function of the soft iron core. (1)

It concentrates the field lines to ensure an efficient flux linkage. ✓
Or similar.

c. How will the magnitude of the voltage on the secondary winding compare to the voltage on the primary winding? (1)

It will be higher (as there are more turns). ✓

Question 11



A positively charged particle enters a region between two parallel plates set at different voltages. The distance between the plates is 21.0 mm. The electric field strength in the region between the plates is 3.50×10^5 V m^{-1}.

a. Calculate the voltage of the bottom plate.

(3)

d = 0.0210 m $E = 3.50 \times 10^5$

E = V / d   so   V = E x d

$V = 3.50 \times 10^5 \times 0.0210$ ✓

V = 7350 V difference ✓

So voltage of bottom = 9350 – 7350

= +2000 V ✓

b. The charged particle experiences a force of magnitude 1.40×10^{-11} N that causes it to deflect towards the bottom plate. Determine the magnitude of charge of the particle.

(2)

$E = 3.50 \times 10^5$ $F = 1.40 \times 10^{-11}$ N   q = ?

E = F / q   So q = F / E = $1.40 \times 10^{-11} / 3.50 \times 10^5$ ✓

$q = 4.00 \times 10^{-17}$ C ✓

c. Use five lines with arrowheads to indicate the uniform electric field in the region between the plates.

(1)

Shown on diagram above ✓

Question 12

In the Standard Model hadrons are particles that are composed of quarks. A baryon is composed of three quarks e.g. utb. A meson is composed of two quarks – one quark is normal matter and the other is an antimatter quark e.g. $d\bar{s}$. A table of quarks is shown below left.

Complete the table below right by giving examples of quark combinations that could make the hadrons described.

(4)

Quark	Charge (e)
Up (u)	$+\frac{2}{3}$
Down (d)	$-\frac{1}{3}$
Top (t)	$+\frac{2}{3}$
Bottom (b)	$-\frac{1}{3}$
Charm (c)	$+\frac{2}{3}$
Strange (s)	$-\frac{1}{3}$

Hadron	Charge (e)	Quark combination
A positively charged baryon	+2	e.g. utc ✓
A neutral baryon	0	e.g. udb ✓
A negatively charged meson	-1	e.g. $d\bar{t}$ ✓
A positively charged meson	+1	e.g. $c\bar{s}$ ✓

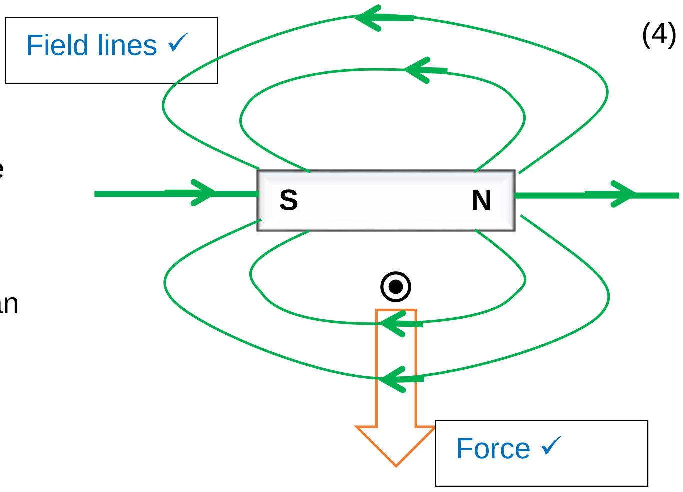
Question 13

(4)

a) The diagram at right shows a permanent magnet and a wire carrying current.

i. Sketch 6 lines to indicate the field of the magnet.

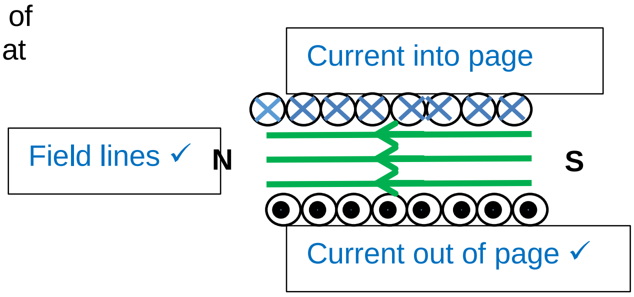
ii. Indicate on the diagram the direction of magnetic force acting on the wire with an arrow labelled "force".



b) The diagram at right shows a cross section of a powered solenoid. The magnetic polarity at each end of the solenoid is shown.

ii. Shown on the diagram, the direction of current that will establish this field.

iii. Sketch 3 magnetic field lines within the solenoid core.



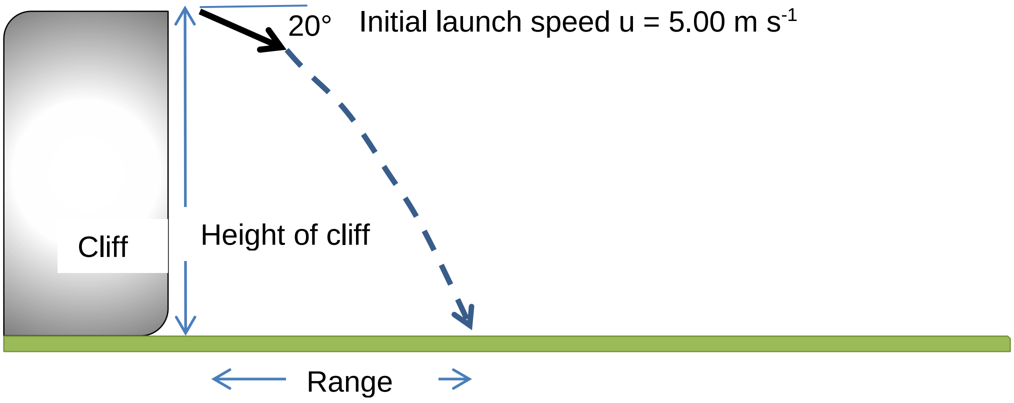
End of Section One

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 (13 marks)

A physics student observes a stone of mass 380 g being catapulted from the top of a cliff. The stone takes a time of 4.00 s to reach the ground. The initial launch speed u is at an angle of 20.0° below the horizontal. You may ignore air resistance for the calculations.



a. Calculate the height of the cliff.

