Rossmoyne Senior High School

Semester 1 examination, 2020

Question/Answer booklet

PHYSICS

UNIT 1

Please place your student identification label in this box

Student number: In figures

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)

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	10	10	45	45	30%
Section Two: Problem Solving	5	5	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 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% (45 marks)**

This section has 10 questions. Answer **all** questions. Answer the questions in the spaces provided.
Suggested working time: 45 minutes.

Question 1 **(4 marks)**

A 2400 W kettle boils 1.20 litres of water in 3 minutes. If the water was initially at 25.0°C, what is the efficiency of the kettle?

<table>
<tr><th colspan="2">Description</th><th>Marks</th></tr>
<tr><td colspan="2">m = 1.2kg
T_i = 25.0°C
Tf = 100.0°C
c = 4180 J/kg/K

$\Delta Q = mc\Delta T$
= 1.2 x 4180 x (100-25)
= 376200 J</td><td>1</td></tr>
<tr><td>P = 2400 W
t = 3 mins = 180 s

E = P x t
= 2400 x 180
= 432000 J</td><td>E = 376200
t = 3 mins = 180 s

P = E ÷ t
= 376200 ÷ 180
= 2090 W</td><td>1</td></tr>
<tr><td>$Efficiency = \frac{output\ energy}{input\ energy} x\ 100$
$= \frac{376200}{432000} x\ 100$</td><td>$Efficiency = \frac{output\ power}{input\ power} x\ 100$
$= \frac{2090}{2400} x\ 100$</td><td>1</td></tr>
<tr><td colspan="2">= 87.1 %</td><td>1</td></tr>
<tr><td colspan="2">Total</td><td>4</td></tr>
</table>

Question 2 **(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
Energy transfers from the body to the water particles **due to a difference in temperature** (hot to cold).	1
The exposed **moisture** on the skin or clothing **evaporates**, decreasing the overall kinetic energy of the water **which increases the rate of heat transfer** from the body to the water via conduction, cooling the person quickly.	1
The **rate of evaporation of the water is increased by the wind**, cooling the person further.	1
Total	3

Question 3 (5 marks)

Complete the following nuclear equations.

(a) $^{14}_{6}C \rightarrow ^{14}_{7}N +$ $\boxed{^{0}_{-1}\beta}$ $+$ $\boxed{^{0}_{0}\bar{\nu}}$

(b) $^{27}_{13}Al + ^{4}_{2}\alpha \rightarrow$ $\boxed{^{30}_{15}P}$ $+ ^{1}_{0}n$

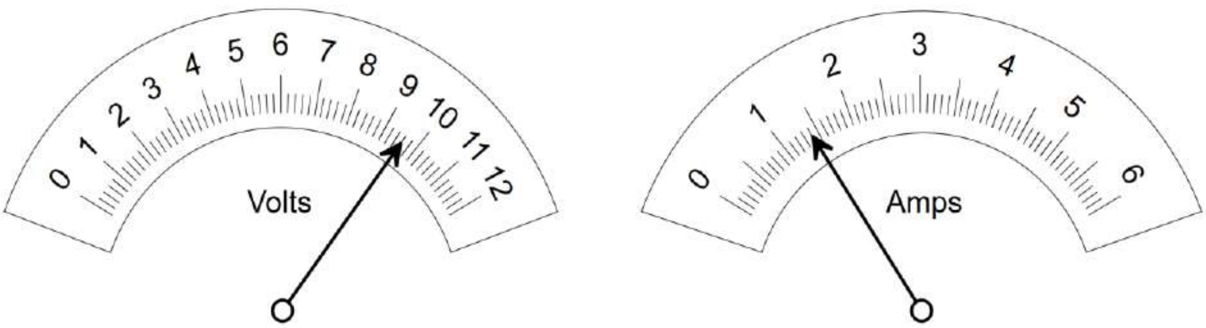
(c) $^{217}_{85}At \rightarrow ^{213}_{83}Bi +$ $\boxed{^{4}_{2}\alpha}$

(d) $^{10}_{5}B + ^{1}_{0}n \rightarrow ^{4}_{2}\alpha +$ $\boxed{^{7}_{3}Li}$

Description	Marks
(a) $^{0}_{-1}\beta + ^{0}_{0}\bar{\nu}$	1-2
(b) $^{30}_{15}P$	1
(c) $^{4}_{2}\alpha$	1
(d) $^{7}_{3}Li$	1
Total	5

Question 4 (3 marks)

Albert is trying to precisely measure the resistance R of a piece of fuse wire. To do so he applies a voltage across the wire and measures current passing through the wire. The meters are shown below.



a) What are the readings on the voltmeter and ammeter?

