Semester 1 Examination 2020
Question & Answer Booklet

PHYSICS
UNIT 1

MARKING KEY

Time allowed for this paper:
Reading time before commencing work: 10 minutes
Working time for paper: 3 hours

Materials required/recommended for this paper
To be provides by the supervisor
This Question/Answer Booklet
Formulae and Data Booklet

To be provided by the candidate
Standard items: pens, pencils (including coloured), sharpener, correction fluid, 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.

Section	Questions	Questions to be attempted	Suggested working time (mins)	Marks available	Percentage of exam
Section One: Short Response	11	11	50	54	30%
Section Two: Problem Solving	6	6	90	90	50%
Section Three: Comprehension	2	2	40	36	20%
			Total	**180**	**100**

STRUCTURE OF THIS PAPER

INSTRUCTIONS TO CANDIDATES

1. Write your answers in the spaces provided beneath each question. The value of each question (out of 180) is shown following each question.

2. Answers to questions involving calculations should be evaluated and given in decimal form. Final answers should be given up 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.

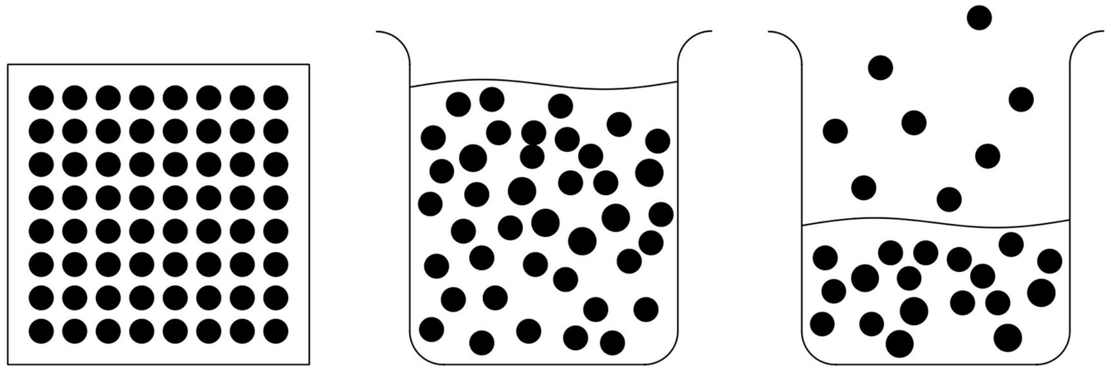
7. Extra/spare graphs have also been provided at the end of this Question & Answer booklet.

Section One: Short Response 30% (54 marks)

This section has 11 questions. Answer **all** questions. Answer the questions in the spaces provided.
Suggested working time: 50 minutes.

Question 1 (4 marks)

The diagram below shows the changes which occur between the solid, liquid and gaseous phases of a substance, with the addition of heat.



Using this diagram and your knowledge of the kinetic particle model, state and explain one change which occurs when the substance changes phase from:

(a) solid to liquid. (2 marks)

Description	Marks
Particles begin to flow OR Material takes the shape of the container	1
As the distance between the particles increase, the strength of interatomic bonds weakens and only cohesive/adhesive forces remain, allowing the particles to move past each other easier, allowing the liquid to flow	1

(b) liquid to gas. (2 marks)

Description	Marks
Loss of material OR Particles move freely or speed up	1
As heat is added, the temperature rises as each particle gains more kinetic energy; eventually the kinetic energy of some particles is enough to overcome the cohesive forces and escape the liquid as gas or vapor (postulate that collisions are elastic and therefore, due to exchange of energy, some particles may have more energy than others – gives rise to energy distribution). OR Distance between particles is large compared to size of particles (postulate that when far apart, attract/repel each other very little)	1

Question 2 **(5 marks)**

Identify the products V, W, X, Y and Z in the following nuclear equations.

(a) $^{1}_{0}n \rightarrow {}^{0}_{-1}e + V$

Description	Marks
$V = \text{proton},\ ^{1}_{1}p$	1

(b) $^{1}_{1}p \rightarrow {}^{1}_{0}n + W$

Description	Marks
$W = \text{positron},\ ^{0}_{1}e$	1

(c) $^{226}_{88}Ra \rightarrow X + {}^{4}_{2}He$

Description	Marks
$X = \text{Radon-222},\ ^{222}_{86}\text{Rn}$	1

(d) $^{200}_{80}Hg + {}^{1}_{0}n \rightarrow {}^{201}_{80}Hg + Y$

Description	Marks
$Y = \text{gamma radiation},\ ^{0}_{0}\gamma$	1

(e) $^{60m}_{27}Co \rightarrow Z + {}^{0}_{0}\gamma$

Description	Marks
$Z = \text{Cobalt-60},\ ^{60}_{27}\text{Co}$	1

Question 3 **(3 marks)**

In cold climates wind chill factor and hypothermia can pose a real threat to the health of an individual. Wind chill is when cooler, moving air replaces relatively still air near the skin, giving the person the sensation that the effective temperature has decreased. Explain why the wind chill is worsened when the person is wet or wearing wet clothes.

Description	Marks
When wind blows, air is replaced near your skin and energy is continually drawn to this cooler air (due to temp difference)	1
If there is exposed moisture on your skin or clothing, then via conduction this cools the person quickly.	1
Additionally, the rate of evaporation of the water increases due to airflow, drawing extra energy from your body to do so, cooling the person further, risking hypothermia.	1

Question 4 **(5 marks)**

A 6.50 kg steel container (specific heat capacity 4.50×10^2 J kg^{-1} K^{-1}) holds 13.0 kg of water at 24.0 °C. When 3.15 kg of a molten alloy, at its melting point of 315 °C, is poured into the water, the water reaches a final temperature of 29.1 °C. If the latent heat of fusion of the alloy is 2.30×10^4 J kg^{-1} determine the specific heat capacity of the alloy.

Description	Marks
Uses the principle of equilibrium: $\Delta Q_{hot} = -\Delta Q_{cold}$	1
Writes the heats correctly: $\Delta Q_{hot} = \Delta Q_{alloy} = m_a c_a \Delta T_a + m_a L_a$ $\Delta Q_{cold} = Q_{water} + Q_{cont} = m_w c_w \Delta T_w + m_c c_c \Delta T_c$	1
Calculates the different heats correctly: $\Delta Q_{cold} = 13 \times 4180 \times (29.1 - 24.0) + 6.5 \times 450 \times (29.1 - 24.0) = 292051.5$ $\Delta Q_{hot} = 3.15 \times c_a \times (29.1 - 315) - 3.15 \times 23000 = -900.585\, c_a - 72450$	1
Arranges heats correctly, $-900.585\, c_a - 72450 = -292051.5$	1
Solves for specific heat, $c_a = 244 \text{ J kg}^{-1} \text{ K}^{-1}$	1

Question 5 **(4 marks)**

At this particular location, the average power received from the Sun during a six-hour period each day is 840 Wm^{-2}. The solar heater has an overall efficiency of 35%. It is required that, during the six-hour period, the solar heater raises the temperature of 140 kg of water by 25K. Determiner the minimum effective area of the solar panels.

Description	Marks
Energy required E = mc **Δ**T E = 140 x 4180 x 25 E= 1.46×10^7 J	1
Incident energy E = 840 x A x 6 x 3600 E = 1.81×10^7 J/m2	1
1.81×10^7 A x 0.35 = 1.46×10^7 A = 2.3 m^2	2
Total	4

Question 6 **(5 marks)**

Domestic smoke detectors use about 0.25 µg of a radioactive source of Americium-241 which produces alpha particles. Under normal operating conditions, the alpha particles ionise oxygen and nitrogen molecules in the air and an electric potential from a battery causes a small ionisation current to flow. When smoke enters the detector the smoke particles absorb alpha particles and thus reduce the ionisation current flowing in the circuit, setting off an alarm.

(a) Explain the effect that using a radioactive source which produces beta particles instead of alpha particles would have, on the operation of a domestic smoke detector. (2 marks)

Description	Marks
The alarm would trigger much quicker (or not trigger at all)	1
Beta radiation penetrates much further in air and so the ionization of oxygen and nitrogen molecules would be less, causing a smaller current to flow.	1

(b) If the half-life of Am-241 is 450 years, how much of the original radioactive material would be left in an old smoke detector that is 50 years old. (3 marks)

Description	Marks
$A = A_0 (0.5)^n$	1
$n = \frac{50}{450} = 0.111$ $A_0 = 0.25\,\mu g$	1
$A = 0.25 \times (0.5)^{0.111} = 0.231\,\mu g$	1

Question 7 **(4 marks)**

A 416 g sample of radioisotope Promethium–147 decays into Samarium–147 as the main product.

