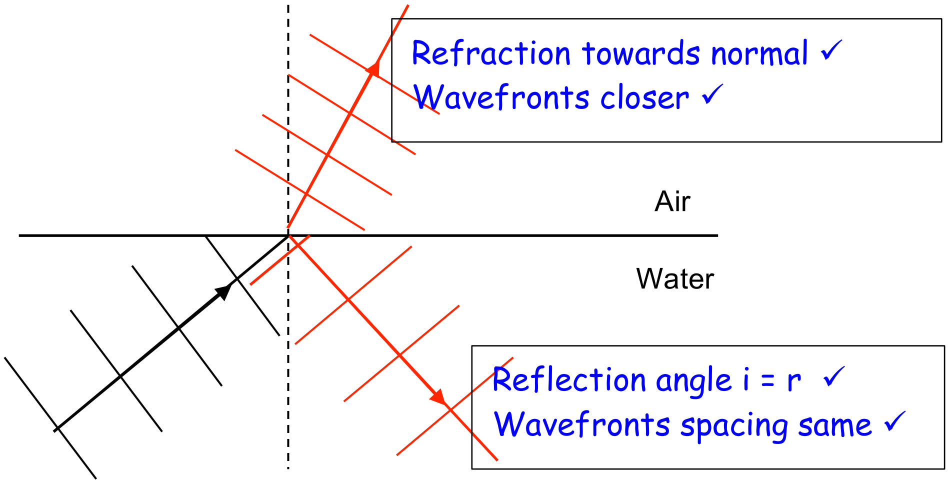
Section One: Short response 30% (54 Marks)

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

When sound waves travelling through water meet a boundary with air there will be some reflection and some refraction. Complete the diagram by showing how the wavefronts behave as they continue from the boundary. You should draw four wavefronts for each case. (The dotted line is a 'normal' which is a geometrical reference line at 90° to the boundary)

(4)



Refraction towards normal ✓
Wavefronts closer ✓

Reflection angle i = r ✓
Wavefronts spacing same ✓

Question 2

When demonstrating the photoelectric effect a beam of light is shone onto a clean metal surface. If the light is above a certain threshold frequency it causes electrons to be ejected from the surface. Explain if this indicates that light is behaving as a particle or a wave.

(3)

Particle ✓

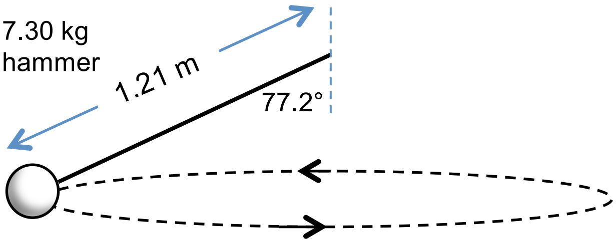
Light is delivered in discrete packets of energy called Photons. ✓

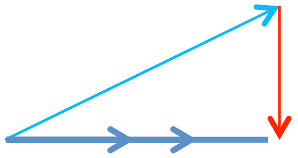
The photon can be absorbed by an atomic electron in the metal and if the resulting increase in PE is enough to ionise the atom then (photo) electrons are detected, where E_{photon} is proportional to frequency. $E_{photon} = h.f$ ✓

The wave model would indicate that waves of any frequency but sufficient amplitude could eject photoelectrons, this is not observed.
(Any 2 good points to support the correct response.)

Question 3

A student is investigating the physics of the hammer throw event at the London Olympics. A hammer of mass 7.30 kg is describing uniform circular motion at a constant height. The length of the hammer is 1.21 m and the wire makes an angle of 77.2° with the vertical. Calculate the time taken for the hammer to make one revolution.





(5)

$m = 7.30$ kg $l = 1.21$ m $\theta = 77.2°$

$\sin\theta = r / 1.21$ so $r = 1.21 \times \sin 77.2 = 1.18$ m ✓

Vector diagram or other analysis of vector components ✓ ✓

$\tan 77.2 = mv^2 / r \div mg = v^2 / gr$

$v^2 = \tan 77.2 \times 9.8 \times 1.18 = 50.896$

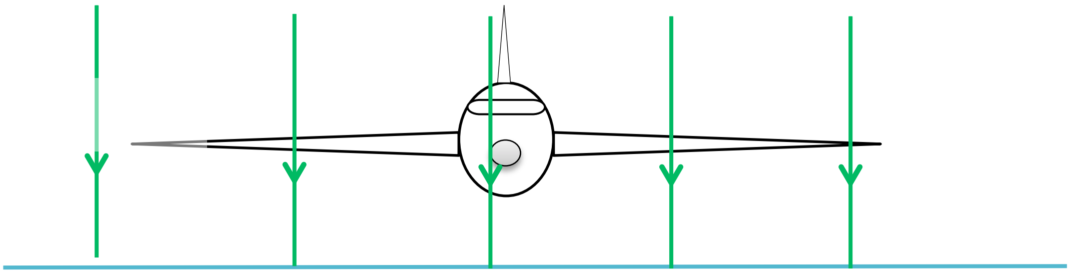
$v = 7.13415$ ✓

$T = 2\pi r / v = 2\pi \times 1.18 / 7.13415 = 1.04$ s ✓

(Alternative methods that lead to correct answer acceptable)

Question 4

A jet is flying directly over the magnetic pole in the Northern geographical hemisphere. The jet is flying at 858 km h^{-1}, it has a wingspan of 15.0 m and the Earth's magnetic flux density at this location is 57.8 μT.



a) Draw the Earth's magnetic field at this location by using 5 lines.

(1)

b) Indicate on the diagram where electrons will build up on the wingspan.

(1)

c) Calculate the emf induced across the wingspan.

(2)

$V = 858 / 3.6 = 238.33\ m\ s^{-1}$ $l = 15.0\ m$ $B = 57.8 \times 10^{-6}\ T$

Emf = v.B.l

$Emf = 238.33 \times 57.8 \times 10^{-6} \times 15.0$ ✓

$Emf = 2.07 \times 10^{-1}\ V$ ✓

Question 5

A spacecraft moving at 95% of the speed of light passes the Earth on a journey to the star Lalande 21185 a distance of 8.29 light years.

a) In the frame of reference of the spacecraft what time and spatial measurements of the journey are different compared to those measured by an Earth based observer?

(2)

The path length through space is shorter than 8.29 light years. (length contraction) ✓

Time is moving slower on the Earth (time dilation means observed time between ticks on Earth clocks takes longer) ✓

b) In the frame of reference of the Earth what time and spatial measurements of the journey are different compared to those measured by an observer on the spacecraft?

(2)

The path length through space is equal to 8.29 light years. (no path length contraction although spaceship is shorter in direction of travel) ✓

Time is moving slower on the Spacecraft (time dilation means observed time between ticks on moving clocks takes longer) ✓

c) Is it possible for the spacecraft to travel at the speed of light in the frame of reference of the spacecraft? Explain briefly.

(1)

No, according to Einstein's Special Relativity only electromagnetic radiation can travel at the speed of light (in a vacuum). ✓

Question 6

There are six flavours of quarks (normal matter versions). These are detailed in the table.

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

a) Determine the charge of the following particles that are made from quarks:

Bottom Xi prime $(\mathbf{dsb})$ -1 e ✓

Kaon-plus $(\mathbf{u\bar{s}})$ +1 e ✓

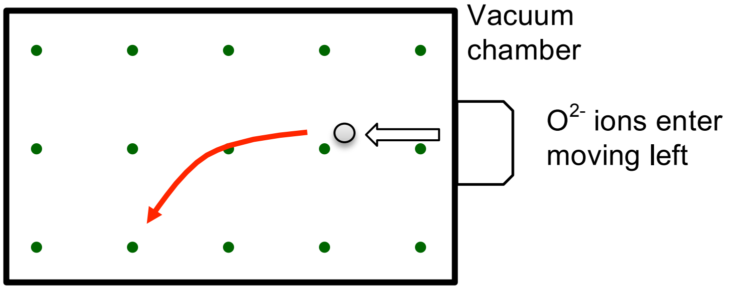
(2)

b) Give an example from your studies of when a neutrino could come into existence. (2)

When a radioactive substance decays by beta plus decay ✓ a neutrino is formed (along with a positron) ✓
(Or words to that effect or another valid example.)