(2 marks)

Description	Marks
9.60 V	1
1.40 A	1
Total	2

b) Determine the resistance R of the fuse wire.

(1 mark)

Description	Marks
$R = \frac{V}{I} = \frac{9.60}{1.40} = 6.86\ \Omega$	1
Total	4

Question 5 **(3 marks)**

One of the uses of radioisotopes is as tracers to locate leaks in long water pipes without digging up the pipe along its entire length. Describe the type of emitter and half-life of the radioisotope that would be suitable for such a task. Explain your answer

Description	Marks
Gamma emitter	1
Short half-life	1
Must be able to penetrate through ground and possibly concrete therefore Gamma only possible source. **or** Short half-life allows enough time for detection without effecting safety	1
Total	3

Question 6 **(7 marks)**

While investigating an electricity supply failure in a workshop it becomes apparent that a fuse has melted within the main electrical panel, leaving an open circuit and preventing charge from flowing. In order to restore the electricity, a worker places a small piece of iron between the two open terminals to allow the flow of charge. This enables the workshop to keep operating as per normal.

(a) Explain why this was not an appropriate fix for this problem and justify your response.

(4 marks)

Description	Marks
A fuse is designed to protect the circuit in the event of excess current	1
If the fuse has melted, there must be some fault in the system which remains unrectified (short or similar)	1
By replacing with a thick conductor larger current will be able to flow before the fuse will melt (or fuse is overrated)	1
Causing damage to the circuits / potential for fire	1
Total	4

(b) Fuses are being phased out of household use. Name an alternative common safety device that performs the same function as a fuse and describe how it functions.

(3 marks)

Description	Marks
Circuit breaker	1
An electromechanical device that detects excessive electrical current **or** mechanical switch output via electromagnetic force (not required for mark)	1
Opening the circuit and prevents the flow of current. *If student put RCD then give this one mark if student had this statement or similar, otherwise zero marks awarded.*	1
Total	3

Question 7 **(5 marks)**

Given the following data, calculate the binding energy per nucleon in, MeV, for a Manganese-55 atom.

Mass of proton	=	1.007276 u
Mass of neutron	=	1.008665 u
Mass of electron	=	0.000548 u
Mass of Hydrogen-1	=	1.007825 u
Mass of Manganese 55 atom	=	54.93800 u

Description	Marks
Manganese 55 = 54.938000u 25 protons = 25 x 1.007276 = 25.1819 u 30 neutrons = 30 x 1.008665 = 30.25995 u 25 electrons = 25 x 0.00548 = 0.0137 u	1-2
Δm = m(constituent particles) – m(Mn-55) = 55.45555 – 54.938000 = 0.51755 u	1
$E = mc^2$ = 0.51755 x 931 = 481.84 MeV	1
BE per nucleon = 481.84/55 = 8.76 MeV per nucleon.	1
Total	5

Question 8 **(3 marks)**

A 416 g sample of radioisotope Promethium–147 decays into Samarium–147 as the main product. Determine the half-life of Promethium–147 if it decays to 13 g in 12 years?

Description			Marks
$A = A_o 0.5^{\frac{t}{t_{½}}}$ $13 = 416\ x\ 0.5^{\frac{12}{t_{½}}}$ $0.03125 = 0.5^{\frac{12}{t_{½}}}$	$A = A_0(0.5)^n$ $13 = 416 \times (0.5)^n$ $\frac{1}{32} = 0.03125 = 0.5^n$	416 ÷ 2 208 ÷ 2 104 ÷ 2 52 ÷ 2 26 ÷ 2 = 13	1
$log 0.3125 = \left(\frac{12}{t_{½}}\right) log 0.5$ $\frac{log 0.3125}{log 0.5} = \left(\frac{12}{t_{½}}\right)$ $5 = \left(\frac{12}{t_{½}}\right)$	Solving for number of half-lives: $n = 5.0$		1
$t_{\frac{1}{2}} = \frac{t}{n}$ $= \frac{12}{5.0}$ $t_{½}$ = 2.40 years			1
Total			3

Question 9 **(6 marks)**

Lorraine adds a handful of ice blocks to her partly empty water bottle. She knows that an average ice block contains approximately 40 mL of water. Lorraine wants to ensure that the ice doesn't melt too quickly and therefore only selects ice blocks that are below freezing point. Estimate how many kilojoules (kJ) of energy were extracted from 18°C tap water in order to produce the ice blocks that Lorraine used.

