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PHYSICS

UNIT 1

2022

MARKING KEY

TIME ALLOWED FOR THIS PAPER

Reading time before commencing work: Ten minutes
Working time for the paper: Three hours

MATERIALS REQUIRED/RECOMMENDED FOR THIS PAPER

To be provided by the supervisor:

- This Question/Answer Booklet
- Formula and Data Booklet

To be provided by the candidate:

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

- Special items: up to three calculators, which do not have the capacity to store programmes or text, are permitted in this ATAR course examination, 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 material. If you have any unauthorised material with you, hand it to the supervisor **before** reading any further.

Structure of this paper

Section	Number of questions available	Number of questions to be answered	Suggested working time (minutes)	Marks available	Percentage of exam
Section One: Short answer	11	11	50	54	30
Section Two: Extended answer	6	6	90	90	50
Section Three: Comprehension and data analysis	2	2	40	36	20
Total				180	100

Instructions to candidates

1. The rules for the conduct of Western Australian external examinations are detailed in the *Year 11 Information Handbook 2022: Part II Examinations*. Sitting this examination implies that you agree to abide by these rules.
2. Write your answers in this Question/Answer booklet preferably using a black/blue pen. Do not use erasable or gel pens.
3. You must be careful to confine your answers to the specific questions asked and follow any instructions that are specific to a particular question.
4. When calculating or estimating answers, show all your working clearly. Your working should be in sufficient detail to allow your answers to be checked readily and for marks to be awarded for reasoning.

In calculations, give final answers to three significant figures and include appropriate units where applicable.

In estimates, give final answers to a maximum of two significant figures and include appropriate units where applicable.

5. Supplementary pages for planning/continuing your answers to questions are provided at the end of this Question/Answer booklet. If you use these pages to continue an answer, indicate in the original answer where the answer is continued, ie – give the page number.
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 **eleven (11)** questions. Answer **all** questions. Write your answers in the space provided.

When calculating numerical answers, show your working and reasoning clearly. Give final answers to **three** significant figures and include appropriate units where applicable.

When estimating numerical answers, show your working and reasoning clearly. Give final answers to a maximum of **two** significant figures and include appropriate units where applicable.

Supplementary pages for planning/continuing your answers to questions are provided at the end of the Question/Answer booklet. If you use these pages to continue an answer, indicate at the original answer where the answer is continued, ie – give the page number.

Suggested working time for this section is 50 minutes.

Question 1**(6 marks)**

A balloon contains helium gas and nitrogen gas. The gases are at a common temperature of 25°C.

- a) Describe the relative speeds of the gas particles. Explain your answer.

(3 marks)

The particles in each gas will possess the same average kinetic energy (same temperature).	1 mark
Mass of nitrogen particles > mass of helium particles.	1 mark
Hence, average speed of nitrogen particles < average speed of helium particles.	1 mark

- b) The gases are heated to 50°C. Describe any change you would expect to notice in the balloon. Explain your answer using the Kinetic Theory.

(3 marks)

The balloon will expand.	1 mark
Increase in temperature of gases mean particles will travel faster.	1 mark
Particles collide more frequently and with more force with the walls of the balloon.	1 mark

Question 2**(6 marks)**

A worker in a uranium mine is exposed to three different types of radiation: alpha, beta and gamma. The worker has a mass of 95.5 kg and absorbs 10.7 J of ionising radiation. The worker estimates that 25.0% of this is due to alpha radiation; 30.0% due to beta radiation; and 45.0% due to gamma radiation. It is assumed that this is a full-body exposure.

- a) Calculate the dose equivalent the worker received.

(4 marks)

$Q(\alpha) = 0.250 \times 10.7 = 2.68 \text{ J};$ $Q(\beta) = 0.300 \times 10.7 = 3.21 \text{ J};$ $Q(\gamma) = 0.450 \times 10.7 = 4.82 \text{ J}$	1 mark
$AD(\alpha) = \frac{2.68}{95.5} = 2.80 \times 10^{-2} \text{ Gy};$ $AD(\beta) = \frac{3.21}{95.5} = 3.36 \times 10^{-2} \text{ Gy};$ $Q(\gamma) = \frac{4.82}{95.5} = 5.04 \times 10^{-2} \text{ Gy}$	1 mark
$\text{Dose equivalent} = 2.80 \times 10^{-2} \times 20 + 3.36 \times 10^{-2} \times 1 + 5.04 \times 10^{-2} \times 1$	1 mark
0.644 Sv	1 mark

- b) During their line of work, workers in uranium mines have dust from minerals landing on their clothing that emit all three types of radiation: alpha, beta and gamma. Which of these emissions do they need most protection from? Explain.

(2 marks)

Gamma radiation.	1 mark
This type of radiation is able to penetrate through the workers' clothing and skin to the interior of their body.	1 mark

Question 3**(5 marks)**

Calculate the binding energy per nucleon of the calcium-40 atom in eV. Use the masses provided in the table to assist you.

Name	Mass of atom (u)
Proton	1.007 276
Neutron	1.008 665
Electron	0.000 548 58
Hydrogen	1.007 825
Calcium-40	39.962591

Description	Marks
$m.d. = 2 \times m({}_1^1H) + (40-20) \times m(n) - m(\text{Ca-40})$	1
$= 20(1.007825) + 20(1.008665) - 39.962591$ $= 0.367209 \text{ u}$	1
$B.E. = m.d. \times 931$ $= 0.367209 \times 931$	1
$= 342 \text{ MeV}$	1
$BE/nuc = 342/40$ $= 8.55 \text{ MeV/nucleon}$	1
Total	5

Question 4**(6 marks)**

An aluminium kettle of mass 1.05 kg contains a quantity of water at a room temperature of 23.0 °C. The kettle has a power rating of 1.80×10^3 W and it takes 2.00 minutes to raise the temperature of the water to 75.0 °C. Assuming no heat is lost to the surroundings, calculate the mass of the water in the kettle.