(3)

Let up be positive (or alternative defined reference frame)

u (vertical) = u.sin θ (down) = -(5 x sin 20) = -1.71 m s^{-1}

t (flight) = 4.00 s a = -9.80 m s^{-1} ✓

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

$s = (-1.71 \times 4) - (4.9 \times 4^2)$ ✓

s = -85.24 m

Height of cliff = 85.2 m ✓

b. Calculate the horizontal range of the stone.

(3)

u (horizontal) = u.cosθ (right) = (5 x cos 20) = 4.6984631 m s^{-1} right
t (flight) = 4.00 s a = 0 ✓

s = u (horizontal) x t
s = (4.6984631 x 4) ✓
s = 18.79385 m

s (horizontal) = 18.8 m right ✓

c. Calculate the kinetic energy of the stone after 3 seconds.

(4)

u (horizontal) = 4.6984631 m s^{-1} right t = 3.00 s

v (vertical) = u + at
v = -1.71 + (-9.80 x 3) = -31.11 m s^{-1} down ✓

speed after 3 seconds = $\sqrt{-31.11^2 + 4.6984631^2} = 31.4629\ m\ s^{-1}$ ✓

KE = $\frac{1}{2}$ m v^2 = $\frac{1}{2}$ x 0.38 x 31.4629^2 ✓= 188 J ✓

d. The final velocity of the stone is achieved as the stone reaches ground level. If the stone had been catapulted at the same launch speed but at an angle of 20° above the horizontal how would the magnitude of final velocity compare to a launch 20° below the horizontal. Circle a response and explain briefly.

(3)

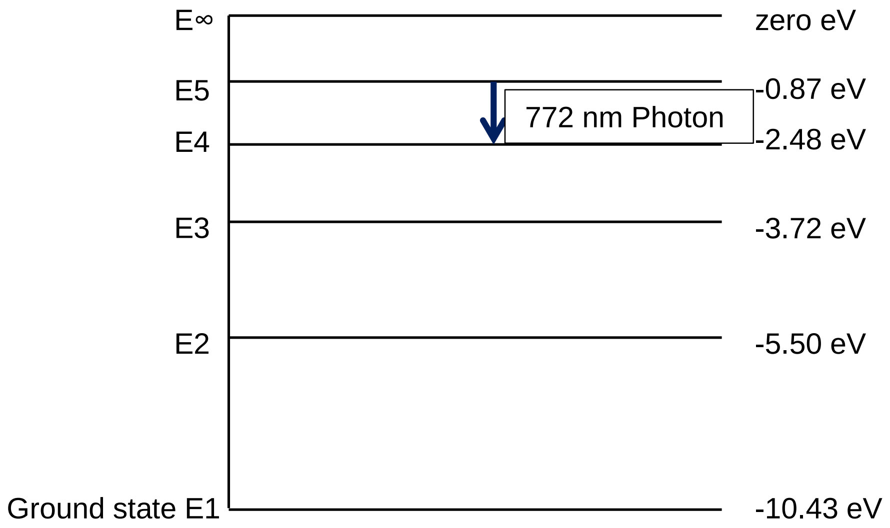
final velocity greater [✓ final velocity the same ✓] final velocity less

u (horizontal) = is constant and is the same value whether launched at an angle above or below the horizontal.
If launching above horizontal then u (vertical) is positive, below the horizontal u (vertical) is the same magnitude but negative ✓

When calculating the vertical component of velocity at a given displacement we use the equation $v^2 = u^2 + 2as$
u^2 is the same value whether u is positive or negative, this leads to the same result for the final velocity (vertical) and the final velocity in 2 dimensions. ✓ (or by using conservation of ME or other similar)

Question 15 (16 marks)

A fluorescent light contains low pressure mercury vapour. When atoms of mercury are bombarded by high speed electrons they emit Ultraviolet photons. These UV photons strike a coating on the inside of the lamp causing it to fluoresce and emit visible light. The diagram below details some of the energy levels for Mercury.



a. Calculate the minimum speed of a bombarding electron that could ionise a ground state mercury atom.

(4)

E (J) = $10.43 \times 1.60 \times 10^{-19}$ ✓ = 1.6688×10^{-18} J ✓

Mass electron = 9.11×10^{-31} kg

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

$1.6688 \times 10^{-18} = \frac{1}{2}\, 9.11 \times 10^{-31} \times v^2$ ✓ (or rearranges $v^2 = \frac{2.KE}{m}$)

v = 1.91×10^6 m s^{-1} ✓

b. Is it possible for a mercury atom to absorb a 10.5 eV photon? Explain briefly.

(2)

Yes, ✓ the energy above 10.43 eV will be in the form of kinetic energy of the ionised atomic electron. ✓

c. Explain why the mercury atom can emit several photon wavelengths but not a continuous emission spectrum.

Line emission is possible when atomic electrons transition down the fixed energy levels of mercury, this allows several photon wavelengths to be emitted✓✓ (The atoms are well separated and independent in the vapour).
Continuous emission occurs in (higher density) substances where energy levels overlap and a vast number of emissions occur across a spectrum of frequencies.

d. The mercury atom can also emit a visible 772 nm photon. Identify the transition on the diagram with an arrow and label the transition "772 nm photon". You must provide supporting calculations to justify your answer.

(4)

$f = \frac{c}{\lambda}$ $E = h\frac{c}{\lambda} = \frac{6.63 \times 10^{-34} \times 3 \times 10^{8}}{772 \times 10^{-9}}$ ✓= 2.57×10^{-19} J ✓

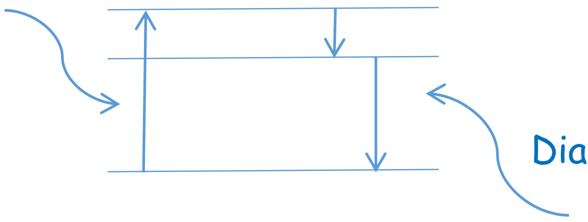
E (eV) = $2.57 \times 10^{-19} / 1.60 \times 10^{-19} = 1.61$ eV ✓

Only possible transition is E5 to E4 (2.48 - 0.87) shown on diagram✓

e. When UV photons strike the phosphor coating on the inside of the lamp the coating "fluoresces". Explain this process with reference to a simple energy level diagram.

(3)

Fluorescence is when materials emit visible light as a result of absorbing electromagnetic radiation. E.g. in this context a UV photon excites atomic electrons up 2 or more energy levels. De-excitation occurs in 2 or more steps down resulting in the emission of visible photons. ✓ ✓ Or similar.