Description	**Marks**
mi = 0.04 kg per ice block Number of ice blocks used = 5 ± 2 (Total mass of ice between 120 and 280 g)	1
Initial temperature of ice blocks is – 4°C ± 3°C (anywhere from –7°C to –1°C)	1
Heat lost = specific heat of water + latent heat of fusion + specific heat of ice **or** $\Delta Q = mc\Delta T + mLf + mc\Delta T$	1
$= (0.04 \times \mathbf{5}) \times (4180 \times (18-0) + 3.34 \times 10^5 + 2100 \times (0-(\mathbf{-5}))$ $= 15048 + 66800 + 2100$	1
= 83948 J Convert to kilojoules = 83.9 kJ	1
Answer to 1 or 2 SF Q = 84 kJ (Allowed range 49kJ to 120kJ)	1
Total	6

Question 10 **(6 marks)**

A laptop is rated at 16.8 V and draws an operating current of 3.80 A. The laptop's battery can store a total charge of 3.00×10^4 C.

a) The laptop runs for 3.00 hours. Calculate the energy drawn from the battery in this time. (3 marks)

Description		**Marks**
V = 16.8 V I = 3.80 A t = 3 hours = 10800 s		1
E = VIt = 16.8 x 3.80 x 10800	P = VI = 16.8 x 3.80 = 63.84 W E = P x t = 63.84 x 10800	1
$= 6.89 \times 10^2$ J		1
Total		3

b) Calculate the time, in hours that the laptop can operate before all of the total charge has been depleted from the battery. (3 marks)

Description	**Marks**
$q = 3.00 \times 10^4$ C I = 3.80 A Q = It t = Q/I	1
= 30,000 / 3.8 = 7895 s	1
7895 ÷ 3600 = 2.19 hours	1
Total	3

END OF SECTION ONE

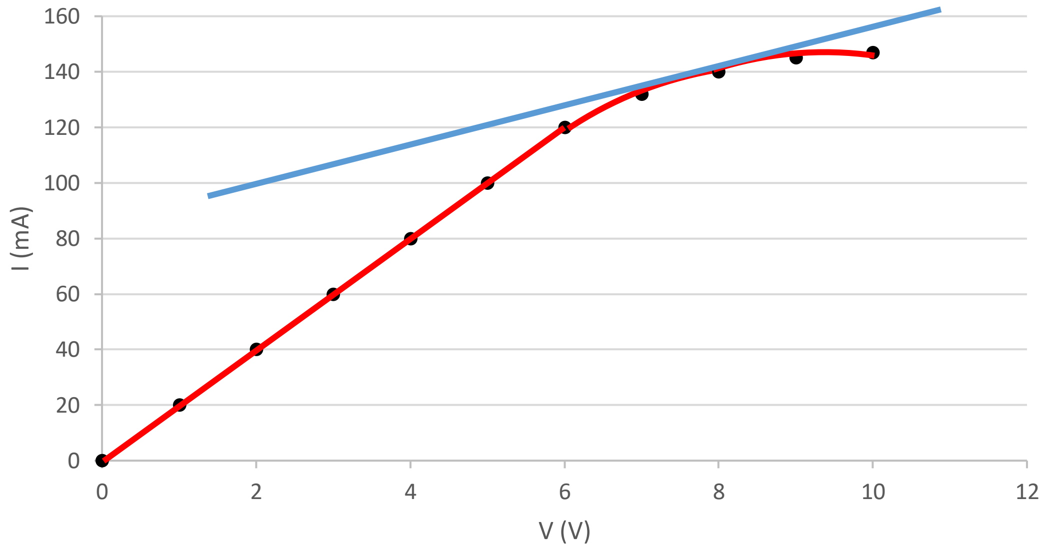
Section Two: Problem Solving **50% (75 marks)**

This section contains 5 questions. Answer **all** questions. Answer the questions in the spaces provided. Suggested working time 75 minutes.

Question 11 **(9 marks)**

A voltage source is connected across a filament light bulb and the current is measured for different voltages. The graph is shown below.

Current v Voltage graph



(a) Draw a line of best fit for the data shown in the graph above. (1 mark)

(b) State the range of voltages where the light bulb is behaving as an ohmic conductor. (1 mark)

Range: ___________0 – 6 V_______________________________

(c) Use the gradient of the graph above, calculate the average resistance of the light bulb when it is behaving as an ohmic conductor. (3 marks)

Description	Marks
$m = \dfrac{y_2 - y_1}{x_2 - x_1} = \dfrac{0.10 - 0}{5.0 - 0} = 0.020\ AV^{-1}$	1
$m = \dfrac{I}{V} = \dfrac{1}{R}$	1
$R = 1/m$ $= 1/0.02$ $= 50\ \Omega$	1
Total	**3**

(d) Calculate the resistance of the filament light bulb when the voltage is at 8.00 V. (2 marks)

Description	**Marks**
Draws tangent line at 8 V	**1**
Uses gradient of tangent to find resistance (100-200 Ω)	**1**
Total	**2**

(e) Explain and account for the difference in calculated resistances for parts (c) and (d). (2 marks)