[Specific heat capacity of aluminium = $904 \text{ J kg}^{-1} \text{ } ^\circ\text{C}^{-1}$]

$P = \frac{Q}{t}; Q = Pt = 1.80 \times 10^3 \times 2.00 \times 60.0$	1 mark
$Q = 2.16 \times 10^5 \text{ J}$	1 mark
$2.16 \times 10^5 = Q_A + Q_w = m_A c_A \Delta T_A + m_w c_w \Delta T_w$	1 mark
$2.16 \times 10^5 = 1.05 \times 904 \times (75.0 - 23.0) + m_w \times 4180 \times (75.0 - 23.0)$	1 mark
$m_w = \frac{2.16 \times 10^5 - 4.94 \times 10^4}{2.17 \times 10^5}$	1 mark
$m_w = 0.767 \text{ kg}$	1 mark

Question 5**(5 marks)**

For the following scenarios, write a balanced nuclear equation.

- (a) Americium-241 emits an alpha particle.

(1 mark)

Description	Marks
${}_{95}^{241}\text{Am} \rightarrow {}_{93}^{237}\text{Np} + {}_2^4\alpha$	1
Total	1

- (b) Strontium-90 has too many neutrons and decays to yttrium-90.

(1 mark)

Description	Marks
${}_{38}^{90}\text{Sr} \rightarrow {}_{39}^{90}\text{Y} + {}_0^{-1}\beta + {}_0^0\bar{\nu}$	1
Total	1

- (c) Uranium-235 captures a thermal neutron and splits into zirconium-103, tellurium-131 and several neutrons.

(2 marks)

Description	Marks
${}_0^1n + {}_{92}^{235}\text{U} \rightarrow {}_{40}^{103}\text{Zr} + {}_{52}^{131}\text{Te} + 2{}_0^1n$	1
Correct number of neutrons emitted	1
Total	2

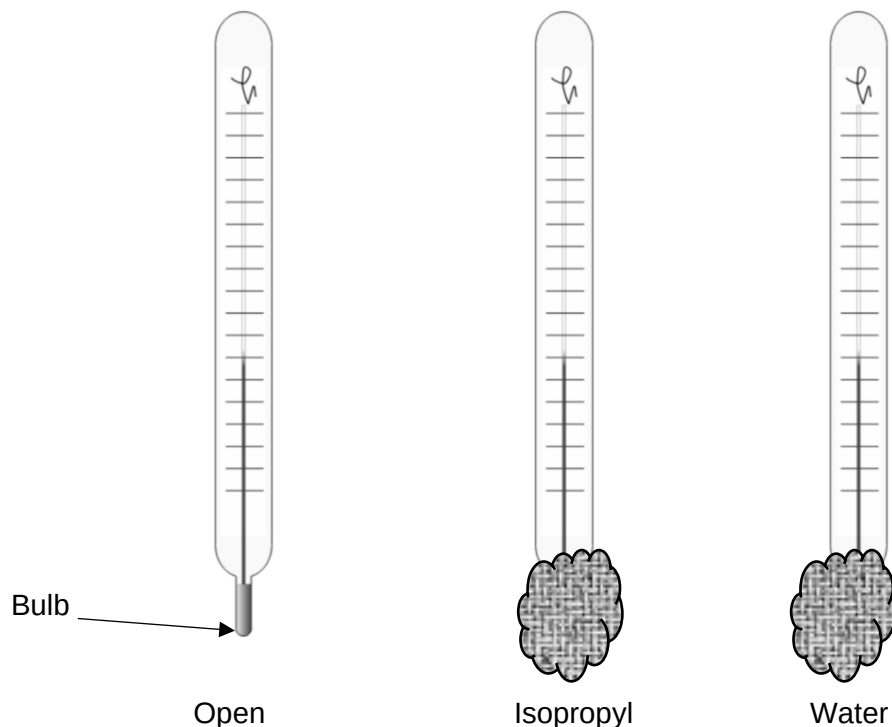
- (d) Hydrogen-2 and hydrogen-1 can fuse to form a gamma ray and helium-3.

(1 mark)

Description	Marks
${}_1^2\text{H} + {}_1^1\text{H} \rightarrow {}_0^0\gamma + {}_2^3\text{He}$	1
Total	1

Question 6**(4 marks)**

Consider the three thermometers below sitting in a room where the air temperature is 24.0°C . One of the thermometer's bulbs is covered in a cloth soaked in water, one is covered in a cloth soaked in isopropyl alcohol (a volatile solvent that readily evaporates) and the other is left open. A fan blows the air across the 3 thermometers.



- (a) In the table below. Place any of the values into the table that would best represent the temperatures of the 3 thermometers after a brief time period.

Options: 30°C 24°C 16°C 18°C 28°C (1 mark)

	Open	Isopropyl alcohol	Water
Temperature	24°C	16°C	18°C

Description	Marks
One mark for all three temperatures correct.	1
Total	1

- (b) Explain why the thermometer soaked in water has a different final temperature to the open thermometer.

(3 marks)

Description	Marks
As air is blown across the water soaked cloth, heat is drawn from the air causing the water to evaporate.	1
This draws heat from the cloth for the required latent heat to evaporate the water.	1
Removing heat from the cloth will reduce the temperature of the cloth	1

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and hence, the temperature of the thermometer.	
Total	3

Question 7**(4 marks)**

Jenny loves a cup of iced tea - and she likes it being ice cold. On a particular day, she brews a pot of tea which contains 0.255 kg of water at 90.0°C. She keeps adding ice at 0.00°C until the water reaches 2.00°C. The pot can be assumed to have no thermal properties and no heat is lost to the surroundings. Calculate the mass of ice that must be added to the water to achieve this.

$Q_{\text{gained}} = Q_{\text{lost}}; m_i L_f + m_i c_w \Delta T_w = m_w c_w \Delta T_w$	1 mark
$m_i \times 3.34 \times 10^5 + m_i \times 4.18 \times 10^3 \times (2.00 - 0.00) = 0.255 \times 4.18 \times 10^3 \times (90.0 -$	1 mark
$3.42 \times 10^5 \times m_i = 9.38 \times 10^4$	1 mark
$m_i = \frac{9.38 \times 10^4}{3.42 \times 10^5} = 0.274 \text{ kg}$	1 mark

Question 8**(5 marks)**

Polonium-218 is an alpha emitter. During this transmutation, it produces the isotope lead-214.

