



Rossmoyne Senior High School

Semester 1 examination, 2021

Question/Answer booklet

PHYSICS

UNIT 1

Student number:

In figures

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In words

Circle teacher's name:

Cooper

Mahabeer

Shashikumar

Time allowed for this paper

Reading time before commencing work:

ten minutes

Working time:

two hours, 30 minutes

Materials required/recommended for this paper

To be provided by the supervisor

This Question/Answer booklet

Number of additional
answer booklets used
(if applicable)

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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, 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 material. If you have any unauthorised material with you, hand it to the supervisor **before** reading any further.

STRUCTURE OF THIS PAPER

Section	Questions	Questions to be attempted	Suggested working time (mins)	Marks available	Percentage of exam
Section One: Short Response	8	8	45	45	30%
Section Two: Problem Solving	6	6	75	75	50%
Section Three: Comprehension	2	2	30	30	20%
Total				150	100

INSTRUCTIONS TO CANDIDATES

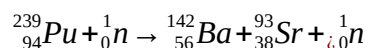
1. Write your answers in the spaces provided beneath each question. The value of each question is shown following each question.
2. Answers to questions involving calculations should be evaluated and given in decimal form. Final answers should be given to three significant figures and include appropriate units.
3. Questions containing the instruction "**ESTIMATE**" may give insufficient numerical data for their solution. Give final answers to a maximum of two significant figures and include appropriate units.
4. Despite an incorrect result, credit may be obtained for method and working providing these are clearly and legibly set out.
5. Questions containing specific instructions to **show working** should be answered with a complete, logical, clear sequence of reasoning showing how the final answer was arrived at; correct answers which do not show working will not be awarded full marks.
6. Supplementary pages for the use of planning/continuing your answer to a question have been provided at the end of this Question & Answer booklet. If you use these pages to continue an answer, indicate at the original answer where the answer is continued, i.e. give the page number.
7. Extra/spare graphs have also been provided at the end of this Question & Answer booklet.

Section One: Short Response**30% (45 marks)**

This section has **8** questions. Answer **all** questions. Answer the questions in the spaces provided.
Suggested working time: 45 minutes.

Question 1**(6 marks)**

Plutonium-239 is a fissile material used in fast-breeder nuclear reactors. One possible fission reaction involving this radioisotope is shown below. The nuclear reaction is incomplete.



- a) Determine the number of neutrons produced by this fission reaction.

(1 mark)

Description	Marks
5 neutrons produced	1
Total	1

The masses of the particles involved in this fission reaction are in the table below.

Pu-239	239.052163 u
neutron	1.00866 u
Ba-142	141.916343 u
Sr-93	92.91403 u

- b) Calculate the energy released (in Joules) by this fission reaction.

(5 marks)

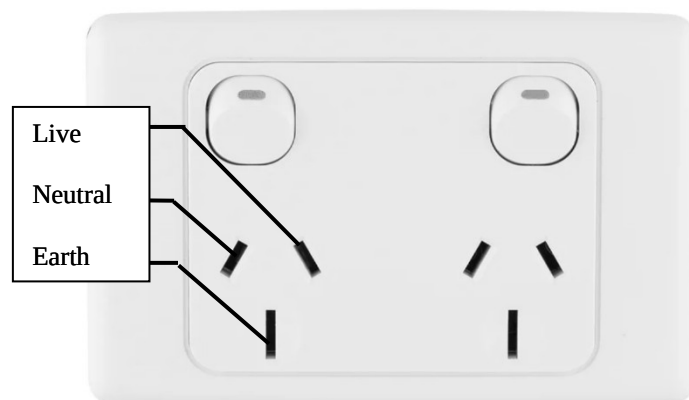
Description	Marks
<i>Mass of reactants</i> = $239.052163 + 1.00866 = 240.060823 \text{ u}$	1
<i>Mass of products</i> = $141.916343 + 92.91403 + 5 \times 1.00866 = 239.873673 \text{ u}$	1
<i>Mass defect</i> = $240.060823 - 239.873673 = 0.18715 \text{ u}$	1
$\therefore \text{Energy released} = 0.18715 \times 931 = 174.23665 \text{ MeV}$	1
$174.23665 \times 1.60 \times 10^{-13} = 2.79 \times 10^{-11} \text{ J}$	1
Total	5

Question 2**(7 marks)**

General power outlets have three points that contact the plug attached to the electrical appliance.

- a) State the potential difference between:
(3 marks)

Description	Total
240 V	1
0 V	1
0 V	1
Total	3



Fuses are being phased out of household use and being replaced by circuit breakers that perform the same function.

- b) Provide one of the benefits of a circuit breaker over a fuse.

(1 mark)

Description	Total
Can be reset instead of needing replacement OR Cheaper than replacing fuses OR Can trip the circuit much faster	1
Total	1

The electrical panel in the workshop also has an earth wire leading from all circuits to a long metal rod that is inserted deep into the ground outside the building.



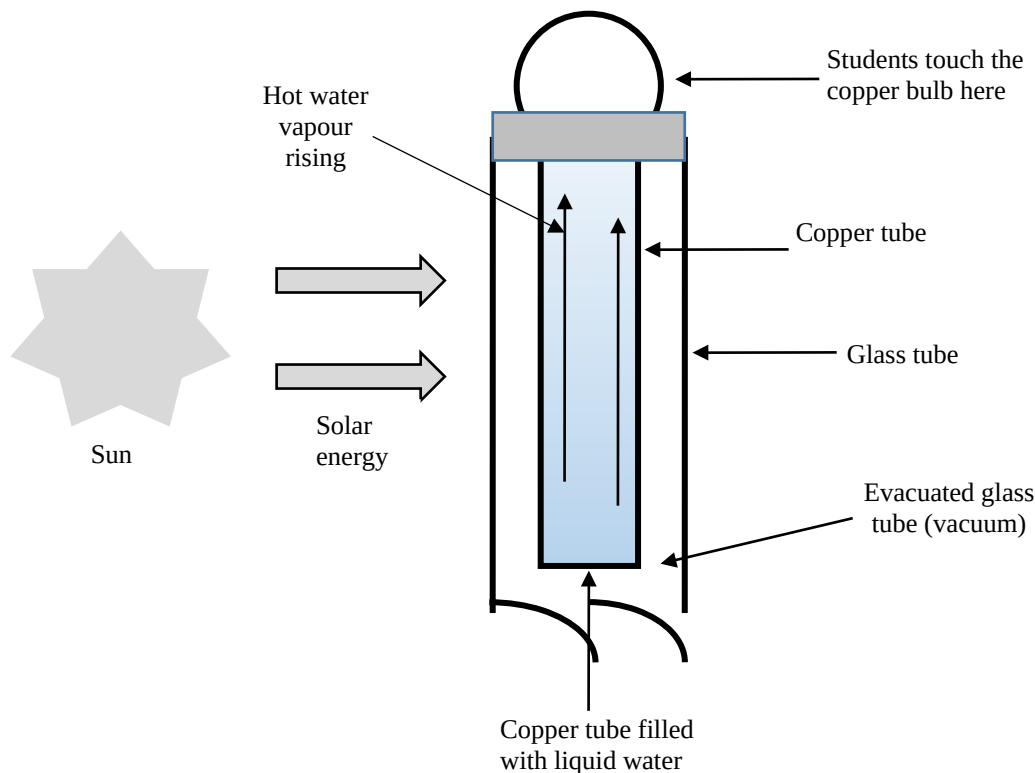
- c) State which hazard this protects the consumer from and explain why a fuse or a circuit breaker cannot protect from this hazard.