Description	**Marks**
As voltage increases, the current through the filament increases, causing it to heat up (as per Ohm's Law and more energy is converted to heat as $P = I^2R$)	1
The higher temperature causes an increase in resistance of the light bulb.	1
Total	**2**

Question 12 **(10 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 boron–11. The boron-11 then decays, producing 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: ${}^{10}_{5}\mathrm{B} + {}^{1}_{0}\mathrm{n} \longrightarrow {}^{11}_{5}\mathrm{B}$ ${}^{11}_{5}\mathrm{B} \longrightarrow {}^{7}_{3}\mathrm{Li} + {}^{4}_{2}\alpha$	
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. (7 marks)

Description	Marks
Mass of B-10 required is $25 \times 2.2 = 55\ \mu g$	1
Finds mass of B-10 atom: $10.013 \times (1.66 \times 10^{-27})\ \mathrm{kg} = 1.662158 \times 10^{-26}\ kg$ Number of B-10 atoms required is $\frac{55 \times 10^{-6} \times 10^{-3}\ \mathrm{kg}}{10.013 \times (1.66 \times 10^{-27})\ \mathrm{kg}} = 3.31 \times 10^{18}$	1-3
Number of neutrons required is 3.31×10^{18}	1
Total energy of neutrons is $3.31 \times 10^{18} \times (0.65\ \mathrm{eV}\ \times 1.6 \times 10^{-19}\ \mathrm{J/eV}) = 0.344\ \mathrm{J}$	1
Absorbed Dose is $\frac{0.344\ \mathrm{J}}{45\ \mathrm{kg}} = 7.65 \times 10^{-3}\ \mathrm{Gy}$	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 is more ionizing, causing more damage to cancer cells.	1

Question 13 **(19 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?

(5 marks)

Description	Marks
Heat required: $Q_{Total} = Q_{water} + Q_{pot} = m_w c_w \Delta T + m_p c_p \Delta T$	1
$Q_{Total} = 5 \times 4180 \times (83) + 1.0 \times 480 \times (83)$ $Q_{Total} = 1.77 \times 10^6$ J	1
Efficiency of 65% means useful heating is 0.65×2.8 kW $= 1.82$ kW $P = \frac{E}{t} \longrightarrow t = \frac{E}{P}$	1
$t = \frac{E}{P} = \frac{1774540}{1820} = 975$ 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: $Q = P \times t = 1.82 \times 10^3 \times (3 \times 60) = 327{,}600$ J	1
$Q = mL$	1

$m = \frac{Q}{L} = \frac{327600}{2.26 \times 10^6}$	
$m = 0.145$ 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? (6 marks)

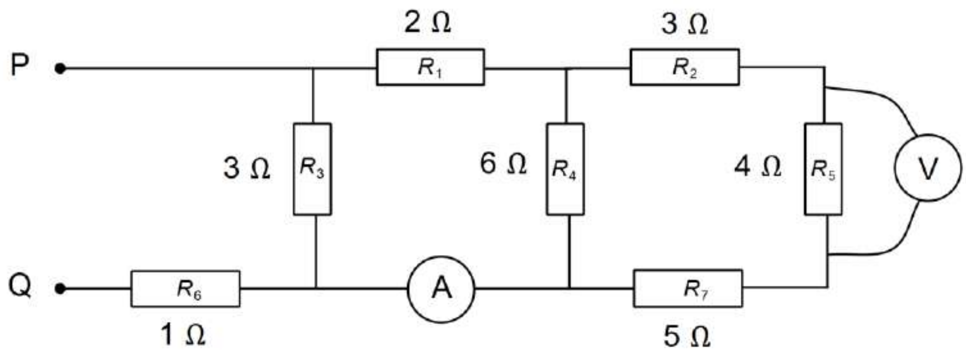
Description	**Marks**
Heat lost by hot water/pot is gained by ingredients $\Delta Q_{water/pot} = -\Delta Q_{ingr}$	1
Use temperature change formulae: $m_w c_w \Delta T + m_{pot} c_{pot} \Delta T_{pot} = -(m_{chi} c_{chi} \Delta T + m_{car} c_{car} \Delta T + m_{noo} c_{noo} \Delta T)$	1
Substitute correct values: $4.8 \times 4180 \times (T - 373) + 1.00 \times 480 \times (T - 373) = -(0.50 \times 4340 \times (T - 288) + 0.65 \times 3920 \times (T - 288) + 0.2 \times 1600 \times (T - 288))$	1-2
Simplifying: $20064T - 7483872 + 480T - 179040 = -(2170T - 624960 + 2548T - 733824 + 320T - 92160)$ Becomes… $24482T = 9113856$	1
Solve for temperature T (K or °C) $T = 356.3$ K $T = 83.3$ °C	1

(e) Explain what is meant by the term 'thermal equilibrium.' (2 marks)

Description	**Marks**
Where the **temperature** of two substances are the **same**	1
Such that there is **no net transfer of heat from one to the other**	1
Total	**2**

Question 14 **(17 marks)**

Consider the circuit shown below, containing seven resistors, an ammeter and a voltmeter.



