Time allowed for this paper

Reading time before commencing work:	ten minutes
Working time for paper:	two hours and thirty minutes

Material required/recommended for this paper

To be provided by the supervisor

This Question/Answer booklet
Formulae and Data booklet

To be provided by the candidate

Standard Items:	pens (blue/black preferred), pencils (including coloured), sharpener, correction fluid/tape, eraser, ruler, highlighters
Special Items:	up to three calculators, which do not have the capacity to create or 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.

Ashdale
Secondary College

Semester One Examination, 2021
Question/Answer Booklet

NAME: KEY

PHYSICS 11
AEPHY

Teacher: ______________________

Student number: In figures [ ][ ] [ ][ ][ ] [ ][ ][ ]

In words ______________________

Structure of this paper

Section	Number of questions available	Number of questions to be answered	Suggested working time (minutes)	Marks available	Percentage of examination
Section One: Short response	10	10	45	44	30
Section Two: Problem-solving	6	6	75	77	50
Section Three: Comprehension	2	2	30	30	20
				Total	**100**

Instructions to candidates

1. The rules for the conduct of Western Australian external examinations are detailed in the *Year 12 Information Handbook 2021: Part II Examinations.* Sitting this examination implies that you agree to abide by these rules.

2. Write answers in this Question/Answer Booklet preferably using a blue/black pen. Do not use erasable or gel pens.

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

4. When calculating or estimating answers, show all your working or reasoning 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 the use of planning/continuing your answer to questions are provided at the end of this Question/Answer booklet. If you use these pages to continue an answer, indicate at the original answer where answer is continued, i.e. 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% (44 marks)

This section has **10** questions. Answer **all** questions. Write your answers in the spaces provided.

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

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

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 at the original answer where answer is continued, i.e. give the page number.

Suggested working time: 45 minutes.

Question 1 (3 marks)

Answer TRUE or FALSE to each of the following.

You place a mercury thermometer and an alcohol thermometer into the same beaker of warm liquid at the same time. When the mercury and alcohol bars reach steady points:

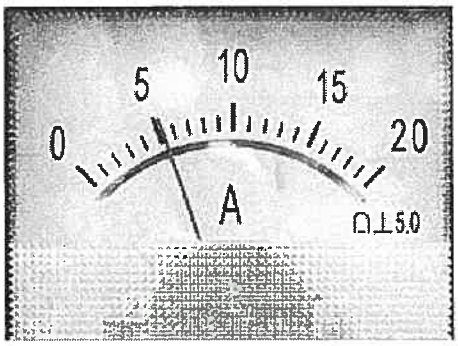
(a) the mercury has the same temperature as the warm liquid. TRUE ✓

(b) the alcohol has the same temperature as the mercury. TRUE ✓

(c) the mercury and alcohol have both absorbed the same amount of heat from the warm liquid.
FALSE ✓

Question 2 (3 marks)

The meter shown was used during an experiment:



(a) What does the meter measure? (1 mark)

CURRENT ✓

(b) What is the absolute uncertainty of the reading? (1 mark)

± 0.5 A ✓

(c) What is the percentage uncertainty of the reading? (1 mark)

$\frac{0.5}{5.2} \times \frac{100}{1}$ %

9.6 % ✓

(based on 5.2 A)

6

Question 3 **(4 marks)**

On a stormy night, a bolt of lightning strikes the ground. It took 0.200s for 1.50×10^{20} electrons to travel from the cloud to the ground.

(a) Calculate the current, in amperes, between the cloud and the ground (2 marks)

$q = 1.6 \times 10^{-19} \times 1.5 \times 10^{20}$
$= 24\ C$

$I = \frac{q}{t}$
$= \frac{24}{0.2}$

120 A

(b) If the potential difference between the storm cloud and the earth was 7.00×10^{8} V, calculate the energy, in joules, that was released by the lightning strike (2 marks)

$W = Vq$
$= 7 \times 10^{8} \times 24$

1.68×10^{10} J

Question 4 **(4 marks)**

A cyclist wants to take a bottle of cold water on a long ride. To prepare the water she places 750 mL of tap water at 22.0 °C in an insulated bottle and adds ice at 0 °C. When all the ice has melted the temperature of the water is 5.0 °C. What mass of ice at 0 °C did she add?