(3 marks)

Description	Total
Shock hazard	1
Fuse or Circuit Breaker only prevents excess current flow through a circuit.	1
As a shock hazard can exist under the fuse/circuit current rating, they do not always protect the consumer from current leakage.	1
Total	3

Question 3**(4 marks)**

Some students conducted an experiment examining methods of heat transfer using the equipment shown below. A glass tube has all air evacuated from its interior creating a vacuum within it. A copper tube filled with water is placed inside the glass tube. The students touch a copper bulb located at the top of the copper tube and notice that after a certain time, it starts to get hotter.



Explain each of the heating processes that occur within the apparatus that cause the students to detect an increase in temperature in the copper bulb.

Description	Marks
Solar energy heats the copper tube by travelling through the vacuum via radiation.	1
The heated copper tube transfers heat to the water via conduction.	1
Hot water vapour rises to the top of the tube and cooler water at the top of the tube falls to the bottom via convection.	1
Heat is conducted from the hot water vapour to the students' fingers via conduction through the copper tube.	1
Total	4

Question 4**(7 marks)**

You are provided with four resistors, each of $2.00\ \Omega$. Show how to connect them to produce an effective resistance of $5.00\ \Omega$.

- a) Draw in the space below, so that points A and B are at either end of the effective resistance. Label the resistors in your diagram R1, R2, R3etc.

(3 marks)

Description	Total
2 in series and 2 in parallel	1
neat straight lines, drawn with ruler	1
appropriately labelled	1
Total	3

The resistor network you have drawn is now constructed and connected correctly to a 9.00V power supply.

- b) Calculate the voltage drop across each of the resistors and write the value in the table below. If you used fewer than five resistors, leave the unused resistor box(es) blank.

(4 marks)

Description	Total
$I_T = V_T / R_T$ $= 9.00 / 5.00$ $= 1.80\text{ A}$	1
$V_1 = V_2 = I_T \cdot R$ $= 1.80 \times 2$ $= 3.60\text{ V}$	1
$V_T = V_P + V_{R1} + V_{R2}$ $9 = V_P + 3.6 + 3.6$	1
$V_P = 1.80\text{ V}$	1
Total	4

Question 5**(6 marks)**

A $1.10 \times 10^3 \text{ W}$ electric water heater has an efficiency, $\eta = 55.0\%$. The heater raises the temperature of 10.0 kg of water from 20.0°C to 75.0°C . Calculate the time (in seconds) taken for the electric water heater to complete this task. Show working.

Description	Marks
$Q_{\text{water}} = mc \Delta T = 10.0 \times 4180 \times (75.0 - 20.0)$	1
$\hookrightarrow 2299000 \text{ J}$	1
$\eta = \frac{\text{Energy output}}{\text{Energy input}} \times 100\%; \therefore$ $\text{Energy input} = \frac{\text{Energy output}}{\eta} \times 100\%$	1
$\hookrightarrow \frac{2299000}{55.0} \times 100$	
$\hookrightarrow 4180000 \text{ J}$	1
$P = \frac{Q}{t}; \therefore t = \frac{Q}{P} = \frac{4180000}{1100}$	1
$t = \frac{4180000}{1100}$	
$\hookrightarrow 3.80 \times 10^3 \text{ s}$	1
Total	6

Question 6**(5 marks)**

A 135 g block of aluminium is heated in an oven and placed into an insulated vessel containing 1.10 kg of water at 19.0°C . The final temperature of the aluminium and water mixture was 35.0°C when they reached thermal equilibrium. Assuming no water boils off, calculate the initial temperature of the aluminium block.

Description	Total
Heat gained by water = Heat lost by aluminium	1
$m_{\text{W}} \times c_{\text{W}} \times (T_{\text{f}} - T_{\text{i}}) = m_{\text{Al}} \times c_{\text{Al}} \times (T_{\text{i}} - T_{\text{f}})$	
$1.10(4180)(35.0 - 19.0) = 0.135(900)(T_{\text{i}} - 35.0)$	1
$73568 = 121.5T_{\text{i}} - 4252.5$ $77820.5 = 121.5T_{\text{i}}$ $T_{\text{i}} = \frac{77820.5}{121.5}$	1
$T_{\text{i}} = 6.40 \times 10^2^\circ\text{C}$	1
3SF	1
Total	5

Question 7

(6 marks)

A family is worried that their electricity bill has risen considerably over the years and decide to modify their home in an effort to reduce their electricity bill. They currently have sixteen 18.0 W halogen globes in the ceiling which have an electrical efficiency of 36.0%. They decide to replace all the globes with 5.00 W energy efficient LEDs. The household determines that, in an average week, the 16 halogen globes each run for 12.0 hours.

- a) Calculate the energy wasted by the halogen globes in one week.

(3 marks)

Description	Total
$E = n \times P \cdot t$ $= 16 \times 18 \times (12 \times 60 \times 60)$ $= 12441600$	1
$\text{Wasted Energy} = E \times (1 - \eta)$ $= 12441600 \times (1 - 0.36)$	1
$= 7.96 \times 10^6 \text{ J}$	1
Total	3

_____ J

- b) Synergy currently charge an average of 32.0 cents per kW h. Calculate how much money the family would save on their electricity bills each year by replacing the halogen globes with the LEDs.

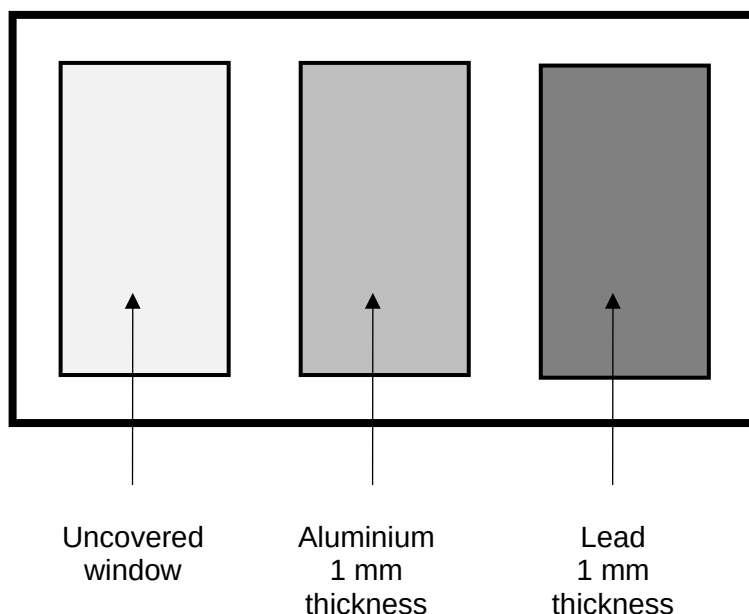
(3 marks)

Description	Total
$\text{Cost} = \text{Power} \times \text{time} \times \text{rate}$ $= 16 \times (18/1000) \times (12 \times 52) \times 0.320$ $= \$57.51$	1
$\text{Cost} = \text{Power} \times \text{time} \times \text{rate}$ $= 16 \times (5/1000) \times (12 \times 52) \times 0.320$ $= \$15.97$	1
$\$57.51 - \$15.97 = \$41.53 = \41.5	1
Total	3

Question 8**(4 marks)**

A hospital physicist is working with some radioactive materials. As part of the safety procedures required when handling this material, the physicist wears a badge containing film which reacts to the radiation. The film is placed behind a number of windows where different filters can be placed.

