ALL SAINTS' COLLEGE

Year 11 PHYSICS ATAR

Semester 2 Examination, 2015

Question/Answer Booklet

Student Number: In figures | | | | | | | | |

In words ______________________________

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Time allowed for this paper

Reading time before commencing work: ten minutes
Working time for paper: three hours

Materials required/recommended for this paper

To be provided by the supervisor This Question/Answer Booklet Formulae and Data Booklet

To be provided by the candidate

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

Special items: up to three non-programmable calculators approved for use in the WACE examinations, drawing templates, drawing compass and a protractor

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 response	12	12	50	54	30
Section Two: Problem-solving	7	7	90	90	50
Section Three: Comprehension	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 2015*. Sitting this examination implies that you agree to abide by these rules.

2. Write your 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.

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

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

6. The Formulae and Data booklet is **not** to be handed in with your Question/Answer Booklet.

Section One: Short response **30% (54 Marks)**

This section has **12** questions. Answer **all** questions. Suggested working time: 50 minutes.

Question 1 **(3 marks)**

Microbats use 100 kHz ultrasound pulses for echolocation to navigate and forage. They generally emerge from their roosts at dusk and hunt for insects in total or near darkness. If a stationary bat emits a pulse and it takes 0.125 s for the pulse to return to the bat from a wall, calculate the distance from the bat to the wall.

f = 100,000 Hz   t = 0.125 s   2s = ? (there and back)

$$2s = v_{wave} \times t$$
$$2s = 346 \times 0.125 \quad ✓$$
$$2s = 43.25 \; ✓$$
$$s = 21.625 = 21.6\,m \; ✓$$

Question 2 **(4 marks)**

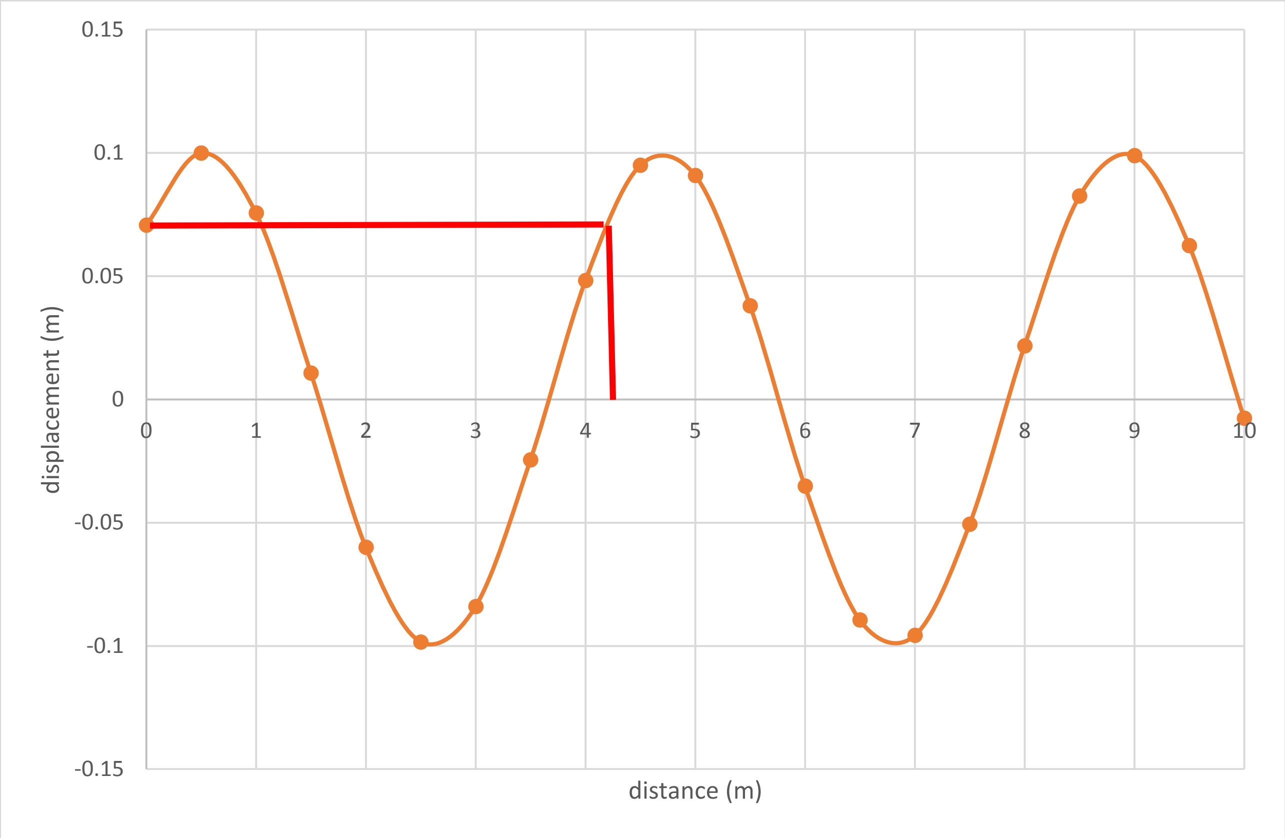
The velocity-time graph below shows the motion of a powered train carriage which moves along flat train tracks placed in a North-South direction. North is considered as positive. The initial displacement of the carriage is 50.0 m South. Refer to the graph to determine its displacement after 40 seconds.

Consider the area bounded by the graph and the time axis

$$A_1 = 0.5 \times 12 \times 22 \;\; A_2 = 8 \times 22 \;\; A_3 = 0.5 \times 6 \times 22 \; ✓$$
$$A_4 = -0.5 \times 10 \times 26 \; ✓$$

$$\Sigma Areas = +244\,m \quad ✓$$
$$Overall\ displacement = -50 + 244 = \; +194\,m\ North \; ✓$$

Question 3 **(4 marks)**



A ripple tank is used to generate water waves as shown in the displacement-distance graph above. Determine the following:

a) The maximum amplitude of the wave. (1 mark)

From the graph = 0.100 m ✓

b) The wavelength of the wave. (1 mark)

From the graph = 4.25 m ✓ (allow +/- 0.05)

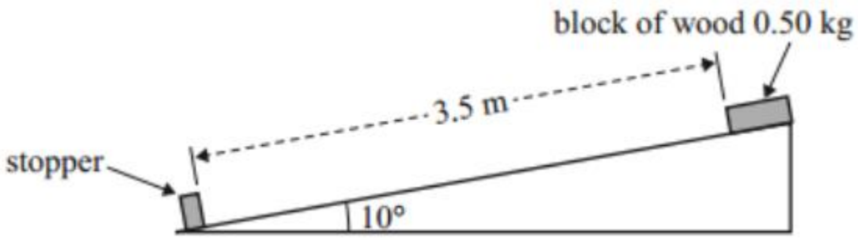
c) The frequency of the wave if the speed of the wave is 3.00 m s^{-1}. (2 marks)

λ = 4.25 m v = 3.00 m

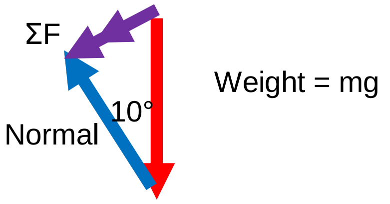
$$f = \frac{v}{\lambda} = \frac{3.00}{4.25} \checkmark = 0.706\ Hz \checkmark$$

Question 4 **(6 marks)**

Students set up an inclined plane surface as shown in the figure. It is angled at 10° to the horizontal. They place a frictionless 500 g block of wood at the top of the incline, so that the distance from the front of the block of wood to the stopper at the bottom is 3.50 m.



a) Draw and label a vector diagram showing the forces acting on the block. (2 marks)



Forces arranged head to tail showing correct ΣF ✓

Labelled ✓

b) Calculate the acceleration of the block as it descends. (2 marks)

$$a = g \times sin\theta = 9.8 \times \sin 10 \checkmark = 1.70\ m\ s^{-2} \checkmark$$

c) Calculate the time that the block of wood takes to reach the stopper once it has been released. If you did not calculate an acceleration for the block assume that it is 1.70 m s^{-2}.