The atomic masses of the particles involved in this decay are:

Po-218: 218.008966 u

Pb-214: 213.999805 u

He-4: 4.002603 u

- a) Write a balanced nuclear equation for this alpha decay.

(2 marks)

$Po_{84}^{218} \rightarrow Pb_{82}^{214} + He_2^4$	
Correct species	1 mark
Atomic numbers and mass numbers balanced	1 mark

- b) Calculate the energy released (in MeV) during this decay.

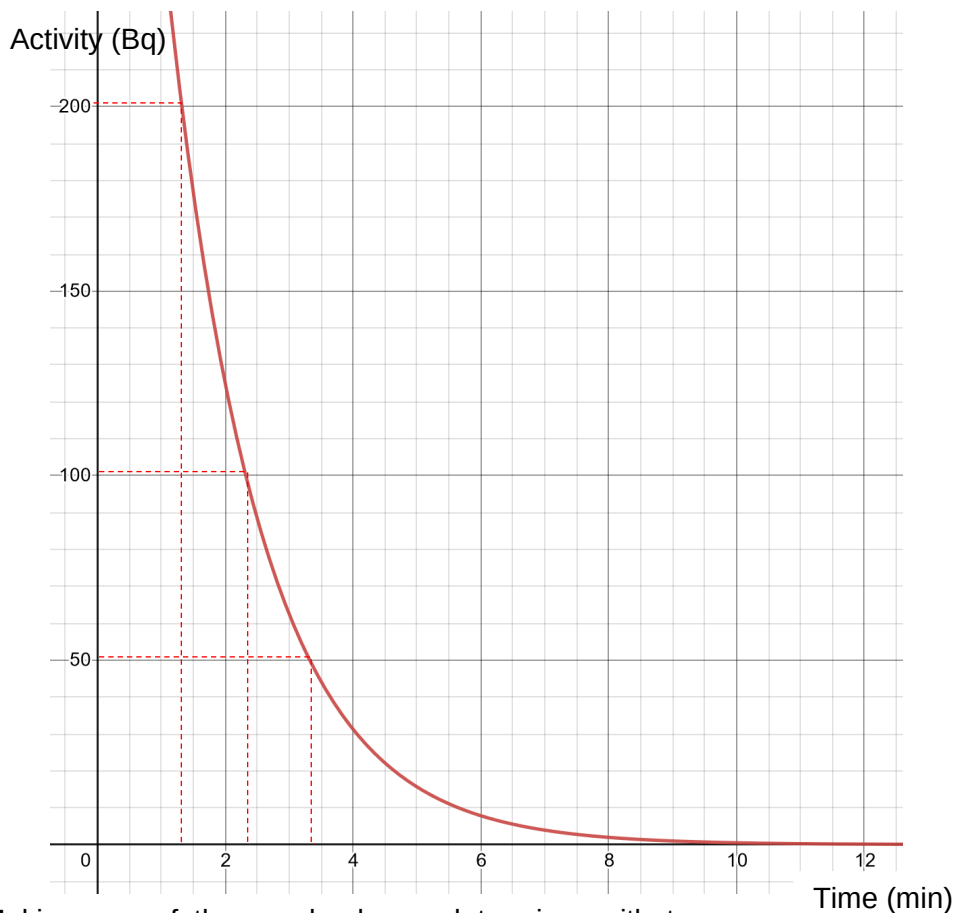
(3 marks)

$\Delta m = 218.008966 - 213.999805 - 4.002603$	1 mark
$\Delta m = 6.56 \times 10^{-3} u$	1 mark
$E_{\text{released}} = 6.56 \times 10^{-3} \times 931 = 6.11 \text{ MeV}$	1 mark

Question 9

(6 marks)

A student measures the activity of a radioisotope over a 12-minute period. He obtains the graph below:



- (a) Making use of the graph above, determine, with two separate calculations, the average half-life of the sample. (3 marks)

Description	Marks
Lines drawn correctly on graph	1
Calcs $t_{1/2}$: $2.3 - 1.3 = 1.00 \text{ min}$ $3.3 - 2.3 = 1.00 \text{ min}$	1
Averages values: $\frac{1 + 1}{2} = 1.00 \text{ minutes}$	1
Total	3

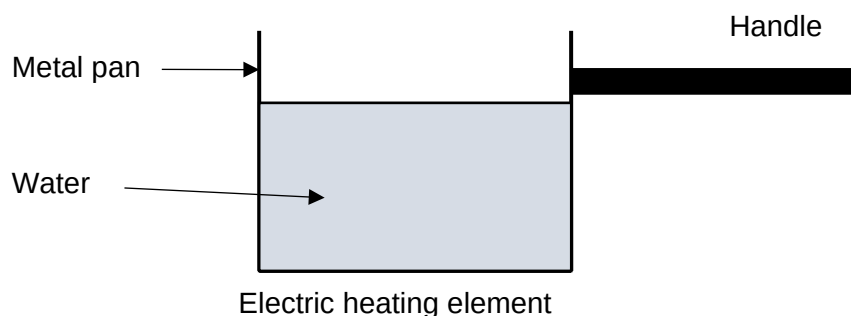
- (b) Given the initial activity of the sample was 500 Bq, calculate the time taken for the activity to drop to 62.5 Bq. (3 marks)

Description	Marks
$A_0/A = 500/62.5 = 8 = 2^3$	1
$\therefore n = 3$	1
$t = n \times t_{1/2}$ $= 3 \times 1.0 \text{ minutes}$	1

= 3.0 minutes.	
Total	3
Note: students can use logarithms to determine n $n = \log(62.5/500)/\log(1.2) = 3$	

Question 10**(6 marks)**

Water is being heated in a metal pan on an electric heating element as shown below. The handle for the pan is covered in hard plastic.



- a) State the form of heat transfer that is primarily responsible for the electric heating element initially heating the water.

(1 mark)

Conduction	1 mark
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- b) In terms of heat transfer, explain why the handle of the pan is made of plastic.

(2 marks)

Plastic is a poor conductor.	1 mark
This prevents conduction of heat from the pan to the hand of a user, this preventing burns.	1 mark

- c) It is found that placing a lid over the pan allows the temperature of the water to rise more quickly. In terms of heat transfer, explain why this is the case.