The structure of the badge is below:



After working with the material, the film is developed. It is found that the film behind both the uncovered window and the aluminium window have turned black (ie – has been exposed to some radiation and reacted with it). State which type of radiation could cause the film in **only** these areas to turn black. Explain your answer by commenting on the penetrating properties of alpha, beta and gamma radiation.

Description	Marks
It is beta radiation.	1
Alpha radiation will not penetrate through the air and therefore none of the films are exposed.	1
Beta radiation will penetrate through 1 mm of aluminium but NOT 1 mm of lead. Thus the uncovered and aluminium windows are exposed.	1
Gamma radiation will penetrate through 1 mm of aluminium AND 1 mm of lead. Thus if gamma was the radioactive source then all windows would have turned black.	1
Total (No marks awarded for just mentioning properties of the alpha, beta and gamma – they need to justify w.r.t the question) Max – 1 mark.	4

END OF SECTION ONE

Section Two: Problem Solving**50% (75 marks)**

This section contains **6** questions. Answer **all** questions. Answer the questions in the spaces provided.

Suggested working time 75 minutes.

Question 9**(15 marks)**

Lead sinkers used in fishing are made by heating masses of the lead to its melting point and then placing it in a mould to achieve the required shape. The lead is then cooled down and solidified by plunging the sinkers into a cool bucket of water.

In one such example of sinker production, 100.0 g of lead is heated to its melting point of 327.5 °C. While it is at this temperature, the lead is moulded into the required shape and then dropped into a bucket of water at 25.0 °C. The mass of the plastic bucket is 800.0 g and it contains 5.00 L of water.

The extra data required to answer the questions that follow is contained in the table below. Other data can be found in the Formulae and Data booklet if required.

Specific heat capacity of lead	130.0 J kg⁻¹ °C⁻¹
Latent heat of fusion of lead	22 900 J kg⁻¹
Specific heat capacity of the plastic bucket	900.0 J kg⁻¹ °C⁻¹
Mass of one (1) litre of water	1.00 kg

The lead, water and the plastic bucket reach thermal equilibrium and achieve a final common temperature of 'T'. For parts a) to d), assume no energy is lost to the surroundings.

- a) Show that the quantity of internal energy lost by the lead as it freezes at its melting point is equal to 2290 J.

(2 marks)

$Q = mL_f = 0.100 \times 22\,900$	1 mark
$\therefore 2290\text{ J}$	1 mark
Total	2 marks

- b) Derive an expression (in terms of 'T') for the **total** internal energy lost by the lead as it achieves a final temperature of 'T'.

(3 marks)

$Q = 2290 + 0.100 \times 130 \times (327.5 - T)$	1 mark
$\hookrightarrow 2290 + 4257.5 - 13T$	1 mark
$\hookrightarrow 6547.5 - 13T$	1 mark

- c) Derive an expression (in terms of 'T') for the **total** internal energy gained by the water and the plastic bucket as they achieve a final temperature of 'T'.

(4 marks)

$Q = 5.00 \times 4180 \times (T - 25) + 0.800 \times 900 \times (T - 25)$	1 mark
$\hookrightarrow 20900 \times (T - 25) + 720 \times (T - 25)$	1 mark
$\hookrightarrow 20900T - 522500 + 720T - 18000$	1 mark
$\hookrightarrow 21620T - 540500$	1 mark

- d) Hence, use the expressions you derived in parts b) and c) to show that the final temperature 'T' is approximately 25 °C.

(3 marks)

$6547.5 - 13T = 21620T - 540500$	1 mark
$21633T = 547047.5; \therefore T = \frac{547047.5}{21633}$	1 mark
$\therefore 25.3^{\circ}\text{C}$	1 mark

- e) The temperature of the water after the system had reached equilibrium was measured and found to be different from the above value. State whether the actual temperature would have been higher or lower than the calculated value and justify your choice.

(3 marks)

The heat gained by the water and the bucket would have been less than calculated in part c).	The heat gained by the water and the bucket would have been more than calculated in part c).	1 mark
Identifies reason (one of the below) In reality, some water evaporates OR heat transferred to the surroundings	Water may have splashed out, reducing the mass of water in the bucket	1 mark
Heat energy leaves the system so heat gained by water and bucket system is lower	Increasing the amount of heat energy gained by the remaining water	1 mark

(No mark for just saying higher/lower value without a proper justification)

Question 10**(8 marks)**

Radon-222 (half-life 3.83 days) is a naturally occurring inert gaseous isotope of radon that forms from the alpha decay of radium-226 (half-life 1.6×10^3 years). Radium-226 is found in many rocks, building materials and buildings. Because radon-222 is a gas and its decay releases tissue-damaging radiation, it can cause lung cancer when inhaled into the lungs over a prolonged period.

- a) Write the equation for the alpha decay of radium-226 to radon-222.

(2 marks)

Description	Total
${}^{226}_{88}\text{Ra} \rightarrow {}^{222}_{86}\text{Rn} + {}^4_2\alpha$	
All particles correctly identified	1
Mass number and atomic number balanced.	1
Total	2

- b) Radon-222 also undergoes alpha decay. Explain why these alpha particles are so much more dangerous to humans than those released by the parent radium.

(3 marks)

Description	Total
Radium exists in rocks which will not come into contact with people's lungs	1
Radon is a gas which can be inhaled	1
meaning the alpha particles can damage the fine blood vessels in the lungs.	1
Total	3

A sample of radon-222 was measured to have an initial activity of 1.40 kBq.

- c) Calculate the activity of the sample 2.00 weeks later.

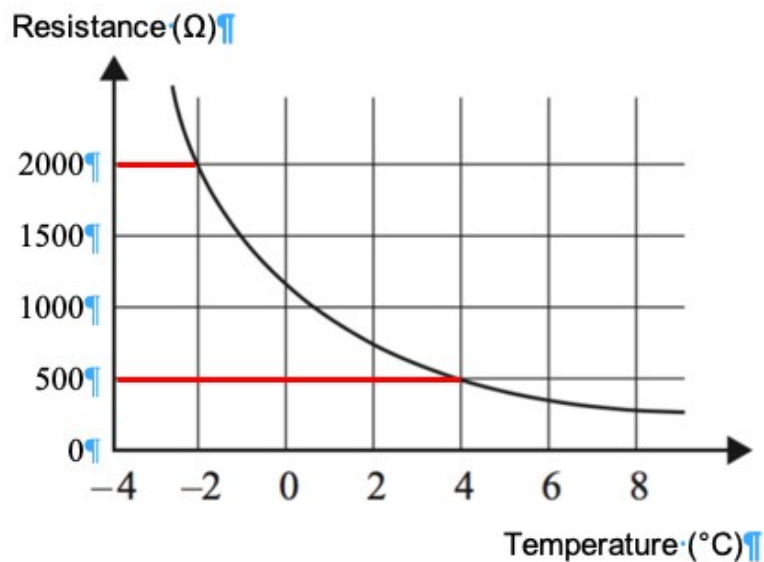
(3 marks)

Description	Total
$A = A_0(1/2)^{t/t_{1/2}}$	1
$= 1.40 \times 10^3 (1/2)^{14/3.83}$	1
$= 111 \text{ Bq}$	1
Total	3

Question 11

(9 marks)

A thermistor is a device in which resistance varies with temperature. The characteristics of a particular thermistor are shown in the diagram.