(a) Identify and state the main decay process of Promethium–147. (1 mark)

Description	Marks
Beta – minus decay	1

(b) Determine the half-life of Promethium–147 if it decays to 13 g in 12 years? (3 marks)

Description	Marks
$A = A_0 (0.5)^n \Rightarrow 13 = 416 \times (0.5)^n \Rightarrow \frac{1}{32} = 0.03125 = 0.5^n$	1
Solving for number of half-lives: $n = 5.0$	1

$t = n \times t_{\frac{1}{2}} ❑\rightarrow t_{\frac{1}{2}} = \frac{t}{n} = \frac{12}{5.0} = 2.4 \text{ years}$	1

Question 8 **(6 marks)**

After running a long-distance marathon, Tori adds a handful of ice blocks to her partly empty water bottle. Tori knows that an average ice block contains anywhere from 30 to 50 mL of water. Tori also wants to ensure that the ice doesn't melt too quickly and therefore only selects ice blocks that are well below freezing point. Using this information estimate how many kilojoules (kJ) of energy were extracted from tap water in order to produce the ice blocks which Tori used.

Description	Marks
Assumptions: Mass of ice block is 40 g ± 10 g (anywhere from 30 g to 50 g) Tori uses 5 ± 2 ice blocks (anywhere from 90 g to 350 g); Initial temperature of ice blocks is –5°C ± 3°C (anywhere from –8°C to –2°C) Temperature of tap water is 15°C ± 3°C (anywhere from 12°C to 18°C)	2
$Q = mc\Delta T_{liquid} + mL_{fusion} + mc\Delta T_{ice}$	1
$Q = m(c\Delta T_{liquid} + L_{fusion} + c\Delta T_{ice}) Q = (0.05 \times 5) \times (4180 \times 15 + 3.34 \times 10^5 + 4180 \times 5)$	1
$Q = 1.04 \times 10^5 \text{ J} = 1.04 \times 10^2 \text{ kJ}$	1
Answer to 1 or 2 SF: $Q = 100 \text{ kJ}$ (Allowed range ¿$35 \text{ kJ to } 160 \text{ kJ}$)	1

Question 9 **(4 marks)**

Question 9 **(4 marks)**

The diagram below shows three linear temperature scales with the freezing and boiling points of water indicated.

(a) What does it mean that the temperature scales are "linear"?

Description	Marks
This means that the amount of expansion or contraction of the liquid per degree of temperature change is the same.	1
Total	1

(b) Rank the following temperatures, highest first: 50°X, 50°W, and 50°Y.

Description	Marks
50°X, 50°Y, 50°W	3
Total	3

Question 10 **(4 marks)**

A hot body is brought into contact with a colder body (made of the same material) until their temperatures are the same. Assume that no other bodies are nearby.

(a) Is the energy lost by one body always equal to the energy gained by the other? Explain.

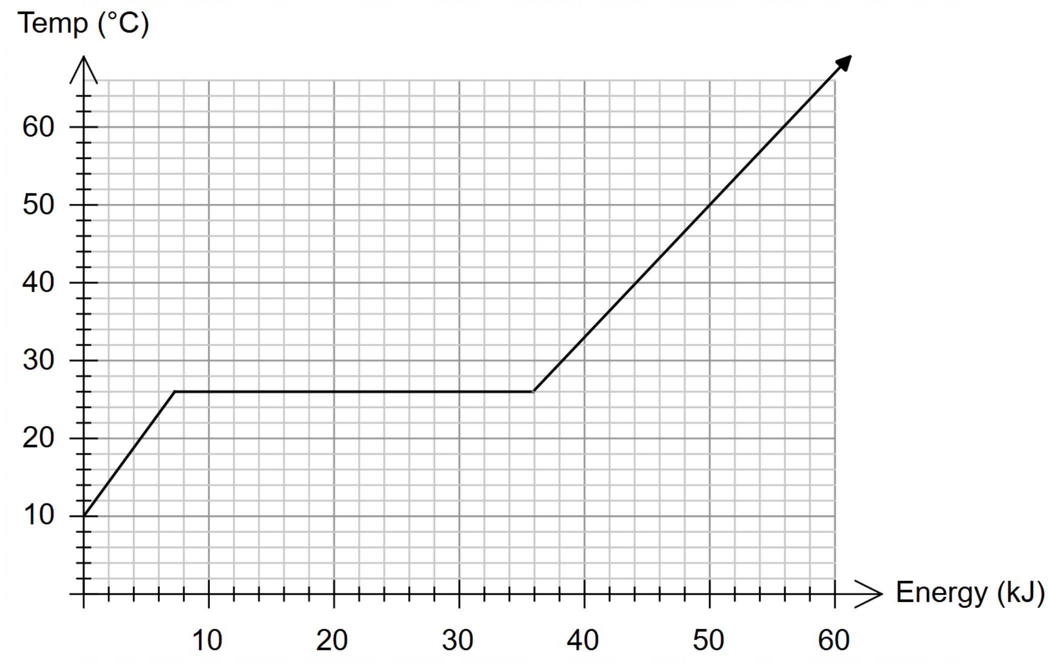
Description	Marks
Yes	1
The thermal energy lost by one body must equal the thermal energy gained by the other because of energy conservation.	1
Total	2

(b) Is the temperature drop of one body always equal to the temperature gained by the other. Explain.

Description	Marks
No	1
The changes in temperature are not, however, necessarily equal because the masses and specific heat capacities may differ.	1
Total	2

Question 11 **(8 marks)**

The heating curve below shows the temperature change of a 285 g sample of solid coconut oil as it is heated, with a small 40 W heating element, from an initial temperature of 10 °C.



(a) How long does it take for the coconut oil to completely melt? (3 marks)

Description	Marks
Energy added for phase change (from graph): $36\ \text{kJ} - 7\ \text{kJ} = 29\ \text{kJ}$	1
$P = \frac{E}{t} \rightarrow \therefore t = \frac{E}{P} = \frac{29 \times 10^3}{40}$	1
$\therefore t = 725\ \text{s}$	1

(b) Use the graph to estimate the specific heat capacity of liquid coconut oil. (5 marks)

Description	Marks
Energy added (from graph): $56\ \text{kJ} - 36\ \text{kJ} = 20\ \text{kJ}$	1
Corresponding temperature change: $60\,°\text{C} - 26\,°\text{C} = 34\,°C$	1
$Q = mc\Delta T \rightarrow \therefore c = \frac{Q}{m\Delta T}$	1
$\therefore c = \frac{20 \times 10^3}{0.285 \times 34} = 2064\ J\,kg^{-1}\,K^{-1}$	1
$\therefore c = 2.1 \times 10^3\ \text{J kg}^{-1}\ \text{K}^{-1}$ (2 Sig. Fig.)	1

END OF SECTION ONE

Section Two: Problem Solving **50% (90 marks)**

This section contains 6 questions. Answer **all** questions. Answer the questions in the spaces provided. Suggested working time 90 minutes.

Question 12 **(18 marks)**

A 900 MW fission reactor uses a Uranium-enriched fuel source containing Uranium–235. This fission reaction involves the absorption of Uranium–235 (235.04393 u) with a single neutron (1.00866 u) produces Strontium–94 (93.91536 u), Xenon–140 (139.92164 u), a number of neutrons and energy.