Question 7

Oxygen ions (O^{2-}) are injected into a vacuum chamber that contains a uniform magnetic field. For the cross section shown the magnetic flux is 2.88 × 10^{-4} Wb in an area 30.0 cm by 20.0 cm. The direction of the magnetic field is indicated and the ions enter at a speed of 2.76 × 10^{4} m s^{-1}.



a) In which direction will the ions be deflected? (Circle the correct response)

up the page [✓ down the page] into the page out of the page

b) Calculate the magnitude of force experienced by each ion. (3)

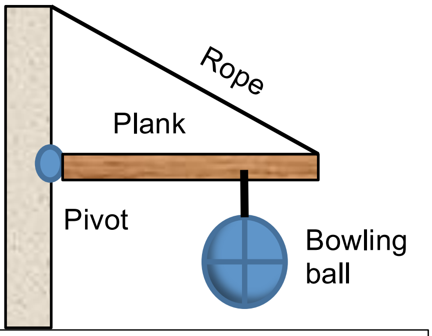
Φ = BA ∴ B = Φ / A = 2.88 × 10^{-4} / (0.30 × 0.20) = 0.00480 T
q = 2 × 1.60 × 10^{-19} C v = 2.76 × 10^{4} m s^{-1} ✓

$F_{mag} = q\ v\ B$

(1)

Question 8

A rigid wooden plank of mass 2.5 kg is attached to a wall by a pivot and is supported by a rope in tension. A 3.5 kg bowling ball is suspended from the plank. The diagram is to scale. **Estimate** the tension in the rope. Express your answer to an appropriate number of significant figures.



Let length of plank = 1.00 m = lever arm to rope

lever arm to ball = 0.750 m lever arm to plank CofM = 0.500 m

θ_{rope} = 30.0° ✓ (or other reasonable estimates)

$\theta_{plank} = \theta_{ball}$ = 90.0° moment = r.F.sin θ

Σacwm = Σcwm about pivot

$r_{rope}.F_{tension}.\sin 30° = r_{ball}.F_{ball}.\sin 90° + r_{plank}.F_{plank}.\sin 90°$

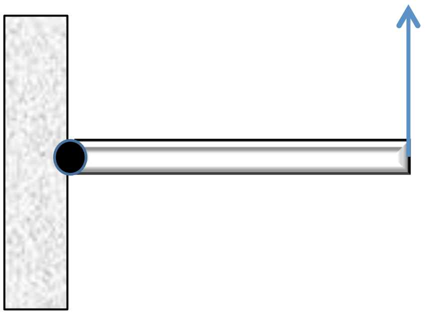
$1*F_{tension}*0.5 = 0.75*3.5*9.8 + 0.50*2.5*9.8$ ✓

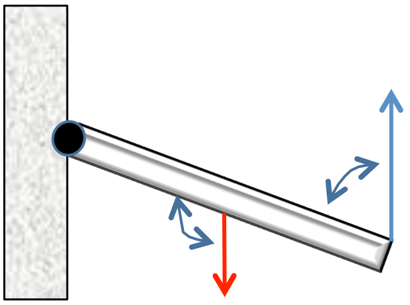
$F_{tension}$ = 75.95 ✓ = 76 N (appropriate sig figs ✓)

(4)

Question 9

A rigid boom of mass m is free to rotate about a frictionless pivot P. The boom is held in static equilibrium by a rope that is in tension. The boom is held in two different positions where the tension in position A is T_A and the tension in position B is T_B. The positions are shown in the diagram below.





a) When comparing the magnitude of tension in each position, circle the best response: (1)

[✓ $T_A = T_B$] $T_A > T_B$ $T_A < T_B$ Insufficient information for a response

b) Clearly explain your choice. (3)

Let boom length = l

Σacwm = Σcwm about pivot

Position A $0.5\times l\times mg\times\sin 90 = l\times T_A\times\sin 90$ ✓

$T_A = 0.5\times mg$ ✓

Position B $0.5\times l\times mg\times\sin 60 = l\times T_B\times\sin 120$ (same method)

$T_B = 0.5\times mg$ ✓

(Or acceptable alternative proof)

Question 10

In the WACE Physics course we assume that the flux linkage between the primary and secondary windings of a transformer is always 100% efficient. However we recognise that the transformer itself may not be 100% efficient.

a) Describe two sources of inefficiency in a transformer.

(2)

b) Describe how these inefficiencies affect the electrical characteristics of a transformer. (1)

c) Explain how the design of a transformer can be modified to minimise the effects of these inefficiencies.

(2)

Eddy currents reduced by making core out of laminations to block current flow ✓

Use of thicker (lower resistance) wires in the transformer windings (∴ I^2R losses reduced) ✓

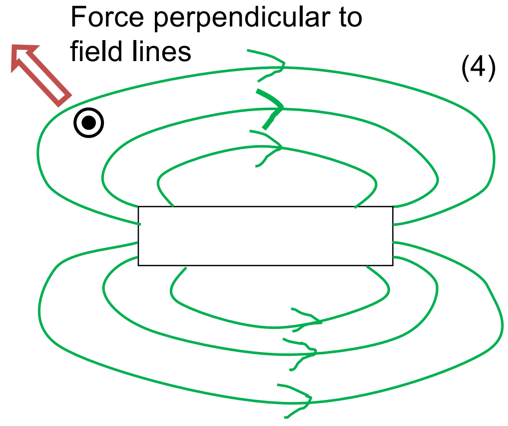
Question 11

(4)

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

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

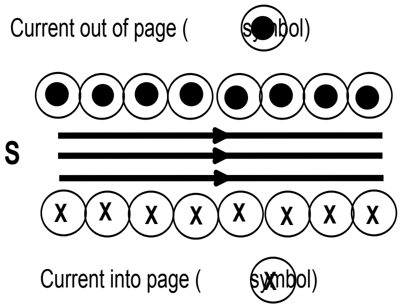
ii. Indicate on the diagram the direction of magnetic force acting on the wire



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

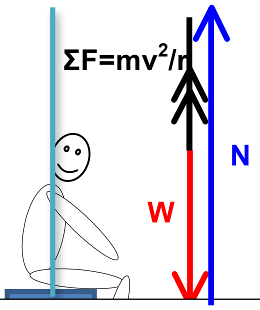
i. Shown on the diagram, the direction of current that will establish this field.

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



Question 12

A person is sitting on a swing that is moving through the arc of a circle. It has reached the lowest point and is moving at maximum speed. Explain with reference to a vector diagram how the person's apparent weight is different compared to being at rest on the swing.



Question 13

The Steady State Theory (also called The Infinite Universe Theory) was a model developed by the respected astronomer Fred Hoyle and others in 1948. It proposed that the universe had no beginning or end over infinite time. Fred Hoyle is reported to have used the phrase 'Big Bang' as a derogatory term when referring to an alternative theory that is nowadays the most widely accepted.

Describe two pieces of observational evidence that support the Big Bang Theory.

(4)

Cosmic microwave background radiation – thermal radiation that fills universe uniformly and is left over from the big bang (observable by sensitive radio telescopes) ✓ ✓

Red shift of light observed from distant galaxies indicates that they are receding. ✓ ✓

Stars such as Cepheid variables indicate distance to galaxies, this information in conjunction with recessional speed data from red shift supports Hubble's Law.
(Any 2 appropriate and well supported points)