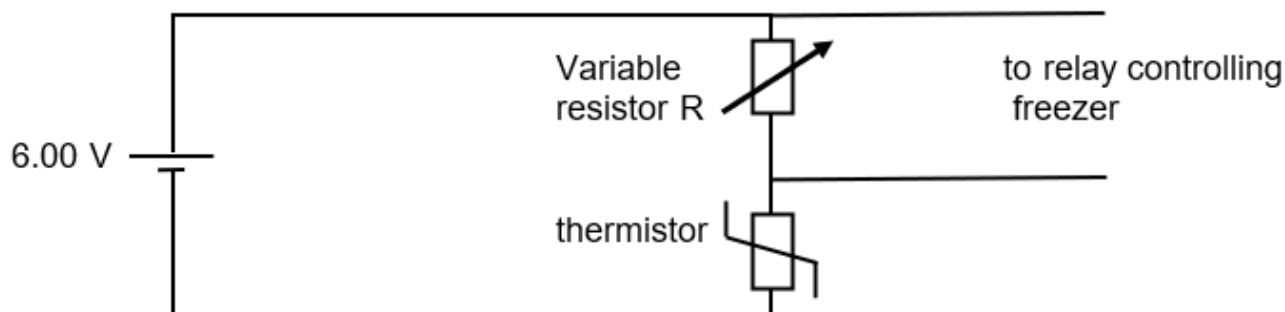


- a) Calculate the current in mA that would flow through the thermistor at 4.00 °C if the voltage across it were 2.50 V. Express your answer to 3 significant figures.

(3 marks)

Description	Total
Resistance determine on graph = 500 Ω	1
$I = V / R = 2.50 / 500$	1
= 5.00 mA (3 sig fig)	1
Total	3
If not expressed to 3 significant figures maximum 2 marks	

This thermistor is now used to control the temperature of a freezer unit of a refrigerator. The circuit is shown below. The switch controlling the freezer switches it on when the voltage across the variable resistor R is equal to (or greater than) 2.00 V. The freezer unit must turn on when the temperature is $-2.00\text{ }^{\circ}\text{C}$ or higher.



- b) Calculate the total current in mA required to flow through the circuit when the temperature is $-2.00\text{ }^{\circ}\text{C}$ in order to meet the required voltage across the resistor.

(4 marks)

Description	Total
Resistance determine on graph = $2000\ \Omega$	1
$V_T = V_{\text{thermistor}} + V_{\text{resistor}}$	1
$V_{\text{thermistor}} = 6.00 - 2.00 = 4.00\text{ V}$	1
$I = V / R = 4.00 / 2000$	1
$= 2.00\text{ mA}$	1
Total	4

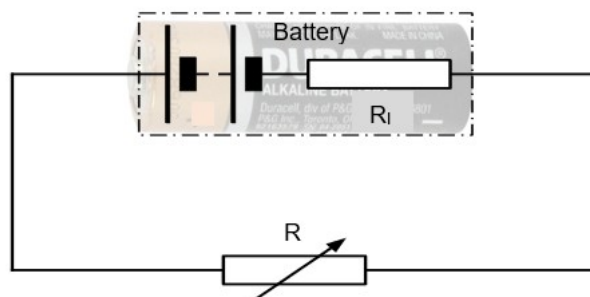
- c) Calculate the resistance that the variable resistor needs to have in order achieve this current. (If you could not obtain an answer to part (b), you may use $I_T = 1.10\text{ mA}$)

(2 marks)

Description	Total
$R_T = V_T / I_T = 6.00 / 0.002 = 3000\ \Omega$ (5450 Ω)	1
$R_{\text{Resistor}} = R_T - R_{\text{Thermistor}}$ $= 6000 - 3000 = 3.00\text{ k}\Omega$ (550 Ω)	1
Total	3

Question 12**(13 marks)**

A cell in a circuit supplies electrical energy to other components of a circuit. If the cell has internal resistance, some of the electrical energy produced is wasted due to heating inside the cell. The internal resistance in the cell can be treated as a resistor that is in series with rest of the circuit. As the battery's internal resistance increases, it has said to have gone "flat", as it can no longer provide a suitable EMF to the circuit.



An interesting observation is that as the current through the circuit increases, the EMF provided by the battery decreases. Consider a cell connected to a resistance R . The cell's EMF is E and its internal resistance is R_i . Given Ohm's Law, current can be expressed as:

$$E = IR + IR_i$$

So $IR = E - IR_i + E.$

Or $V = E - R_i \cdot I + E.$

Students conduct an experiment to test the internal resistance of two 1.5 Volt batteries to determine if they are flat or not. They use a variable resistor to vary the total resistance of the circuit and obtain the following values.

Current (A)	Voltage (V)	
	Battery 1	Battery 2
0.00	1.50	1.50
0.20	1.32	1.45
0.40	1.12	1.40
0.60	0.93	1.36
0.80	0.73	1.32
1.00	0.55	1.25

- a) On the graph on the following page, plot a graph of Voltage vs Current for both batteries. A spare grid is provided on the end of this Question/Answer booklet. If you need to use it, cross out this attempt and clearly indicate that you have redrawn it on the spare page.

(5 marks)

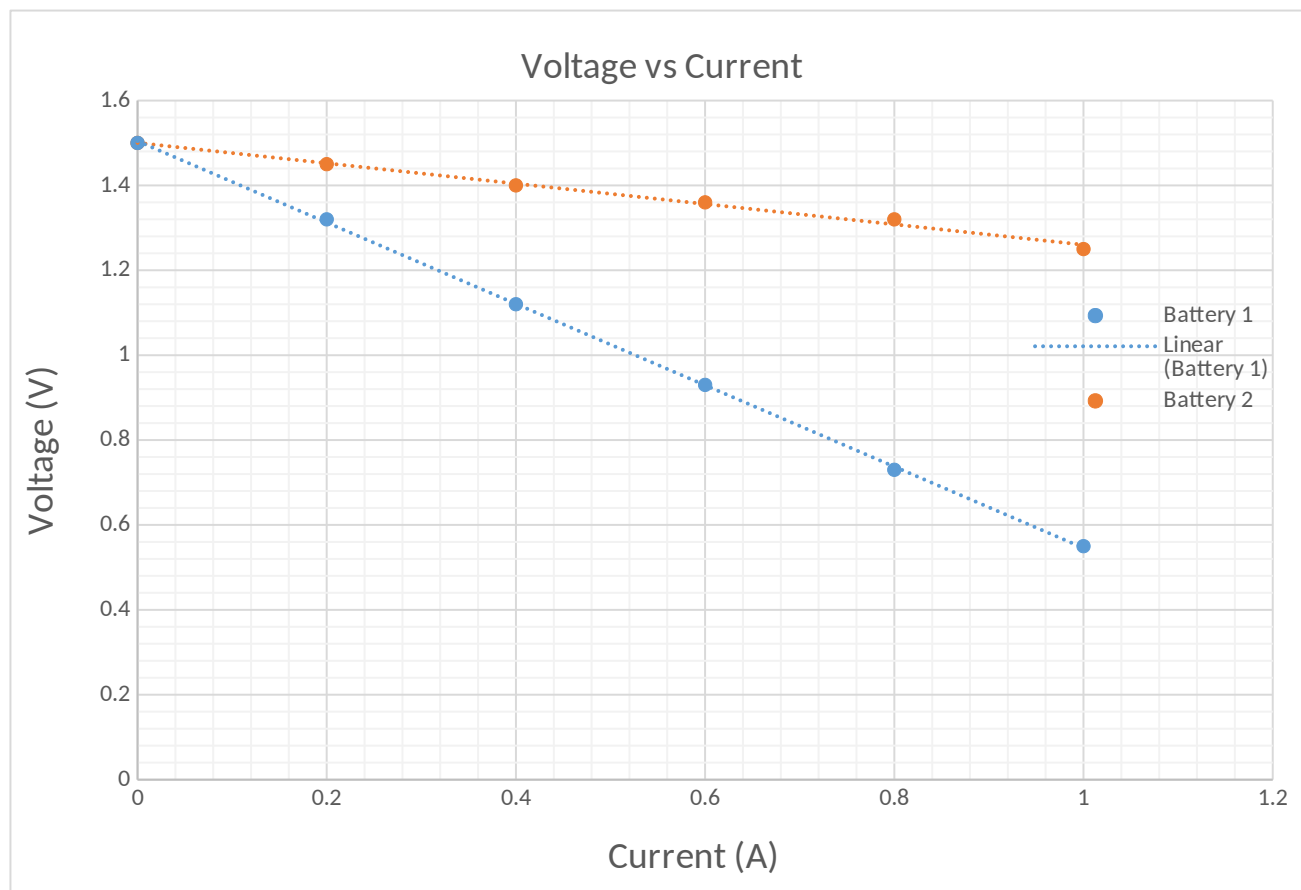
- b) Calculate the gradient of both graphs.