(3 marks)

Heat is transferred to the air above the water via conduction.	1 mark
The hotter air just above the water rises and transfers heat away from the water via convection.	1 mark
The lid prevents this air from rising and halts the convection of heat from the pan.	1 mark

Question 11**(5 marks)****Question 6****(5 marks)**

A mechanic adds 0.600 kg of antifreeze at 20.0 °C ($c = 3400 \text{ J kg}^{-1} \text{ K}^{-1}$) to a car radiator containing 5.60 kg of water in a 6.05 kg aluminium radiator ($c = 900 \text{ J kg}^{-1} \text{ K}^{-1}$) both of which are at 86.0 °C. Assuming no energy loss to surroundings, calculate the final temperature of the mixture.

Description	Marks
$Q_{\text{lost}} + Q_{\text{gained}} = 0$ $m c_{\text{radiator}} \Delta T_{\text{radiator}} + m c_{\text{water}} \Delta T_{\text{water}} + m c_{\text{antifreeze}} \Delta T_{\text{antifreeze}} = 0$	1
$6.05 \times 900 \times (T_f - 86.0) + 5.60 \times 4180 \times (T_f - 86.0) + 0.600 \times 3400 \times (T_f - 20) = 0$	1
$5445 T_f - 468,270 + 23,408 T_f - 2,013,088 + 2040 T_f - 40,800 = 0$	1
$30,893 T_f = 2,522,158$	1
$T_f = 81.6 \text{ °C}$	1
Total	5

End of Section One

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

This section has **six (6)** questions. You must answer **all** questions. Write your answers in the space provided.

When calculating numerical answers, show your working and reasoning clearly. Give final answers to **three** significant figures and include appropriate units where applicable.

When estimating numerical answers, show your working and reasoning clearly. Give final answers to a maximum of **two** significant figures and include appropriate units where applicable.

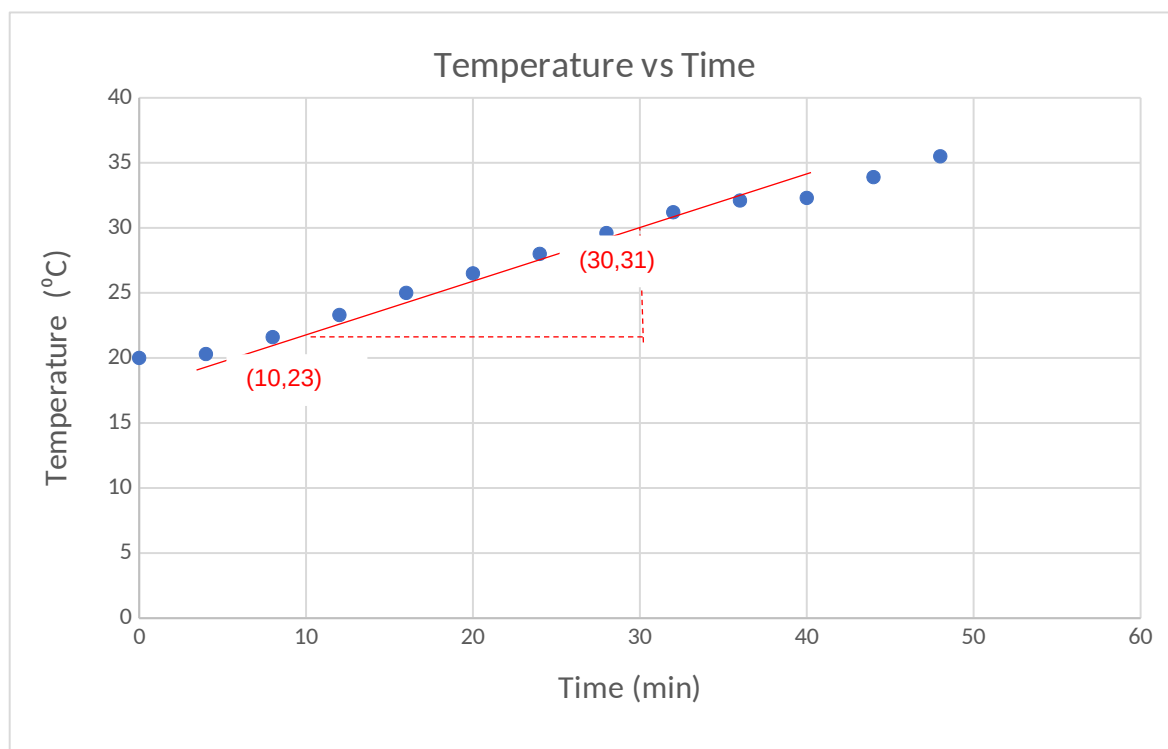
Supplementary pages for planning/continuing your answers to questions are provided at the end of the Question/Answer booklet. If you use these pages to continue an answer, indicate at the original answer where the answer is continued, ie – give the page number.

Suggested working time for this section is 90 minutes.

Question 12**(16 marks)**

The students decide to place the solar box out in the sun and record the temperature with a data logger and stop recording if the temperature reaches 55.0 °C. Their data is shown in the table to the left.

- (a) On the graph on the following page, plot a graph of temperature vs time. Do not draw a line of best fit yet. 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.

(4 marks)

Description	Marks
-------------	-------

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Correct orientation of axes	1
Correct labelling of axes including units	1
Accurate plotting	1
Title	1
Total	4

- (b) Show how the students were able to derive an equation relating the variable shown above.

(4 marks)

Description	Marks
$P_{out} = 0.9 P_{in}$ $Q = mc\Delta T$	1
$0.9P = Q/t = \frac{mc\Delta T}{t}$	1
Converting time to seconds = $t \div 60$ $0.9P = 60 \times \frac{mc\Delta T}{t}$	1
$P = 60 \times \frac{mc \Delta T}{0.9 t} = 66.7 \frac{mc \Delta y}{\Delta x}$	1
Total	4

Between 32 minutes and 40 minutes an anomaly occurred which produced unreliable data.

The students decided to exclude the data after 32 minutes as well as the first 4 minutes.

- (c) Using this information, draw a line of best fit and determine the gradient of this region. Express your answer to 2 significant figures.