(a) Write a balanced nuclear equation for the neutron bombardment of Uranium–235 described above, clearly stating the number of neutrons produced. (3 marks)

Description	Marks
Writes a nuclear equation in the correct format: $${}^{1}_{0}n+{}^{235}_{92}U \rightarrow {}^{236}_{92}U \rightarrow {}^{94}_{38}\text{Sr}+{}^{140}_{54}\text{Xe}+2\,{}^{1}_{0}n$$	1
Includes correct fission products & bombarding neutron	1
Clearly identifies the two (2) neutrons produced.	1

(b) Explain why several neutrons are released and outline, using a relevant formula, the source of the energy released during this fission reaction. (3 marks)

Description	Marks
Neutrons are released in order to balance the overall mass number	1
Energy is released as a result of a mass defect – a difference in mass between reactants and products.	1
The energy released is given by Einstein's famous formula $E=mc^2$	1

(c) Calculate the amount of energy, in joules, produced by this nuclear reaction. (5 marks)

Description	Marks
Mass of reactants: $$235.04393\ \text{u}+1.00866\ \text{u}=236.05259\ \text{u}$$	1
Mass of products: $$93.91536\ \text{u}+139.92164\ \text{u}+2\times 1.00866\ \text{u}=235.85432\ \text{u}$$	1
Mass defect: $$m=236.05259\ \text{u}-235.85432\ \text{u}=0.19827\ \text{u}$$	1
Use energy associated with 1 u: $$E=0.19827\times 931=184.6\ \text{MeV}$$ OR Convert m to kg: $$m=0.19827\ \text{u}=0.19827\times 1.66\times 10^{-27}\ \text{kg}=3.29\times 10^{-28}\ \text{kg}$$	1
Convert the energy to J:	1

$E = 184.6\ \text{MeV} \times 10^{6} \times 1.6 \times 10^{-19}\ \text{J/eV}\, E = 2.95 \times 10^{-11}\ \text{J}$ (OR) Use mass-energy principle: $E = mc^2 = (3.29 \times 10^{-28})(3 \times 10^{8})^2 = 2.95 \times 10^{-11}\ \text{J}$	

(d) Calculate the mass, in kilograms, of Uranium–235 fuel required to operate this nuclear reactor for one year. **Note**: if you did not calculate part (c) you may use a value of 3.0 × 10^{-11} J for the energy released per fission reaction of Uranium–235. (4 marks)

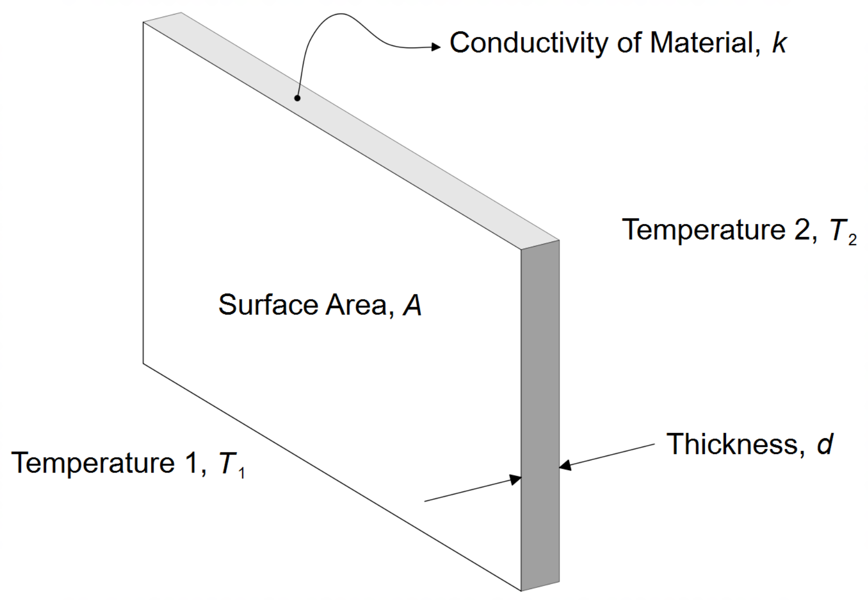
Description	**Marks**
Number of seconds in 1 year: $t = 365 \times 24 \times 60 \times 60 = 3.1536 \times 10^{7}\ \text{s}$	1
Energy required in 1 year: $E = P \times t = 900 \times 10^{6} \times 3.1536 \times 10^{7} = 2.84 \times 10^{16}\ \text{J}$	1
Number of fission reactions required: $n = \frac{E_t}{E_f} = \frac{2.84 \times 10^{16}\ \text{J}}{2.95 \times 10^{-11}\ \text{J}} = 9.62 \times 10^{26}\ \text{particles}$	1
Mass of U-235: $m = 235.04393 \times 1.66 \times 10^{-27} \times 9.62 \times 10^{26} = 375\ \text{kg}$	1

(e) A radiation limit for workers at the nuclear facility is set at 100 mSv per year. If an 82 kg worker at the nuclear reactor is accidentally exposed to 12 J of beta radiation from spent fuel rods, determine the Absorbed Dose, the Dose Equivalent and whether it is safe for the worker to continue working. (3 marks)

Description	**Marks**
Absorbed Dose: $AD = \frac{E}{m} = \frac{12}{82} = 0.146\ \text{Gy}$	1
Dose Equivalent: $DE = AD \times QF = 0.146 \times 1 = 0.146\ \text{Sv}$	1
Since the $DE = 146\ \text{mSv}$ is greater than the safety limit (100 mSv), it is NOT safe for the worker to continue working.	1

Question 13 **(21 marks)**

The rate at which heat is conducted through a material depends on several quantities relating to the physical environment and the shape and size of the material, as shown in the diagram below.



The rate at which heat is conducted through a material depends on temperature (K) on both sides of the material (T_1 and T_2), the surface area A (m^2) exposed, the thickness of the material d (m) and the property of the material known as conductivity k.

The rate of heat transfer through the material is power P (units of J s^{-1}) and is given by:

$$P = \frac{Q}{t} = \frac{kA(T_2 - T_1)}{d}$$

(a) Correctly determine the units of conductivity k. (1 mark)

Description	Marks
$\text{J s}^{-1}\ \text{m}^{-1}\ \text{K}^{-1}$	1

(b) A single 1.2 m high by 2.3 m wide by 6 mm thick glass window separates a 28 °C exterior from the 18 °C interior office space. The window is letting heat in at a rate of 3.59 kW.

i) Determine the conductivity k of the glass window. (3 marks)

Description	Marks
$k = \frac{Qd}{tA(T_2 - T_1)}$	1
$k = \frac{Qd}{tA(T_2 - T_1)} = \frac{3590 \times 0.006}{1 \times (1.2 \times 2.3)(28 - 18)}$	1
$k = 0.78$	1

ii) Calculate the theoretical rise in temperature of the 215 kg of air within the office over a period of 15 minutes (the specific heat capacity of air is 1.10×10^3 J kg^{-1} K^{-1}). (3 marks)

Description	Marks
$Q = P \times t = 3590 \times (15 \times 60) = 3.231 \times 10^6$ J	1
$\therefore \Delta T = \frac{Q}{mc} = \frac{3.231 \times 10^6 \text{ J}}{215 \times 1100}$	1
$\therefore \Delta T = 13.7\,°C$	1

iii) Explain why the answer to part b) ii) is impossible. Use relevant physics concept to justify your response. (2 marks)

Description	Marks
Impossible, since the air in the office would be warmer than the air outside the office	1
Heat flow $Q \propto \Delta T$ When the change in temperature is zero, heat will stop flowing.	1

(c) The owner of the office decides to replace the window with a double-glazed window in order to reduce heat transfer. The double-glazed window has identical dimensions to the single pane window (1.2 m by 2.3 m) but is 30 mm thick and consists of two panes of glass separated by a sealed section containing air.

In order to test this double-glazed window, the amount of energy conducted per second through the window and the difference in temperature across the window is recorded for eight trials, as shown below.