HEAT GAINED BY ICE = HEAT LOST BY WATER

$mL_f + (mc\Delta T)_{ice} = (mc\Delta T)_{water}$

$m \times 3.34 \times 10^{5} + m \times 4180 \times 5 = 0.75 \times 4180 \times (22-5)$

$m_{ice} \times 3.34 \times 10^{5} + m_{ice} \times 20900 = 53295$

$354900\ m_{ice} = 53295$

$m_{ice} = 1.5 \times 10^{-1}$ kg

0.15 kg

Question 5 **(6 marks)**

An ageing nuclear plant is being dismantled by some workers. During the dismantling process, one of the workers' hands comes into contact with an object that is emitting 24 000 alpha particles every 5 minutes. The worker's hand has a mass of 0.500 kg and absorbs 6.00 µJ of ionising radiation energy.

(a) Calculate the activity of the sample in becquerels (Bq).
[Note: 1 Bq = 1 decay per second] (2 marks)

$A = \frac{24\,000}{5 \times 60}$

80 Bq

(b) Calculate:

(i) the absorbed dose received by the worker's hand. (2 marks)

$A.D. = \frac{E}{m}$

$= \frac{6 \times 10^{-6}}{0.5}$

1.2×10^{-5} Gy

(ii) the dose equivalent received by the worker's hand. (2 marks)

$D.E. = A.D. \times Q.F.$

$= 1.2 \times 10^{-5} \times 20$

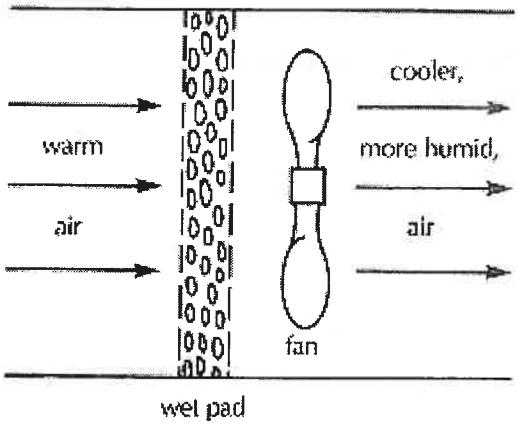
2.4×10^{-4} Sv

14

Question 6 **(4 marks)**

The diagram to the right shows the workings of an *evaporative cooler*.

The fan causes air to flow through a grill containing a pad kept wet with water.

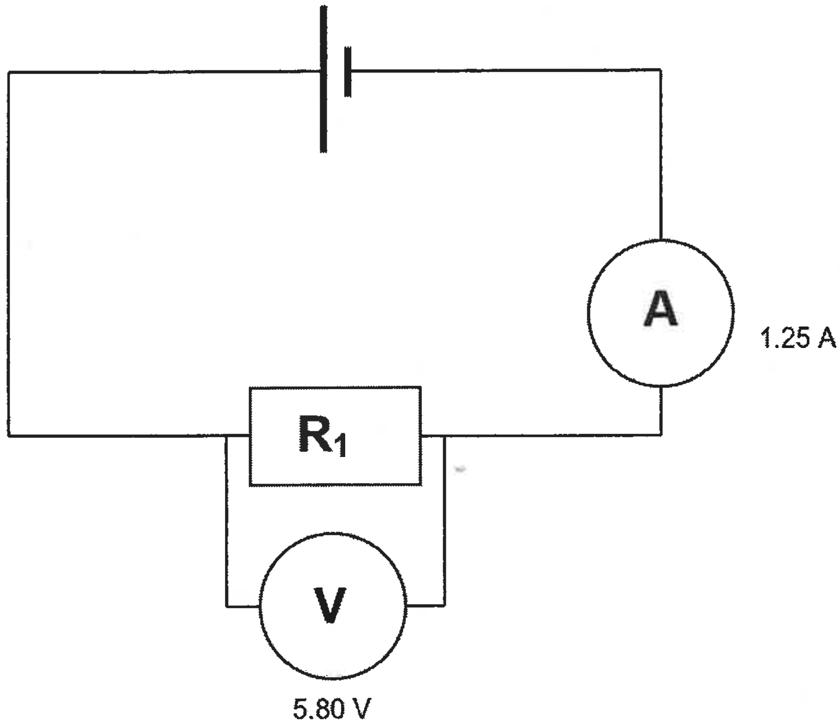


Using the diagram as a guide, explain how air is cooled by this method.