(5 marks)

Description	Marks
Drawn correctly.	1
$m = \frac{y_2 - y_1}{x_2 - x_1} = \frac{31 - 23}{30 - 10}$	1
$= 0.40$ (allow 0.38 – 0.42)	1
$^{\circ}\text{C min}^{-1}$ (units present)	1
Expressed to 2 significant figures.	1
Total	5

- (d) Use the gradient and the equation provided to estimate the solar constant.

(3 marks)

Description	Marks
$P = 66.7 mc \times \frac{\Delta y}{\Delta x}$	1
$= 66.7 (0.030)(950) \times 0.40$	1
$= 760 \text{ W}$	1
Total	3
Must be to 2 significant figures.	

Question 13**(14 marks)**

Whilst making a cup of coffee, 355 mL of hot water is added to a 320.0 g ceramic coffee mug. Both reach a common temperature of 90.0°C.

It is known that water at this temperature can cause third degree burns – so a decision is made to cool it down to 55.0 °C. This is achieved by adding ice at -8.50 °C until this final cooler temperature is achieved.

Assume no heat is transferred to the surroundings.

- a) Show that the heat energy lost by the water and the ceramic mug as their temperature drops to 55.0 °C is approximately 7.00×10^4 J. The specific heat capacity of ceramic is $1.49 \times 10^3 \text{ J kg}^{-1} \text{ }^\circ\text{C}^{-1}$.

(3 marks)

$Q_1 + Q_2 = m_w c_w \Delta T_w + m_c c_c \Delta T_c$	1 mark
$0.355 \times 4180 \times 35.0) + (0.320 \times 1.49 \times 10^3 \times 35.0)$	1 mark
$6.86 \times 10^4 \text{ J}$	1 mark

- b) The mass 'm' of the ice added is unknown. In terms of 'm', calculate the thermal energy gained by the ice as it is heated to 55.0 °C.

(5 marks)

$= Q_3 + Q_4 + Q_5 = m_i c_i \Delta T_i + m_i L + m_i c_w \Delta T_w$	2 marks
$= (m \times 2100 \times 8.50) + (m \times 3.34 \times 10^5) + (m \times 4180 \times 55.0)$	2 marks
$= m \times 5.82 \times 10^5 J$	1 mark

- c) Hence, use the answers from parts a) and b) to calculate 'm' - the unknown mass of ice added.

[Note: if you were unable to calculate and answer for part a), use $7.00 \times 10^4 J$. If you were unable to get an answer for part b), use $m \times 6.00 \times 10^5 J$]

(3 marks)

$= Q_{lost}$	
$32 \times 10^5 = 6.86 \times 10^4$	1 mark
$\frac{36 \times 10^4}{32 \times 10^5}$	1 mark
$118 kg (0.114 kg \vee 0.117 kg \vee 0.120 kg)$	1 mark

- d) Instead of a ceramic mug, a Styrofoam cup (which is an effective thermal insulator) is used. State and explain the effect on the amount of ice that would have to be used to cool the coffee to 55.0 °C when compared to using a ceramic cup. Assume no heat is lost to the surroundings.

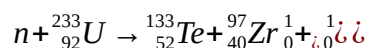
(3 marks)

The Styrofoam cup will not absorb or release any thermal energy.	1 mark
Hence, the only substance that needs to be cooled to 55.0 °C is the hot water.	1 mark
Hence, less ice is required.	1 mark

Question 14**(16 marks)**

A fission reaction used in nuclear power plants is the splitting of uranium-233 through thermal neutron absorption. One possible fission event produces tellurium-133 and zirconium-97 as daughter isotopes.

- (a) Complete the reaction by filling in how many neutrons are produced.

(1 mark)

Given:

Uranium-233	$3.86846 \times 10^{-25} \text{ kg}$
Tellurium-133	$2.20632 \times 10^{-25} \text{ kg}$
Zirconium-97	$1.60872 \times 10^{-25} \text{ kg}$
Neutron-1	$1.67492 \times 10^{-27} \text{ kg}$
1u =	$1.66055 \times 10^{-27} \text{ kg}$

Description	Marks
X = (233+1) – (133 + 97) = 4 (arithmetic not required for mark)	1
Total	1

- (b) Determine the mass defect in atomic mass units (amu) that results from this reaction. Provide your answer to the correct number of decimal places.

(5 marks)

Description	Marks
m.d. = [m(U-233) + m(n)] – [m(Te) + m(Zr) + 4 m(n)]	1
= [$3.86846 \times 10^{-25} + 1.67492 \times 10^{-27}$] – [$2.20632 \times 10^{-25} + 1.60872 \times 10^{-25} + 4 \times 1.67492 \times 10^{-27}$]	1
= $0.31724 \times 10^{-27} \div 1.66055 \times 10^{-27}$	1
= 0.19105 u	1
Answer expressed to 5 decimal places	1
Total	5

- (c) Calculate the energy produced by this reaction in MeV and joules. If you could not obtain an answer to part (b), use m = 0.100 u.)

(3 marks)

Description	Marks
E = m.d. x 931 = 0.19105 x 931	1
= 178 MeV x $1.60 \times 10^6 \times 10^{-19}$ (93.1)	1
= $2.85 \times 10^{-11} \text{ J}$ (1.49 x 10^{-11})	1
Total	3

Consider a reactor that releases $3.40 \times 10^6 \text{ W}$ of energy due to the reaction above.

- (d) Calculate the amount of mass, in kg, that is converted to energy in one day of operation.

(4 marks)

Description	Marks
Total events = Power x time / (E/n) = $\frac{3.40 \times 10^6 (24 \times 60 \times 60)}{2.85 \times 10^{-11}}$	1
= 1.03×10^{22} events.	1
Mass = events x mass defect = $1.03 \times 10^{22} \times 0.31724 \times 10^{-27}$	1
= 3.27×10^{-6} kg	1
Total	4

OR

Description	Marks
Total energy = Power x time = $3.40 \times 10^6 (24 \times 60 \times 60)$	1
= 2.86×10^{11} J	1
Mass = energy \div c^2 = $2.94 \times 10^{11} \div (9.00 \times 10^{16})$	1
= 3.27×10^{-6} kg	1
Total	4

If the engineers want to shut down the reactor, they need to insert a certain component into the reactor core.