(4 marks)

Description	Total
$m_1 = \frac{y_2 - y_1}{x_2 - x_1} = \frac{1.48 - 0.64}{0.90 - 0.04}$	1
$= -0.96$	1
$m_2 = \frac{y_2 - y_1}{x_2 - x_1} = \frac{1.48 - 1.28}{0.90 - 0.20}$	1
$= -0.25$	1
Total	4

- c) Determine the internal resistance of both batteries and state which battery is 'flatter'. (2 marks)

Description	Total
$R_{\text{internal}} = -\text{gradient}$ $R_1 = 0.95 \, \Omega$ $R_2 = 0.25 \, \Omega$	1
Since R_1 has a greater internal resistance, it is "flatter"	1
Total	2



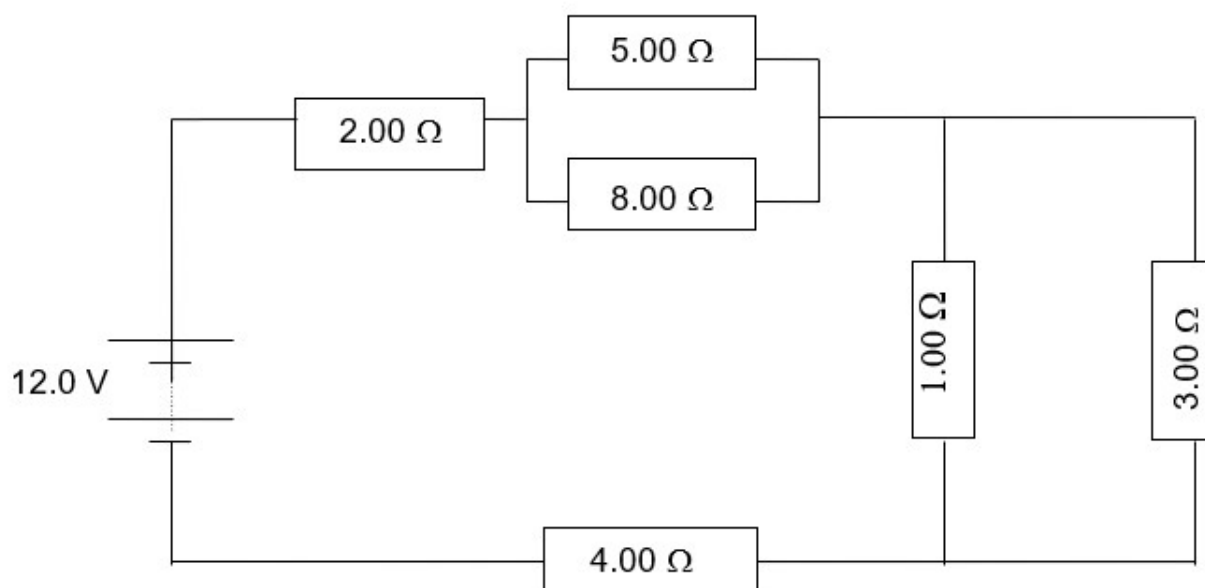
Description	Total
correct orientation of axes	1
correct labelling of axes including units and Title.	1
accurate plotting	1
key provided identifying each data series.	1
line of best fit (LOBF)	1
Total	5

- d) Based on the information above, explain why testing the voltage across a flat 1.50 V battery with a voltmeter might display a voltage of 1.50 V even though it is flat and no current flows through. (2 marks)

Description	Total
When there is no current flowing through the battery,	1
there is no voltage drop across the internal resistance.	1
So $V = E$ and the reading will display 1.50 V	1
Total	3

Question 13**(16 marks)**

Consider the following complex circuit diagram below:



- a) Show that the total resistance of the circuit is 9.83 Ω.

(5 marks)

Description	Total
$\frac{1}{R_{E1}} = \frac{1}{5} + \frac{1}{8} = \frac{8}{40} + \frac{5}{40} = \frac{13}{40},$	1
$R_{E1} = \frac{40}{13} = 3.08 \Omega$	1
$\frac{1}{R_{E2}} = \frac{1}{1} + \frac{1}{3} = \frac{4}{3},$	1
$R_{E2} = \frac{3}{4} = 0.750 \Omega$	1
$R_T = 2.00 + 3.08 + 0.750 + 4.00$ $= 9.83 \Omega$	1
Total	5

- b) Calculate the voltage drop across the 2.00 Ω resistor.

(4 marks)

Description	Total
$I_T = V / R$ $= 12.0 / 9.83$	1
$= 1.22 \text{ A}$	1
$V_2 = I_T \cdot R_2$	1

$= 1.22 \times 2$	
$= 2.44 \text{ V}$	1
Total	4

- c) Calculate the current that flows through the $8.00 \, \Omega$ resistor.

(4 marks)

Description	Total
$I_T = V_P / R_{E1}$ $V_P = I_T \cdot R_{E1}$	1
$= 1.22 \text{ (3.08)}$ $= 3.75 \text{ V}$	1
$I_8 = V / R$ $= 3.75 / 8$ $= 0.469 \text{ A}$	1
3 sig figs	1
Total	4

Markers notes:

Paid for using proportionality as a method of finding the current split HOWEVER many students did not realise that current splits such that more current flows down branch with least resistance.

Paid 1 mark for any indication of using Ohm's Law to find any unknown

Some students thinking that voltage remaining after the $2 \, \Omega$ resistor all goes through each branch of the 5 and $8 \, \Omega$ section – this is not the case as the remaining voltage is distributed across all resistors in the circuit.

- d) Explain what would happen to the power drawn by the circuit if the $3.00 \, \Omega$ resistor was removed from the circuit.