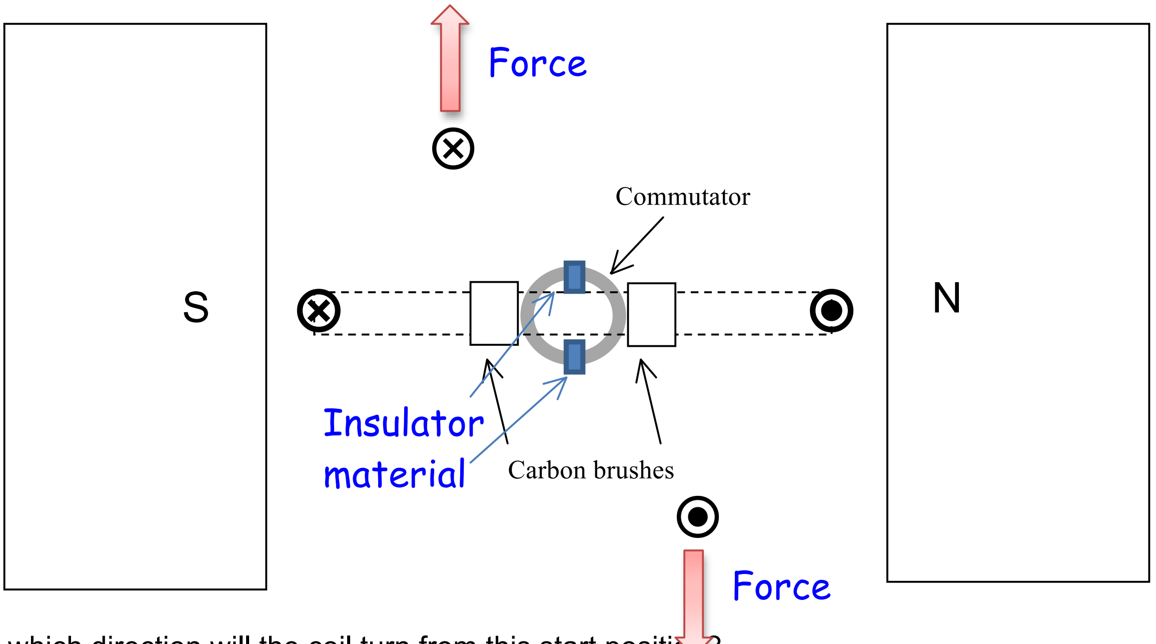
End of Section One

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 14 (13 marks)

The diagram shows the side view of a DC electric motor. A square coil is placed flat in the uniform magnetic field between the North and South magnetic poles. Current direction in the coil is shown on the sides adjacent to the magnetic poles. The commutator and carbon brushes are also shown.



a. In which direction will the coil turn from this start position? (1)

b. On the diagram sketch and label the location/s of insulator materials on the commutator at this start position. (1)

c. Explain the function of the brush and commutator arrangement. (2)

An electrical connection that allows an external source of emf to feed current via fixed brushes into the rotating coil. ✓

The arrangement breaks the connection every 180° to ensure that the current direction is switched. ✓

d. Using the symbols ⦿ and ⊗ sketch on the above diagram the location of the coil after 60° of rotation from this start position. Put arrows on your symbols to indicate the direction of magnetic force acting on them. (as above – approx. 60° & direction up/down) (2)

e. At this new position after 60° of rotation from the start position; state the torque value of the motor as a percentage of maximum torque.

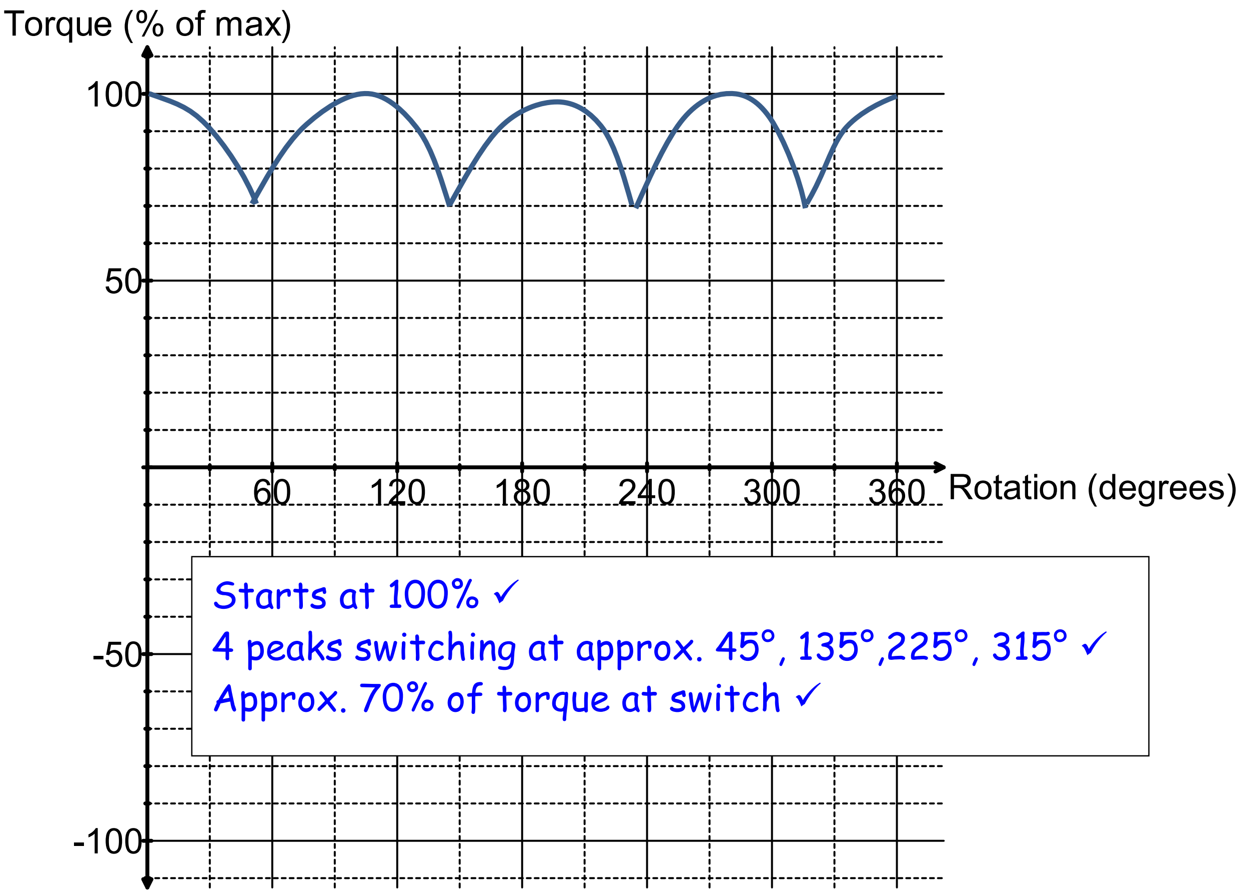
2)

f. A single 90.0 mm length of wire adjacent to a magnetic pole experiences a 0.0240 N force when a current of 6.20 A flows through it. Calculate the magnetic flux density between the poles.

(2)

g. The motor is later modified to have two sets of evenly spaced coils and a commutator with four segments. On the axes below, sketch the shape of the torque output curve for one revolution from the start position shown.

(3)



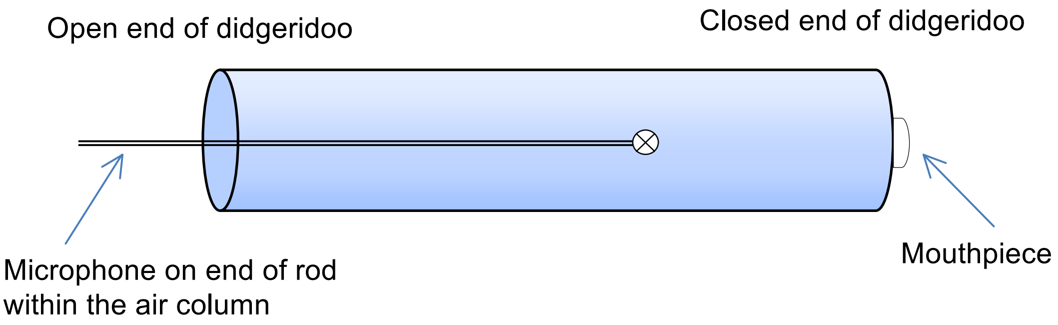
Starts at 100% ✓

4 peaks switching at approx. 45°, 135°,225°, 315° ✓

Approx. 70% of torque at switch ✓

Question 15 (13 marks)

A recording studio builds a simple didgeridoo, which is a wind instrument closed at one end. The effective length of the didgeridoo is 135 cm and is fixed.



a) The didgeridoo has a fundamental frequency of 64.0 Hz. Calculate the speed of sound of air in the studio.

(3)

b) Explain how a musician can play notes of a higher frequency on this fixed length instrument.