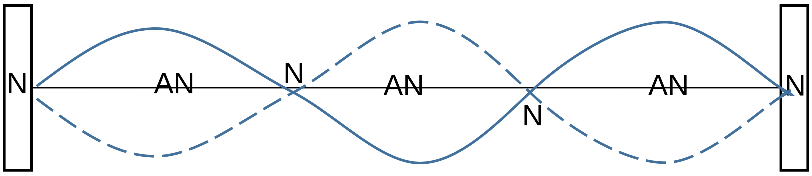
(2 marks)

$$s = ut + \frac{1}{2}at^2$$
$$3.50 = 0 + .5 \times 1.70 \times t^2 \checkmark$$
$$t = 2.03\ s \checkmark$$

Question 5 **(6 marks)**

The diagram shows a string stretched between two fixed ends. The string has a length of 0.65 m.

a) Sketch the standing wave produced by the 3rd harmonic on the diagram. (1 mark)



b) Label the nodes and antinodes on the diagram. (1 mark)

c) Calculate the wavelength of the 3rd harmonic. (2 marks)

$$\lambda = \frac{2}{3}L = \frac{2}{3}0.65 \checkmark = 0.433\ m \checkmark$$

d) If the frequency of the 3rd harmonic of the stretched string shown above is 300 Hz, calculate the frequency of the 5th harmonic. (2 marks)

$f_{fundamental} = f_n / n = 300 / 3 = 100$ Hz ✓
Fifth harmonic = $f_{fundamental}$ x 5 = 100 x 5 = 500 Hz ✓

Question 6 **(4 marks)**

A student heated 337 g of nickel in a Bunsen burner flame until it reached a temperature of 534 °C. She then placed the nickel into 1.59 L of water at a temperature of 21.0 °C. The final temperature of the nickel and water mixture was 32.3 °C when thermal equilibrium was reached.

a) Calculate the energy that transferred out of the nickel into the water. (2 marks)

Concept
energy transferred out of nickel = -(energy transferred into water)

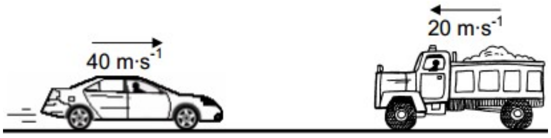
$Q = -m.c.\Delta T = -1.59 \times 4180 \times (32.3 - 21.0)$ ✓
$Q = -75{,}102.06\ J = -7.51 \times 10^4\ J$ ✓

b) Calculate the specific heat of the nickel. (2 marks)

$Q = m.c.\Delta T$
$-75{,}102.06 = 0.337.c.(32.3 – 534)$ ✓
$c = 444$ J kg^{-1} K^{-1} ✓

Question 7 **(6 marks)**

A 1500 kg car travelling at 40.0 m s^{-1} to the right and a 5000 kg truck travelling at 20.0 m s^{-1} to the left are involved in a head on collision.



a) If the car and truck are effectively joined together after the collision calculate their final velocity. (3 marks)

Using the conservation of momentum principle.

$m_1u_1 + m_2u_2 = (m_1 + m_2)v$
$(1500 \times 40) + (5000 \times -20)$ ✓ $= (6500)\ v$ ✓
$v = -6.15$ m s^{-1} (negative = left) ✓

b) Is the collision elastic or inelastic? Circle your answer and explain your choice using calculations. (3 marks)

Elastic Inelastic Impossible to determine

Compare sum of kinetic energies before and after

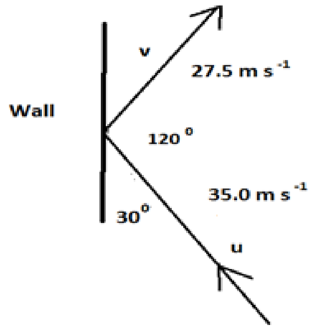
ΣKE (before) $= \frac{1}{2} m_1u_1^2 + \frac{1}{2} m_2u_2^2 = \frac{1}{2}\ 1500 \times 40^2 + \frac{1}{2}\ 5000 \times -20^2$
ΣKE (before) $= = 2\ 200\ 000$ J ✓

ΣKE (after) $= \frac{1}{2}(m_1 + m_2)v^2 = \frac{1}{2}\ 6500\ (6.15)^2 = 122\ 923.125$ J ✓

ΣKE (after) is less than ΣKE (before) therefore inelastic ✓

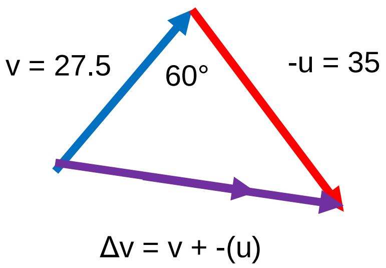
Question 8 **(6 marks)**

As shown in the diagram, a squash player hits a ball at a speed of 35.0 m s^{-1} at an angle of 30^0 to the side wall of the court. The ball rebounds at 120^0 to the original direction at a speed of 27.5 m s^{-1}.



a) Draw a fully labelled vector diagram showing the change in velocity of the ball.

(2 marks)



Correctly placed head to tail ✓

Shows correct Δv ✓

b) Calculate the change in velocity of the ball. (Note this is a vector quantity) (4 marks)

Using the cosine rule

$$a = \sqrt{b^2 + c^2 - 2bc\ \cos A}$$
$$\Delta v = \sqrt{27.5^2 + 35^2 - 2 \times 27.5 \times 35\ \cos 60}$$
$$\Delta v = \sqrt{27.5^2 + 35^2 - 2 \times 27.5 \times 35\ \cos 60} \checkmark$$
$$\Delta v = 31.91786334 \ \checkmark$$

Using sine rule

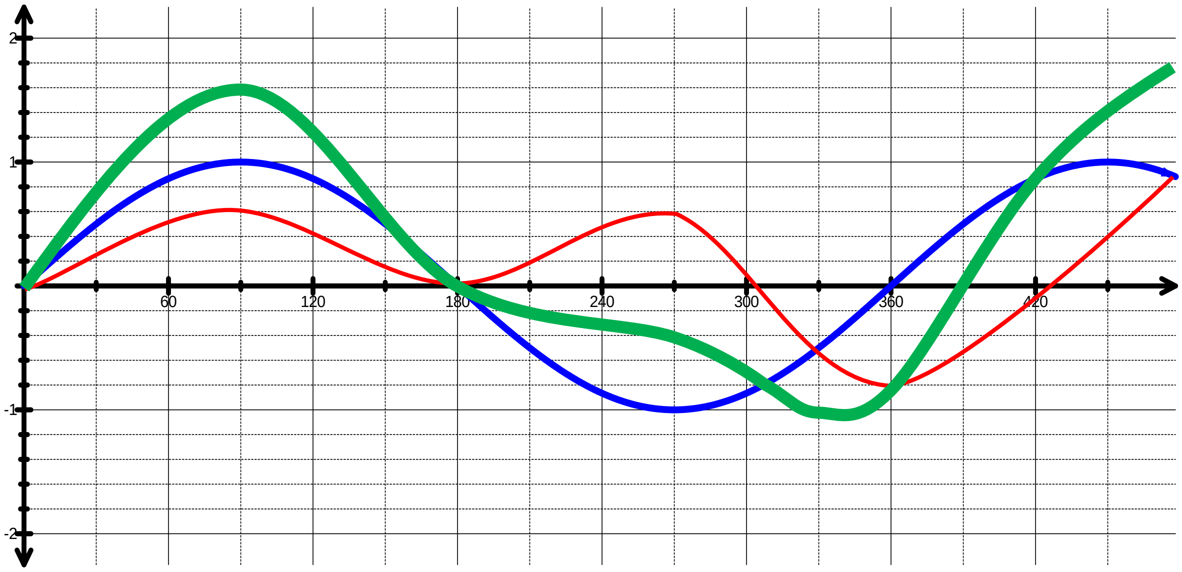
$$\frac{a}{\sin A} = \frac{c}{\sin C} = \frac{31.91786334}{\sin 60} = \frac{35}{\sin C} \checkmark$$