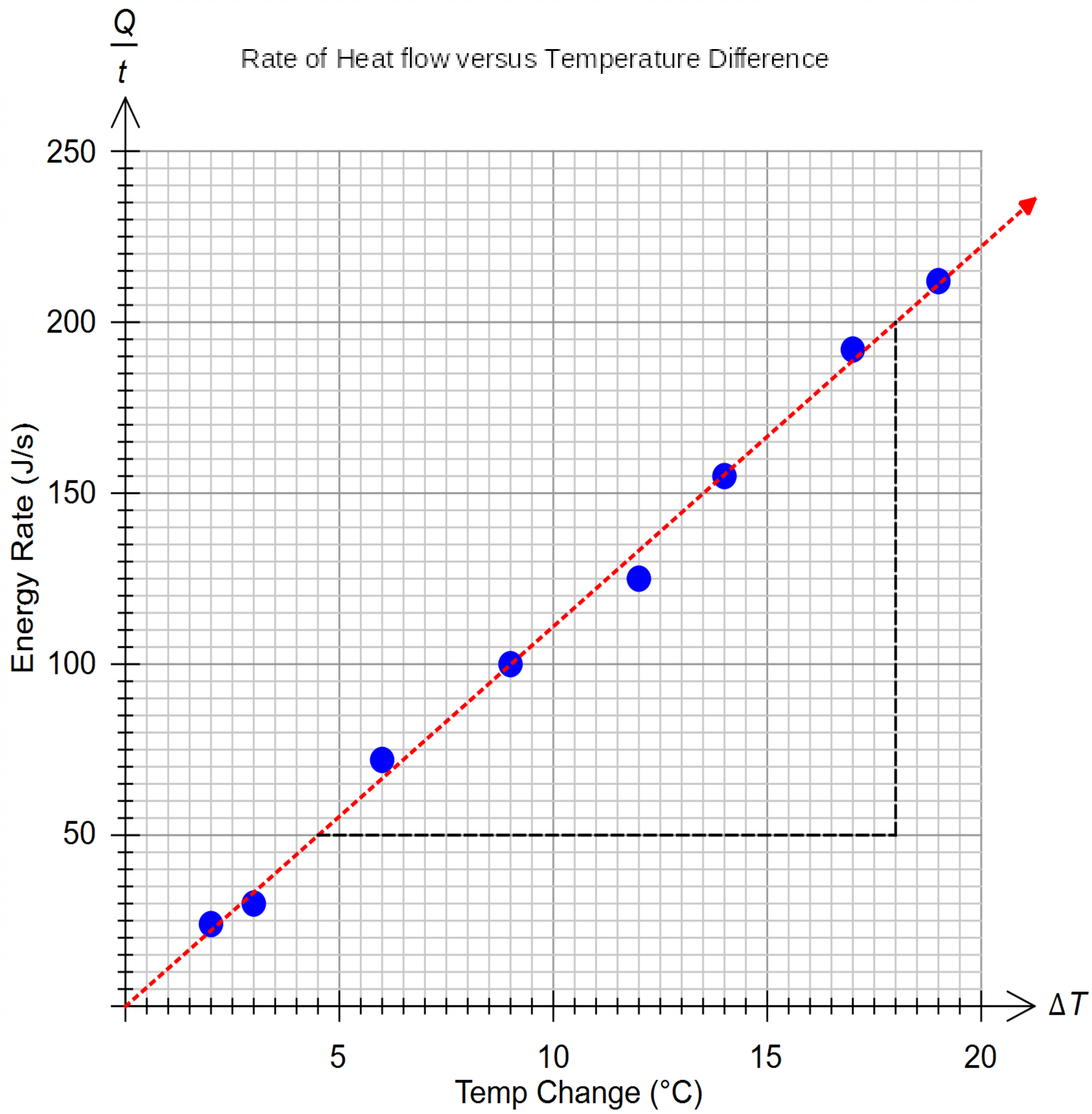
Trial	1	2	3	4	5	6	7	8
Temp Difference ΔT (K)	2	3	6	9	12	14	17	19
Energy Rate Q/t (J s^{-1})	24	30	72	100	125	155	192	212

i) Explain why the sealed section containing air reduces heat transfer. (1 mark)

Description	Marks
Air is a good thermal insulator (poor conductor)	1

ii) Use the data in the table above to construct a graph by plotting Energy Rate Q/t on the vertical axis and Temp Difference ΔT on the horizontal axis. Include title, axes labels, units and a line of best fit. (5 marks)

(Question 14 continued)



Description	Marks
Data plotted correctly	1
Title	1
Axes labels	1
Units/Scale	1
Line of best fit	1

(Question 14 continued)

iii) Calculate the gradient of the line of best fit. Indicate construction lines on the graph. (3 marks)

Description	Marks
Construction lines drawn on graph	1
Uses coordinates of points from line of best fit: $m=\frac{(200-50)}{(18-4.5)}$	1
$m=11.1$	1

iv) Use the value of the gradient of the line of best fit and information given in the question to determine a value for the conductivity *k* of the double-glazed window. **Note**: if you didn't determine a value for the gradient, you may use a gradient of 11.0 J s^{-1} K^{-1}. (3 marks)

Description	Marks
$m=\frac{kA}{d} \therefore k=\frac{md}{A}$	1
$\therefore k=\frac{md}{A}=\frac{11.1\times 0.03}{(1.2\times 2.3)}$	1
$\therefore k=0.121$	1

Question 15 **(17 marks)**

Consider the diagram below which shows the binding energy per nucleon against the nucleon number for a number of elements.

(a) Explain what is meant by the term "binding energy"? (2 marks)

Description	**Marks**
Binding energy is the minimum *energy* required	1
to disassemble a nucleus into its separate parts.	1
Total	2

(b) The unit for binding energy is MeV. Is this a unit of potential difference? Explain your answer (2 marks)

Description	**Marks**
No	1
MeV is short for mega electron volts which is a unit of energy	1
Total	2

(c) Why is the binding energy per nucleon for hydrogen, ${}^{1}_{1}H$ zero? (1 mark)

Description	**Marks**
Hydrogen has no binding energy because it has only one nucleon in its nucleus.	1
Total	1

(d) The curve has a maximum for A = 62 corresponding to nickel. What does this say about the nickel nucleus? (1 mark)

Description	**Marks**
That it is the most stable nucleus	1
Total	1

Uranium-235 can be made to undergo fission by the bombardment of neutrons to form krypton-89 and barium-144.

(e) Write the reaction to show all likely products of this reaction. (3 marks)

Description	**Marks**
${}^{235}_{92}U + {}^{1}_{0}n \rightarrow {}^{144}_{56}Ba + 3{}^{1}_{0}n + {}^{89}_{36}Kr$	3
Total	3

Now consider one of the nuclear fusion reactions that occurs in stars:

$$^{21}_{10}Ne + ^{4}_{2}He \rightarrow ^{24}_{12}Mg + ^{1}_{0}n$$

where the masses are: $^{21}_{10}Ne = 20.993849\,u$: $^{24}_{11}Mg = 23.985042\,u$: $^{4}_{2}He = 4.002603\,u$: $^{1}_{0}n = 1.008665\,u$.

(f) Calculate the mass defect (in kg) **AND** the amount of energy (in MeV) released in this reaction.
(6 marks)

Description	**Marks**
Mass defect = (Mass of neon + helium) – (Mass of Mg + neutron) = ($20.993849\,u$ + $4.002603\,u$) – ($23.985042\,u$+ 1.008665u) = 0.002745u	2
= 0.002745 x 1.66 10^{-27} kg = 4.56 x 10^{-30} kg	2
E = mc^2 E = 4.56 x 10^{-30} x (3 x 10^8)^2 E = 4.10 x 10^{-13} J	1
E = 4.10 x 10^{-13} /1.6 x 10^{-19} E = 2.56 MeV	1
Total	6

Question 16 **(15 marks)**

A cook is preparing a pot of chicken noodle soup. The cook is using a gas stove whose flame produces heat at a rate of 2.8 kW and is 65% efficient (65% is useful) at heating objects on the stove.

The ingredients of the soup are:

5 L of water, at 17 °C (assume the density of water ρ = 1.00 kg L^{-1})
500 g chicken at 15 °C (specific heat capacity: 4.34 × 10^3 J kg^{-1} K^{-1})
650 g carrots at 15 °C (specific heat capacity: 3.92 × 10^3 J kg^{-1} K^{-1})
200 g of noodles at 15 °C (specific heat capacity: 1.60 × 10^3 J kg^{-1} K^{-1})

(a) The cook starts heating the water in a 1.0 kg steel pot with the lid on. If the steel pot has a specific heat capacity of 4.80 × 10^2 J kg^{-1} K^{-1}, how long it will take for the water to boil? Assume the pot is at the same temperature as the water. (4 marks)

Description	Marks
Heat required: $Q_{Total}=Q_{water}+Q_{pot}=m_w c_w \Delta T+m_p c_p \Delta T$	1
$Q_{Total}=5\times4180\times(83)+1.0\times480\times(83)Q_{Total}=1.77\times10^{6}\ \mathrm{J}$	1
Efficiency of 65% means useful heating is $0.65\times2.8\ \mathrm{kW}=1.82\ \mathrm{kW}$ $P=\frac{E}{t} \rightarrow t=\frac{E}{P}$	1
$t=\frac{E}{P}=\frac{1774540}{1820}=975\ \mathrm{s}\quad(16\ \mathrm{min},\ 15\ \mathrm{s})$	1

(b) Use your knowledge of heating and cooling and the kinetic particle model to explain the benefits of boiling the water with the lid on the pot. (3 marks)

Description	Marks
By keeping the lid on, there is limited loss of mass of water vapor	1
Since particles with greater kinetic energy are not able to escape the liquid, there is reduced evaporation rate.	1
This produces a higher average kinetic energy and therefore a higher temperature will be reached more quickly.	1

(c) The cook allows the water to boil for an extra 3 minutes, but without the lid. Determine how much water will evaporate. (3 marks)

Description	Marks
Heat provided: $Q=P\times t=1.82\times10^3\times(3\times60)=327{,}600\ \text{J}$	1
$Q=mL\quad m=\frac{Q}{L}=\frac{327600}{2.26\times10^6}$	1
$m=0.145\ \text{kg}$ (or 145 mL)	1