(2)

By vibrating his lips at driving frequencies that correspond to other standing waves that can resonate in this length. ✓
The standing waves will always have a pressure antinode at the closed end and a pressure node at the open end so the length can contain wavelengths of λ/4, 3λ/4, 5λ/4 etc. ✓
(or similar)

c) The musician is unable to produce a sound of frequency 128 Hz on this didgeridoo. Explain why this is not possible.

(2)

128 Hz has a wavelength of 2.70 m. This means the air column would need to contain $\frac{1}{2}$ a wave which requires either a node at each end or an antinode at each end. This is not possible when one end is open and the other closed (open ends support pressure nodes and closed ends support pressure antinodes)

When the didgeridoo is playing a note of frequency 320 Hz, a sound technician slides a small microphone into the tube without disrupting the sound. As he does he notices the sound volume varies between loud and soft.

d) Explain why there are loud and soft spots within the instrument.

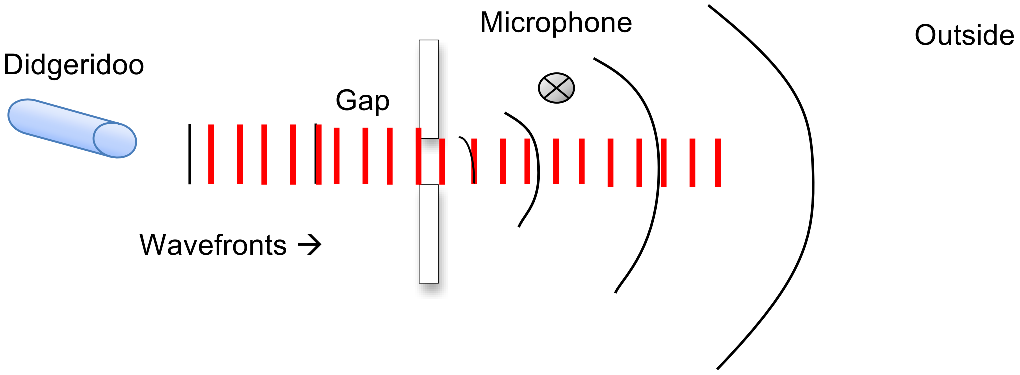
(2)

For a given note played on a musical instrument, the dominant frequency heard is called the fundamental frequency or the first harmonic. Harmonic frequencies above the fundamental frequency, that are present, are known as overtones. Harmonics above the fundamental frequency are known as the first overtone, the second overtone etc.

e) The studio has a simple stringed instrument in which a steel string in tension can oscillate between two fixed bridges. On the diagram below sketch the wave envelope of the second overtone.

(1)

f) When the didgeridoo is sounding a note of 64.0 Hz sound waves travel through a small gap in a partially open window to the outside where reflections are negligible. A microphone placed to the side of the gap can still detect these sound waves. This is shown in the following diagram.



i. Explain the wave phenomenon that causes the didgeridoo sound to be detected by to the microphone.

(2)

Diffraction of sound is occurring as the wavelength is longer than the gap width which causes the wavefronts to curve and spread out ✓ ✓

(Or similar well supported explanation)

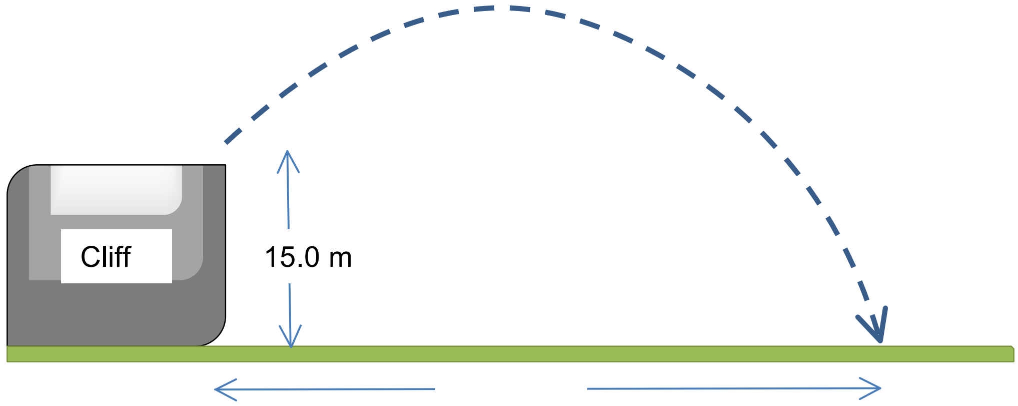
ii. Show on the diagram how wavefronts from the stringed instrument sounding at 320 Hz will reach the window and continue through the gap. You must show relative wavefront dimensions approximately to scale originating from the same location as the didgeridoo.

Shorter wavelengths, more directional ✓

(1)

Question 16 (12 marks)

A physics student observes a stone of mass 350 g being catapulted from the top of a cliff. The launch position at the top of the cliff is 15.0 m above ground level and it takes the stone a time of 5.00 seconds to reach the ground. The stone lands 88.0 m in front of the launch position. You may ignore air resistance for the calculations.



a) Calculate the vertical component of the velocity when the stone is launched.

(3)

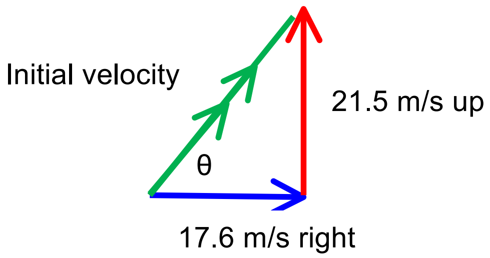
b) Considering the kinetic energy of the stone along its flight path. Circle the best response for the following statement. The kinetic energy of the stone at maximum height is:

Maximum 50% of maximum Zero [✓ Minimum] Equal to all other positions

(1)

c) Calculate the initial velocity of the stone, referring to the angle of elevation above the horizontal for direction.

(4)



d) Calculate the kinetic energy of the 350 g stone just before it hits the ground.

(4)

Considering the conservation of mechanical energy

Total Mechanical Energy = constant at any height.

At this position TME = KE + GPE = $\frac{1}{2}$ mv^2 + mgh
identifies variables✓
TME = ($\frac{1}{2}$ × 0.35 × 772.01) + (0.35 × 9.8 × 15) ✓
TME = 186.55 J ✓

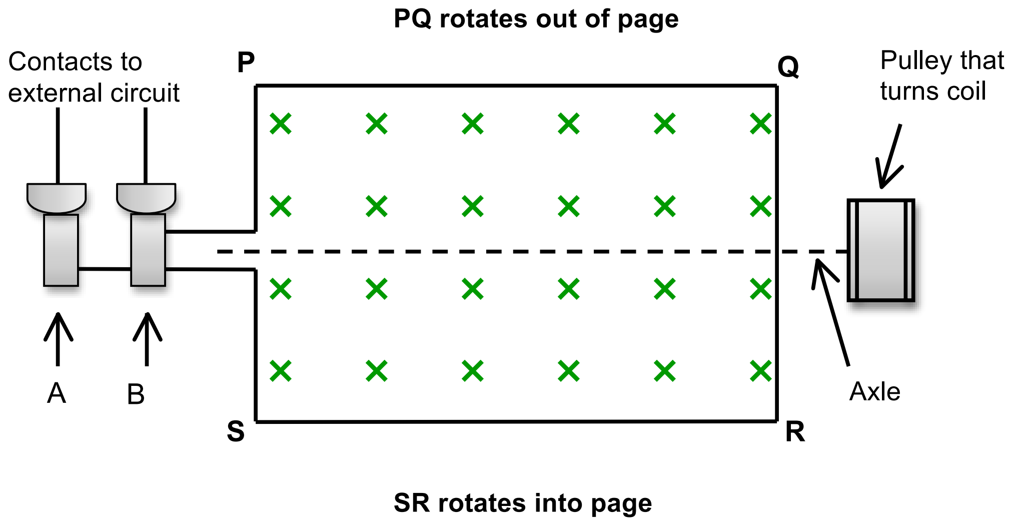
At end of flight GPE = zero ∴ TME is all kinetic
Kinetic energy just before stone hits ground = 187 J ✓

Alternatively in vertical v = u + at = 21.5 + (-9.8*5) = -27.5 ✓ ✓
in horizontal v = 17.6 final v^2 = 27.5^2 + 17.6^2 = 1066.01 ✓
KE = $\frac{1}{2}$ m v^2 = 0.5*0.35*1066.01 = 187 J ✓

Question 17 (13 marks)

The diagram shows the coil PQRS of an AC generator placed between magnetic poles.