C = 71.8° (opposite –u)

So angle from vertical = 30 + 71.8 = 102° ✓

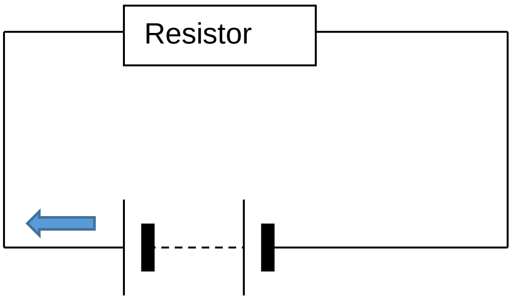
Question 9 **(2 marks)**

Add the two waves in the diagram to show their superposition waveform.



Question 10 **(3 marks)**

A resistor is connected to a battery as shown in the diagram below.



a) Use an arrow to indicate the direction of conventional current on the diagram. (1 mark)

b) If 5.54×10^{20} electrons pass through the resistor in a time of 70.0 s. Calculate the current in the resistor. (2 marks)

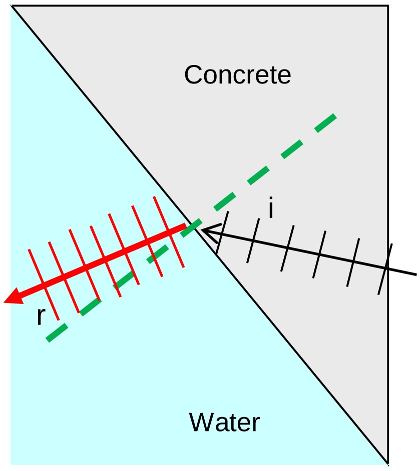
$q = q_e \times n_e$

$q = 1.60 \times 10^{-19} \times 5.54 \times 10^{20} = 88.64$ C ✓

$I = q / t = 88.64 / 70 = 1.27$ A ✓

Question 11 **(5 marks)**

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



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

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

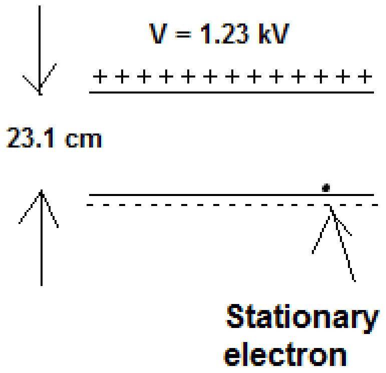
c) Is it possible for total internal reflection to occur as the sound wave travels through the concrete and meets the boundary with water? The sound waves can approach the boundary from any angle. Explain briefly.
(2 marks)

No, the wave speed is slowing down and refracting towards the normal.
The opposite must be true for TIR to allow the possibility for the angle of refraction to reach 90° (or similar) ✓
Wave speed must increase in medium 2. ✓

Any 2 well linked points

Question 12 **(5 marks)**

The figure shows an electron which is initially stationary and adjacent to the negative plate. The electron is released and accelerated towards the positive plate. A potential difference of 1.23 kV exists between the plates. Gravity has negligible effect in this scenario.



a) Calculate the work done in joules when the electron is accelerated across the gap. (2 marks)

$W = Vq = 1230 \times 1.60 \times 10^{-19}$ ✓
$W = 1.968 \times 10^{-16}$ J = 1.97×10^{-16} J ✓

b) Calculate the speed of the electron as it arrives at the positive plate. (3 marks)

$W = \Delta KE = \frac{1}{2} m v^2 - \frac{1}{2} m u^2$ (u = 0)
1.968×10^{-16} ✓ $= \frac{1}{2}\, 9.11 \times 10^{-31}\, v^2 - 0$ ✓
$v = 2.08 \times 10^7$ m s^{-1} ✓

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

This section has **seven (7)** questions. Answer **all** questions. Write your answers in the spaces provided.

Suggested working time: 90 minutes.

Question 13 (13 marks)

Bernard Tomic celebrates a victory by climbing into the crowd and smashing a tennis ball vertically upwards.

The ball is hit from a position 2.75 m above the ground with an initial velocity of 55.1 m s^{-1} upwards.

The ball has a mass of 57.3 g.

a) Calculate the time the ball takes to reach the ground. (3 marks)

(u = +55.1 m/s s = -2.75 a = -9.8)
Calculate velocity on arrival at ground level

$v^2 = u^2 + 2as$
$v^2 = 55.1^2 + 2 \times -9.8 \times -2.75$ ✓
v = -55.5869 m s^{-1} ✓ Take negative root as going down

Solve for t

$$t = \frac{(v-u)}{a} = \frac{(-55.589 - 55.1)}{-9.8} = 11.3\ seconds ✓$$

Alternatively use $s = ut + ½ at^2$ and use general solution of quadratic
$-2.75 = +55.1t - 4.9t^2$
$0 = -4.9t^2 + 55.1t + 2.75$

b) Calculate the velocity of the ball after 7.10 s. (2 marks)

v = u + at
v = +55.1 + (-9.8 x 7.10) ✓
v = -14.48 = -14.5 m s^{-1} ✓ (down)

c) Calculate the total distance that the ball travels from release to reaching the ground.

(3 marks)

Need to find maximum height above launch

$v^2 = u^2 + 2as$

$0^2 = 55.1^2 + 2 \times -9.8 \times s$ ✓

$s = 55.1^2/19.6 = +154.8984684$ m ✓

Total distance = 2 x 154.8984684 + 2.75 = 312.54 = 313 m ✓

d) Calculate the total mechanical energy of the ball relative to the ground whilst in flight.

(3 marks)

TME = KE + GPE = $\frac{1}{2} m u^2 + m.g.h$ ✓ concept

TME = $\frac{1}{2}\, 0.0573 \times 55.1^2 + 0.0573 \times 9.8 \times 2.75$ ✓

TME = 88.5 J ✓

e) The tennis racquet makes initial contact with the ball when the ball is momentarily at rest. The racquet is in contact with the ball for 0.085 s. Use the principal of impulse and change in momentum to determine the magnitude of force applied to the ball.

(2 marks)

$F.\Delta t = m v - m u$ (u = 0)

$F \times 0.085 = 0.0573 \times 55.1 - 0$ ✓

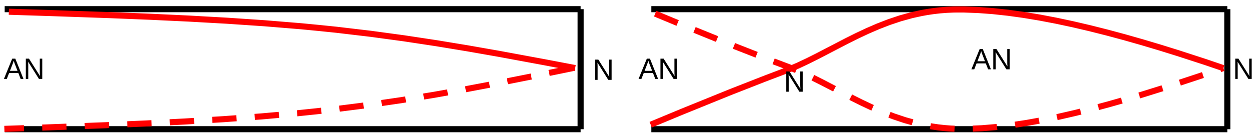
F = 37.1 N ✓

Question 14 **(13 marks)**

A bassoon is a woodwind instrument that is considered to be an air column closed at one end. When the bassoon resonates standing waves form.

a) Draw simple sketches to show the standing wave envelope for **particle displacement** for the **fundamental** and **first overtone**.