(3 marks)

Description	Total
Since the $3 \, \Omega$ resistor is in parallel, removing it would increase the total resistance of the circuit.	1
With the voltage supplied remaining constant, increasing the resistance would decrease the current as per $V = IR$.	1
As $P = IV$, the power drawn by the circuit would decrease.	1
Total	3

Markers notes:

Accepted the interpretation that the wires were still connected if stated that a short circuit formed.

Needed at least one formula ($V=IR$ or $P=IV$) in description (even if in words) to explain the relationship between variables

Did not pay follow through on explanation – treated as discriminator.

Question 14**(14 marks)**

The radioisotope most widely used in medicine is an isotope of Technetium, Tc-99. It is employed in some 80% of all nuclear medicine procedures. Tc-99 has almost the ideal characteristics for a nuclear medicine scan. These are:

- It has a half-life of 6 hours.
- It mainly emits gamma rays.
- The chemistry of technetium is so versatile it can form tracers by being incorporated into a range of biologically-active substances that ensure it concentrates in the tissue or organ of interest.

Its logistics also favour its use. Technetium generators – a lead pot enclosing a glass tube containing the radioisotope – are supplied to hospitals from the nuclear reactor where the isotopes are made. They contain molybdenum-99 (Mo-99), with a half-life of 66 hours, which progressively decays to Tc-99. The Tc-99 is washed out of the lead pot by saline solution when it is required. After two weeks or less the generator is returned for recharging.

- a) As stated, Tc-99 is gained from the decay of Mo-99 atoms. Identify the type of decay that occurs in Mo-99 by writing a balanced nuclear equation for this transmutation.

(3 marks)

$Mo_{42}^{99} \rightarrow Tc_{43}^{99} + e_{-1}^0$	
All species identified with correct chemical/particle symbols.	1 mark
Mass numbers and atomic numbers balanced.	1 mark
Identifies Mo-99 as a beta-emitter.	1 mark

- b) Tc-99 mainly emits gamma rays. This also makes it very useful for medical scans. State two (2) reasons for this.

(2 marks)

Gamma rays escape easily from the human body and can be used for external scans.	1 mark
Gamma rays have the least ionising power of the three most common types of radiation and, therefore, will do less damage to the human body.	1 mark

- c) Explain why the half-life of Tc-99 makes it an ideal radioisotope to use for a medical scan.

(2 marks)

The short half-life ensures that Tc-99 decays to very low levels of radioactivity in a very short time.	1 mark
Hence, in the longer run, less damage is inflicted on the human body by the radioisotope.	1 mark

A 50.0 g sample of solid Tc-99 arrives at a hospital.

- d) Calculate the mass of solid, radioactive Tc-99 that remains after 15 hours. Show working. (3 marks)

$N = N_0 \left(\frac{1}{2} \right)^n$; where $N_0 = 50.0 \text{ g}$; $n = \frac{15}{6} = 2.5 \text{ half lives}$	1 mark
$N = 50.0 \left(\frac{1}{2} \right)^{2.5}$	1 mark
$\therefore N = 8.84 \text{ g}$	1 mark

_____ kg

- e) Once the mass of a sample of Tc-99 drops below 5.00 g, a new sample of Tc-99 needs to be brought into the hospital. Calculate how long it will take for this sample of Tc-99 to drop below this mass.

(4 marks)

$N = N_0 \left(\frac{1}{2} \right)^n$; where $N_0 = 50.0 \text{ g}$; $N = 5.00 \text{ g}$	
$5.00 = 50.0 \left(\frac{1}{2} \right)^n$; $\left(\frac{1}{2} \right)^n = 0.100$	1 mark
$\therefore n = \frac{\log 0.100}{\log 0.5}$	1 mark
$\therefore 3.32 \text{ half lives}$	1 mark
$\therefore t = 3.32 \times 6 = 19.9 \text{ hours}$	1 mark

END OF SECTION TWO

Section Three: Comprehension

20% (30 Marks)

This section has **2** questions. Answer both questions and write your answers in the spaces provided.

Suggested working time: 30 minutes.

Question 15

(16 marks)

Nuclear Astrophysics: Nucleosynthesis in the Universe

From Lepine-Szily and Descouvemont (2012)

The role of nuclear reactions in our Universe is two-fold: the production of energy and the formation of elements – a process called nucleosynthesis.

The idea of energy production in stars occurring through the nuclear fusion of H-1 and H-2 into He-4 was first raised by A.S. Eddington in 1920.

In 1931, Georges Lemaitre, a Belgian Priest and astrophysicist, proposed the idea of the 'Big Bang' (not the name, however, which was suggested later by Fred Hoyle), based on the evident expansion of the Universe: if projected backwards, this expansion suggested that everything began from a very small region in the past.

After the Big Bang, the first generation of stars was formed from Hydrogen and Helium only. Heavier elements necessary for a carbon-based life were produced by nucleosynthesis in stars. Then the elements absolutely essential for life were made in supernova explosions of massive stars. These processes took place on massively long timescales – billions of years.

In 1939, Hans Bethe established which nuclear reactions could be responsible for the production of He-4 from Hydrogen in the stars. He introduced the mechanism of the proton-proton (pp) chain and the Carbon-Nitrogen-Oxygen (CNO) cycle. C-12 itself is produced by a "triple- α " process (three α -particles combining in two steps to form C-12).

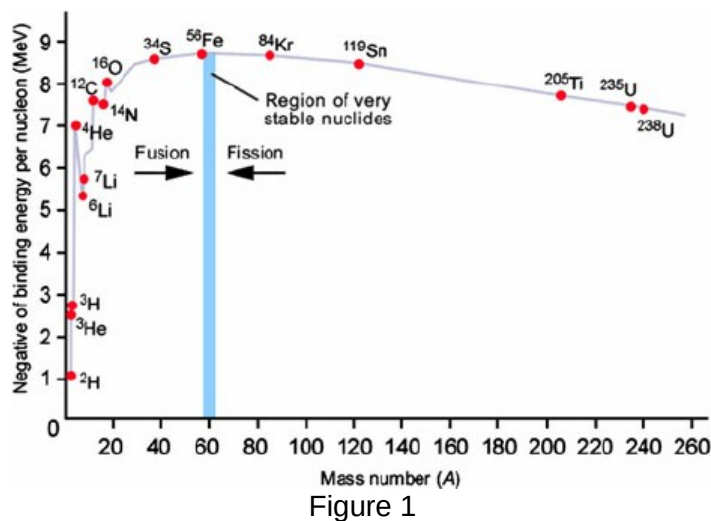
In 1948, Alpher, Bethe and Gamow proposed that ALL elements could be produced during the Big Bang and subsequent star formation through successive neutron captures and photon emissions.

Relevant to this process of nucleosynthesis and energy production is the concept of nuclear binding energies. Let us consider a nucleus made of Z protons and N neutrons (where the mass number $A = Z + N$). The binding energy of this nucleus is defined as the energy required to break this nucleus into ' A ' individual nucleons.

How binding energy per nucleon (in MeV) varies against mass number (A) is displayed in Figure 1. This graph illustrates some important information about nuclei and their binding energy.

The behaviour of the nuclear binding energy with ' A ' in Figure 1 shows that for $A < 56$, binding energy per nucleon is increased as the mass of isotopes increase; or, in other words, by isotopes 'capturing' another nucleon (p or n) or an α -particle. This is the origin of fusion reactions occurring in stars and fusion reactors.