(d) After boiling off for a bit longer, exactly 4.8 L of water is left in the pot and the pot is removed from the stove. The cook now adds all the ingredients (chicken, carrots and noodles). What is the equilibrium temperature of the hot water and pot after adding the ingredients? (5 marks)

1.0 kg of steel pot at 100 °C (specific heat capacity 4.80×10^2 J kg^{-1} K^{-1})
4.8 L of water, at 100 °C (assume the density of water ρ = 1.00 kg L^{-1})
500 g chicken at 15 °C (specific heat capacity 4.34×10^3 J kg^{-1} K^{-1})
650 g carrots at 15 °C (specific heat capacity 3.92×10^3 J kg^{-1} K^{-1})
200 g of noodles at 15 °C (specific heat capacity 1.60×10^3 J kg^{-1} K^{-1})

Description	Marks
Heat lost by hot water/pot is gained by ingredients $\Delta Q_{water/pot}=-\Delta Q_{ingr}$	1
Use temperature change formulae: $m_w c_w \Delta T+m_{pot} c_{pot} \Delta T_{pot}=-(m_{chi} c_{chi} \Delta T+m_{car} c_{car} \Delta T+m_{noo} c_{noo} \Delta T)$	1
Substitute correct values: $4.8\times4180\times(T-373)+1.00\times480\times(T-373)=¿$ $-(0.50\times4340\times(T-288)+0.65\times3920\times(T-288)+0.2\times1600\times(T-288))$	1
Simplifying: $20064T-7483872+480T-179040=¿$ $-(2170T-624960+2548T-733824+320T-92160)$ Becomes… $24482T=9113856$	1
Solve for temperature T (K or °C) $T=356.3\ \text{K}\quad T=83.1\,°C$	1

Question 17 (8 marks)

An experimental technique in the field of radiography in treating aggressive brain tumours is that of Boron Neutron Capture Therapy. This technique uses the fact that when boron–10 is injected into the body of a patient it collects in the brain tumours.

The patient is then bombarded with neutrons which are strongly absorbed by the boron–10, becoming fissile boron–11 which produces lithium–7 and high-energy alpha particles which then kill the cancer cells. On average, each neutron has an energy of 0.65 eV.

(a) Write two nuclear equations describing the above two processes. (2 marks)

Description	Marks
Answer: ${}^{10}_{5}\mathrm{B} + {}^{1}_{0}\mathrm{n} \rightarrow {}^{11}_{5}\mathrm{B}$ ${}^{11}_{5}\mathrm{B} \rightarrow {}^{7}_{3}\mathrm{Li} + {}^{4}_{2}\alpha + \text{energy}$	
Absorption of neutron to produce B-11	1
Fission of B-11 to produce Li-7 and alpha particle	1

(b) Given that the amount of boron–10 (10.013 u) required to treat a 2.2 g brain tumour is 25 µg per gram of tumour, determine the absorbed dose administered on a 45 kg patient. (5 marks)

Description	Marks
Mass of B-10 required is $25 \times 2.2 = 55\,\mu g$	1
Number of B-10 atoms required is $$\frac{55 \times 10^{-6} \times 10^{-3}\ \text{kg}}{10.013 \times \left(1.66 \times 10^{-27}\right)\ \text{kg}} = 3.31 \times 10^{18}$$	1
Number of neutrons required is 3.31×10^{18}	1
Total energy of neutrons is $3.31 \times 10^{18} \times \left(0.65\ \text{eV} \times 1.6 \times 10^{-19}\ \text{J/eV}\right) = 0.344\ \text{J}$	1
Absorbed Dose is $$\frac{0.344\ \text{J}}{45\ \text{kg}} = 7.65 \times 10^{-3}\ \text{Gy}$$	1

(c) Suggest a possible reason why an alpha source (the fission of boron–11) is used in this context rather than a beta source. (1 mark)

Description	Marks
Alpha radiation won't penetrate as far into surrounding tissue, causing less damage to the patient. OR Alpha radiation will be near to the cancer cells.	1

END OF SECTION TWO

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Questions continue on the next page

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

This section has two questions. Answer **both** questions. Answer the questions in the spaces provided.
Suggested working time: 40 minutes.

Question 18 **(18 marks)**

Simultaneous Photovoltaic Membrane Distillation (PV–MD)

Typically, solar panels are quite inefficient, as they usually only capture about 15% of the solar energy incident on the panels. The remaining 85% of the solar energy is either reflected or absorbed as heat.

There have been recent attempts to harness some of the energy not used by the solar panel to produce another useful product – clean water. One such design mounts a solar panel on top of a distillation unit.

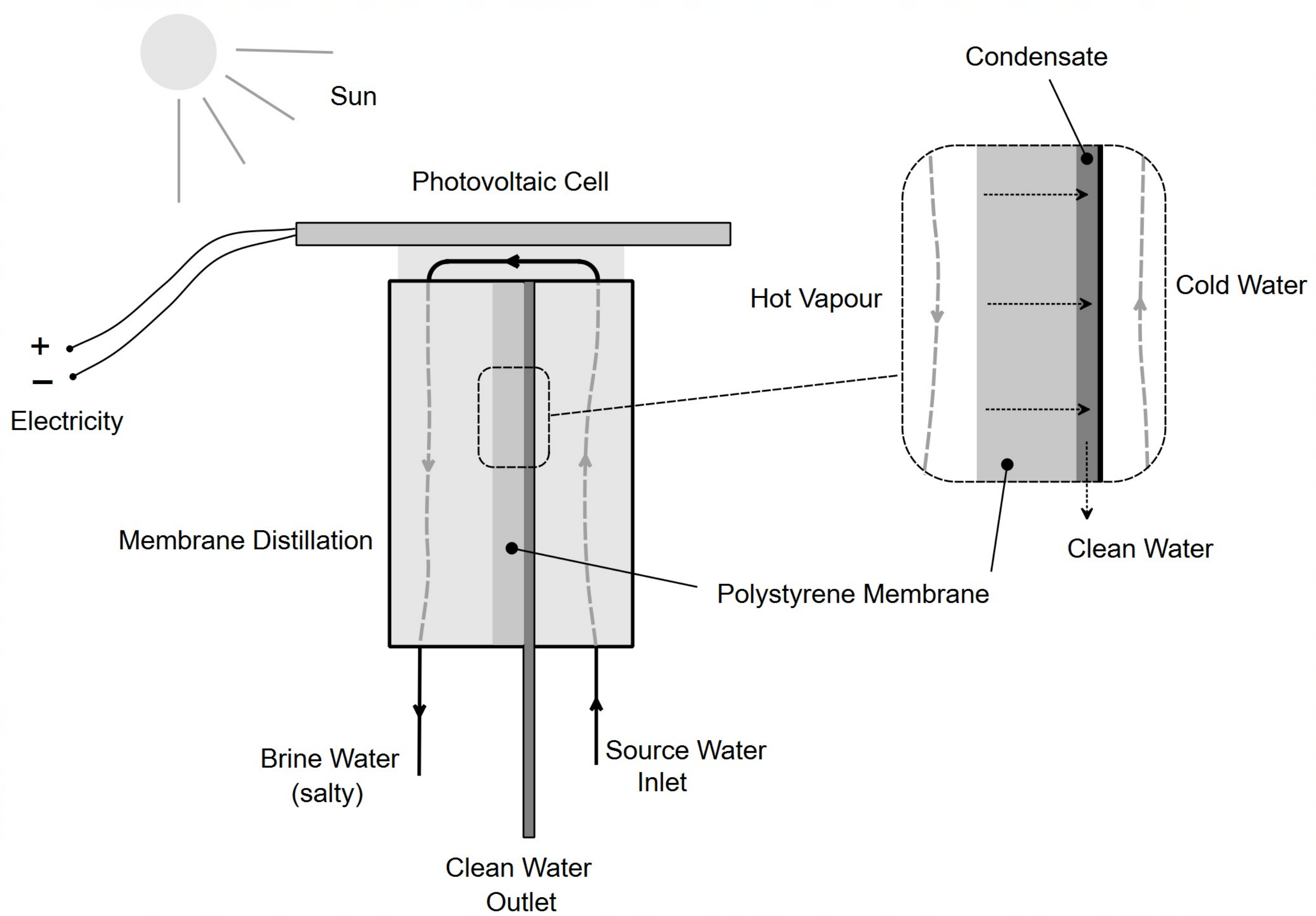


Figure 1 Schematic diagram for a typical PV-MD device

As shown in the schematic diagram of Figure 1, that whilst the solar panel produces electricity, heat from the sun heats up the PV-MD device, driving evaporation in the distillation unit below.