- The wet pad contains water
- Warm air passes through the wet pad due to forced convection and causes evaporation.
- Evaporation is an endothermic process which absorbs heat from the surroundings.
- The surroundings include the air passing through which cools.

Question 7 **(7 marks)**

A student constructed the following circuit and measured the current and voltage flowing through a resistor.



(a) Calculate the value of the resistor, R_1 (in ohms). (2 marks)

$R = \frac{V}{I}$

$= \frac{5.80}{1.25}$

4.64 Ω

(b) Calculate the number of electrons that flow through the resistor in one (1) minute. (3 marks)

$I = \frac{q}{t}$

$q = It$

$= 1.25 \times 60$

$= 75$ C

$n(\text{electrons}) = \frac{\text{CHARGE}}{q(\text{electron})}$

$= \frac{75}{1.6 \times 10^{-19}}$

4.69×10^{20} electrons

(c) Calculate the work done on the electrons in this circuit during this time. (2 marks)

~~$W = \frac{V}{q}$~~ $V = \frac{W}{q}$

$W = Vq$

$= 5.8 \times 75$

435 J

11

Question 8 **(4 marks)**

A jeweller is making a gold bar by melting small pieces of pure gold. The gold pieces have a total mass of 4.00 × 10^{-2} kg and are initially at 23.0°C. The energy required to bring the gold up to its melting point is 5.24 × 10^{3} J. If the specific heat capacity of gold is 126 J kg^{-1} K^{-1}, determine the melting point of gold.

$Q = 5.24 \times 10^3$ J
$m = 4 \times 10^{-2}$ kg
$c = 126$ J kg^{-1} K^{-1}
$T_i = 23$ °C
$T_f = ?$

$Q = mc\Delta T$

$5.24 \times 10^3 = 4 \times 10^{-2} \times 126 \times \Delta T$

$\Delta T = \frac{5.24 \times 10^3}{4 \times 10^{-2} \times 126}$

$= 1039.7$ °C

$\Delta T = T_f - T_i$

$T_f = 1039.7 + 23$

1063 °C

Question 9 **(3 marks)**

Many multi-outlet power boards are rated for a maximum current of 7.50 A. Why should we **not** connect a portable electric heater that is rated at 240 V, 2.4 kW to such a board? Explain, showing relevant calculations.

$P = VI$

$2400 = 240 \times I$

$I = 10$ A

The current drawn by the heater will exceed the maximum rated current of the power board.

Question 10 **(6 marks)**

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

$$^{239}_{94}Pu + ^{1}_{0}n \rightarrow ^{142}_{56}Ba + ^{93}_{38}Sr + \underline{\quad 5 \quad} ^{1}_{0}n$$

(a) Determine the number of neutrons produced by this fission reaction. (1 mark)

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

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

(b) Calculate the energy released by this fission reaction. Include units in your answer (5 marks)

REACTANTS: 239.052163 + 1.00866 = 240.060823 u

PRODUCTS: 141.916343 + 92.91403 + 5 × 1.00866
= 239.873673 u

MASS DEFECT: 240.060823 − 239.873673
= 0.18715 u

∴ Energy released = 0.18715 × 931

174.24 × 1.6 × 10⁻¹⁹ = 2.79 × 10⁻¹¹ J

174.24 unit: MeV

or 2.79 × 10⁻¹¹ J

End of Section One

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Section Two: Problem-solving 50% (77 marks)

This section has **six** questions. Answer **all** questions. Write your answers in the spaces provided.

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

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

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 answer is continued, i.e. give the page number.

Suggested working time: 75 minutes.

Question 11 **(12 marks)**

Electrical energy can be converted into other forms of energy. A common conversion is the heat produced when an electrical current flows through a resistor. Electric kettles, electric hot water systems and bar heaters all depend on this energy conversion.