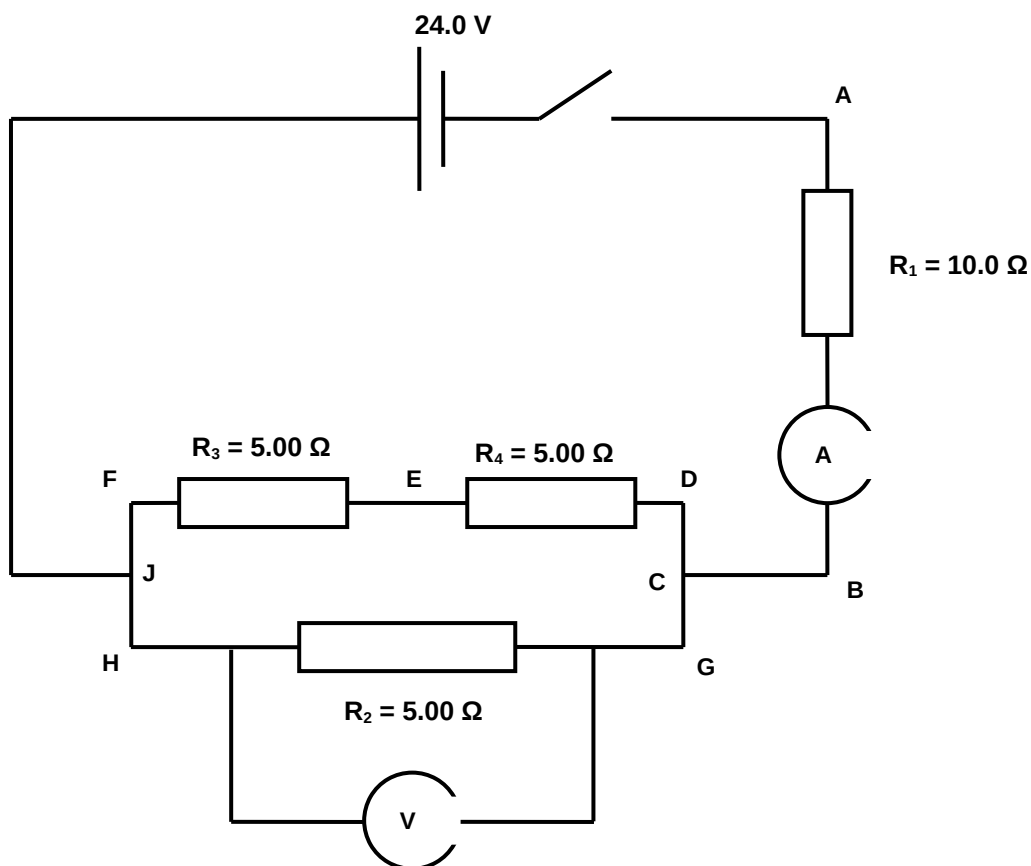
- (e) State the name of this component and explain how it is able to shut down the reactor.

(3 marks)

Description	Marks
Control rods	1
These are components that are good at absorbing free neutrons and can reduce the criticality of the reactor.	1
By being inserted into varying depths they can reduce the reactor to sub-critical which stops the chain reaction of fission from occurring.	1
Total	3

Question 15**(15 marks)**

A student constructs the circuit below to investigate current, voltage and electric power. Note the positions of the ammeter and voltmeter. In the questions that follow, the resistance of the connecting wires and the power source are equal to zero.



- a) Show with a calculation that the combined resistance between 'C' and 'J' is about 3 Ω.

(3 marks)

$\frac{1}{R_2} + \frac{1}{R_{3/4}}; \frac{1}{R_T} = \frac{1}{5.00} + \frac{1}{(5.00+5.00)}$	1 mark
.300	1 mark
33 Ω	1 mark

- b) Hence, show with a calculation that reading on the ammeter is 1.80 A.

(2 marks)

$= 3.33 + 10.0 = 13.3 \Omega$	1 mark
$; I = \frac{V}{R} = \frac{24.0}{13.3}$	1 mark
0 A	1 mark

- c) Hence, calculate the reading on the voltmeter.

(3 marks)

$= IR = 1.80 \times 10.0 = 18.0 V$	1 mark
$_{0\Omega} = 18.0 V$ dd	1 mark
$24.0 - 18.0 = 6.00 V$	1 mark

- d) Calculate the power generated in
- R_4
- .

(3 marks)

$5.00 + 5.00 = 10.0 \Omega$	1 mark
$; I = \frac{V}{R} = \frac{6.00}{10.0} = 0.600 A$	1 mark
$P = (0.600)^2 \times 5.00 = 1.80 W$	1 mark

- e) During the experiment, a break in the circuit occurs between 'C' and 'D'. Without performing any calculations, explain how the readings in the ammeter and voltmeter changed compared to before the break occurred.

(4 marks)

The break between 'C' and 'D' removes R_3 and R_4 from the circuit.	1 mark
This creates an increase in the overall resistance of the circuit.	1 mark
Overall circuit voltage remains constant; hence, the overall current through both R_1 and R_2 and the ammeter decreases.	1 mark
Voltmeter reading increases since resistance of that part of the network increases relative to R_1 .	1 mark

Question 16

(17 marks)

Radiocarbon dating is a process that is used to determine the age of fossilised bones. All living cells contain the element carbon – the vast majority of which is the stable isotope carbon-12 and the radioisotope carbon-14 (which is a beta emitter (β^-) and has a half-life of 5730 years).

In a living organism, the ratio of carbon-14 : carbon-12 nuclei is a constant value of about 1:100 000. After an organism dies, this ratio decreases.

- a) Write a nuclear equation for the beta decay (β^-) of carbon-14.

(3 marks)

$N_7^{14} + \beta_{-1}^0$	
Correct symbols used	1 mark
Atomic numbers balanced.	1 mark
Mass numbers balanced.	1 mark

- b) Explain why the carbon-14 : carbon-12 nuclei ratio decreases after an organism dies.