- The uniform magnetic field of flux density 0.0386 T is indicated.
- The dimensions of the coil are: PQ = SR = 7.00 cm and PS = QR = 5.00 cm
- The coil rotates about the axle as indicated as a torque is applied to the pulley.
- The coil has 400 turns of wire and is rotated at 750 rpm.



a) Identify the components shown on the diagram, explain their function and explain why they are used rather than a commutator. (3)

b) Mark on the diagram the direction of current along PQ and SR as the coil rotates from the position shown and explain briefly how you arrived at your answer. (2)

As per diagram P to Q and R to S ✓

By Lenz's law as the coil rotates from a position of maximum flux contained flux is being lost. Current will be induced to flow in such a way that its flux will replace the loss.✓

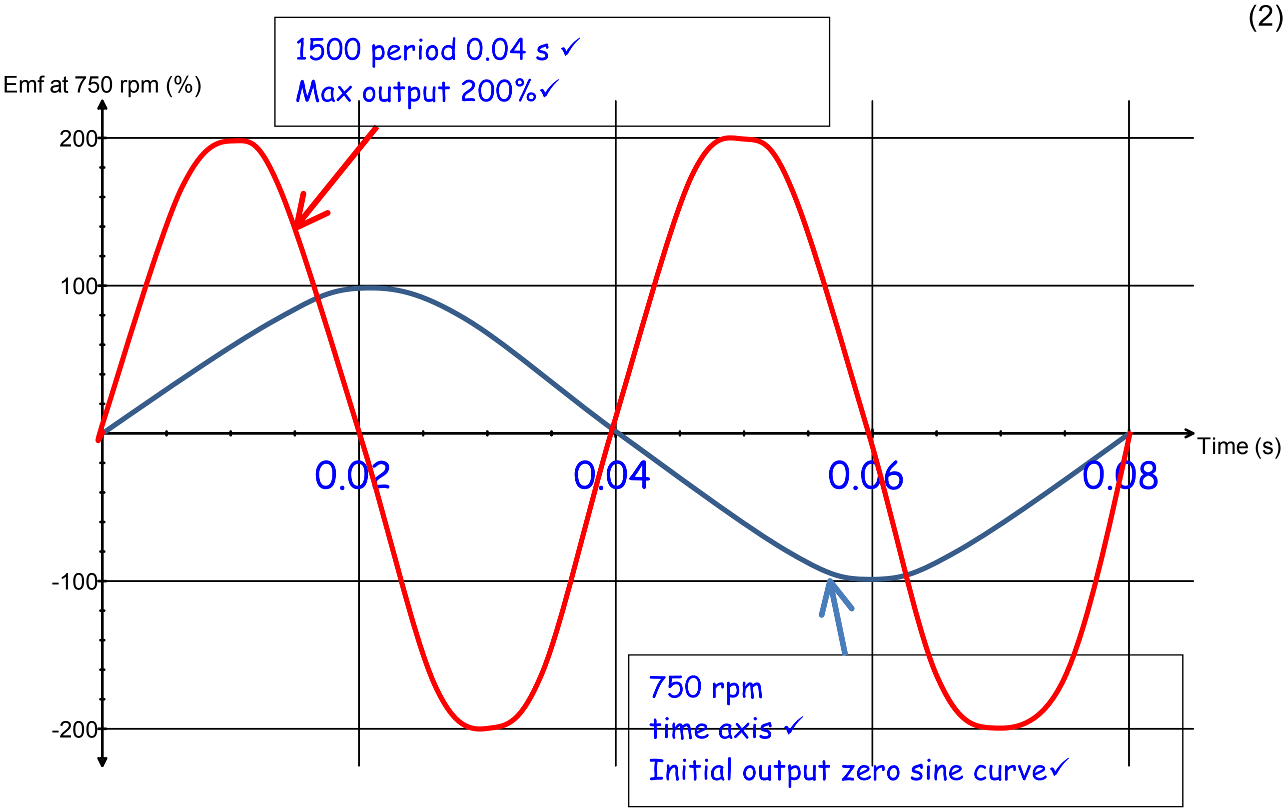
Or by right hand palm rule. Positive charge in PQ moving down in the field experiences a push to the right. ✓

c) Calculate the magnitude of the average induced emf from the AC generator by considering one quarter of a rotation from the position shown.

(4)

d) On the axes shown below, sketch the shape of the emf output for this generator as it rotates one full turn from the initial position shown. Put in a suitable numerical time scale on the time axis and label your curve '750 rpm'.

(2)



1500 period 0.04 s ✓
Max output 200%✓

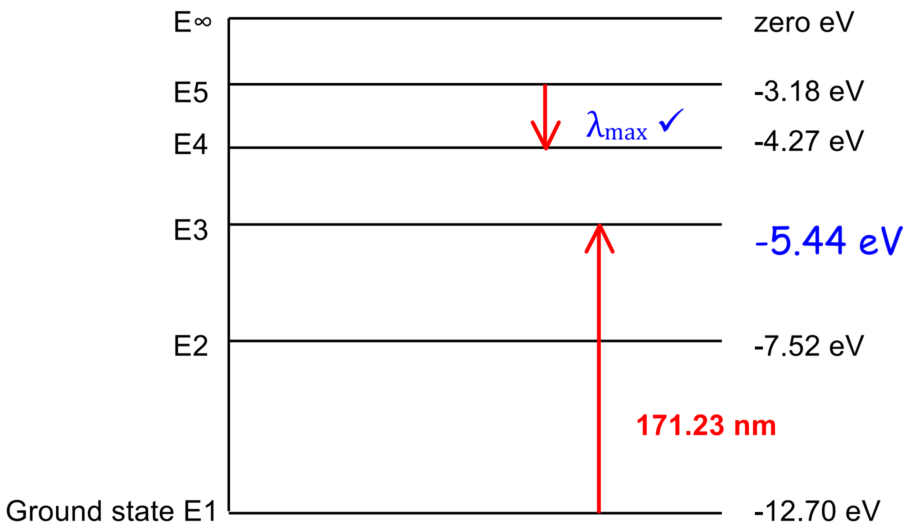
750 rpm
time axis ✓
Initial output zero sine curve✓

e) Sketch a second shape of the emf output for a rate of rotation of 1500 rpm and label this curve '1500 rpm'.

(2)

Question 18 (13 marks)

The energy level diagram below is for an atom that can fluoresce.



a) The atom is bombarded by 4 photons with energies detailed below. Circle all of the photon energies that could be absorbed by the atom whilst in its ground state. (1)

5.08 eV [✓ 5.18 eV] [✓ 8.43 eV] [✓ 13.0 eV]

b) Whilst in the ground state the atom absorbs a photon of wavelength 171.23 nm which excites the atomic electron to E3. Calculate the energy level of E3 and write it on the diagram and also illustrate the transition on the diagram. Label the transition '171.23 nm'. (4)

$\lambda = 171.23 \times 10^{-9}$ m $c = f.\lambda$ $f = c/\lambda = 1.752 \times 10^{15}$ Hz✓

$E = h.f = 6.63 \times 10^{-34} \times 1.752 \times 10^{15}$
$E = 1.1615955 \times 10^{-18}$ J✓

$E\ (eV) = 1.1615955 \times 10^{-18} / 1.60 \times 10^{-19}$
$E\ (eV) = 7.26$ eV✓

$E3 = E1 + 7.26$
$E3 = -12.70 + 7.26 = -5.44$ eV✓

c) Which part of the electromagnetic spectrum does the 171.23 nm photon belong to? (1)