(a) Show that the total resistance between terminals P and Q is 3 Ω. (5 marks)

Description	Marks
$R_8 = R_2 + R_5 + R_7 = 3 + 4 + 5 = 12\,\Omega$	1
$R_9 = \left(\frac{1}{R_8} + \frac{1}{R_4}\right)^{-1} = \left(\frac{1}{6} + \frac{1}{12}\right)^{-1} = \left(\frac{3}{12}\right)^{-1} = 4\,\Omega$	1
$R_{10} = R_9 + R_1 = 4 + 2 = 6\,\Omega$	1
$R_{11} = \left(\frac{1}{R_{10}} + \frac{1}{R_3}\right)^{-1} = \left(\frac{1}{6} + \frac{1}{3}\right)^{-1} = \left(\frac{3}{6}\right)^{-1} = 2\,\Omega$	1
$R_{Total} = R_{11} + R_6 = 2 + 1 = 3\,\Omega$	1

(b) If a voltage source of 9.0 volts is placed across the terminals P and Q:

i) Find the total current drawn by the circuit. (1 mark)

Description	Marks
$I_T = \frac{V_T}{R_T} = \frac{9.0}{3.0} = 3.0\text{ A}$	1

ii) Find the amount of charge drawn by the circuit in a time of 45 seconds. (2 marks)

Description	Marks
$I = \frac{q}{t} \quad \therefore q = It$	1
$q = 3.0 \times 45 = 135\text{ C}$	1

iii) Show that the current measured at the ammeter is 1 A. (4 marks)

Description	**Marks**
Voltage drop across R_{11} = voltage drop across R_{10}. (Current through $R_{11} = 3.0\ \mathrm{A}$)	1
Voltage drop across R_{11} is: $V = IR = 3.0 \times 2.0 = 6.0\ \mathrm{V}$	1
Voltage drop across R_{10} is also 6.0 volts. Resistance of $R_{10} = 6\ \Omega$	1
$V_{10} = IR = 6.0 = I \times 6.0$ $\therefore I = \frac{6.0}{6.0} = 1.0\ \mathrm{A}$	1

iv) Determine the voltage measured by the voltmeter. (5 marks)

Description	**Marks**
Current through $R_9 = 1.0\ \mathrm{A}$	1
Voltage drop: $V_9 = I_9 R_9 = 1.0 \times 4.0 = 4.0\ \mathrm{V}$	1
Voltage drop: $V_8 = V_9 = 4.0\ \mathrm{V}$	1
Current through R_8 is: $I_8 = \frac{V_8}{R_8} = \frac{4}{12} = 0.33\ \mathrm{A}$	1
$V = V_5 = I_5 R_5 = 0.33 \times 4 = 1.33\ \mathrm{V}$	1

Question 15 **(20 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: $^{1}_{0}\mathrm{n} + ^{235}_{92}\mathrm{U} \longrightarrow ^{236}_{92}\mathrm{U} \longrightarrow ^{94}_{38}\mathrm{Sr} + ^{140}_{54}\mathrm{Xe} + 2\ ^{1}_{0}\mathrm{n}$	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. (6 marks)

Description	Marks
Mass of reactants: $235.04393\ \mathrm{u} + 1.00866\ \mathrm{u} = 236.05259\ \mathrm{u}$	1
Mass of products: $93.91536\ \mathrm{u} + 139.92164\ \mathrm{u} + 2 \times 1.00866\ \mathrm{u} = 235.85432\ \mathrm{u}$	1
Mass defect: $m = 236.05259\ \mathrm{u} - 235.85432\ \mathrm{u} = 0.19827\ \mathrm{u}$	1
Use energy associated with 1 u: $E = 0.19827 \times 931 = 184.6\ \mathrm{MeV}$ OR Convert m to kg: $m = 0.19827\ \mathrm{u} = 0.19827 \times 1.66 \times 10^{-27}\ \mathrm{kg} = 3.29 \times 10^{-28}\ \mathrm{kg}$	1
Convert the energy to J: $E = 184.6\ \mathrm{MeV}\ \times 10^{6} \times 1.6 \times 10^{-19}\ \mathrm{J/eV}$ $E = 2.95 \times 10^{-11}\ \mathrm{J}$ (OR) Use mass-energy principle: $E = mc^2 = (3.29 \times 10^{-28})(3 \times 10^{8})^2 = 2.95 \times 10^{-11}\ \mathrm{J}$	1-2