(3 marks)

When an organism dies, it stops ingesting carbon/maintaining its carbon levels via eating, etc.	1 mark
The carbon-12 level remains stable – its quantity does not change after the organism dies.	1 mark
Carbon-14 is an unstable radioisotope – it decays and its quantity, therefore, reduces after the organism dies.	1 mark

- c) A carbon-14 nucleus has a mass of 14.00324 u. A proton has a mass of 1.00727 u; a neutron has a mass of 1.00867 u. Use this data to calculate the binding energy per nucleon of carbon-14.

(4 marks)

total mass ($C-14$) = $6 \times 1.00727 + 8 \times 1.00867 = 14.11298 \text{ u}$	1 mark
mass defect = $14.11298 - 14.00324 = 0.10974 \text{ u}$	1 mark
binding energy = $0.10974 \times 931 = 102.16794 \text{ MeV}$	1 mark
binding energy per nucleon = $\frac{102.16794}{14} = 7.30 \text{ MeV}$	1 mark

- d) Compare and explain the difference in the binding energy per nucleon between a carbon-12 and a carbon-14 nucleus.

(3 marks)

BE/nucleon (C-12) > BE/nucleon (C-14)	1 mark
C-12 atoms are stable; C-14 atoms are unstable.	1 mark
Hence, C-14 atoms have inadequate BE/nucleon to hold the nucleons together in a stable formation.	1 mark

- e) A fossilised bone is analysed and it is found that the carbon-14 : carbon-12 ratio has decreased to 15.0% of its value for a living organism. Using the half-life of carbon-14, estimate a value for the age of the fossilised bone.

(4 marks)

$(0.5)^n; A = 15.0\%; A_0 = 100\%; 15.0 = 100(0.5)^n$	1 mark
$\frac{0.15}{0.5} = 2.74 \text{ half lives}$	1 mark
$4 \times 5730 = 1.6 \times 10^4 \text{ years}$	1 mark
1 or 2 significant figures	1 mark

Question 17

(18 marks)

A kettle contains 0.400 kg of water at a room temperature of 22.0 °C. The metal body of the kettle is made of aluminium ($c = 900 \text{ J kg}^{-1} \text{ K}^{-1}$) and has a mass of 0.350 kg. When the kettle is switched on, the heating element draws a current of 9.50 A from mains power ($V = 240 \text{ V}$).

- (a) Calculate the heat needed to bring the kettle and water to the water's boiling point. (3 marks)

Description	Marks
$Q = mc\Delta T_{\text{water}} + mc\Delta T_{\text{kettle}}$	1
$= (0.400)(4180)(100 - 22.0) + (0.350)(900)(100 - 22.0)$	1
$= 1.55 \times 10^5 \text{ J}$	1
Total	3

- (a) Calculate the power of the kettle and use this value to calculate the time taken for the water to boil. (4 marks)

Description	Marks
$P = IV$ $= 9.50 \times 240$	1
$= 2280 \text{ W}$	1
$t = E / P$ $= 1.55 \times 10^5 / 2280$	1
$= 68.0 \text{ s}$	1
Total	4

- (c) Describe, making reference to the kinetic theory of matter, what is happening to the water molecules as the water is heated, prior to reaching its boiling point. (2 marks)

Description	Marks
As the kettle provides heat to the water, they increase their kinetic energy and hence their mean translational velocities.	1
As temperature is a measure of the mean translational velocities of particles in a substance, the temperature increases.	1
OR As the kettle provides heat to the water they increase the internal energy of the water, as $U = \Sigma E_k + \Sigma E_p$	1
Since the water is not going through a phase change (E_p), only the kinetic energy of the water molecules increase, and as temperature is a measure of the mean translational velocities of particles in a substance, the temperature increases.	1
Total	2

The student is surprised to find that when he measures the actual time taken with a stopwatch, it is 84.5 seconds.

- (d) Calculate the efficiency of the kettle.

(3 marks)

Description	Marks
$\eta = \frac{E_{\text{out}}}{E_{\text{in}}} \times 100$ $E_{\text{in}} = IVt$	1
$= \frac{1.55 \times 10^5}{9.50(240)(84.5)} \times 100$	1
$= 80.5\%$	1
Total	3

The thermostat in the kettle does not switch off the power immediately as the water boils but continues to heat the water for an extra 18.0 seconds after it boils.

- (e) Describe, making reference to the kinetic theory of matter, what is happening to the water molecules during this 18.0 second period.

(2 marks)

Description	Marks
As the kettle provided heat to the water, the additional energy is transferred to potential energy as the water is already at its boiling point.	1
This provides some of the water molecules with sufficient latent heat of vaporization to change phase.	1
Total	2

- (f) Calculate the mass of steam that leaves the kettle in this 18 second period.

(4 marks)

Description	Marks
$E = IVt \times 0.805$	1
$= 9.5(240)(18.0)(0.805)$	
$= 3.30 \times 10^4 \text{ J}$	1
$Q = mL_v$	
$m = \frac{3.30 \times 10^4}{22.6 \times 10^5}$	1
$= 0.0146 \text{ kg}$	1
Total	4
Note, if students omit efficiency, $m = 0.0182 \text{ kg}$: maximum 3 marks.	

End of Section Two

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Section Three: Comprehension

20% (36 Marks)

This section contains **two (2)** questions. You must answer both questions. Write your answers in the spaces provided.

When calculating numerical answers, show your working and reasoning clearly. Give final answers to **three** significant figures and include appropriate units where applicable.

When estimating numerical answers, show your working and reasoning clearly. Give final answers to a maximum of **two** significant figures and include appropriate units where applicable.

Supplementary pages for planning/continuing your answers to questions are provided at the end of the Question/Answer booklet. If you use these pages to continue an answer, indicate at the original answer where the answer is continued, ie – give the page number.

Suggested working time for this section is 40 minutes.

Question 18

(18 marks)

Racing toward Absolute Zero

The coldest theoretical temperature allowed by thermodynamics is called 'absolute zero' – a temperature that is colder than outer space. This temperature is assigned a value of zero degrees kelvin and is equal to -273.15 degrees Celsius or -459.67 degrees Fahrenheit. This is technically the temperature when a 'system' (such as a thermometer) reaches its lowest possible energy.