Excitation by UV photon

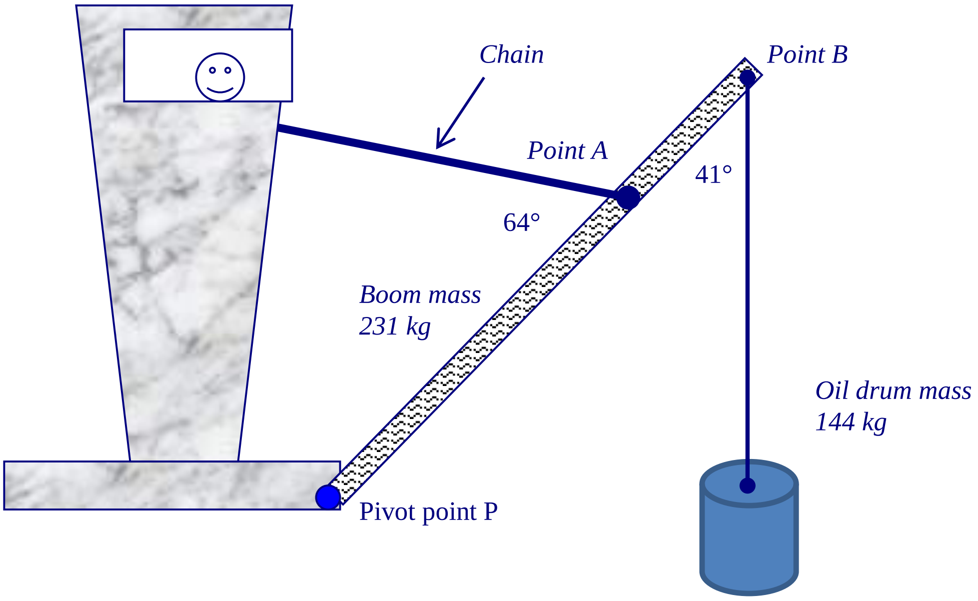
Diagram ✓

Visible light emitted on de-excitation

Question 16 (9 marks)

A crane at Fremantle port is unloading an oil drum from a ship.

- The boom of the crane has a mass of 231 kg and is pivoted at point P.
- The oil drum of mass 144 kg is suspended from point B. Its rope makes an angle of 41° with the boom.
- A chain attached at point A is holding the boom in position. The distance from P to A is 3.80 m.
- The chain makes an angle of 64° with the boom.
- The boom has a length of 4.50 m from P to B with uniform mass distribution.



a. Demonstrate by calculation that the tension in the chain = 2.20 x 10^3 N.

(4)

Consider boom in static equilibrium, $\Sigma M = 0$

Select pivot at P and take moments

$\Sigma acwm = \Sigma cwm$ Concept ✓

$3.80 \times F_T \times \sin 64$ ✓ $= (4.50 \times 144 \times 9.8 \times \sin 41) + (2.25 \times 231 \times 9.8 \times \sin 41)$ ✓

$F_T = 7507.9 / (3.80 \times \sin 64)$

$F_T = 2198.23 = 2.20 \times 10^3$ N ✓

b. Calculate the magnitude of the **reaction force** acting on the boom from the pivot.

(3)

Consider boom in static equilibrium, ΣF = 0

Construct vector diagram (or solve by components) (Concept)

θ = 180 – (41+64) = 75°

Combined weight = (231 + 144) x 9.8 = 3675 N down ✓

By Cosine Rule $R^2 = W^2 + T^2 - 2.W.T.\cos 75°$ (state this basis)

$R^2 = 3675^2 + 2200^2 - 2 \times 3675 \times 2200 \times \cos 75°$ ✓

R = 3763 = 3.76 × 10^3 N ✓

c. Calculate the direction of the **reaction force** acting on the boom from the pivot.

(2)

By Sine rule $\frac{T}{\sin\Phi} = \frac{R}{\sin 75}$

$\sin\Phi = \frac{T \times \sin 75}{R} = \frac{2200 \times \sin 75}{3763}$ ✓

$\sin\Phi = 0.56471879$

Φ = 34.4° from vertical (or 55.6° above horizontal)

Must correspond to angle shown on diagram. ✓

A solution using components in vertical and horizontal is also possible.

Question 17 (12 marks)

A circular coil is placed in the uniform magnetic field between 2 magnetic poles such that the plane of the coil is perpendicular to the field lines. The circular coil has a diameter of 16.0 cm and is made from 150 turns of wire. The magnetic field has a flux density of 186 mT. The right edge of the coil is initially 2 cm from the limit of the field. The coil is moved to the right at a constant speed of 40 cm s^{-1} for 0.500 seconds.

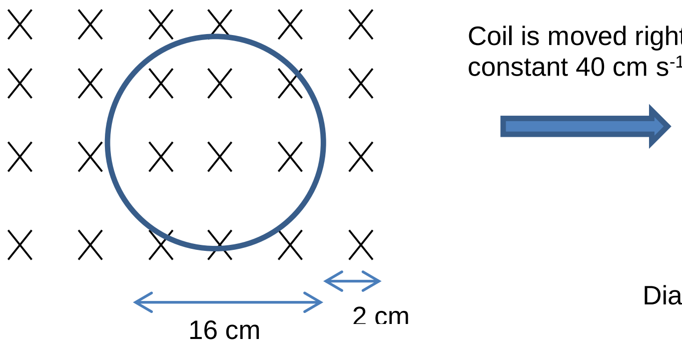


Diagram 1

a. Calculate the magnetic flux enclosed by the coil when it is fully within the magnetic field. (2)

$A = \pi.r^2 = \pi \times (0.08)^2$ $B = 0.186$ T

$\Phi_1 = B.A = 0.186 \times \pi \times (0.08)^2$ ✓ $= 3.74 \times 10^{-3}$ Wb ✓

b. Calculate the **average** value of induced emf as the coil is removed from the field (4)