The water from a source (usually salty water) is pumped up into the unit, underneath the solar panel. As it absorbs heat from the solar panel, it vaporises, re-enters the distillation unit where it encounters a porous polystyrene membrane, which filters out salt and other contaminants. The water vapour eventually condenses and is collected and delivered to the clean water outlet.

The use of the thermal heat has no effect on the electricity produced by the solar cell. Not surprisingly, there is a push to install PV-MD devices in applications where both clean water and electricity is required.

Figure 2 below shows the energy flow of 100 J of solar energy incident on the PV-MD device. The solar panel is 15% efficient (converting 15 J out of every 100 J into electrical energy), 25 J is reflected as light, and of the remaining 60 J absorbed as heat, 36 J of heat is used to create clean drinking water with 24 J of heat lost to the surrounding environment.

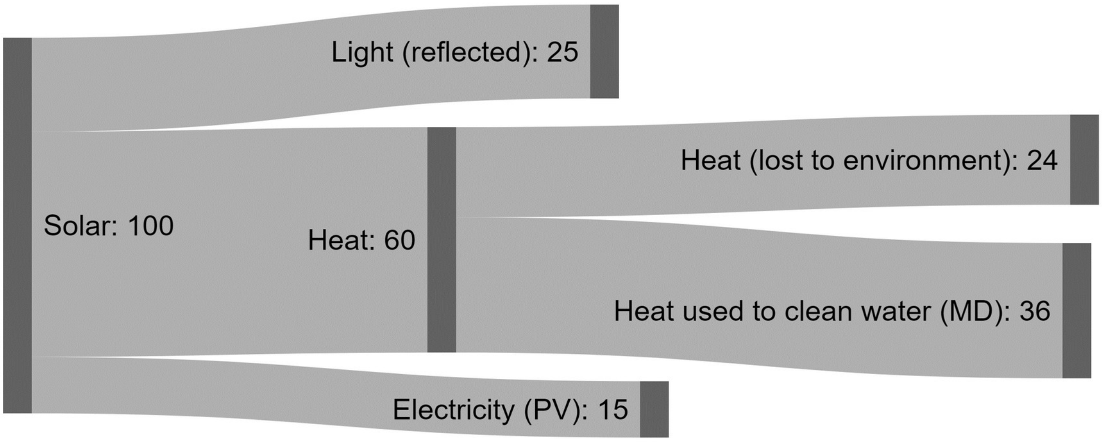


Figure 2 Energy flow diagram for 100 J of incoming solar energy

(a) State one energy transformation taking place in a typical PV–MD device. (1 mark)

Description	Marks
Light energy (or Solar) to Electrical energy OR Light energy to Thermal energy	1

(b) With reference to the design of a typical PV-MD device and the kinetic particle model, explain why the hot vapour condenses as it nears the clean water outlet. (3 marks)

Description	Marks
As the hot vapor permeates the porous polystyrene membrane, it encounters the cold-water stream on the other side.	1
Heat will flow to the cold-water stream, allowing the vapor to lose heat, reducing the kinetic energy and thus temperature of the vapor	1
As it cools to boiling point it continues to lose (potential) energy and changes phase to form liquid condensate	1

(c) Using data from Figure 2, explain how a PV-MD device makes better use of solar energy than a conventional solar panel. As part of your explanation determine an overall efficiency of the PV-MD device described in Figure 2. (3 marks)

Description	Marks
Conventional solar panels will only transform about 15% (15 J out of 100 J) to electricity	1
A PV-MD device, however, makes use of 51 J out of every 100 J (15 J as electricity and 36 J towards clean water)	1
51% efficient	1

(d) The prototype used in the lab experiments consisted of a solar panel measuring 12 cm by 12 cm, placed under a lamp of intensity 1 kW m^{-2} (like that of the Sun) for one hour, during which time the solar panel produced 1296 C of charge. Given that the efficiency of the solar panel used is 15%:

i) determine the radiant energy incident on the solar panel in one hour. (3 marks)

Description	Marks
Area: $A=0.12\times 0.12=0.0144\ \text{m}^2$	1
Power: $P=I\times A=1000\times 0.0144=14.4\ \text{W}$	1
Solar Energy: $E_{solar}=P\times t=14.4\times(60\times 60)=51840\ \text{J}$	1

ii) determine the electrical energy produced by the panel in one hour. (1 mark)

Description	Marks
Electrical Energy: $E_{elec}=eff\times E_{solar}=0.15\times 51840=7776\ \text{J}$	1

iii) determine the output current and voltage of the panel. (2 marks)

Description	Marks
$I=\frac{q}{t}=\frac{1296}{3600}=0.36\ \text{A}$	1
$V=\frac{W}{q}=\frac{7776}{1296}=6\ \text{V}$	1

iv) making any assumptions as needed, show that the amount of clean water produced by the prototype is about 0.5 kg per hour per square meter. State your assumptions clearly.
Note: If you could not calculate a value for part (i) you may use a value of 5.0 × 10^4 J of solar energy incident on the solar panel in one hour. (5 marks)

Description	Marks
Assumptions of the cold-water stream: Change in temperature: $\Delta T\sim 82\,°\text{C}$ Specific heat capacity & Latent heat are that of water as per data sheet.	1
Energy used to heat the water is 60% of heat absorbed (which is 60% of the solar energy) incident in one hour: $E_{water}=0.60\times(0.60\times 51840)=18662\ \text{J}$	1
Heat Equation: $Q=mc\Delta T+mL=m(c\Delta T+L)18662=m(4180\times 82+2260000)$	1
$m=0.00717\ \text{kg}$ (7.2 grams for an area of 0.0144 m^2)	1
Per square meter: $m=\frac{0.00717\ \text{kg}}{0.0144\ \text{m}^2}=0.50\ \text{kg h}^{-1}\ \text{m}^{-2}$	1

Question 19 **(18 marks)**

Modelling the Decay of Polonium–218

When an isotope decays it often passes through multiple stages of decay and will produce daughter nuclei that are often radioactive and will themselves decay. As this process of decay continues, eventually the daughter nucleus is stable and will not decay any further. Depending on the stability of the intermediate nuclei, this process of decay, from beginning to end, can be extremely slow or very fast.

The sequence of radioisotopes produced when an isotope decays is called a decay chain or radioactive series and are often depicted graphically, listing the isotopes produced.

One such long decay series, is that of Uranium–238 which is shown below in Figure 2.

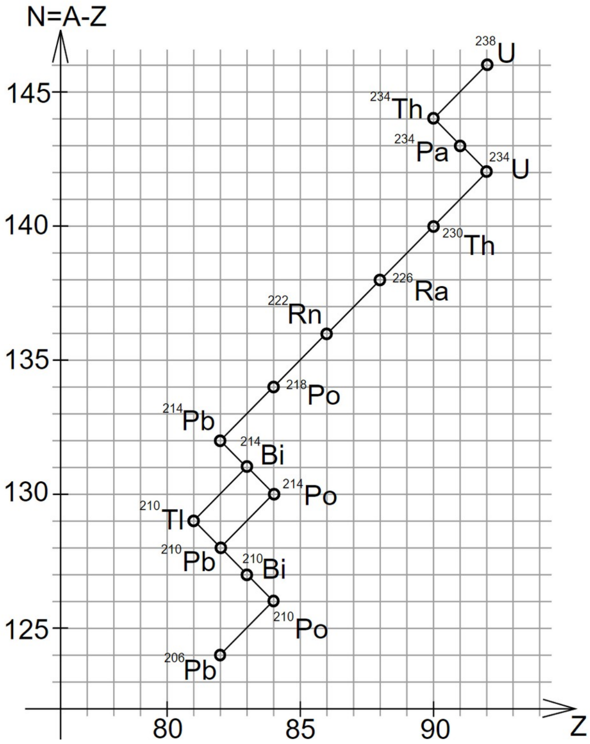


Figure 3 – Decay Series for Uranium-238

Part of the decay of Uranium–238 is that of the decay of Polonium–218. The radioactive decay series of Polonium–218 is as follows, where the mode of decay and half-lives of the relevant isotopes are indicated above the arrows:

$$^{218}_{84}Po \xrightarrow{\alpha\ (3.0\ mins)} {}^{214}_{82}Pb \xrightarrow{\beta\ (27\ mins)} {}^{214}_{83}Bi \xrightarrow{\alpha\ (20\ mins)} {}^{210}_{81}Tl \xrightarrow{\beta\ (1.3\ min)} {}^{210}_{82}Pb$$

The decay of Polonium-218 was mathematically simulated using the half-lives given, by assuming:

1. The simulation started with 1000 nuclei of Polonium-218
2. The simulation ran for 120 minutes
3. The decay series of Polonium-218 would eventually produce Lead-210 (half-life of 22 years)

Figure 3 shows a graph of how the amounts of each isotope of the decay of Polonium-218 varied over the 120-minute period.