Ultraviolet ✓

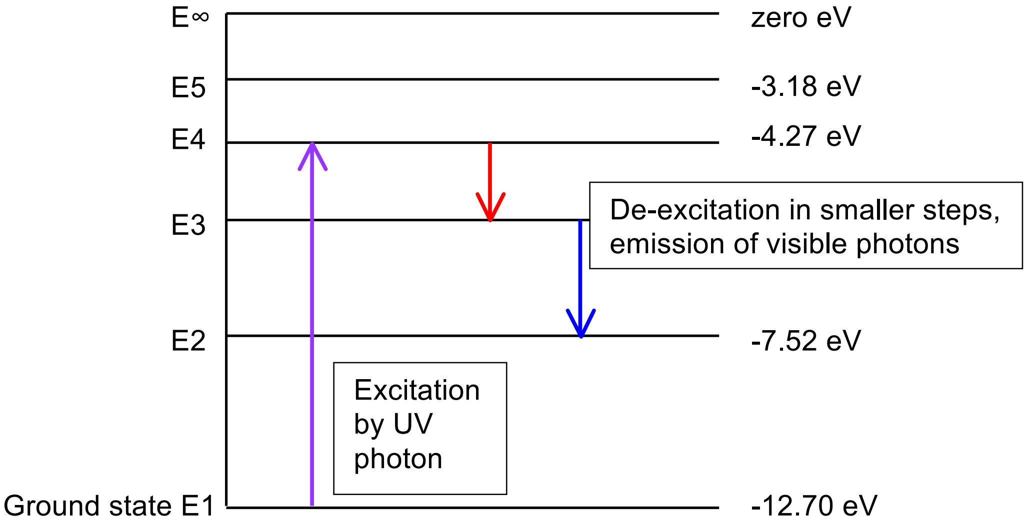
d) For the energy levels shown on the diagram which transition will result in line emission of the longest wavelength? Illustrate this transition on the diagram and label it **'λ_{max}'**

(1)

e) Explain how a line absorption spectrum could be formed by a collection of these atoms.

(3)

f) Explain the process of fluorescence. You may use the energy level diagram below to aid your response.



When an atomic electron absorbs a high energy photon such as a non-visible UV photon then excitation can occur across several energy levels. ✓

On de-excitation the atomic electron makes several smaller steps back to the ground state. These steps result in the emission of photons which can be visible. ✓

Use of diagram or very clear explanation of steps. ✓

(Or similar)

(3)

Question 19 (13 marks)

Venus is a planet whose orbit is between the Earth's and the Sun. The radius of Venus is 6.05 $\times 10^6$ m. The Magellan spacecraft was launched by NASA in 1995 for the purpose of radar mapping Venus. At one stage Magellan was put into a circular orbit of Venus at an altitude of 346 km. It took Magellan 94 minutes to complete this orbit. Magellan had a mass of 1035 kg.

a) Calculate the centripetal acceleration of the Magellan satellite in this orbit.

(3)

b) Calculate the mass of the planet Venus using the satellite data provided.

(3)

$a_{centripetal}$ = 7.93798 m s^{-2}

Orbital radius = $6.05 \times 10^6 + 346 \times 10^3 = 6.396 \times 10^6$ m

Orbital period = $94 \times 60 = 5640$ s

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

$7.93798 = G\,M / (6.396 \times 10^6)^2$ ✓

$M = (7.93798 \times (6.396 \times 10^6)^2)/(6.67 \times 10^{-11})$ ✓

$M = 4.87 \times 10^{24}$ 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) If the Magellan spacecraft was double the mass in this orbit explain how its orbital period would be affected.

(2)

d) There is a location between the Earth and the Sun where the net gravitational field strength due to the Earth and the Sun is zero. Calculate the distance from Earth to this location.

(5)

Earth Sun distance = 1.50×10^{11} m

Let distance from Earth to this location = x

Then distance from Sun to this location = $(1.50 \times 10^{11} - x)$ ✓

Magnitude of gravitational field strength is equal at this location

$GM_{sun} / r_{sun}{}^2 = GM_{Earth} / r_{Earth}{}^2$ ✓ (concept)

$$\frac{M_{sun}}{M_{Earth}} = \frac{(1.50\times10^{11} - x)^2}{x^2}$$

$$\sqrt{\frac{1.99\times10^{30}}{5.97\times10^{24}}} = \frac{1.50\times10^{11} - x}{x}$$

✓

$$577.350 = \frac{1.50\times10^{11} - x}{x}$$

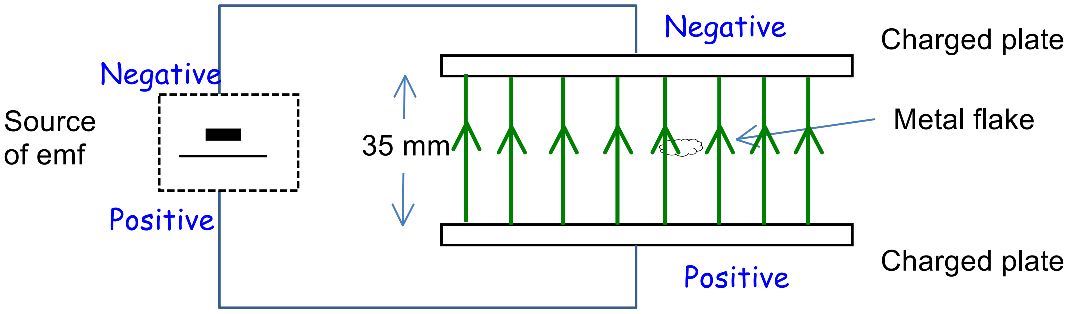
$$578.350x = 1.50\times10^{11}$$

✓

$x = 2.60 \times 10^8$ m from Earth ✓

Question 20 (7 marks)

An uncharged flake of metal is stripped of 9.57 million electrons and fed into the space between two horizontal plates set 35.0 mm apart. The plates are charged by a source of emf that establishes an electric field strength of 6.40 × 10^4 N C^{-1} in the space. The metal flake is seen to rise up in the space between the plates.



a) Indicate on the diagram the polarity of the source of emf, the charge polarity on each plate and sketch at least five field lines for the uniform electric field.

(2)

b) Calculate the magnitude of the potential difference across the parallel plates.

(2)

$E = 6.40 \times 10^4$ N C^{-1} (V m^{-1}) $d = 0.035$ m

$E = V / d$

$V = E \times d = 6.40 \times 10^4 \times 0.035$
$V = 2240$ V

c) Calculate the magnitude of the electric force acting on the metal flake.

(3)

$q = 9.57 \times 10^6 \times 1.60 \times 10^{-19} = 1.53 \times 10^{-12}$ C ✓

$E = F / q$

$F = E \times q$
$F = 6.40 \times 10^4 \times 1.53 \times 10^{-12}$ ✓

$F = 9.80 \times 10^{-8}$ N ✓

Question 21 (6 marks)

NGC 2768 is a galaxy group that can be observed from the Hubble Space telescope. The line absorption spectrum of light passing through a metallic vapour in this galaxy shows one line with a wavelength of 742.540 nm. The same line in the spectrum measured on Earth is 740.400 nm.

a. Calculate the recessional velocity of NGC 2768 using the following relationship:

(3)

$$\frac{\Delta\lambda}{\lambda_{rest}} = \frac{v}{c_0}$$ where $\Delta\lambda = \lambda_{shifted} - \lambda_{rest}$ and v = recessional velocity ($m\ s^{-1}$)

b. Using Hubble's law, calculate the distance in Mpc to galaxy NGC 2768 using the velocity you calculated. *(If you could not solve for the velocity then use a value of 8.67×10^5 m s^{-1})*

(2)

Hubble's law states that: $v = H_0 d$

v = recessional velocity ($km\ s^{-1}$)
d = distance in megaparsec (Mpc)
$H_0 = 74.0\ km\ s^{-1}\ Mpc^{-1}$

$$v = 8.67\times10^2\ km\ s^{-1}$$

$$d = \frac{v}{H_0}$$ ✓

$$d = \frac{8.67\times10^2}{74.0}$$ d = 11.7 Mpc ✓

c. How many years has it taken light from this galaxy to reach Earth? (1 parsec = 3.26 light year)

(1)

Distance = 11.7 × 10^6 × 3.26 = 38.2 million light years

It took 38.2 million years ✓

End of Section 2

Section Three: Comprehension 20% (36 Marks)