Fundamental frequency *First overtone*



(2 marks)

b) Indicate the nodes and antinodes on the sketches. (1 mark)

c) The lowest note of a bassoon is B-flat 1 and has a fundamental frequency of 58.3 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^{-1}. (3 marks)

$$\lambda = \frac{v}{f} = \frac{346}{58.3} = 5.9348 \checkmark$$

At fundamental L = ¼ λ = ¼ x 5.9348 ✓ = 1.48 m ✓

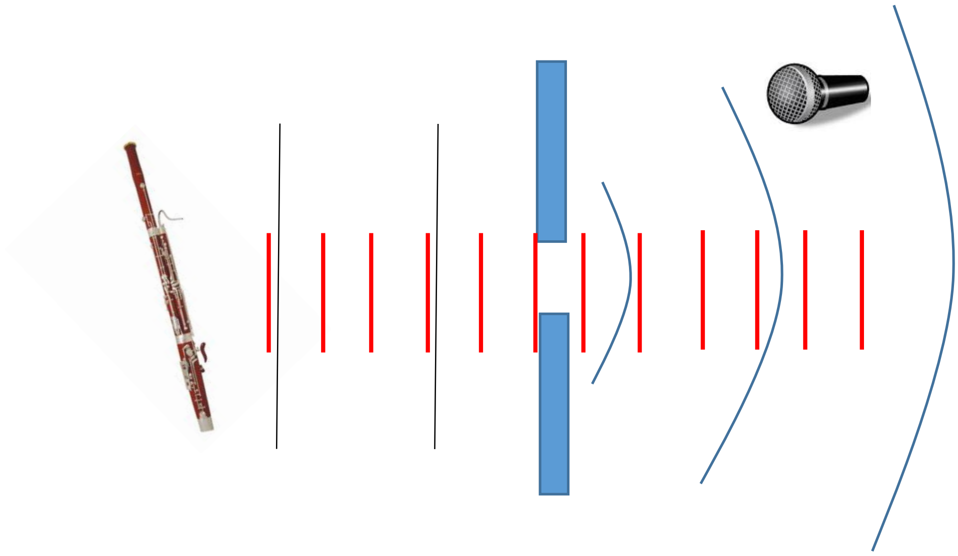
Or use $\lambda = \frac{4\ell}{2n-1}$ where n = 1

d) Briefly explain why an open pipe of the same length cannot resonate with a standing wave of frequency 58.3 Hz in this situation.

(3 marks)

For an open pipe the fundamental wavelength = 2L and it cannot be any longer. ✓
This leads to a frequency that is double that of the closed pipe. ✓
Or similar logical reasoning

e) When the bassoon is sounding a note of 58.3 Hz sound waves travel through a small gap in a partially open door to the outside. Reflections of sound waves 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 bassoon sound to be detected by the microphone and why it is able to occur in this case.

(2 marks)

This is diffraction where the wavefronts become more circular ✓ after passing through a gap where the gap width is less than the wavelength ✓

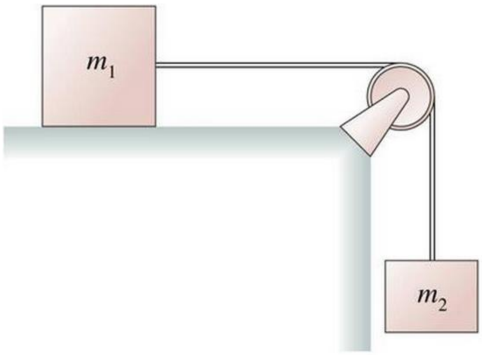
ii) Show on the diagram how wavefronts from a clarinet sounding at 175 Hz will reach the open door and continue through the air gap. You must show relative dimensions approximately to scale originating from the same location as the bassoon.

(2 marks)

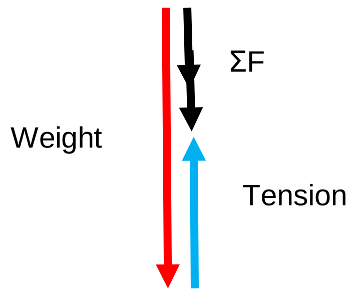
Shows less diffraction ✓
Wavelength approximately 1/3 in comparison ✓

Question 15 **(11 marks)**

As shown in the figure two masses are attached to a massless rope which runs over a massless and frictionless pulley. The mass of m_1 is $2.00\ kg$ and it rests on a frictionless table. The mass of m_2 is $4.00\ kg$ and it hangs vertically and is initially held stationary.



a) Draw a vector diagram showing the forces and sum of the forces acting on m_2 after it is released. (2 marks)



b) Calculate the acceleration of m_2 as it falls. (3 marks)

Nett force acting to accelerate the system = 4.00 x 9.8 = 39.2 N ✓

Acceleration of system $a = \frac{F}{m} = \frac{39.2}{6}$ ✓

a = 6.53 m s^{-2} (This applies to both m_1 and m_2) ✓

c) Calculate the tension in the rope as m_2 is falling. If you could not calculate the acceleration in the last question assume a value of 6.50 m s^{-2}. (2 marks)

T = W - ΣF = mg - ma = (4 x 9.8) – (4 x 6.53) ✓

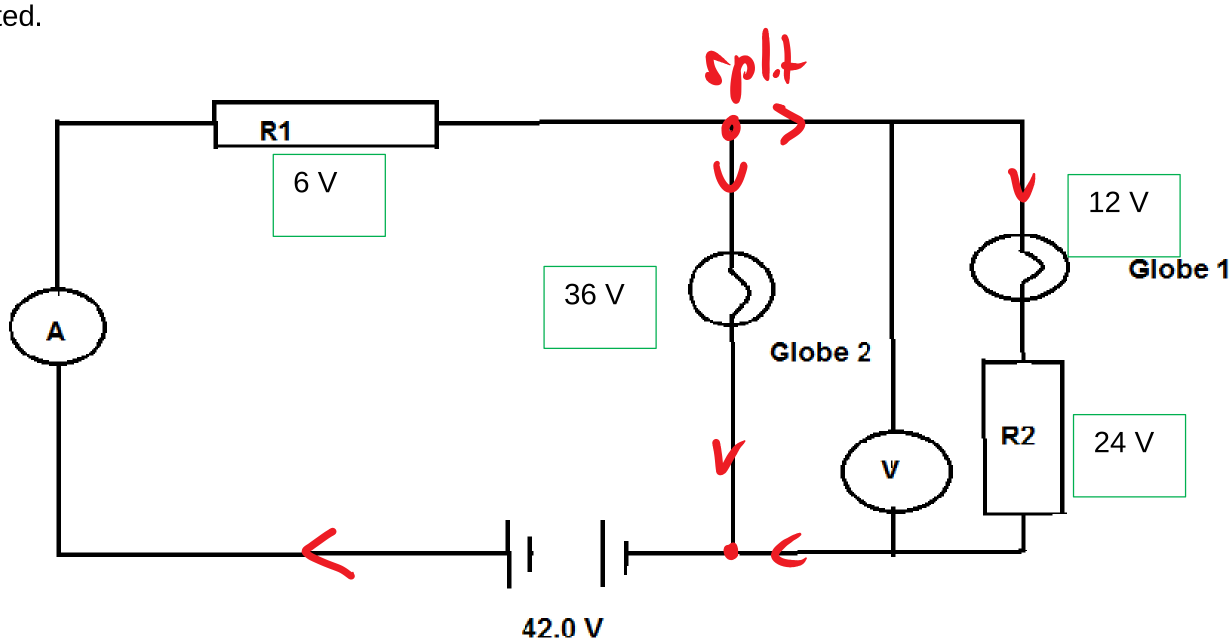
T = 13.1 N ✓ (up)

d) Calculate the kinetic energy of m_2 after it has fallen a distance of 60.0 cm. (4 marks)

$v^2 = u^2 + 2as$ (let down = positive)
$v^2 = 0^2 + 2 \times 6.53 \times 0.6$ ✓
$v^2 = 7.836$ ✓
KE = ½ m v^2
KE = ½ 4 x 7.836 ✓
KE = 15.7 J ✓ (up)