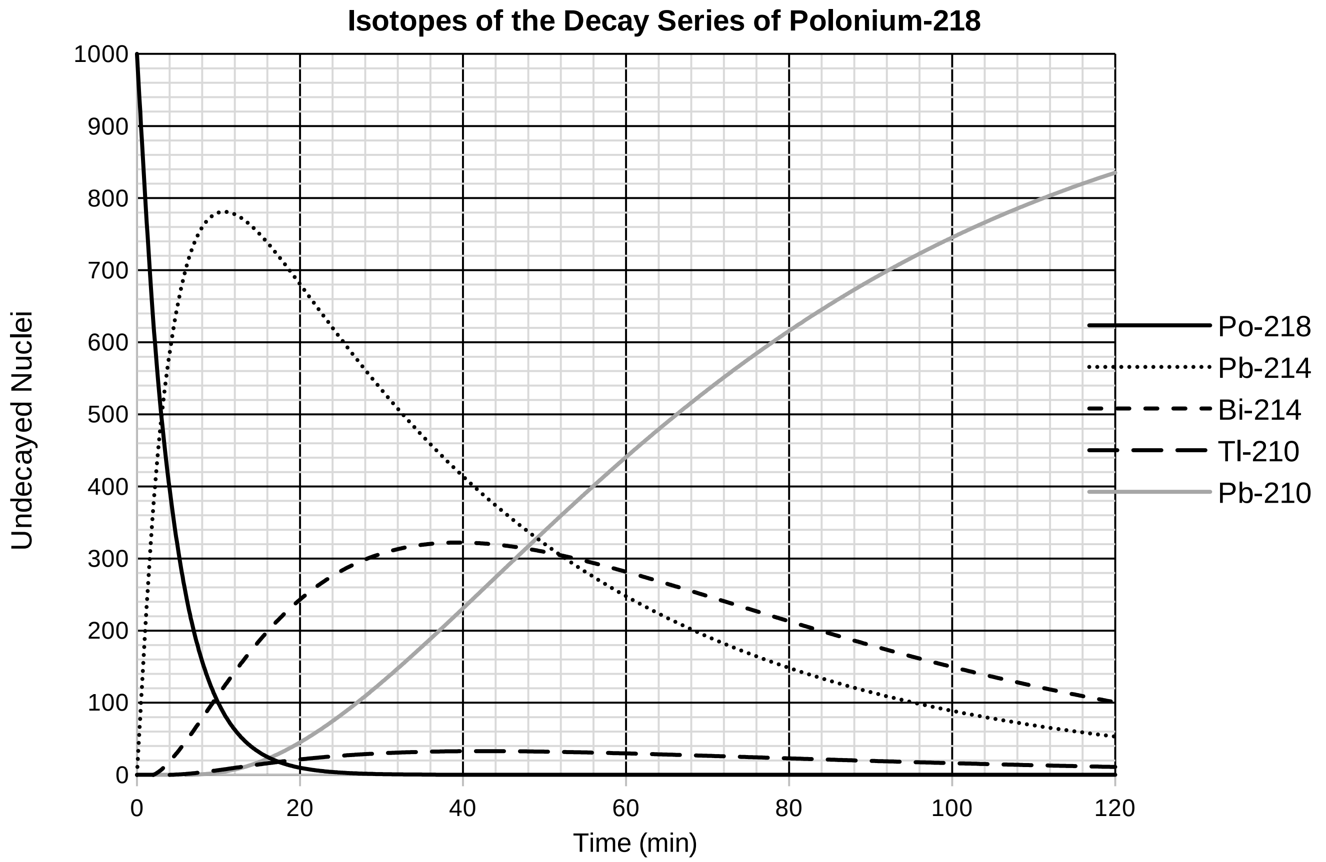


Figure 4 – Abundance of Isotopes in the Decay Series of Polonium-218 (per 1000)

(a) Define the term "half-life". (1 mark)

Description	Marks
"half-life" is the time it takes for half of the substance to decay	1

(b) What does the vertical axis represent in Figure 3 on the previous page? (1 mark)

Description	Marks
The number of neutrons	1

(c) Compare the ratio of neutrons : protons for Uranium-238, Polonium-214 and Lead-206. Explain the significance of these ratios. (4 marks)

Description	Marks
Uranium-238: 92p, 146n Polonium-214: 84p, 130n Lead-206: 82p, 124n	1
$Uranium=\frac{146}{92}=1.59\ Polonium=\frac{130}{84}=1.55\ Lead=\frac{124}{82}=1.51$	1
The closer the ratio of n : p = 1, the more stable the nucleus	1
Therefore, Lead-206 is the most stable and Uranium-238 the least stable	1

(d) In the Polonium-218 decay series, explain the basis for the assumption that most of the decayed isotopes will end up as Lead-210. (2 marks)

Description	Marks
The half-lives from Polonium-218 to Lead-210 are all in the order of minutes (3, 27, 20, 1.3), whereas the half-life of Lead-210 is 22 years	1
Compared to these half-lives, Lead-210 is stable and all the in between products will end up as Lead-210.	1

(e) With reference to Figure 4:

i) Why does the amount of isotope of Bismuth-214 initially increase but then, after about 40 minutes, begin to decrease? (2 marks)

Description	Marks
As Polonium-218 decays, it begins producing rapidly (half-life of 3 mins) and Lead-214 and Bismuth-214 begin to be produced…	1
As time goes on, the rate at which Bismuth-214 decays (half-life 20 mins) is faster than the rate at which Bismuth is produced (half-life 27 mins);	1

ii) Explain clearly why the amount of Thallium-210 remains relatively low. (2 marks)

Description	Marks
The half-life of Thallium-210 is 1.3 mins and low compared to all the rest of the half-lives.	1
Hence, any Thallium-210 produced will quickly decay and not accumulate.	1

iii) Estimate the maximum percentage of Bismuth-214 that one would find in a sample of Polonium-218 undergoing decay? (1 mark)

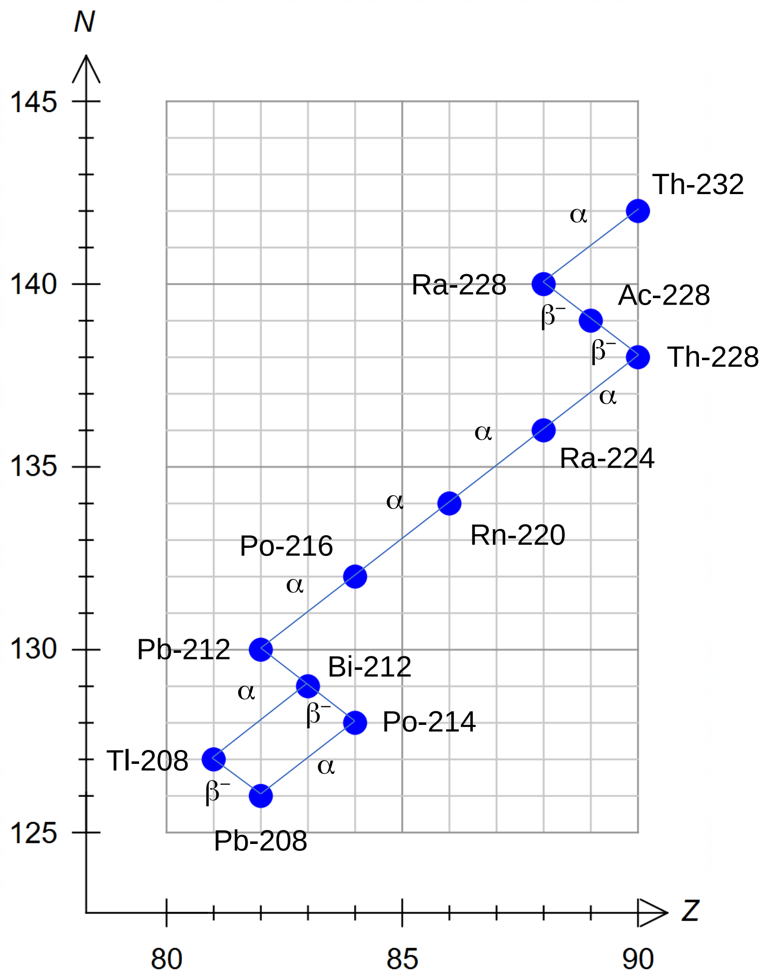
Description	Marks
30% or 32% (max from graph ~ 320 out of 1000) (1 or 2 SF)	1

(f) Another decay series is that of Thorium-232. Use the information in the table below to complete the graph of N versus Z below. Label each decay process as well as each isotope on the graph.