(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. (5 marks)

Description	**Marks**
Number of seconds in 1 year: $t = 365 \times 24 \times 60 \times 60 = 3.1536 \times 10^7\ s$	1
Energy required in 1 year: $E = P \times t = 900 \times 10^6 \times 3.1536 \times 10^7 = 2.84 \times 10^{16}\ \mathrm{J}$	1
Number of fission reactions required: $n = \frac{E_t}{E_f} = \frac{2.84 \times 10^{16}\ \mathrm{J}}{2.95 \times 10^{-11}\ \mathrm{J}} = 9.62 \times 10^{26}\ \mathrm{particles}$	1
Converts mass of U-235 from u to kg $m = 235.04393 \times 1.66 \times 10^{-27} = 3.90 \times 10^{-25}\ kg$	1
Find total mass of U-235 required: $m = 3.90 \times 10^{-25} \times 9.62 \times 10^{26} = 375\ \mathrm{kg}$	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: $AD = \frac{E}{m} = \frac{12}{82} = 0.146\ \mathrm{Gy}$	1
Dose Equivalent: $DE = AD \times QF = 0.146 \times 1 = 0.146\ \mathrm{Sv}$	1
Since the $DE = 146\ \mathrm{mSv}$ is greater than the safety limit (100 mSv), it is NOT safe for the worker to continue working.	1

END OF SECTION TWO

Section Three: Comprehension **20% (30 Marks)**

This section has **two** questions. Answer both questions and write your answers in the spaces provided.
Suggested working time: 30 minutes.

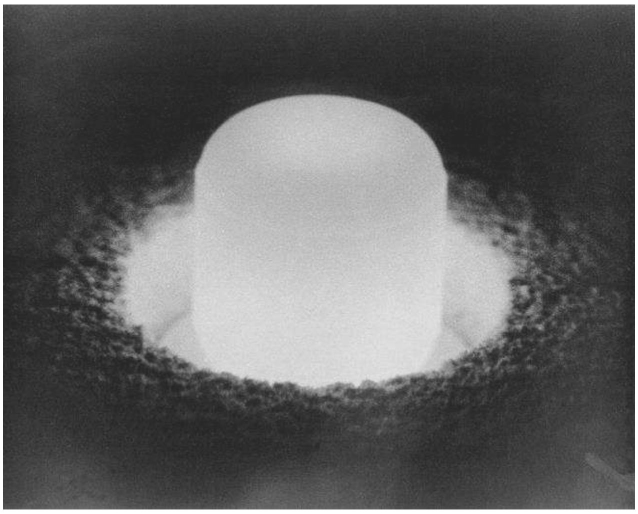
Question 16 **(20 marks)**

The secretive Element 94

You might have heard in chemistry class that there are 92 naturally occurring elements existing on Earth and, up until 79 years ago, that was all the building blocks we had to play with. In the mid-1930s, Enrico Fermi reported that his team of scientists had produced a mysterious *Element 94*, but it wasn't until 1941, midway through World War II that it was chemically identified and confirmed as a new element at the University of California, Berkley. Wartime secrecy prevented the University of California team from publishing its discovery until 1948 so much investigation and testing went on in secrecy by the American and Allied nations during the early 1940s. Since uranium had been named after the planet Uranus and neptunium after the planet Neptune, element 94 was named after Pluto, (which at the time was considered to be a planet as well).

Plutonium was first produced by a neutron bombardment of uranium-238; producing uranium-239 (half-life 23.5 minutes) which beta-decayed into neptunium-239 (half-life 2.35 days) which subsequently beta-decayed to form this new element with atomic number 94 and atomic weight 239 (half-life 24,100 years).

Further investigation from team at the Cavendish Laboratory in Cambridge, realized that a slow neutron reactor fuelled with uranium would theoretically produce substantial amounts of plutonium-239 as a by-product. They calculated that element 94 would be fissile and had the added advantage of being chemically different from uranium and could easily be separated from it.