Time taken to remove coil = s / v = 0.16 /0.40 ✓= 0.400 s ✓

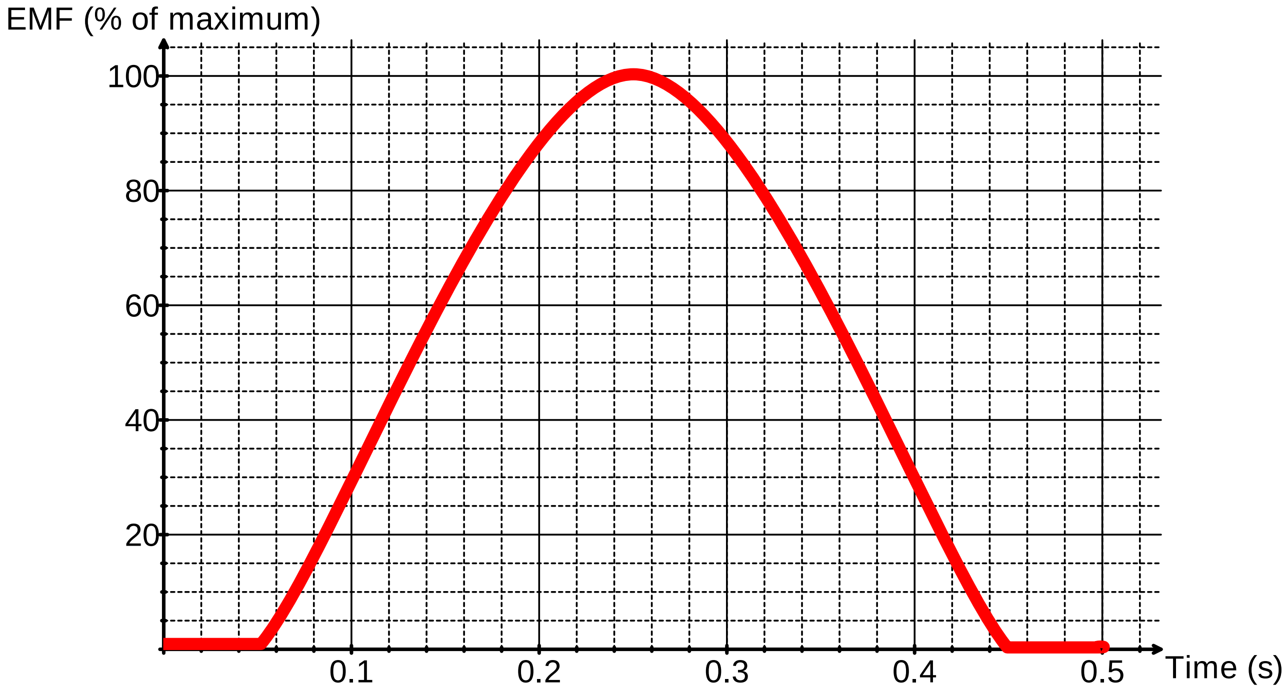
$\Phi_2 = 0$

(Note: for first 2 cm of travel the flux within the ring does not change)

emf = $-N (\Phi_2 - \Phi_1) / t$

emf = $-150 (0 - 3.74 \times 10^{-3}) / 0.400$ ✓

emf = 1.40 V ✓



c. On the graph above sketch the approximate shape of the emf versus time as the circular coil is moved right from the start position shown in diagram 1. Pay careful attention to the time axis. Briefly explain the shape of your graph.

(4)

Curve correctly sketched ✓ Explain curve features – emf starts after 0.05 s (time taken for coil to move 2 cm right) ✓ emf is proportional to rate of change of flux within coil which increase from zero to a maximum as middle of coil exits field and then decreases back to zero. ✓

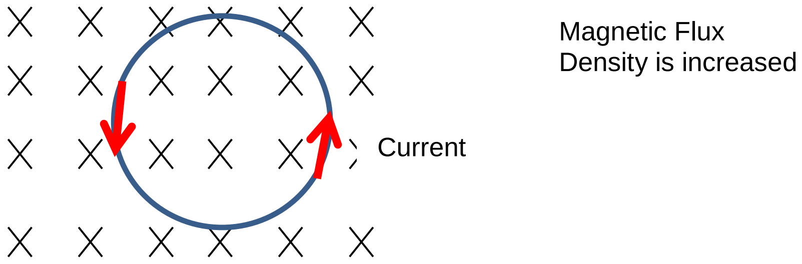
Coil is exiting field for a time of 0.400 s (s/t = 0.16/0.40). ✓

.

The diagram below shows the circular coil in the magnetic field in another experiment.

d. Show the direction of induced current if the magnetic flux density increases. Draw an arrow on the coil to indicate current direction and label it 'current'. Briefly explain your answer.

(2)



Current is anti-clockwise ✓ According to Lenz's law – a current will establish in a direction so that its field will oppose the change that caused. ✓ (so its field out of page opposes increase of flux into page).

Question 18 (16 marks)

Kepler-186f is a planet in orbit around the red dwarf star Kepler-186. A full public announcement about the planet was made by NASA on 17 April 2014. It is the first discovery of a planet with a similar radius to that of Earth in the habitable zone of another star.

Kepler-186f is a distance of 151 ± 18 parsecs from Earth (1 parsec = 3.26 Light Years). It has an orbital radius of 0.391 AU from its host star (The Astronomical Unit (AU) = Sun-Earth distance). It has an orbital period of 129.9 days.

a) Calculate the speed of Kepler-186f around its host star

(3)

Orbital radius = $0.391 \times 1.50 \times 10^{11} = 5.87 \times 10^{10}$

Orbital period = $129.9 \times 24 \times 60 \times 60 = 11\ 223\ 360$ s ✓

$v = 2\pi r / T = (2 \times \pi \times 5.87 \times 10^{10}) / 11\ 223\ 360$ ✓

$v = 3.28 \times 10^4$ m s^{-1} ✓

b) Calculate the mass of the host star Kepler-186 based on the information given.

(4)

Orbital radius = $0.391 \times 1.50 \times 10^{11} = 5.87 \times 10^{10}$

Orbital period = $129.9 \times 24 \times 60 \times 60 = 11\ 223\ 360$ s

$v = 3.28 \times 10^4$ m s^{-1} ✓

$a_{centripetal} = v^2 / r$ = gravitational field strength = GM / r^2

$M = (v^2 \times r) / G$ ✓

$M = ((3.28 \times 10^4)^2 \times 5.87 \times 10^{10}) / (6.67 \times 10^{-11})$ ✓

$M = 9.48 \times 10^{29}$ kg ✓

Alternatively

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

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

c) The mass of the planet Kepler-186f is difficult to estimate and is thought to be in a range of 32% to 377% the mass of the Earth. Explain how this high degree of uncertainty affects estimates for the mass of the host star.