Question 16 **(16 marks)**

For some crazy weekend fun Yasmine and Georgia assembled the circuit shown below. To assemble the circuit they used a 42.0 V DC power source, two resistors, two globes and an ammeter and voltmeter. Globe 1 is rated at 12.0 V and 3.00 W and Globe 2 is rated at 36.0 V and 12.0 W. Assume that this circuit allows both globes to work at the exact values at which they are rated.



a) Calculate the current in Globe 1 (2 marks)

$$I = \frac{P}{V} = \frac{3}{12} \checkmark = 0.250\ A \checkmark$$

b) Calculate the current in Globe 2 (2 marks)

$$I = \frac{P}{V} = \frac{12}{36} \checkmark = 0.333\ A \checkmark$$

c) Calculate the resistance of R2 (2 marks)

Deduction of potential differences (on diagram)

$$R = \frac{V}{I} = \frac{24}{0.25} \checkmark = 96.0\ \Omega \checkmark$$

d) Calculate the resistance of R1. (2 marks)

Deduction of total current = 0.250 + 0.333 = 0.58333 A

$$R = \frac{V}{I} = \frac{6}{0.58333} \checkmark = 10.3\ \Omega \checkmark$$

e) Calculate the total resistance of the circuit. (2 marks)

By consideration of total potential difference across battery (concept)

$$R = \frac{V}{I} = \frac{42}{0.58333} \checkmark = 72.0\ \Omega \checkmark$$

f) Determine the reading on the:

(i) ammeter (1 marks)

Current = 0.583 A ✓

(ii) voltmeter (1 mark)

Potential difference = 36.0 V ✓

g) Calculate the power of R2. (2 marks)

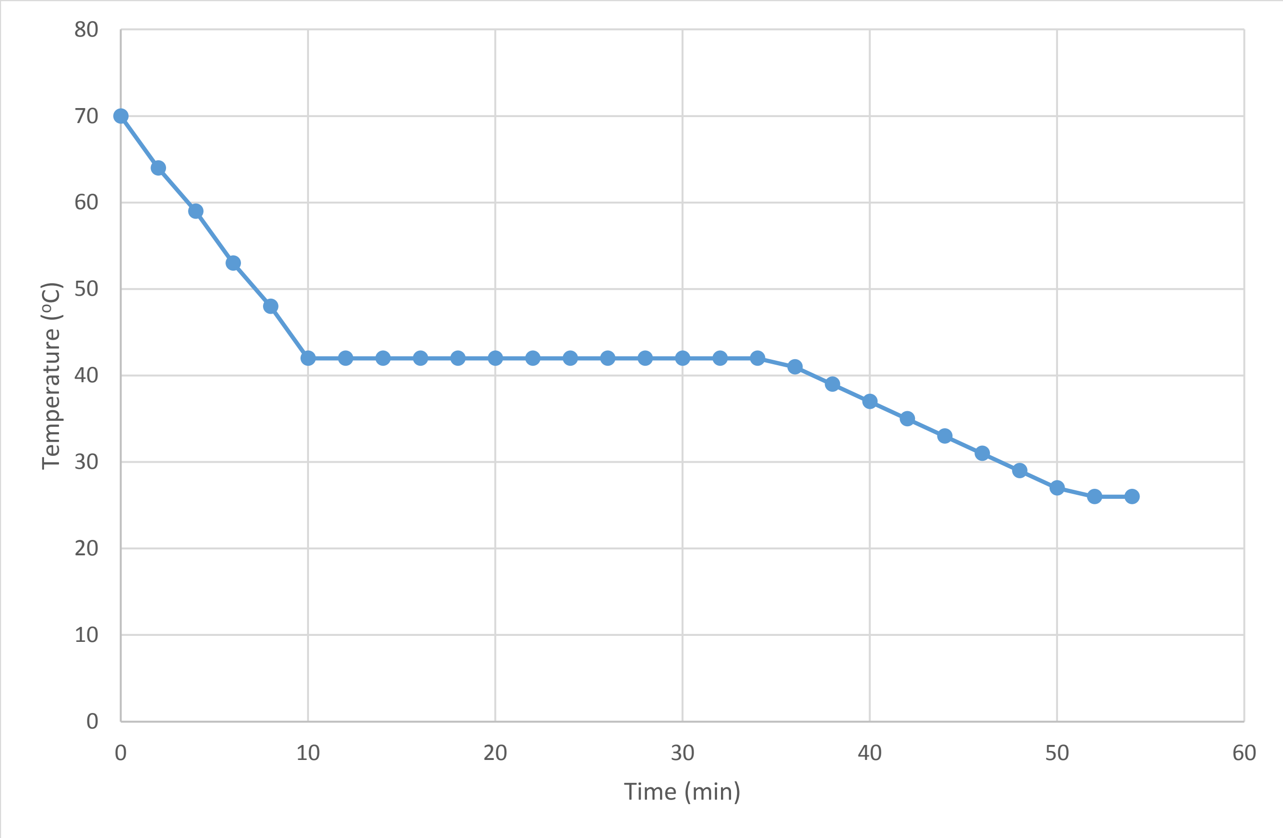
P = V I = 24 x 0.25 ✓ = 6.00 W ✓

h) Describe the difference between an ohmic and a non-ohmic conductor. (2 marks)

Ohmic = constant resistance at any PD ✓
Ohmic = variable resistance as PD changes ✓

Question 17 **(8 marks)**

Some liquid alcohol of mass 1.30 g was placed in a sealed glass container and vaporised at 70 ºC. The container with the vapour was placed in a large water bath that was kept at room temperature. The change in temperature of the alcohol was recorded every two minutes and is shown in the graph below. There was constant rate of energy output from the alcohol such that 2340 J of energy was transferred out in a 52 minute time period. Assume that heat loss to the surroundings was negligible and the room temperature was 26 ^{0}C.



a) Using the graph calculate the specific heat capacity of the alcohol vapour. (3 marks)

Rate of energy output = 2340 / 52 = 45 J per minute
Energy transferred out in vapour phase = 10 x 45 = 450 J ✓

$$c = \frac{Q}{m.\Delta T} = \frac{-450}{0.0013 \times (42-70)} ✓$$

c = 12362.63736 = 1.24 x 10^4 J/kg/K ✓

b) List the states of matter present in the container between fifteen and twenty five minutes. (1 mark)

Vapour (gas) and liquid ✓

c) Determine the latent heat of vaporisation of the alcohol. (2 marks)

Rate of energy output = 2340 / 52 = 45 J per minute
Energy transferred out in vapour phase = 10 x 45 = 450 J ✓

$$L_v = \frac{Q}{m.} = \frac{-45 \times 24}{0.0013} ✓$$

L_v = 830769.2308 = 8.31 x 10^5 J/kg ✓

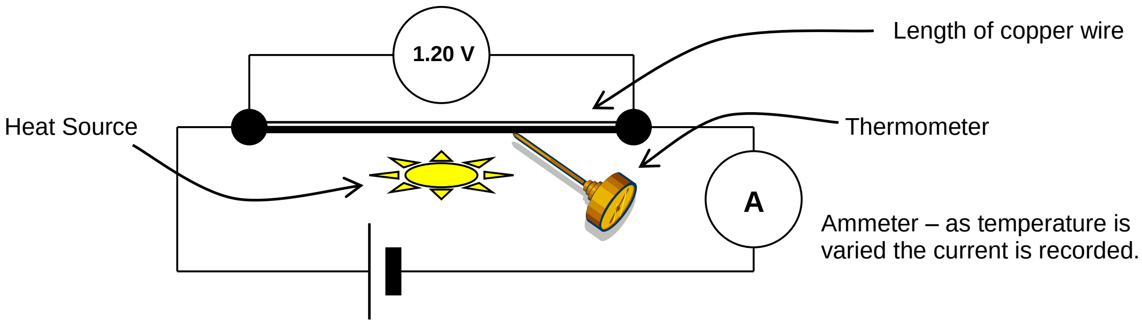
d) In terms of energy, explain why the temperature of the substance did not decrease while energy transferred from it to the water between fifteen and thirty minutes. (2 marks)

Energy transfer out is a reduction in PE ✓
Temperature relates to KE which remains constant at a fixed temperature. ✓

Question 18 **(13 marks)**

Electronic engineers at a manufacturer of high fidelity audio amplifiers are studying the resistance properties of copper wire in response to changes in temperature. They want to confirm to what extent copper wire is a **non-ohmic** conductor.