In contrast, for masses $A > 56$, as the mass of isotopes increases, the binding energy per nucleon decreases. Hence, nuclei can increase their binding energy per nucleon by emitting particles. In this region, many nuclei are unstable and emit α -particles. Spontaneous fission occurs in the uranium region ($A > 200$).



- a) According to the graph in Figure 1, the isotope with the greatest binding energy per nucleon is Fe-56. Use the data in the table below (and information from your Data Booklet) to show that the binding energy per nucleon for Fe-56 is about 8.6 MeV. Show all working.

(4 marks)

PARTICLE	MASS (u)
Fe-56	55.9349375
Proton	1.00727647
Neutron	1.008665

Description	Marks
$\text{Expected Mass of Fe-56} = 26 \times 1.00727647 + 30 \times 1.008665$ $\hookrightarrow 56.44913822 \text{ u}$	1
$\text{Mass Defect} = 56.44913822 - 55.9349375$ $\hookrightarrow 0.51420072 \text{ u}$	1
$\therefore \text{Binding Energy} = 0.51420072 \times 931$ $\hookrightarrow 478.7208703 \text{ MeV}$	1
$\text{Binding Energy per Nucleon} = \frac{478.7208703}{56}$ $\hookrightarrow 8.54858697 \text{ MeV}$	1
Total	4

- b) The isotope Fe-56 is situated in a region on the graph at the beginning of this question called the “Region of very stable nuclides”. The radioisotope U-235 is not located in this region.

- i. Use Figure 1 to estimate the binding energy per nucleon (in MeV) for U-235.

(1 mark)

Description	Marks
Use graph to find value; BE/nucleon = 7.50 MeV (acceptable range: 7.30-7.70 MeV)	1
Total	1

- ii. Compare the binding energy per nucleon values for both U-235 and Fe-56. Use this comparison to explain why Fe-56 can be called a ‘stable nuclide’, while U-235 cannot be called this.

(3 marks)

Description	Marks
BE/Nucleon for Fe-56 (8.5 MeV) > BE/Nucleon for U-235 (7.5 MeV).	1
The BE/Nucleon for Fe-56 (and other isotopes in this region) means work can be done to overcome the repulsive forces between the protons in its nucleus and is, therefore, stable.	1
Isotopes outside this region (like U-235) have lower BE/Nucleon and are therefore less stable and more likely to decay to become stable.	1
Total	3

- c) Use the information in the article to briefly describe why isotopes in the region with mass numbers such that $A < 56$ are more likely to undergo **fusion**, while those isotopes with mass numbers such that $A > 200$ are more likely to undergo **fission**.

(2 marks)

Description	Marks
For $A < 56$, binding energy per nucleon is increased as the mass of isotopes increase; hence, particle capture is more likely.	1
For masses $A > 200$, as the mass of isotopes increases, the binding energy per nucleon decreases; hence, nuclei can increase their binding energy per nucleon by emitting particles.	1
Total	2

- d) In your own words, describe the process of 'nucleosynthesis'.

(2 marks)

Description	Marks
Describes the process of how heavier elements are formed by lighter elements.	1
Heavier nuclei are formed when lighter nuclei capture particles like neutrons and protons to form larger nuclei.	1
Total	2

- e) Like many isotopes in the region $A > 56$, the radioisotope Ti-205 is an α -emitter. Write a balanced nuclear equation for this nuclear decay.

(2 marks)

Description	Marks
${}_{81}^{205}\text{Ti} \rightarrow {}_{79}^{201}\text{Au} + {}_2^4\alpha$	
All three reactant and product particles are correctly identified.	1
Atomic numbers and mass numbers are balanced.	1
Total	2

- f) The article describes the process whereby the important isotope of Carbon, C-12, is produced by a "triple- α " process (ie, three α -particles combining in two steps to form C-12). In the space below, write **two (2)** balanced nuclear equations illustrating the "triple- α " process.

(2 marks)

Description	Marks
${}_2^4\alpha + {}_2^4\alpha \rightarrow {}_4^8\text{Be}$	
${}_4^8\text{Be} + {}_2^4\alpha \rightarrow {}_6^{12}\text{C}$	
All reactant and product particles are correctly identified in both equations.	1
Atomic numbers and mass numbers are balanced in both equations.	1
Total	2

Question 16

(14 marks)

The Space Shuttle's Thermal Protection System



The Space Shuttle Orbiter was an amazing technological achievement that remained in service for thirty years between 1976 and 2006. It was the world's first reusable spacecraft.

One of the most visible aspects of the Orbiter was its external tiles (seen above as both black and white in colour). These tiles formed part of the Orbiter's Thermal Protection System (TPS), which worked to protect both the spacecraft and its human occupants from the extreme temperatures created by friction during its re-entry into the Earth's atmosphere.

Early vehicles that had to re-enter the Earth's atmosphere used a variety of techniques to avoid combusting. Two examples included heat sinks that absorbed the enormous heat that would have been absorbed by the vehicle itself and ablative materials that actually ignited, burned and charred as they absorbed the heat created by re-entry.

However, none of these early vehicles were reusable. Hence, the materials used to protect these vehicles were rendered essentially unusable after the space flight. Reusable vehicles posed a different challenge. Scientists figured that a combination of metals and ceramic materials could not only withstand but also survive the high temperatures of re-entry.

In the case of the Orbiter, scientists chose the conventional aluminium for the main body due to its low density and light mass. A TPS that essentially coated the main body with a layer of heat resistant materials was then added to the exterior.

The properties of aluminium demanded that the maximum temperature of the Orbiter's structure remained lower than 175 °C. At this temperature, the aluminium begins to soften and its shape can be permanently distorted by the extreme heat. The temperatures experienced by the Orbiter during re-entry were, however, much higher than the melting point of aluminium (660 °C).

During the 1960's, NASA developed a silica-based insulation material (silicon dioxide). NASA designers constructed tiles made from this material to coat the Orbiter's aluminium body.

The part of the Orbiter that experienced the highest temperatures during re-entry was on the underside of its body. This part of the Orbiter was covered with about 20 000 black High-Temperature Reusable Surface Insulation (or HRSI tiles) made from the silica-based insulation material. These tiles experienced maximum surface temperatures of between 650 °C and 1260 °C.

These tiles have very different thermal properties to the aluminium. Some of these are shown in the table below:

	ALUMINIUM	SILICON DIOXIDE
MELTING POINT	660 °C	1710 °C
SPECIFIC HEAT CAPACITY	900 Jkg ⁻¹ °C ⁻¹	628 Jkg ⁻¹ °C ⁻¹
THERMAL CONDUCTIVITY	180 Wm ⁻¹ °C ⁻¹	0.0485 Wm ⁻¹ °C ⁻¹

As can be seen from the table, the thermal conductivity of silicon dioxide is vastly lower than that of aluminium. Thermal conductivity (often denoted by 'k') refers to the intrinsic ability of a material to transfer heat by conduction. It is also defined as the amount of heat per unit time (ie, Joules per second), per unit area (in square metres) that can be conducted through a flat surface of unit length or thickness of a given material (ie - per metre), the faces of the plate differing by one unit of temperature (per degree Celsius). Thermal conductivity can be calculated using the equation below:

$$k = \frac{Q}{t} \cdot \frac{L}{A(T_2 - T_1)} \quad (1)$$

where: k = thermal conductivity (Wm⁻¹°C⁻¹)
 Q/t = rate of flow of thermal energy (W)
 L = length or thickness of the conducting material (m)
 A = surface area of the material (m²)
 $T_2 - T_1$ = temperature difference across the length of the material (°C)

- a) Identify **two (2)** thermal properties that materials used as 'heat sinks' would need to have when protecting a spacecraft during re-entry.