(2)

The equations used to calculate the mass of the host star do not use the mass of the planet e.g. $M = (r^3 \times 4\pi^2) / (6.67 \times 10^{-11} \times T^2)$ or $M = (v^2 \times r) / G$ ✓

So this variation in mass for the planet has no effect on estimating the mass of the star ✓

d) The radius of the planet Kepler-186f is 1.11 ± 0.14 times that of the Earth. Use this information and the uncertainty range for the mass of Kepler-186f to calculate the possible range for the gravitational field strength on the surface of the planet compared to "g" on Earth.

(3)

Highest value of field strength when planet radius is minimum and mass is maximum. Lowest value when radius maximum and mass minimum (concept) ✓

$g = GM/r^2$

r (min) = 1.11 – 0.14 = 0.97R m (max) = 3.77M

r (max) = 1.11 + 0.14 = 1.25R m (min) = 0.32M

$g_{maximum} = G \times 3.77 \times M / (0.97 \times R)^2 = 4.01g$ ✓

($g_{maximum}$ = 39.2 N kg^{-1} if calculated)

$g_{minimum} = G \times 0.32 \times M / (1.25 \times R)^2 = 0.205g$ ✓

($g_{minimum}$ = 2.00 N kg^{-1} if calculated)

e) Calculate the percentage uncertainty (relative uncertainty) for the distance from Earth to Kepler-186f.

(1)

151±18 parsecs

Relative uncertainty = 18/151 = 0.119 = 11.9% ✓ (151 ±11.9%)

f) The SETI institute (Search for Extra-Terrestrial Intelligence) in California started to listen to radio emissions from Kepler-186f in April 2014. As yet, no signals attributable to intelligent life have been detected. If such a signal was detected in 2014 what would be the latest year in Earth history that the signal was transmitted from Kepler-186f?

(3)

Latest transmission = shortest distance = 151 -18 = 133 parsecs ✓

133 parsecs = 133 x 3.26 Light Years = 433.58 Light Years ✓

2014 – 433.58 = the Earth year 1580 ✓

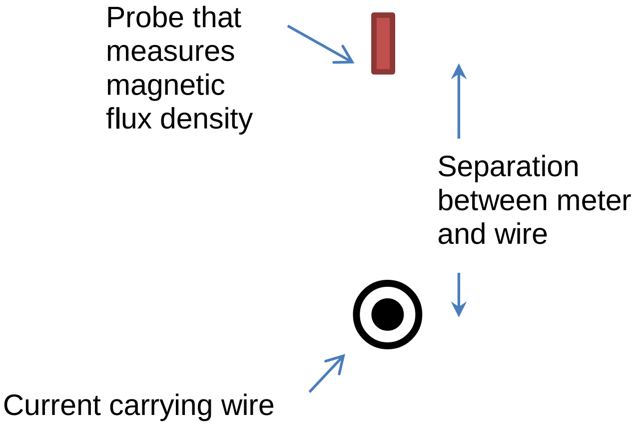
Question 19 (16 marks)

Some university students are investigating the circular magnetic field formed around a long straight wire carrying electrical current. They use a probe that measures magnetic flux density at different radii of separation from the wire.

The students know that the magnetic flux density decreases with increasing distance from the wire.

The students put a 90 cm straight length of wire between two clamps such that no objects (other than the probe) are closer than 40 cm to the centre of the wire.

A steady current of 2200 A is fed into the wire from an external power supply.



The probe that measures magnetic flux density is placed at set distances from the middle of the wire and measurements recorded.

The students analyse the difficulty obtaining a precise measurement of magnetic flux density and decide to record this data with an uncertainty of ±7%.

The magnetic flux density B, due to a current I, passing in a wire is given by the expression:

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

Where, μ_0 = the permeability of free space (H m^{-1}), which is a measure of the extent to which the surrounding medium reinforces the magnetic field.

r = radius of separation (m)

The results obtained are as follows:

Radius of separation (m)	**1/r (m^{-1})**	**Magnetic Flux Density (x 10^{-3} T)**
0.065	15.4	6.70 ± 0.47
0.080	12.5	5.90 ± 0.41
0.100	10.0	4.50 ± 0.32
0.125	8.0	3.50 ± 0.25
0.200	5.0	2.10 ± 0.15
0.500	2.0	0.90 ± 0.06

Answer the following questions:

a. Complete the second column of the table $\frac{1}{r}$, so that you can plot a straight line graph. One value has been done for you.

As table values ✓ (1)