They applied a fixed potential difference of 1.20 V across a length of wire and measured the current as they varied the temperature of the wire. The results are recorded in the table below.



They are referring to this equation which they found in an electrical engineering text book:

$$R_\theta = \alpha.\Delta T.R_0 + R_0$$

R_θ = resistance at temperature ΔT (Ω)
α = temperature coefficient of resistance (K^{-1})
ΔT = temperature difference from 0°C
R_0 = resistance at 0°C (Ω)

The main objective is to determine the temperature coefficient of resistance (α) of the copper wire.

The students decide to graph Resistance (Ω) on the y-axis against Temperature (°C) on the x-axis. This will 'linearise' the data into a **y** = **m.x** + **c** format, such that the gradient of the line of best fit is an average value of **(α .R_0)**

Results table:

Temperature (°C)	Current (A)	Resistance (Ω)
40	7.32	0.164
80	6.38	0.188
120	5.55	0.216
160	5.08	0.236
180	4.89	0.245

a) Fill in the missing values in the table. *(Follow the format shown)*

Correct calculations ✓ Follows format ✓ (2)

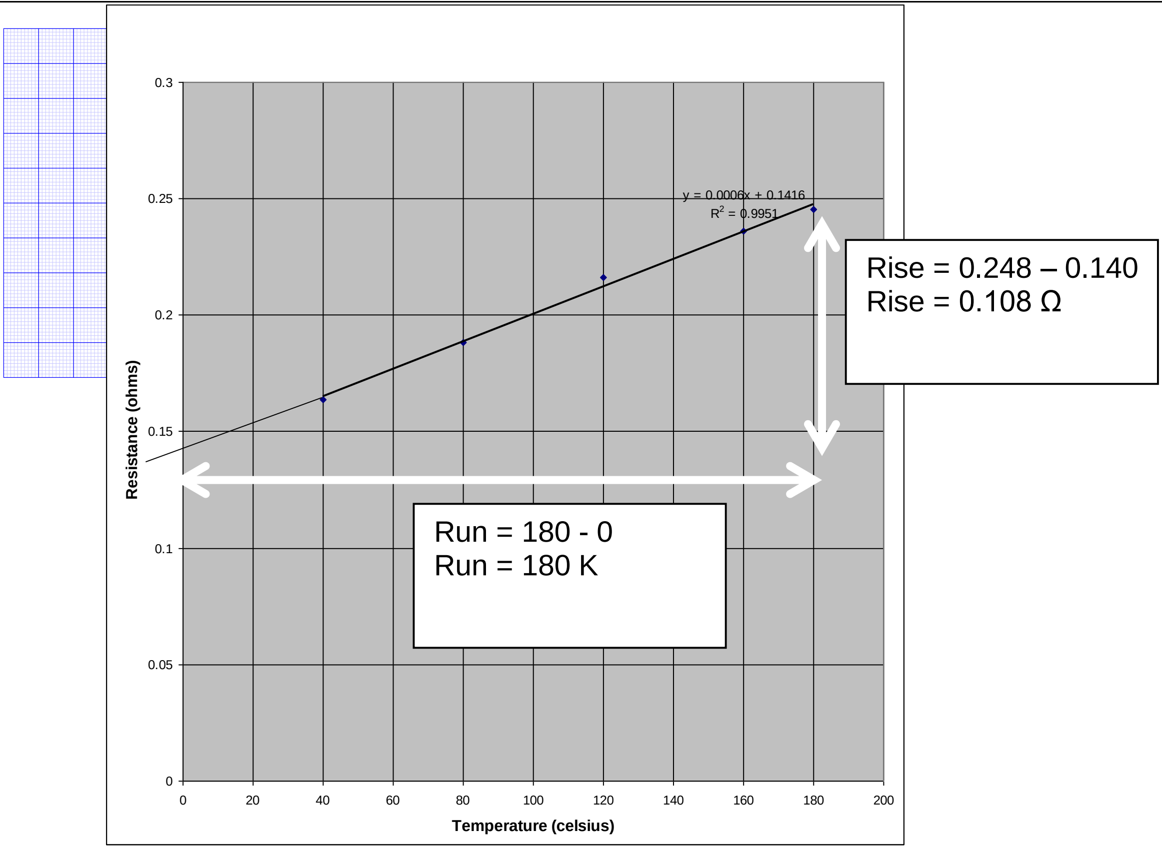
b) Plot your data points onto the graph paper (include all appropriate axes labels and units) and draw a straight line of best fit through your data points. Both axes **must start from zero** for this experiment. You should use the full height of the graph paper for the y-axis.

(5)

c) Determine the value of the intercept on the vertical axis and state what value this corresponds to in the equation.

(1)

Intercept = R_0 = 0.140 Ω ✓



Correct axis scaling (x: 0-200°C) (y: 0 – 0.25 Ω)✓
Correct plotting of data ✓
Correct axis labels ✓
Correct axis units ✓
Appropriate line of best fit through data with intercept✓

d) Determine the gradient of your line of best fit with careful reference to the units on each axis. (3)

Gradient = Rise / Run (must clearly refer to the line of best fit and not just 2 data pairs from the table) ✓
Gradient = (0.108) / (180) ✓ Gradient = $\underline{6.00 \times 10^{-4}\ \Omega\ K^{-1}}$ ✓

e) Substitute values to determine the temperature coefficient of resistance (α) of the copper wire. (If you were unable to determine the gradient of the graph use a value of 6.00×10^{-4}) (2)

gradient = $\alpha . R_0$
α = gradient / R_0

α = $\underline{6.00 \times 10^{-4}}$ / (0.14) ✓= $\underline{4.28 \times 10^{-3}\ K^{-1}}$ ✓

Question 19 **(16 marks)**

In one of the most remarkable phenomena in nature, a slow neutron can be captured by a uranium nucleus, rendering it unstable. The unstable nucleus then splits which produces more neutrons which continue the reaction and release a large amount of energy. In some reactions a single fission event can yield over 200 million times the energy of the neutron which triggered it!

In one such nuclear reaction the Uranium-235 atom absorbs one slow moving neutron. It then fissions into two daughter nuclei, one of which is Barium-141. It also produces three neutrons and releases energy.

Using the information in your Formula and Constants sheet, answer the questions that follow.

a) Write the equation for the nuclear reaction described above and identify the other fission product. You can omit the energy term when writing the equation. (2 marks)

$$^{235}_{92}U + ^{1}_{0}n \xrightarrow{fission} ^{141}_{56}Ba + ^{92}_{36}Kr + 3^{1}_{0}n$$

Balanced✓ correct elements identified. ✓

b) Calculate the energy released by the reaction. Give your answer in MeV to six decimal places.

(3 marks)

Δm = mass of reactants – mass of products

Δm = *(234.993454 + 1.00867)*
- *(140.883686 + 91.906404 + 3 x 1.00867)* ✓

Δm = 0.186024 u ✓

E (Mev) = Δm x 931 = 173.188344 Mev ✓

c) Calculate the binding energy per nucleon for a Barium-141 nucleus. Give your answer in MeV/nucleon to six decimal places.