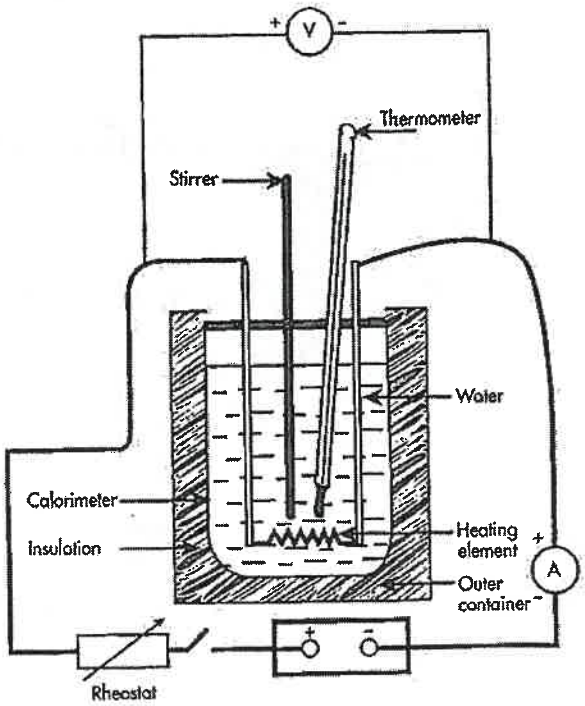
(a) Using any Physics concepts you have learned, explain why a current flowing through a resistor can produce heat. (2 marks)

· The flowing charge in the current can collide/interact with particles in the conductor.
· These collisions cause the charge to transfer energy to the particles increasing their E_K.

A group of Physics students decided to conduct an experiment to examine the efficiency of this energy conversion. They used an arrangement of the equipment shown in the circuit diagram on the right. The heater was turned on for a certain amount of time and the temperature rise of the water – along with other critical measurements – were recorded.

The calorimeter is made of copper and its walls are insulated by foam. The lid is made of plastic.

During the experiment, the students gathered the data in the table below.



DATA TABLE

Mass of copper calorimeter	76.2 g
Volume of water	120 mL
Specific heat capacity of water	4180 J kg^{-1} °C^{-1}
Specific heat capacity of copper	390 J kg^{-1} °C^{-1}
Initial temperature of the water	23 °C
Final temperature of the water	72 °C
Reading on voltmeter	5.4 V
Reading on ammeter	2.3 A
Heating time	43 minutes

(b) Calculate the amount of electrical energy supplied to the water and the copper calorimeter by the heater. (2 marks)

$Q = VIt$
$= 5.4 \times 2.3 \times (43 \times 60)$
$= 32\ 044$

3.20×10^4 J

(c) Calculate the amount of heat energy absorbed by the water and the copper calorimeter, using their masses and increase in temperature. (3 marks)

$Q = (mc\Delta T)_w + (mc\Delta T)_c$
$= 0.120 \times 4180 \times (72-23) + 0.0762 \times 390 \times (72-23)$
$= 26\ 035$

2.60×10^4 J

(d) Compare the two energy amounts in parts (b) and (c). Explain any discrepancies between the two. (2 marks)

E(electrical) > E(heat)
- Some heat escapes the system.
- Hence, not all electrical energy heats the calorimeter + water!

(e) Calculate the overall percentage efficiency of the heater as it warmed the water. (3 marks)