(a) Complete the three separate nuclear equations that show the synthesis of plutonium through the neutron bombardment of uranium. (3 marks)

Description	Marks
${}^{238}_{92}U + {}^{1}_{0}n \rightarrow {}^{239}_{92}U$	1
${}^{239}_{92}U \rightarrow {}^{239}_{93}Np + {}^{0}_{-1}\beta + {}^{0}_{0}\bar{\upsilon}$	1
${}^{239}_{93}Np \rightarrow {}^{239}_{94}Pu + {}^{0}_{-1}\beta + {}^{0}_{0}\bar{\upsilon}$	1
Total	**3**

(b) Suppose 212 grams of U – 239 was synthesised in a lab. Calculate the mass of Np-239 that would be synthesised in a time of 3.40 hours. (4 marks)

Description	Marks
$t = 3.4 \times 60$ $= 204$ minutes; $t_{1/2} = 23.5$ minutes; $n = t/t_{1/2} = (204/23.5) = 8.68$	1
$m = m_0(1/2)^{t/t1/2}$	1
$= 212\,(1/2)^{(204/23.5)}$	
$= 0.517$ grams **(1 mark)** Mass of Np 212 **-** .517 = **211g(1 mark)**	2
Total	**4**

(c) Explain why the value calculated in (b) is likely to be an over-estimate when scientists come to extract the sample of Np-239 in a time of 3.40 hours. (2 marks)

Description	**Marks**
Np-239 is part of a decay series	**1**
Some of the Np-239 would have decayed to Pu-239	**1**
Total	**2**

When plutonium-239 was first synthesised into macroscopic pieces, scientists marvelled that the sample of heavy silver metal was warm to touch. When isotope samples undergo radioactive decay, internal interactions are absorbed and produces “decay heat”. Different isotopes produce different amounts of heat per mass. The decay heat is usually listed as watt/kilogram, or milliwatt/gram.

Radioisotope	Decay Heat (W/kg)
Pu-238	560
Pu-240	6.8
Am-241	114
Po-210	141
U-235	3.0

A 5.00 kg mass of pure Pu-239 contains about 12.5 $\times 10^{24}$ atoms. With a half-life of 24,100 years, about 11.5x 10^{12} of its atoms decay each second by emitting a 5.16 MeV alpha particle. This amounts to 9.49 watts of power. Heat produced by the deceleration of these alpha particles makes it warm to the touch.

(d) Calculate the decay heat for Pu-239. (2 marks)

Description	**Marks**
Decay Heat = Power / mass = 9.49 / 5.00	**1**
= 1.90 Wkg^{-1}	**1**
Total	**2**

With all fission reactors, the removal of the decay heat is a significant reactor safety concern, especially shortly after normal shutdown or following a loss-of-coolant accident. Failure to remove decay heat may cause the reactor core temperature to rise to dangerous levels and has caused nuclear accidents, including the nuclear accidents at Three Mile Island and Fukushima I. The heat removal is usually achieved through several redundant systems, from which heat is removed via heat exchangers. Water is passed through the secondary side of the heat exchanger via the essential service water system. which dissipates the heat into the 'ultimate heat sink', often a sea, river or large lake. In locations without a suitable body of water, the heat is dissipated into the air by recirculating the water via a cooling tower.

Consider a nuclear reactor initially containing fuel rods of Pu-239 of mass 53.5 kg. A loss of coolant event sees no thermal energy removed in a period of 12.5 minutes.

(e) Calculate the energy released via decay heat of the fuel rods in this time period. (If you could not answer (d), use a decay heat of 2.0 Wkg^{-1}) (3 marks)

Description		**Marks**
Energy = Decay Heat x mass x time	Formula	**1**
= 1.90 x 53.5 x (12.5 x 60)		**1**
= 76, 200 J (80,300 J) = 7.62×10^4 J		**1**
	Total	**3**

Nuclear physicists attempt to estimate the decay heat that occurs in reactors by monitoring the power output of the reactor at various stages of operation (full power, control rods partially inserted, reactor shut down). This is important as, aside from energy released from nuclear fission, the decay heat can contribute a significant amount to power production.

(f) Provide and explain one reason why the decay heat within the reactor can only be considered an estimate. (3 marks)

Description	**Marks**
Fission fragments are also produced	**1**
These radioisotopes are random	**1**
Which produce their own decay heat	**1**

Consider a fission reactor that contains 3.00 x10^4 kg of water entering at a temperature of 22.0 °C and exiting at a temperature of 225 °C.

(g) If the flow rate of the water is 115 kg/s, determine the rate of heat transfer from the reactor.
(3 marks)

Description	Marks
$\frac{Q}{t} = \frac{mc\Delta T}{t} = \frac{m}{t} c\Delta T_{water} + mL_v + \underline{m}\ c\Delta T_{steam}$	1
$= 115(4180)(78)+(115 \times 2.26 \times 10^6) +(115 \times 2010 \times 125)$ where t = 1 second **OR** $Q/t = 3 \times 10^4(4180)(78)+(3 \times 10^4 \times 2.26 \times 10^6) +(3 \times 10^4 \times 2010 \times 125)$ where $t = 3 \times 10^4/115$ = 260.8695 seconds	1
Q/t = **3.26 x10^8 W or J/s**	1
(-1 if no 3 S.F) Total	3

Question 17 **(10 marks)**

How much money will you save by switching to LED light bulbs?