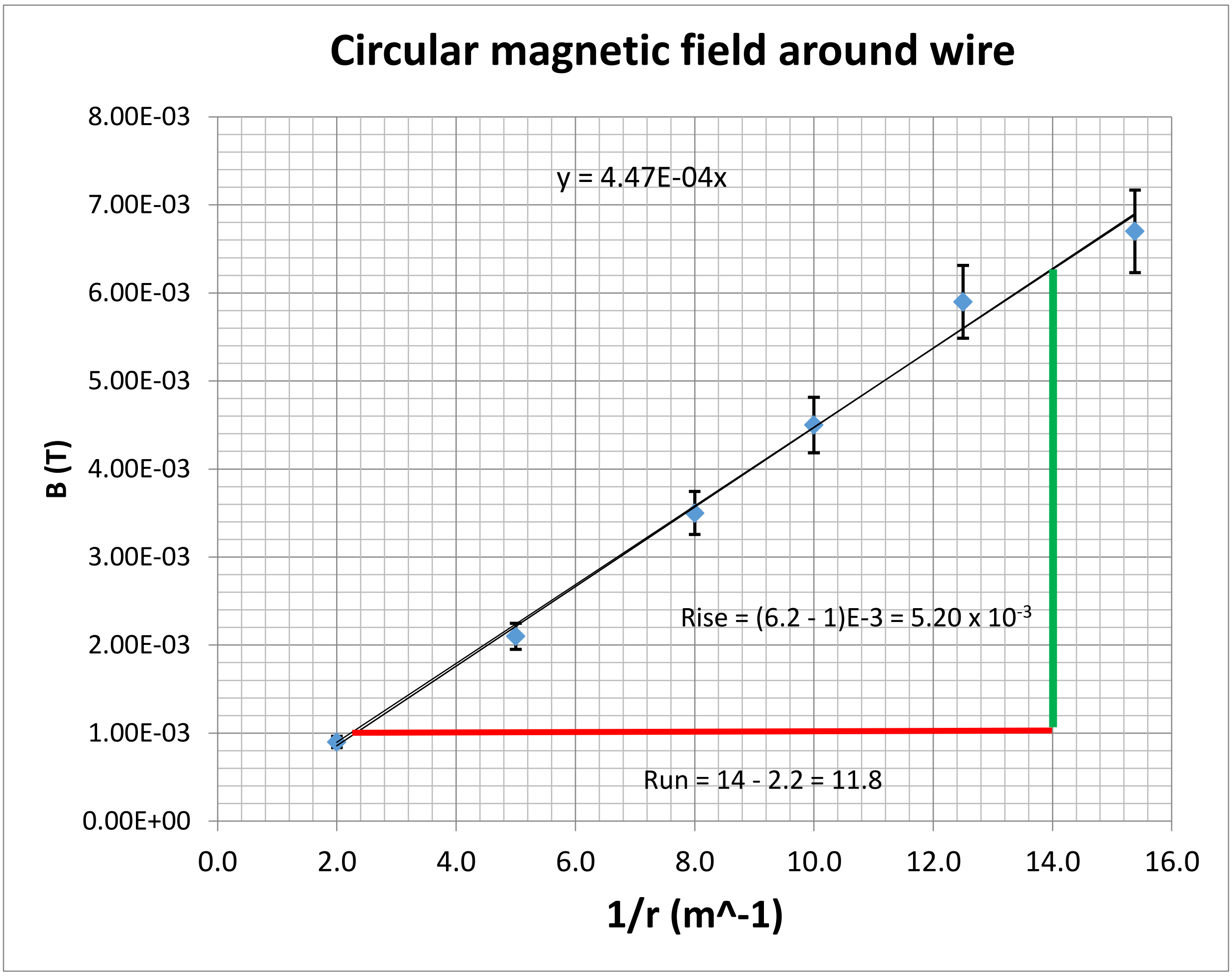
b. Complete the third column of the table **(Magnetic Flux Density)** to include the uncertainty for each measurement. Two values have been done for you.

As table values ✓ (1)

c. Plot a graph of Magnetic Flux Density (B) on the vertical axis versus $\frac{1}{r}$ 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.

(3)

Clearly show rise and run construction lines on the graph✓

gradient = 0.0052/11.8 ✓ = 4.41 x 10^{-4} T m ✓

e. Determine the value of $\boldsymbol{\mu_0}$, the permeability of free space, from the value of the gradient that you obtained. (If you could not determine the gradient use the numerical value 4.40 x 10^{-4}).

(3)

$\frac{\mu_0 I}{2\pi}$ = 4.40 x 10^{-4} I = 2200 A

$$\mu_0 = \frac{4.40 \text{ x } 10^{-4} \times 2\pi}{2200} = 1.26 \times 10^{-6}$$

f. Describe a possible source of experimental error in this experiment.

(2)

For example

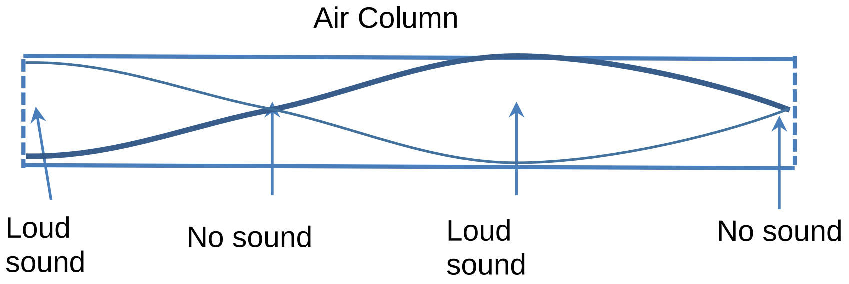
The Earth's magnetic field could be adding to the circular field being measured causing a systematic error. ✓ ✓
Or other valid point.

Spare graph paper

(3)

Question 20 (8 marks)

The diagram shows an air column that is resonating because a standing wave has formed inside it. A small microphone can slide inside the pipe without interfering with the standing wave. The microphone has detected loud regions and regions with no sound associated with this standing wave.



a) Sketch the standing wave envelope for pressure variation within this air column. ✓

(1)

b) Explain briefly why there are loud regions and regions with no sound.

(2)

Sound waves are travelling along the pipe and reflecting from each end.
The standing wave is an interference pattern of the incident waves and reflected rays.
Loud spots are points of constructive interference and no sound heard at points of destructive interference. (Or similar) ✓ ✓

c) The air column has an effective length of 36.0 cm. The speed of sound in air is 346 m s^{-1}. Calculate the frequency of this standing wave.

(3)

$\frac{3}{4}$ λ = 0.36 m ✓
λ = 0.480 m

f = v / λ = 346 / 0.480 ✓ = 721 Hz ✓

d) Calculate the frequency produced by the air column if it were vibrating in its fundamental mode.

(2)

$\frac{1}{4}$ λ = 0.36 m
λ = 1.44 m

f = v / λ = 346 / 1.44 ✓ = 240 Hz ✓

End of Section 2

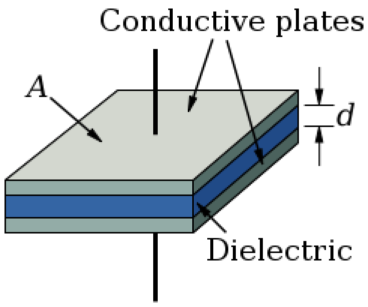
Section Three: Comprehension 20% (36 Marks)

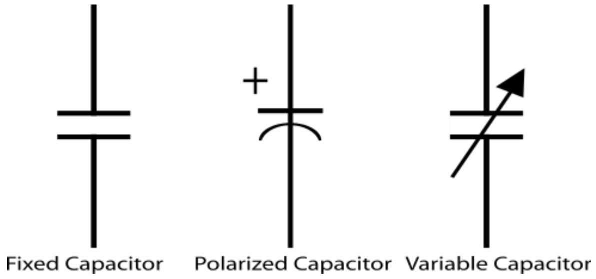
This section contains **two (2)** questions. You must answer both questions. Write your answers in the space provided. Suggested working time for this section is 40 minutes.

Question 21 Electric Fields, Capacitance and Dielectrics (18 marks)

When an electric potential difference is connected across 2 parallel plates in a circuit then opposite charges are established on each plate and an electric field is formed between them.