(3 marks)

Δm = mass of nucleons – mass of nucleus

Δm = ((141 – 56) x 1.00867)+(56 x 1.00728))
- (140.883686)

Δm = 1.260944 u ✓

Binding Energy E (Mev) = Δm x 931 = 1173.938864 Mev ✓

Binding energy / #nucleon = 1173.938864 /141 = 8.325808 MeV ✓

d) Barium-141 undergoes beta negative decay to form Lanthanum-141. If a Geiger counter measured the initial decay rate of a sample of Barium-141 to be 1520 Bq and 8.00 minutes later it measured it to be 1120 Bq, calculate the half-life of Barium-141.

(4 marks)

$$N = N_0 \left(\frac{1}{2}\right)^n$$

$$1120 = 1520 \left(\frac{1}{2}\right)^n \checkmark$$

$$\log\frac{1120}{1520} = n \times \log\frac{1}{2}$$

$$n = 0.4405725914 \checkmark$$

$$n = \frac{t}{t_{\frac{1}{2}}}$$

$$t_{\frac{1}{2}} = \frac{t}{n} = \frac{8}{0.44057} \checkmark = 18.2\ minutes \checkmark$$

(1092 seconds)

Louis Slotin was a physicist and chemist who worked on the Manhattan Project. Slotin assembled the core for Trinity, the first detonated atomic device, and became known as the "chief armorer of the United States" for his expertise in assembling nuclear weapons. On 21 May 1946, Slotin accidentally began a fission reaction, which released a burst of radiation. He received a lethal dose of radiation and died of acute radiation syndrome nine days later.

It was estimated that he was exposed to an absorbed dose of 10.0 Gy of radiation from fast neutrons and 1.14 Gy from gamma radiation.

e) If Mr Slotin had a mass of 85.0 kg calculate the total amount of energy which he absorbed from the fast neutrons and gamma radiation.

(2 marks)

$$absorbed\ dose = \frac{E}{m}$$

$$\Sigma E = \Sigma(absorbed\ dose\ \times mass) = 10 \times 85 + 1.14\ \times 85 \checkmark$$
$$E\ = 946.9\ J = 947\ J \checkmark$$

f) Calculate the total dose equivalent from his exposure to the fast neutrons and the gamma radiation.

(2 marks)

$$dose\ equivalent = \ absorbed\ dose\ \times QF$$

$$\Sigma DE = \Sigma(absorbed\ dose\ \times QF) = 10 \times 10 + 1.14\ \times 1 \checkmark$$
$$DE = 101.14\ Sv = 101\ Sv \checkmark$$

End of Section Two

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

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

Question 20 **(20 marks)**

Alpha Particles Target Cancer **By Calla Cofield**

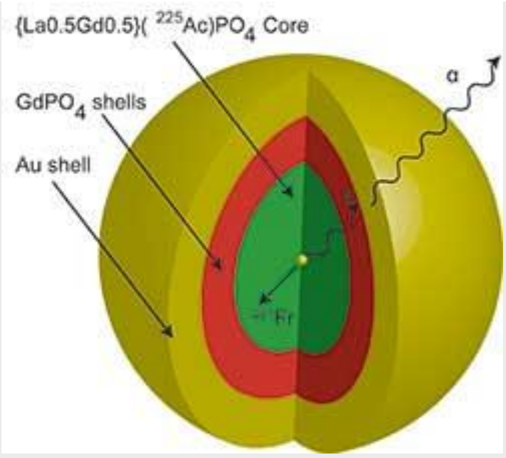


Photo courtesy of J. David Robertson/University of Missouri

In 2013, the Food and Drug Administration (FDA) approved the first cancer treatment drug containing an alpha-emitting isotope. In a 2014 APS Meeting, J. David Robertson, professor of chemistry at the University of Missouri, discussed a new technique that involves embedding alpha emitters inside a layered, gold-coated nanoparticle to make them safe for treatment for even more cancers.

Endoradiotherapy is a form of internal radiation therapy in which a radioactive substance is ingested by, or injected into the patient. Until last year endoradiotherapy used beta emitters. While surgery is usually the best option for sizeable, isolated tumours, chemotherapy is utilized to destroy small groups of cancer cells (or “micrometastases”) in multiple locations.

Endoradiotherapy drugs offer a targeted alternative to chemotherapy for attacking micrometastases. The drugs can be engineered to bind to receptors that are found on the cancer cells. When released nearby, beta particles do significant damage to cell DNA by ionizing other atoms and creating reactive chemical species in the cells. However, healthy cells nearby can also be affected.

Alpha particles are more direct, delivering energy directly to the cancer cell DNA and fatally disrupting adverse chemical reactions. And while beta particles deliver a few hundred keV of energy over a few millimetres, alpha particles deliver a bigger punch of 5 MeV, but stop after a distance of a few microns. “That very large amount of energy deposited in short range…makes them more cytotoxic to the cell than beta emitters,” said Robertson. “And it will allow you to get the same therapeutic effect with [about an order of magnitude] less radioactivity.”

Robertson and his collaborators from Oak Ridge National Laboratory and the University of Tennessee are in the preclinical phase of research to adapt the alpha emitter Actinium-225 for endoradiotherapy. The isotope has a half-life of 11 days, which is ideal, since it gives the researchers plenty of time to synthesize the drug (about 2 days) and then let it pass through the body and accumulate at the target site (another 2 to 3 days).

But decaying particles come with certain challenges: In the case of Ac-225, the alpha particle breaks free of the actinium nucleus with an energy of 5 to 6 MeV. This gives the daughters of the actinium a kick of about 100 keV, which is more than enough to tear through a molecular chain or a layer of cells, and send the daughters traveling through the body. The isotope Ac-225 eventually decays to bismuth, which has a 46-minute half-life and can be toxic if it builds up in the kidneys.

Robertson and his colleagues think they have found a solution: wrap the actinium in a layered nanoparticle to absorb the recoil energy and contain the daughter isotopes. The final product includes inner layers of lanthanide phosphate and gadolinium phosphate, and an outer layer of gold. The alpha particles still manage to escape the nanoparticle with only 0.1% energy loss, but after 24 hours 90% of the bismuth is contained in the nanoparticle or in nearby cells. Robertson says previous efforts to contain the bismuth by product of Ac-225 decay have succeeded in containing only 10 to 20 percent.

“We’re close to the goal of 100% [retention of bismuth],” said Robertson. The gold nanoparticle is currently being tested in the first phase of preclinical trials. Now Robertson and colleagues will have to see if the retention of bismuth is good enough to justify using the drug in humans. It comes down to the same question that doctors must ask of so many cancer drugs - “Does the benefit outweigh the risk?”

a) Explain why the layered nanoparticle coating is important both functionally and for the safety of the patient.

(3 marks)

Allows 99.9% of alpha particle energy to be delivered. ✓
Able to absorb the recoil energy. ✓
Able to contain the hazardous daughter products. ✓

b) Write a balanced nuclear equation for the alpha decay of Actinium-225.

(3 marks)

$${}^{225}_{89}Ac \xrightarrow{alpha\ decay} {}^{221}_{87}Fr + {}^{4}_{2}\alpha + (energy)$$

Balanced top✓ & bottom✓ correct elements identified.✓

c) List three advantages of using an alpha particle emitter for endoradiotherapy rather than a beta particle emitter.

(3 marks)

<u>Advantage 1</u> Energy delivered more directly. ✓

<u>Advantage 2</u> Much more energy can be delivered. ✓

<u>Advantage 3</u> Same therapeutic effect with less harmful radiation. ✓

d) Explain how nuclear radiation can be damaging to healthy cells and what health risks this poses for a human patient.

(3 marks)

Ionising radiation can damage DNA/Chromosomes ✓and lead to formation of cancerous cells. ✓
Highly reactive free radicals can also be formed which produce harmful chemical reactions in the human body. ✓
Any 3 good linked points

e) Explain why the alpha and beta particle emitters used in endoradiotherapy drugs need to be ingested or injected into the patient rather than the patient undergo surgery.