Humans have an intuitive understanding of temperature due to their experience with the sensations of feeling 'hot' and 'cold'. However, what humans are really experiencing in situations where they are distinguishing between hot and cold objects is the amount of internal energy that these objects contain. Internal energy is partly defined by the amount of movement the particles in an object have (ie – their 'thermal motion'). An ice cube, for example, contains less internal energy than a cup of hot water because its particles are not moving as much as in the water. At absolute zero, the thermal motion of the particles would be at their minimum.

The concept of 'absolute zero' first emerged in the early 1700's when a French physicist and inventor called Guillaume Amontons related temperature to the amount of heat in a system. Amontons hypothesised that there would be a minimum amount of heat a system could possess and that this would correspond to a minimum temperature.

In the early 1900's, the Dutch physicist, Heike Onnes, used several precooling stages and a process called the Hampson-Linde Cycle to liquefy helium gas for the first time. In this experiment, he lowered the helium gas to a temperature just below its boiling point: -269 °C.

Onnes' high-powered cooling system has been adopted by refrigeration systems used in physics laboratories around the world. The cooling process is like that which occurs when you blow on a hot beverage.

The latest step in the quest to achieving absolute zero is being pursued by the Quantum Matter Team at the University of Cambridge's Cavendish Laboratory. As they lower the

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temperature of materials to super-cold levels, they are discovering exotic quantum properties that only emerge at these temperatures – some of which are extremely useful. Advances in technology enables this team to measure and observe energies at evermore extreme scales and at lower temperatures that are getting closer and closer to zero kelvin.

The Quantum Matter Team know, however, that achieving absolute zero is theoretically impossible. The refrigeration systems needed to achieve this consume energy as they operate. The work done by these systems increases exponentially as the temperature gets closer and closer to absolute zero. In theory, to achieve this temperature an *infinite* amount of work needs to be done. In addition, quantum mechanics dictates that even at absolute zero the particles' thermal motion would not be at a minimum: they would still have some form of *irreducible* motion.

Nonetheless, the best refrigeration systems - based on Onnes' original designs – are getting closer to this lowest temperature and are now able to reach a few millikelvins.

- a) Define 'heat energy'. As part of your answer, define 'internal energy' and describe the energy possessed by particles in a substance.

(4)

Internal energy is equal to the sum of the kinetic and potential energies of the particles in a substance.	1 mark
Internal energy consists of the kinetic energy of the particles and	1 mark
the potential energy of the particles.	1 mark
Heat energy is the flow of internal energy from a higher temperature object to a lower temperature object.	1 mark

- b) Explain three (3) reasons why a small block of ice has less internal energy than a large cup of hot water.

(5)

A bowl of soup consists of more particles than ice cream in a cone.	1 mark
The strength of attraction between the particles in a liquid are generally less than that in a solid.	1 mark
Therefore, a liquid's particles generally have a higher potential energy than a solid.	1 mark
The ice cream's temperature is lower than that of the bowl of soup.	1 mark
Therefore, the average kinetic energy of the particles in the ice cream is less than that in a bowl of soup.	1 mark

- c) The Celsius and the Kelvin scales are both the same – they just have different origins. Complete the table below converting the temperatures shown between degrees Celsius and Kelvin. Round your answers for 'Temperature (°C)' to the nearest 0.01 of a degree.

(2)

Temperature (°C)	Temperature (K)
-273.15	0
-173.15	100
-269	4.15

$T = -173.15 = 100 \text{ K}$	1 mark
$T = -269 = 4.15 \text{ K}$	1 mark

- d) The article states that a temperature of 'absolute zero' would be impossible to reach experimentally.

- (i) Explain what should theoretically happen to an object's particles at a temperature of zero Kelvin.

(2)

A temperature of absolute zero should mean an average kinetic energy of the particles equal to zero.	1 mark
Hence, the particles should stop moving completely (ie – become stationary).	1 mark

- (ii) Hence, explain why scientists believe that is impossible to reach absolute zero.

(2)

Quantum physics implies that particles would always have some irreducible motion.	1 mark
Hence, the particles will always have some kinetic energy (ie - the kinetic energy of the particles can never be zero).	1 mark

- e) Explain how blowing on a cup of coffee can cause it to cool down.

(3)

The blowing causes high energy water particles to evaporate at a faster rate.	1 mark
Hence, the lower energy particles remain in the coffee which reduces the overall average kinetic energy of the particles.	1 mark
Hence, the temperature of the coffee will reduce.	1 mark

Question 19**(13 marks)**

- (a) Of the 6 modes of neutron interaction, place the numbers into the table that corresponds to the effect on criticality.

(2 marks)

Description		Marks				
<table><tr><td>Increase</td><td>Decrease</td></tr><tr><td>4, 5</td><td>1, 3</td></tr></table>			Increase	Decrease	4, 5	1, 3
Increase	Decrease					
4, 5	1, 3					
1 mark off for each error.		1-2				
Total		2				

- (b) Explain why the Core was able to remain subcritical when sitting on its own.

(3 marks)

Description		Marks
Any two of the following:		
When sitting on its own, many neutrons escaped the mass.		1-2
The purity (number of fissile nuclei) was also kept low enough		
Or shape (hemispheres)		
Any one of the following:		
Meaning less neutrons were absorbed for every neutron emitted.		1
not enough events to sustain a chain reaction		
Total		3

- (c) Explain the role of the beryllium shell and the tungsten carbide blocks in relation to the criticality of the demon core.

(3 marks)

Description	Marks
The Be Shell and W-Carbide blocks were able to reflect free neutrons back into the mass.	1
This increases the ratio of neutrons emitted to neutrons absorbed OR This increases the potential to produce more subsequent fission events Which increases the criticality of the mass.	1
Total	3

- (d) Calculate the Dose Equivalent of Louis Slotin,

(3 marks)

Description	Marks
D.E. = A.D x QF	1
= (10 x10) + (1.14 x1)	1
= 101 Sv	1
Total	3

Theodore Perlman received a lower dose and did not suffer the effects of acute radiation sickness.

- (e) Making reference to Image 4, explain why Perlman received a lower dose.

(2 marks)

Description	Marks
Perlman was much further away from the Core.	1
Increasing distance reduces the amount of absorbed radiation ($I \propto 1/r^2$)	1
Total	2