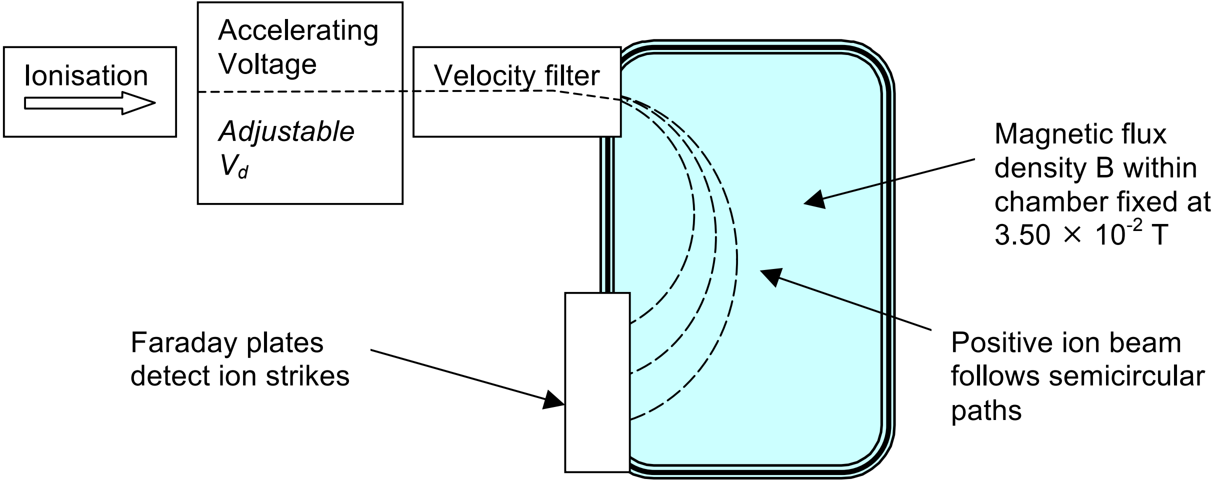
This section contains **two (2)** questions. You must answer both questions. Write your answers in the space provided. Suggested working time for this section is 40 minutes.

Question 22 Using a mass spectrometer for a crime scene investigation. (18 marks)

Australian Federal Police have isolated an element found at a crime scene. They think the element may be sodium or potassium so have asked the forensic laboratory to run tests on the element to identify it. The laboratory is able to ionise the element to give it a single positive charge. They then accelerate the ions through a potential difference (V_d) and by use of a velocity filter are able to send ions that have reached their maximum kinetic energy into a mass spectrometer. When the ions enter the mass spectrometer they are acted on by a uniform magnetic field and follow a semi - circular path.

Technicians conduct a series of tests and measure the radius of circular motion for different values of potential difference used to accelerate the charged ions.

Schematic diagram of mass spectrometer



The table below shows the results obtained when the magnetic flux density B in the mass spectrometer was fixed at 3.50×10^{-2} T. Measurements of radius have been expressed with an uncertainty of ±5% and radius squared with an uncertainty ±10%.

Potential difference V_d (volts)	Radius of circular path (metres)	Radius squared (metres squared)
200	0.270 ± 0.014	0.073 ± 0.007
400	0.370 ± 0.019	0.137 ± 0.014
600	0.490 ± 0.025	0.240 ± 0.024
800	0.530 ± 0.053	0.281 ± 0.028
1000	0.620 ± 0.027	0.384 ± 0.038
1200	0.670 ± 0.034	0.449 ± 0.045

Mass of a potassium K^+ ion = 6.49×10^{-26} kg Mass of sodium Na^+ ion = 3.82×10^{-26} kg

It can be shown that the radius ***r*** of circular motion for an ion of mass ***m*** and charge ***q***, entering the mass spectrometer at speed ***v*** and being deflected by a magnetic field of flux density ***B*** is as follows:

$$\boldsymbol{r = \frac{m.v}{q.B}}$$

Answer the following questions

a) Use the equation $r = \frac{m.v}{q.B}$ and other equations on the formulae and constant sheet that link the concepts of kinetic energy in (joules) attained by a mass of charge **q** (coulombs) in a potential difference $\mathbf{V_d}$ (volts) and derive the following expression:

(3)

$$r^2 = \frac{2.m}{q.B^2}.V_d$$

$\boldsymbol{r = \frac{m.v}{q.B}}$ $\boldsymbol{r^2 = \frac{m^2.v^2}{q^2.B^2}}$ ✓

For a charge of mass m, $\boldsymbol{work\ done = \Delta KE = V.q}$

If accelerated from rest, $\boldsymbol{\frac{1}{2}mv^2 = V_d.q\ \ so,\ V_d = \frac{mv^2}{2q}}$ ✓

$$\boldsymbol{r^2 = \frac{m^2.v^2}{q^2.B^2} = \frac{2m.}{q.B^2} \times \frac{mv^2}{2q} = \frac{2.m}{q.B^2}.V_d}$$ ✓

The equation follows the format **y = mx + c** for values of r^2 plotted against V_d

b) Complete the table by filling in the values of radius squared $\mathbf{r^2}$ with the appropriate uncertainty range. Two values have been done for you.

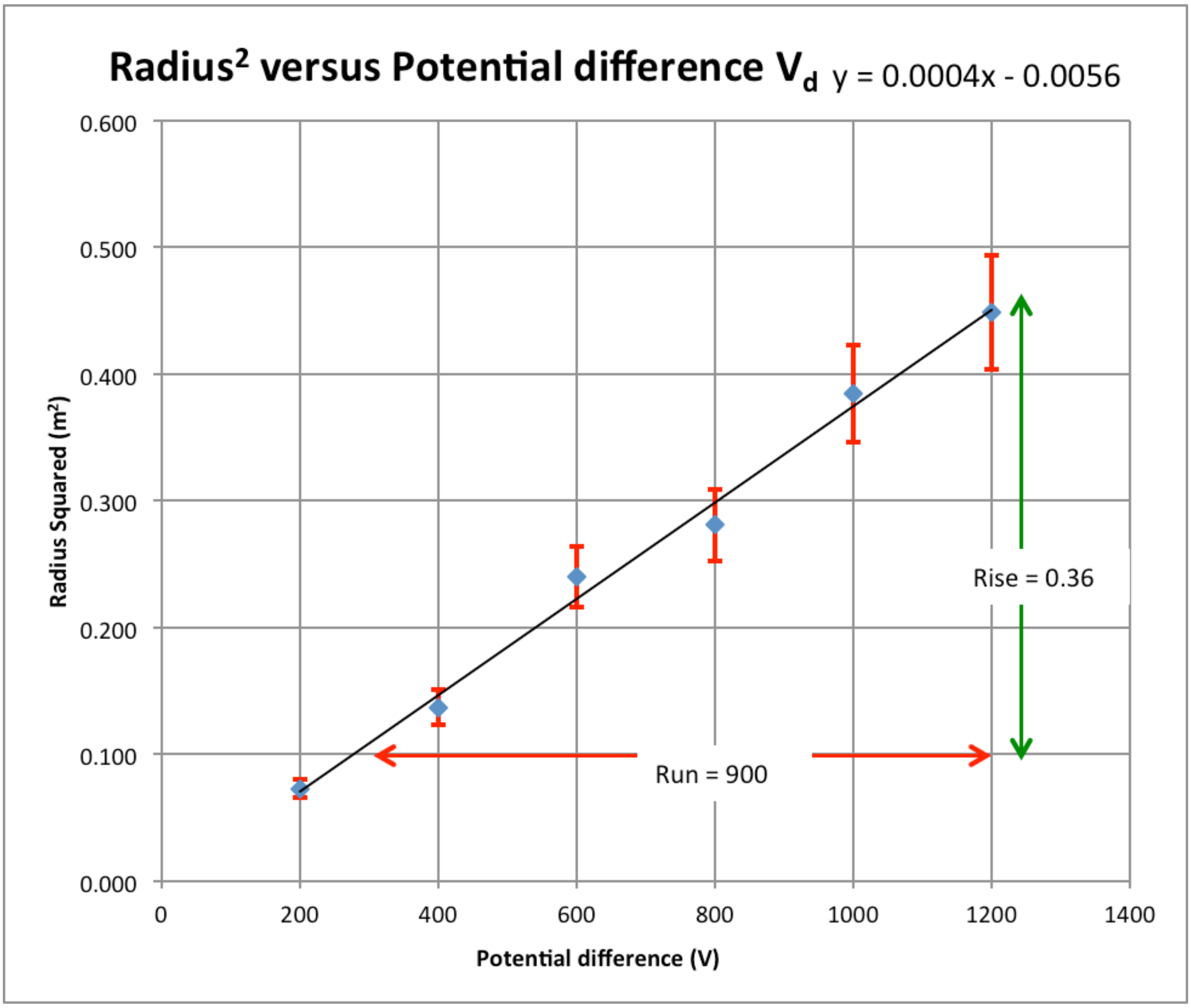
(3)

values ✓ significant figures ✓ uncertainty format ✓

c) Plot the graph of $\mathbf{r^2}$ (vertical axis) versus **Potential difference** $\mathbf{V_d}$ (horizontal axis) on the graph paper next to the table. Include error bars and a line of best fit.