(3 marks)

Better for targeting small groups of cancers in multiple areas. ✓
If injected/ingested they engineered to seek out ✓ and then bind to receptors on cancer cells. ✓
Any 3 good linked points

f) Explain why it is advantageous for the Actinium-225 isotope to have a half-life of 11 days.

(2 marks)

The half life is short enough to provide sufficient radioactive energy. ✓
The half-life is long enough to allow time for manufacture and delivery into patient. ✓
Or similar

g) Calculate the percentage of an Actinium-225 sample's original nuclei that remain after it has decayed for 52 days.

(3 marks)

n = 52 / 11 = 4.72727 ✓

$$N = N_0 \left(\frac{1}{2}\right)^n$$

$$N = 100 \left(\frac{1}{2}\right)^{4.72727} \checkmark$$

N = 3.78% ✓.

Question 21 **(16 marks)**

How safe is your car?

Crash Protection Features

Crash protection features provide greater levels of injury protection to drivers and passengers in car crashes, they include:

Crumple zones

Modern cars protect drivers and passengers in frontal, rear and offset crashes by using crumple zones to absorb crash energy. This means that the car absorbs the impact of the crash, not the driver or passengers.

Strong occupant compartment

The cabin of the car should keep its shape in frontal crashes to protect the driver and passenger's space. The steering column, dashboard, roof pillars, pedals and floor panels should not be pushed excessively inwards, where they are more likely to injure drivers and passengers. Doors should remain closed during a crash and should be able to be opened afterwards to assist in quick rescue, while strong roof pillars can provide extra protection in rollover crashes.

Side impact protection

Increased side door strength, internal padding and better seats can improve protection in side impact crashes. Most new cars have side intrusion beams or other protection within the door structure. Some cars also have padding on the inside door panels.

Increasingly, car manufacturers are installing side airbags that provide protection from severe injury. Head-protecting side airbags, such as curtain airbags, are highly effective in side impact and rollover crashes.

Seat belts

A properly worn seat belt provides good protection but does not always prevent injuries. Three point lap/sash seat belts offer superior protection to two point seat belts and should be installed in all seating positions. Recent improvements to seat belt effectiveness include:

- webbing clamps that stop more seat belt reeling out as it tightens on the spool
- pretensioners that pull the seat belt tight before the occupant starts to move
- load limiters that manage the forces applied to the body in a crash
- seat belt warning systems to remind you if seat belts have not been fastened.

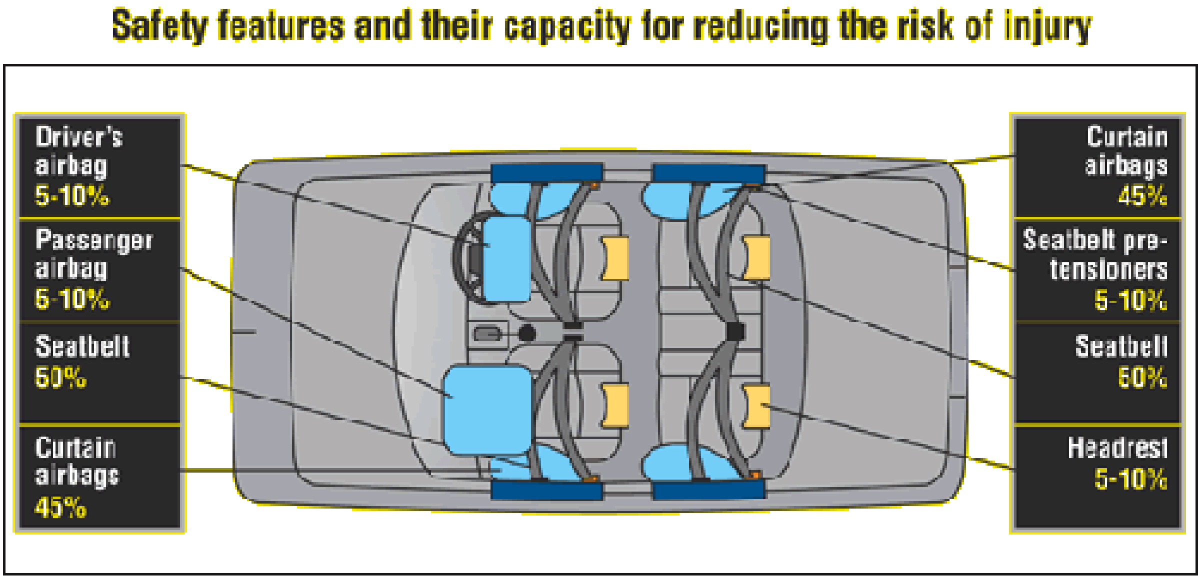
Airbags

Australian airbags are designed to supplement the protection provided by seat belts - they are not a substitute. The best protection in frontal crashes is achieved using a properly worn seat belt in combination with an airbag.

Head rests

Head rests are important safety features and should be fitted to all seats - front and back. Head rest position is critical for preventing whiplash in rear impact crashes. Whiplash is caused by the head extending backward from the torso in the initial stage of rear impact, then being thrown forward. To prevent whiplash the head rest should be at least as high as the head's centre of gravity (eye level and higher) and as close to the back of the head as possible.

Diagram and Information courtesy of Folksam Research, 2005 (SWEDEN)



a) “Modern cars protect drivers and passengers in frontal, rear and offset crashes by using crumple zones to absorb crash energy.” Explain the energy transformations that occur when a car’s crumple zone absorbs energy in a crash.

(2 marks)

Kinetic energy of the car in motion ✓ is transformed into heat, sound and energy required to deform the crumple zone material ✓
Or similar

b) Explain using physics principles how crumple zones reduce the force experienced by car passengers when a car crashes.

(4 marks)

In a collision work must be done to transform Kinetic energy into other forms ✓
That means a force must act over a displacement. A crumple allows a greater displacement during the collision event hence reducing force ✓
When considering impulse (Ft)= change in momentum (Δp)
Crumple zones increase the contact time. ✓
For a given change in momentum this is offset by a decrease in Force ✓
Any 4 well linked points that respond to the question.

If only time or distance addressed solely then subtract at least one mark

c) Describe 2 recent design features of seat belts that assist in holding a passenger in place on their seat.

(2 marks)

Webbing clamps that stop more seat belt reeling out as it tightens on the spool✓
Pre-tensioners that pull the seat belt tight before the occupant starts to move✓

d) Name and briefly explain three safety design features that enhance passenger protection in the event of a rollover crash. (When the car becomes upside down after or during a collision.)

(3 marks)

Rigid pillars to stop the passenger compartment being crushed✓
Seatbelts to hold the passenger in place✓
Side airbags to prevent impact with the side of the vehicle. ✓

e) Explain how head rests reduce the chance of whiplash injuries in a car crash where the vehicle is hit from behind.

(3 marks)

In a rear end collision the car is forced forward ✓ but because of inertia the mass of the head tends to stay in position ✓
The head rest prevents over extension of the neck as it would tend to be wrapped backwards over the seat as the car moves forward✓

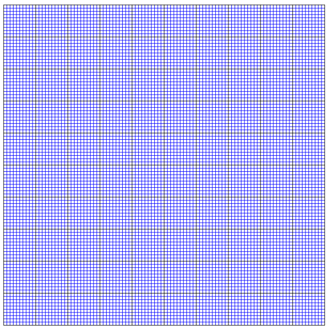
a) Should the metal that forms the "occupant compartment" be designed to crumple in a collision? Respond and discuss briefly.

(2 marks)

No ✓
It must be rigid to prevent intrusion of such items as the steering wheel, side pillars, pedals etc. which can injure occupants by impact. ✓

END OF EXAMINATION

Spare graph paper



Additional working space