(5 marks)

Step	Decay
1	Th-232 → Ra-228
2	Ra-228 → Ac-228
3	Ac-228 → Th-228
4	Th-228 → Ra-224
5	Ra-224 → Rn-220
6	Rn-220 → Po-216

Step	Decay
7	Po-216 → Pb-212
8	Pb-212 → Bi-212
9	Bi-212 → Tl-208
10	Tl-208 → Po-212
11	Po-212 → Pb-208
12	Pb-208 (stable)



Description	Marks
Correctly plotting points of *N* versus *Z*	1 – 2
Labelling decay processes correctly	1 – 2
Labelling of each isotope	1

END OF EXAMINATION

Extra Working Space

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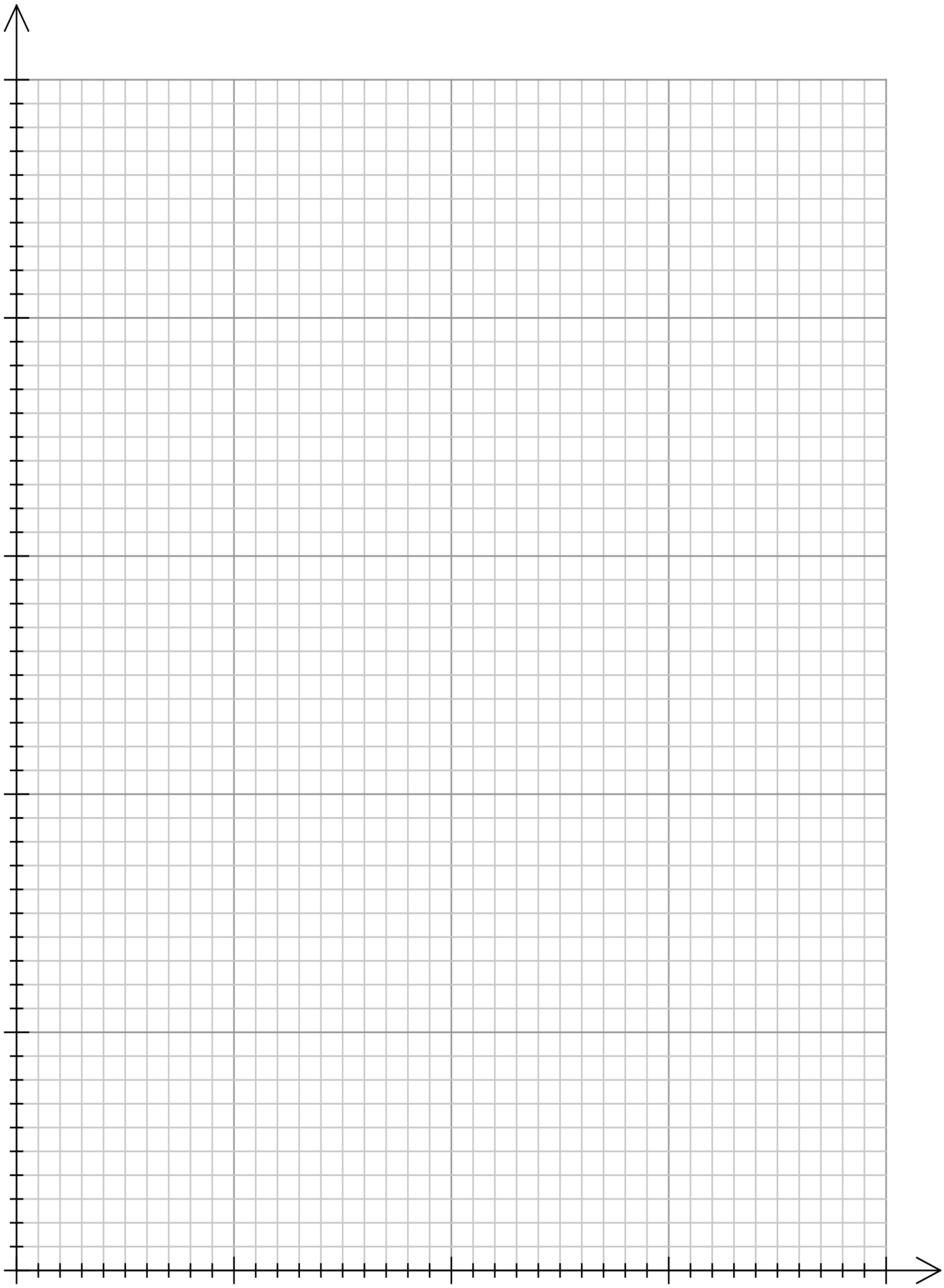
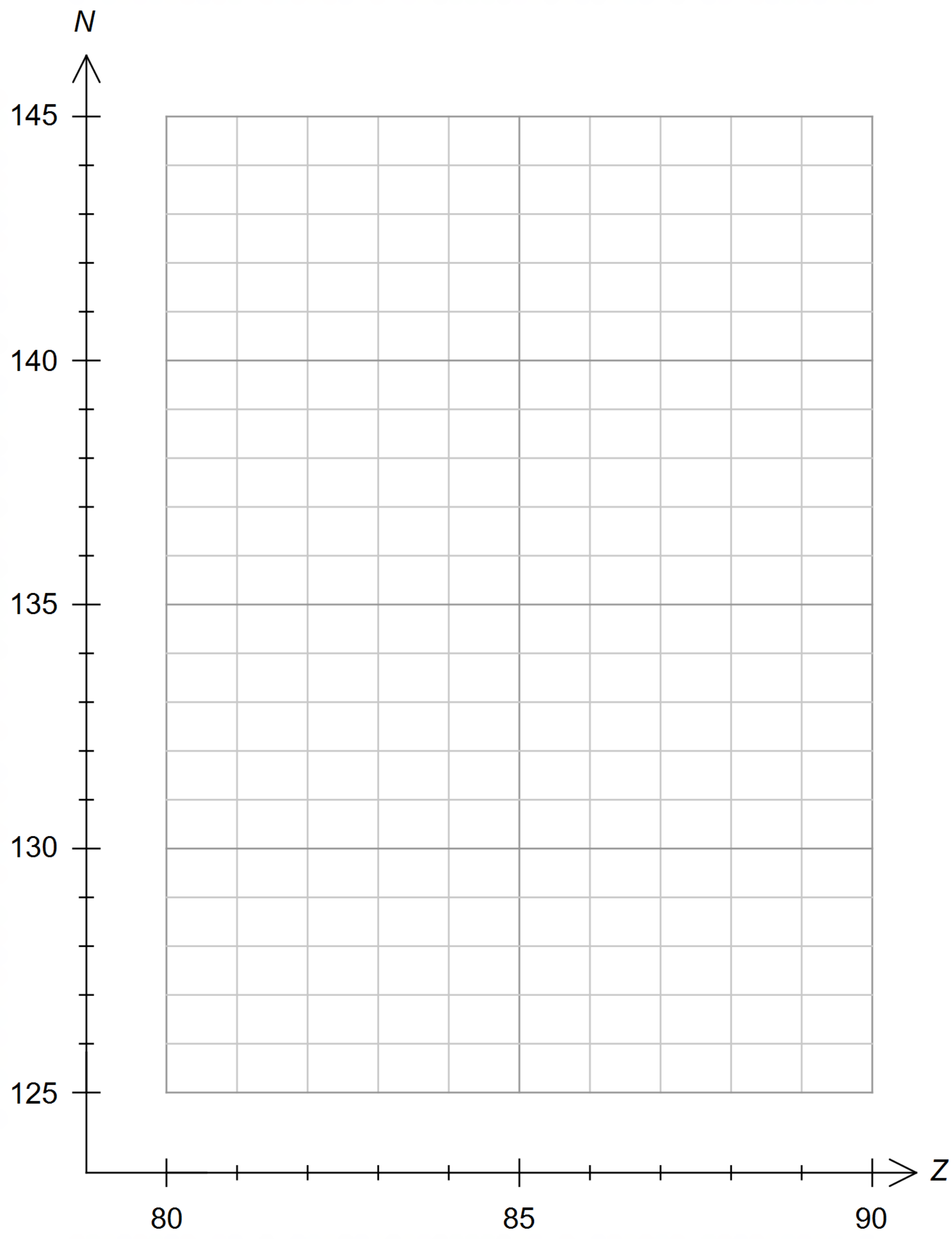
Spare Graph for Question 14



Spare graph for Question 19



Acknowledgements

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