(5)

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.



Accurate Plots ✓ ✓

Axes labelled, Axes units labelled ✓

Line of best fit ✓

Error bars ✓

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

(3)

e) Use the value of the gradient that you obtained to calculate the mass of the charged ions. (If you could not obtain a gradient use the numerical value 4.00 × 10^{-4})

(3)

Gradient = $4.00 \times 10^{-4} = \frac{2.m}{q.B^2}$ ✓

$$m = \frac{4.00 \times 10^{-4} \times q \times B^2}{2}$$

$$m = \frac{4.00 \times 10^{-4} \times 1.60 \times 10^{-19} \times (3.50 \times 10^{-2})^2}{2}$$ ✓

m = 3.92×10^{-26} kg ✓

f) Based on the results you have calculated, what is the identity of the charged ion?

(1)

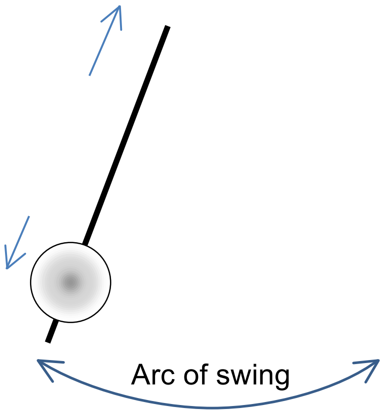
The closest match is Sodium ✓

Question 23 Clocks (18 marks)

Our lives are governed by time. The concept of a day divided into 24 hours originated in ancient Egypt. The hour divided into 60 minutes with each minute having 60 seconds has its origins in ancient Greece but is based on the astronomy of the older Babylonian and Sumerian cultures. It was not until the 14th century and the advent of mechanical clocks that hours of fixed length came into general use.

Pendulum Clocks

The pendulum clock was invented by the Dutch scientist Christiaan Huygens in 1656. A mass placed at the end of a string or rod will swing back and forth in a precise time interval depending on the length of the pendulum. The 'escapement' mechanism in this clock is powered by either a spiral spring that stores energy or by a weight hanging vertically down on a cord to turn a pulley. As the pendulum swings to one side the 'escapement' pushes on an arrangement of cogs and gears that rotate the hour and minute hands by small increments. This is audible as a 'tick'. The escapement also gives the pendulum a small push to compensate for the effects of atmospheric drag. A spring must be "wound up" every few days and a hanging weight needs to be lifted back to the top of its pulley position as it reaches its lowest point. A pendulum made from a bob (mass) attached at the end of an iron rod is susceptible to the effects of thermal expansion. For this reason the position of the bob can be adjusted on the rod to adjust the effective length of the pendulum. The introduction of pendulum clocks increased accuracy from about 15 minutes per day to about 15 seconds per day.



Quartz Clocks

If you look at your wristwatch or a wall mounted clock it is likely that you will see the word Quartz written on the face. Nowadays, timepieces using quartz technology are the most widely used in the world. A quartz clock uses an electronic oscillator regulated by a quartz crystal. The oscillator generates a very precise frequency which governs the mechanism.

Quartz (silicon dioxide) is a piezoelectric material. When it is bent it creates an electrical potential across planes in the crystal. This effect is used in reverse in a timepiece – when an electrical potential is connected across the crystal it resonates at a fixed frequency. The frequency is related to the shape, size and crystal plane of the quartz. Variations in temperature have a negligible effect on this frequency.

Quartz clocks use a quartz crystal that is a cantilever, laser trimmed into the shape of a small tuning fork and calibrated to oscillate at 32 768 Hz. This number is a power of two and is chosen so that simple digital logic circuits can derive the 1 Hz signal that controls the second hand.

The formula for the fundamental frequency of vibration of a cantilever is as follows:

$$f = \frac{1.875^2}{2\pi} \cdot \frac{a}{l^2} \cdot \sqrt{\frac{E}{12\rho}}$$

A standard quality quartz watch will have an accuracy of around ±15 seconds per month. A quartz watch that has been 'rated' at the factory against an atomic clock can be regulated to have an accuracy of around ±10 seconds per year.

Atomic Clocks

The operation of an atomic clock is based on the principle of the emission of electromagnetic radiation when electrons in atoms change energy levels. Atomic clocks based on Caesium-133 have a cavity containing Cs-133 as a gas. The gas is stimulated by microwaves and controlled by an electronic amplifier which cause it to resonate and emit radiation at exactly 9 192 631 770 cycles per second. This is now the basis of the SI unit of time. Atomic clocks have an accuracy of one second per million years or better.

Questions

a) In a pendulum clock energy is required to advance the hour and minute hands. Describe one possible source of energy that the passage refers to and briefly describe the energy transformations that occur.

(2)

Potential energy (elastic) in a spring is transformed into kinetic energy of the cogs and gears.
Or, gravitational potential energy in a weight is transformed into kinetic energy of the cogs and gears. ✓✓

b) Would it be practical to have a wristwatch based on a pendulum mechanism? Explain briefly.

(1)

No, the pendulum needs to be stable to oscillate freely. ✓
Any sensible response.

c) A certain pendulum clock is calibrated in the winter. In summertime the pendulum will need to be adjusted to keep more accurate time. The formula for the period of a pendulum is as follows:

$$T = 2.\pi\sqrt{\frac{l}{g}}$$

i. Explain what effect an increase in temperature would have on the accuracy of the clock. Will it run fast, slow or be unaffected?

(2)

Increase in temperature results in an increase in length. ✓
If l increases so does T, therefore the clock will run slow. ✓

ii. Explain what adjustment would need to be made to the position of the bob on the end of the rod to compensate for the change in temperature.

(1)

The bob needs to be raised to reduce the effective length. ✓

d) Is the quartz crystal in a watch behaving more like an electric generator or an electric motor? Explain briefly.

(2)

Like a motor. ✓
It is supplied with electricity that is transformed into motion.✓

e) The frequency of a crystal oscillator in a wristwatch is 32 768 Hz. Referring to the formula in the passage, calculate the length of a quartz crystal which has a thickness of 0.3 mm, Young's Modulus of 1.00 × 10^{11} N m^{-2} and a density of 2634 kg m^{-3}.

(3)

$$f = \frac{1.875^2}{2\pi}.\frac{a}{l^2}.\sqrt{\frac{E}{12\rho}}$$ re-arrange $$l^2 = \frac{1.875^2}{2\pi}.\frac{a}{f}.\sqrt{\frac{E}{12\rho}}$$ ✓

$$l^2 = \frac{1.875^2}{2\pi}.\frac{0.0003}{32\ 768}.\sqrt{\frac{10^{11}}{12 \times 2634}}$$ ✓

$l = 3.01 \times 10^{-3}\ m$ ✓

f) The number 32 768 is a power of 2. (That means that 32 768 = 2^x). Determine which power of 2 this is.

(1)

g) Would a typical person's ear be able to hear the quartz crystal oscillating at 32 768 Hz? Explain briefly.

(2)

No ✓

This is beyond the upper threshold frequency of the human hearing range. which is approximately 20 Hz to 20 000 Hz ✓

h) Are atomic clocks based on the principle of "radioactivity"? Explain briefly.

(2)

No radioactive decay involves the spontaneous emission of particles or radiation from the nucleus ✓

Atomic clocks use the principle of photon emission on de-excitation between energy levels in an atom.✓

i) For the atomic clock described in the passage, calculate the difference in energy level values (joules) for the line emission referred to in the Caesium atom.

(2)

E = h.f. ✓

$E = 6.63 \times 10^{-34} \times 9\ 192\ 631\ 770$ ✓

$E = 6.07 \times 10^{-24}$ J ✓

End of questions