Article adapted from: https://www.moneymag.com.au/halogen-vs-led-light-bulb

LED lighting is arguably the most profound change the lighting industry has witnessed since the invention of electric light bulb itself. Why? For a start, LEDs use 80% less electrical power than halogen and incandescent bulbs and are much more energy efficient, which means savings on electricity bills. And you don't have to change your light bulbs so often with LEDs.

Although a good value LED bulb might cost $30 at the shops, they have a lifespan of 20 to 25 years while standard incandescent bulbs typically last for around 18 months. Philips' newly launched 15-watt master LED bulb, which is designed to replace a 60-watt incandescent light bulb, has a life of 25,000 hours, compared to 1000 hours for a standard 60-watt incandescent bulb.

LEDs last 10 times longer than the often corkscrew-shaped, energy-saving compact fluorescent lights (CFLs). They activate instantly and are dimmable, unlike CFLs. LEDs don't contain the array of heavy toxins such as mercury, lead, cadmium and others found in CFLs, or the by-products from halogens such as infra-red and UV radiation, so LEDs are easier to recycle. LEDs are common in bicycle lights, torches, garden lights, street lighting and traffic lights. They are now available in down lights and in commercial and home lights.

General Manager of Phillips Australia, Michael Downie says LED bulbs pay for themselves in as little as 18 months or less, if they are used more frequently, while the contribution to the environment starts right away. A consumer could save a couple of hundred dollars off their power bill in the first year by switching from incandescent to LEDs.

Downie says that for every 1000 60-watt incandescent light bulbs replaced with LED bulbs, there would be a saving of approximately $13,300 in energy-related costs and 66 tons of carbon emissions annually. Watch out for cheap LED imports as they can lack brightness, light quality, lifespan (and therefore warranty) and aesthetics. And just in case you're wondering, the federal government is yet to make a statement on where it stands on LEDs.

(a) Explain how LEDs can provide savings on electricity bills. (3 marks)

Description	Marks
LEDs draw less electrical power	1
And are also more energy efficient	1
Meaning less energy is required and hence less money spent on electricity.	1
Total	**3**

You can get a good idea of how much money you can save by switching to LED bulbs using a simple calculation. All you need to know is: 1: The power of the bulbs you have and the power of the new bulbs you will be using and: 2: Your unit price or “cost per kWh”. In Australia, the average unit price for electricity is $0.262.

The running cost for each bulb can be calculated as:

$$\text{Cost} = \frac{\textbf{bulb power (W)} \times \textbf{time used per day hours} \times \textbf{cost per kWh}}{\textbf{1000}}$$

(b) Calculate the cost of running 5 incandescent 60.0 W bulbs for a time of 8.00 hours. (2 marks)

Description	Marks
Cost $= \dfrac{60.0 \times 8.00 \times 0.262}{1000}$ x 5	1
= $0.629	1
Total	**2**

The cost savings per year per bulb can be calculated using the following equation:

$$\textbf{Saving} = \frac{\textbf{difference in bulb powers (W)} \times \textbf{time used per day hours} \times \textbf{cost per kWh}}{\textbf{1000}} \times \textbf{365}$$

A house replaces 15 incandescent 60 W bulbs with the 15 W master LED bulbs,

(c) Given that the bulbs are used for an average of 5.00 hours, calculate the electrical savings in a year if the house were to change to LEDs. (2 marks)

Description	Marks
Saving $= \dfrac{(60.0 - 15) \times 5.00 \times 0.262}{1000}$ x 365 x15	1
= $323	1
Total	**2**

(d) Using your value from part (c), with the use of an appropriate calculation, comment on the validity of the statement from Downie that "LED bulbs pay for themselves in as little as 18 months". (If you could not complete part (c), use a value of $265). (3 marks)

Description	Marks
Time to pay for bulb = (15 x $30) $\div \frac{\$323}{year}$ If $265 will require more than 20 months	**1**
= 1.39 years x 12 (1.70)	
= 16.7 months (20.3)	**1**
Downie's comment is valid as this is close to the time mentioned.	**1**
Total	**3**

END OF EXAMINATION

Supplementary page

Question number: ________________

Supplementary page

Question number: ________________

Question number: ________________

Section	Questions	Marks Available	Your Mark	Section Total	Section as % of Exam
1	1 **(SC)**	**4**			
	2	**3**			
	3	**5**			
	4	**3**			
	5	**3**		**/45**	
	6	**7**			
	7	**5**			
	8	**3**			
	9	**6**			
	10	**6**			
2	11 **(YM)**	**9**			
	12	**10**			
	13	**19**			
	14	**17**		**/75**	
	15 **(MS)**	**20**			
3	16	**20**		**/30**	
	17	**10**			

Total % [ ] (3SF)