This arrangement of parallel plates is referred to as a capacitor and is an energy storage device. A battery can be used to apply a potential difference across a capacitor so that it becomes charged. If the battery is removed the capacitor can hold the charge. If the charged capacitor is connected to a circuit component it will deliver its charge to that component.





Circuit symbols for capacitors

Capacitors can be used when a rapid discharge of energy is required. (Batteries supply charge at a much slower rate). For this reason they are the basic component in camera flashes, Tasers and heart defibrillators. A defibrillator is a device that administers a controlled electric shock to a person experiencing cardiac arrest.

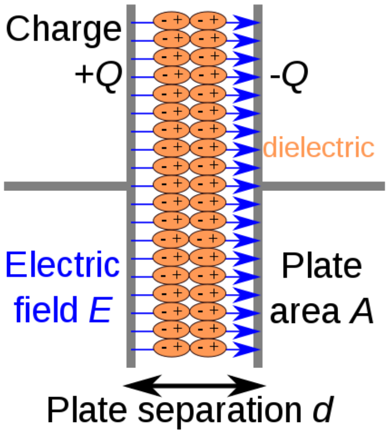
Capacitors are widely used in electronic circuits for blocking direct current while allowing alternating current to pass. In analogue filter networks, they smooth the output of power supplies. In resonant circuits they tune radios to particular frequencies. In electric power transmission systems, they stabilize voltage and power flow.

Some of the basic equations governing capacitors are shown below:

$$C = \frac{Q}{V} \qquad C = k.\epsilon_o.\frac{A}{d} \qquad E_p = \frac{1}{2}QV$$

C = capacitance (F - farads)
ε_0 = permittivity of free space (8.854×10^{-12} F m^{-1})
k = the relative permittivity of a dielectric
A = the surface area of each parallel plate (m^2)
Q = magnitude of charge on each plate (C)
V = potential difference across the capacitor. (V)
d = plate separation (m)
E_p = electric potential energy stored in a capacitor (J)

A material called a **dieletric** is placed in the gap between the parallel plates. The dielectric acts to increase the capacitor's charge capacity. A dielectric material is classified as an insulator. In order to maximise the charge that a capacitor can hold, the dielectric material needs to have as high a permittivity as possible, while also having as high a breakdown voltage as possible.



Schematic of a parallel plate capacitor with a dielectric spacer. Two plates each with area A are separated by a distance d. When charge is established on the plates, an electric field exists in the region between the plates. The dielectric material becomes polarised due to the charge displacement and increases the capacitance.

The permittivity of a medium describes how much electric field is 'generated' per unit charge in that medium. More electric field exists in a medium with a high permittivity (per unit charge) because of polarization effects. Permittivity is directly related to electric susceptibility, which is a measure of how easily a dielectric polarizes in response to an electric field. Thus, permittivity relates to a material's ability to transmit (or "permit") an electric field.

Above a particular electric field strength, known as the dielectric strength, the dielectric in a capacitor becomes conductive. The voltage at which this occurs is called the breakdown voltage of the device, and is given by the product of the dielectric strength and the separation between the conductors.

A table of information relating to dielectric materials is shown below.

Dielectric material	**Relative Permittivity k**	**Dielectric Strength ($V\ m^{-1}$)**
Air/Vacuum	1	
Paper	3.85	15×10^6
Oil	4.00	12×10^6
Neoprene rubber	6.70	12×10^6
Mica	7.00	150×10^6
Strontium titanate	300	8×10^6

Questions

a) A defibrillator is a device used to resuscitate victims after a heart attack. Explain why defibrillators use capacitors rather than batteries.

(2)

Batteries deliver charge too slowly. ✓

Capacitor provides a rapid discharge required for this application ✓

b) Two plates of a capacitor hold +2500 μC and -2500 μC of charge respectively when the potential difference across the plates is 850 V. Calculate the capacitance of this capacitor.

(3)

$C = Q / V$ ✓ $= 2500 \times 10^{-6} / 850$ ✓ $= 2.94 \times 10^{-6}$ F ✓

Must have correct units

c) A capacitor consists of two square parallel plates separated by 0.17 mm with a mica dielectric material. The capacitor is rated at 22 nF. Calculate the side length of each square plate.

(4)

$d = 0.17 \times 10^{-3}$ $C = 22 \times 10^{-9}$ $A = \text{length}^2$ k (mica) = 7 ✓

$$C = k.\epsilon_0.\frac{A}{d}$$

re-arranging

$$A = \frac{C.d}{k.\epsilon_0}$$ ✓ (concept) $$A = \frac{22 \times 10^{-9} \times 0.17 \times 10^{-3}}{7 \times 8.854 \times 10^{-12}}$$ ✓

$A = 0.06034999$

$\ell = \sqrt{0.06034999} = 0.246$ m ✓

d) Calculate the breakdown voltage for the capacitor in the previous question.

(2)

d = 0.17 x 10^{-3} E = 150 x 10^{6}

$E = \frac{V}{d}$ $V = E \times d$

V = 150 x 10^{6} x 0.17 x 10^{-3} ✓

V = 2.55 x 10^{4} V ✓

e) For the capacitor in the previous question describe three (3) physical design changes that would increase its capacitance. (do not refer to charge or voltage as part of your response)

(3)

Increase plate surface area ✓

Decrease plate separation ✓

Increase relative permittivity with a different dielectric ✓

f) Explain why aluminium foil is not suitable as a dielectric material.

(2)

Dielectric needs to be an insulator ✓

Aluminium is a conductor ✓

g) The potential energy stored by a capacitor can also be stated as: $E_P = \frac{1}{2}CV^2$. Derive this formula from equations in the passage.

(2)

$E_p = \frac{1}{2}QV$ $C = \frac{Q}{V}$ $therefore\ Q = C.V$

By substitution

$$E_p = \frac{1}{2}C.V.V \quad ✓$$

Therefore $E_P = \frac{1}{2}CV^2$. ✓

Question 22 Satellites, Space Probes and Relativity (18 marks)

The Global Positioning System (GPS) is a satellite-based navigation system that was originally developed by the US military but is now accessible to the general public in cars and on smart phones. It is a network of 24 satellites in high orbits around the Earth. Each satellite is at an altitude of about 20,000 km above the ground, and has an orbital speed of about 14,000 km hr^{-1} with an orbital period of approximately 12 hours. The satellite orbits are distributed so that at least 4 satellites are always visible from any point on the Earth at any given instant. Each satellite carries with it an atomic clock that "ticks" with an accuracy of 1 nanosecond.