(2marks)

Description	Marks
High melting point.	1
High specific heat capacity.	1
Total	2

- b) Use the kinetic theory of matter to describe what is happening to the aluminium as its temperature increases from below 175 °C to above its melting point of 660 °C.

(4 marks)

Description	Marks
Below 660 °C, as thermal energy is added, the average kinetic energy of the particles increases.	1
The particles, therefore, move faster and further causing expansion and a softening of the aluminium.	1
At 660 °C, any further added thermal energy increases the potential energy of the particles without changing the kinetic energy of the particles.	1
This changes the force of attraction from strong to weak and causes a change of phase from solid to liquid.	1
Total	4

A typical HRSI tile has the following specifications:

mass = 1.02 kg; dimensions = 15 cm x 15 cm; thickness = 2.54 cm

- c) During re-entry, an HRSI tile will typically experience a temperature gradient of 1260 °C on its exterior to about 170 °C on its interior. Using equation (1), determine how much heat energy is passed through the tile every second during re-entry.

(4 marks)

Description	Marks
$k = 0.0485 \text{ Wm}^{-1}\text{°C}^{-1};$ $L = 0.0254 \text{ m};$ $A = 0.15 \times 0.15 = 2.25 \times 10^{-2} \text{ m}^2;$ $T_2 - T_1 = 1260 - 170 = 1.09 \times 10^3 \text{ °C}$	1
$k = \frac{Q}{t} \cdot \frac{L}{A(T_2 - T_1)};$ $0.0485 = \frac{Q}{1} \cdot \frac{0.0254}{2.25 \times 10^{-2} \times 1.09 \times 10^3}$	1
$Q = \frac{0.0485 \times 24.5}{0.0254 \times 1}$	1
$Q = 46.8 \text{ J}$	1
Total	4

- d) A human can hold a HRSI tile in their bare hands even if it has been raised to temperatures similar to those experienced during re-entry. This certainly could not be done with an aluminium object. Using data from the table, explain why. (3 marks)

Description	Marks
Silicon dioxide's low thermal conductivity means that the rate it conducts thermal energy into human skin is very slow and would not raise its temperature markedly.	1
Aluminium has a thermal conductivity that is much higher than silicon dioxide (~3700 times larger).	1
Hence, aluminium would conduct thermal energy into skin far quicker than silicon dioxide and would cause a rapid and significant increase in temperature.	1
Total	3

- e) The HRSI tiles are black in colour. Explain why this colour also assists with protecting the aluminium Orbiter body from absorbing excessive amounts of heat. (1 mark)

Description	Marks
Black objects are excellent absorbers and emitters of thermal radiation. The tiles will, therefore, absorb much more of the radiant energy than that absorbed by the aluminium.	1
Total	1

END OF EXAMINATION

Question number: _____

Question number: _____

Supplementary page

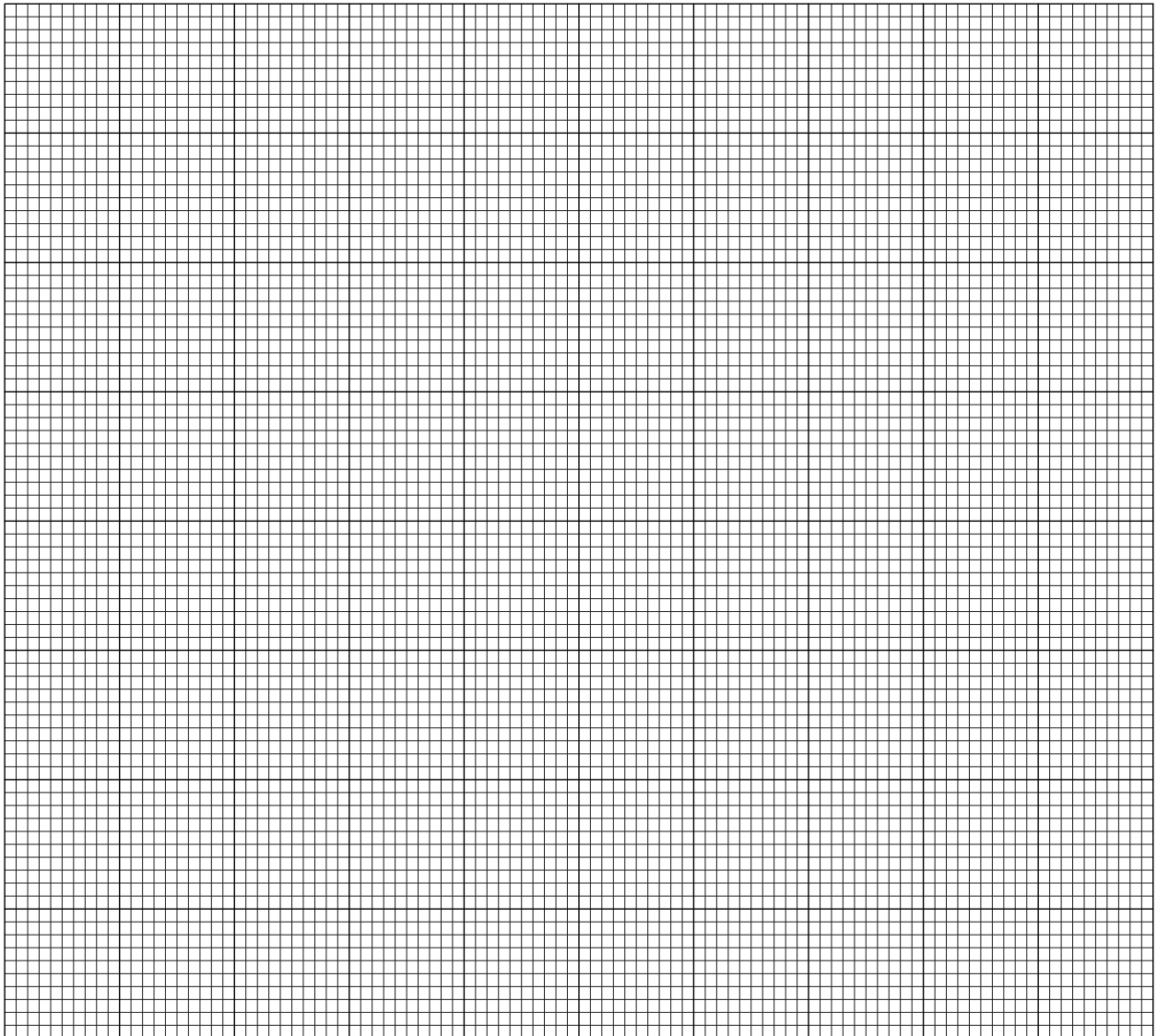
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Supplementary page

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Supplementary graph page

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Section		Qu. N°	Marks Available	Your Mark	Section Total	Section as % of Exam
1	SC	1	6		/45	
		2	7			
		3	4			
		4	7			
		5	6			
	MS	6	5			
		7	6			
		8	4			
2	MS	9	15		/75	
	SC	10	8			
		11	9			
		12	13			
	YM	13	16			
		14	14			
3	YM	15	16		/30	
		16	14			
Total				/150		%