To achieve the level of precision required for reliable navigation, the clock ticks from the GPS satellites must be known to an accuracy of 20-30 nanoseconds. However, because the satellites are constantly moving relative to observers on the Earth, effects predicted by the Special and General theories of Relativity must be taken into account.

Because an observer on the Earth sees the satellites in motion relative to them, Special Relativity predicts that the clocks on the satellites are ticking more slowly by 7 microseconds per day in the frame of reference of the Earth. This can be demonstrated by use of the formulas below.

For Special Relativity:

Time dilation can be calculated using the formula:

$$t_v = \gamma . t_0$$

Where γ is the time dilation factor given by:

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

t_v = time between “clock ticks” on a moving object

t_0 = time between “clock ticks” in a stationery reference frame
The units of time are arbitrary but must be the same for t and t_0

v = the speed of the moving object (m s^{-1})

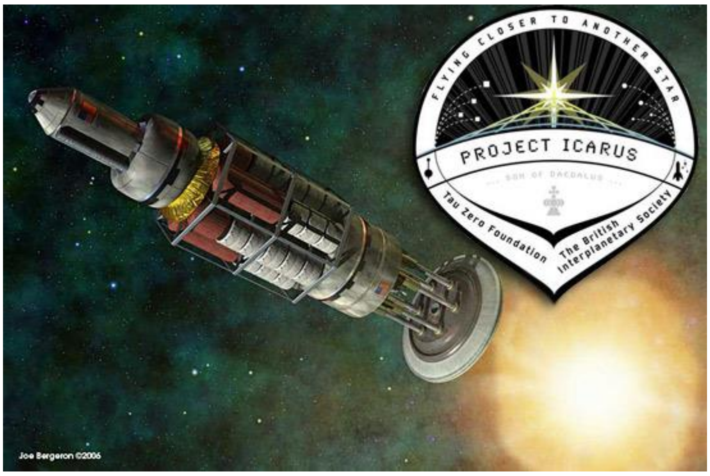
c = speed of light in a vacuum (m s^{-1})

General Relativity states that time passes at a slower rate in regions where gravitational field strength is stronger. This is known as gravitational time dilation and is often referred to in the context of the “curvature of space-time”. The GPS satellites are in orbits high above the Earth, where the curvature of space-time due to the Earth's mass is less than it is at the Earth's surface. General Relativity results in a difference of 45 microseconds per day for time on the GPS satellites compared to the surface of the Earth.

The combination of these two relativistic effects means that the clocks placed on-board each GPS satellite must be calibrated on Earth so that when in orbit they tick at the same rate as Earth based clocks. If these effects were not properly taken into account, a navigational fix based on the GPS constellation would be false after only 2 minutes, and errors in global positions would continue to accumulate at a rate of about 10 kilometres each day.

There are many weather satellites in orbit around the Earth. If they are geosynchronous they stay above one location on the equator at an altitude of 35,880 km. They can also be in polar orbits in which case they circle the Earth at a typical altitude of 850 km passing over both poles in their continuous flight. Polar orbiting weather satellites offer a much better resolution than their geostationary counterparts due their closeness to the Earth.

As well as monitoring our home planet there are plans in the scientific community to send spacecraft on missions to other solar systems. Project Icarus is an engineering study by the British Interplanetary Society to design an interstellar spacecraft. They have demonstrated that it is possible, by using current or credible extrapolations of existing technology, to launch an interstellar probe that could reach another solar system on timescales of a normal human lifetime.



Project Icarus predicts that it will be possible to send out spacecraft with a speed of 15% of the speed of light. Communication with these spacecraft will also require computations that compensate for relativity effects.

Questions

a) How many nanoseconds are there in 45 microseconds?

(1)

45,000 ✓

b) Are GPS satellites in geosynchronous orbits? Support your response with information from the passage.

(2)

No✓
There is only a single satellite period for a given separation (according to Kepler's Law) and the geostationary orbit is at a greater separation according to the passage.✓

c) According to General Relativity are GPS satellite clocks running faster or slower than identical Earth based clocks? Support your response with information from the passage.

(3)

At GPS altitude separation is greater than surface of Earth✓
so the gravitational field strength is less compared Earth surface ✓ and according to General Relativity the clocks tick faster. ✓
(passage states time passes slower in higher gravitational fields)

d) Consider a geostationary weather satellite at an altitude of 35,880 km. Would the combined time dilation due to general and special relativity cause the weather satellite clock to tick faster, slower or at the same rate compared to the GPS satellite clock in the reference frame of the Earth? Circle a response and explain clearly with reference to both relativity theories.

(4)

[✓ Tick faster] Tick slower Tick at the same rate Impossible to determine

✓

At geostationary altitude separation is greater, so the gravitational field strength is less compared GPS altitude and according to General Relativity the clocks tick faster✓

Geostationary means no relative speed between Earth observer and satellite so no Special Relativity effects compared to GPS which tick slower✓

Therefore the geostationary clocks tick faster than GPS in Earth frame of reference. ✓

e) Calculate the Special Relativity time dilation factor for an Icarus spacecraft moving away from Earth at 0.15c relative to the Earth. Give your answer to as many decimal places that your calculator will allow.

(3)

v = 0.15c ✓

$$\gamma = \frac{1}{\sqrt{1 - \frac{0.15^2}{1^2}}} \checkmark$$

$$\gamma = 1.0113475 \checkmark$$

f) Use your previous answer to calculate the time difference that will accumulate between a clock on the Icarus spacecraft and an identical clock on Earth during the course of one Earth day, according to Special Relativity. Give your answer in minutes to three significant figures. (If you could not determine the previous answer use a numerical value of 1.01144)

(3)

time (moving object) = rest time / γ

time (moving object) = (24 x 60) / 1.01144✓

time (moving object) = 1423.71 minutes ✓

(note – you should calculate less time than 1440 minutes)

Time difference = (24 x 60) – 1423.71 = 16.3 minutes✓

g) A radio signal is sent from Earth towards the Icarus spacecraft moving away at 0.15c. What is the speed of the radio signal (m s^{-1}) in the frame of reference of Icarus? Support your response with reference to physics principles.

(2)

$c = 3 \times 10^8$ m s^{-1} ✓

According to SR fixed speed for EMR in vacuum✓

End of questions

Additional working space