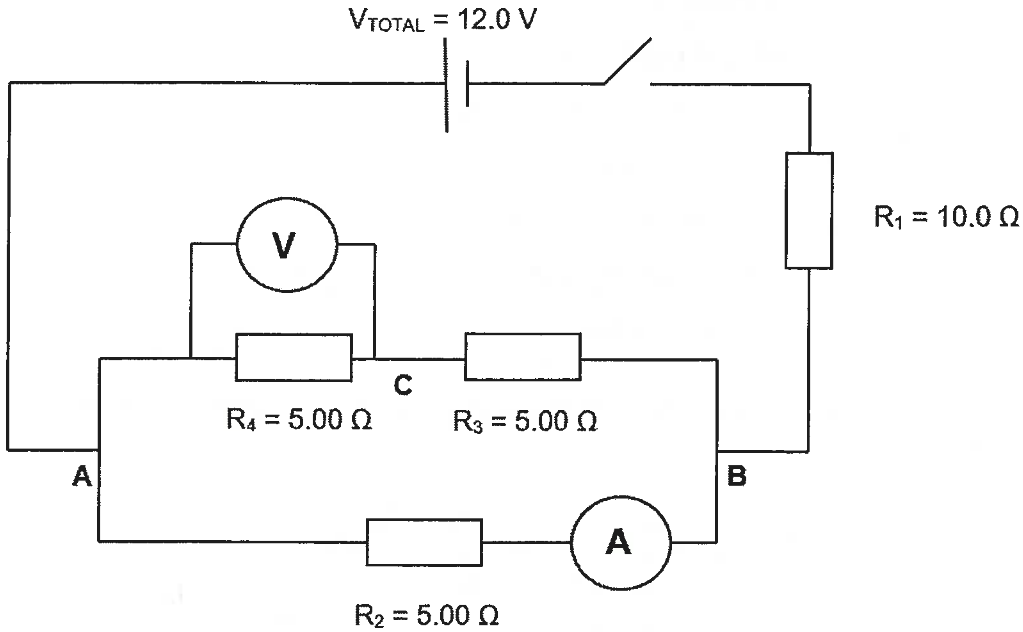
$\eta = \frac{2.60 \times 10^4}{3.20 \times 10^4} \times 100\%$

81.25 %

(12)

Question 12 **(17 marks)**

A Physics student built the circuit shown below:



(a) Calculate the total resistance between the points 'A' and 'B' (R_{AB}) in the circuit. Show working. (3 marks)

$$\frac{1}{R_{AB}} = \frac{1}{10} + \frac{1}{5}$$

$$\frac{1}{R_{AB}} = \frac{3}{10}$$

$$R_{AB} = 3.33\ \Omega$$

3.33 Ω

(b) Hence, calculate the total resistance in the entire circuit (R_T). (2 marks)

$$R_T = 10 + 3.33$$

13.3 Ω

(c) Calculate the total current flowing in the circuit (I_T). (2 marks)

$V_T = I_T R_T$

$I_T = \frac{12}{13.3}$

0.9 A

(d) Calculate the reading in the ammeter. (3 marks)

$V_{AB} = I_{AB} R_{AB}$

$= 0.9 \times 3.33$

$= 3\ V$

$\therefore V_{AB} = I_{\text{ammeter}} \times R$

$3 = I \times 5$

Reading: 0.6 A

(e) Calculate the reading in the voltmeter (V_V). (3 marks)

$I_c = 0.9 - 0.6$

$= 0.3\ A$

$V = IR$

$= 0.3 \times 5$

Reading: 1.50 V

(f) The student creates a break in the circuit at point 'C'. Does the power generated in the 10.0 Ω resistor (R_1) change? Explain using calculations. (4 marks)

BEFORE BREAK: $P_{R_1} = VI$

$= 9 \times 0.9 = 8.10\ W$

AFTER BREAK: $R_T = 10 + 5 = 15\ \Omega$

$I_T = \frac{12}{15} = 0.8\ A$ $V_{R_1} = 0.8 \times 10 = 8\ V$

$P_{R_1} = VI$

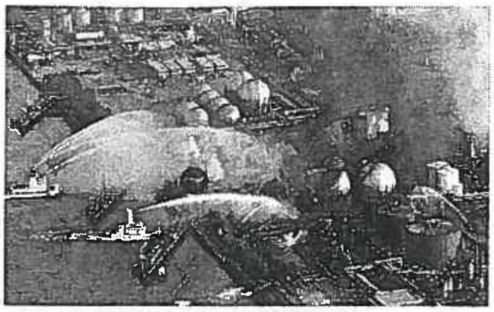
$= 8 \times 0.8 = 6.40\ W$

Power decreases.

17

Question 13 **(17 marks)**

Japan's Fukushima nuclear power station was crippled by the tsunami on 11 March 2011. According to the World Nuclear Organisation (WNO), a number of radioactive isotopes were released from the damaged reactors. Some of the data for the radioisotopes is shown in table below.



Radioisotope	Type of Radiation Released	Half-life	Soluble in Water	Quality Factor Q
Iodine-131	Beta	8 days	No	1
Caesium-137	Gamma	30 years	Yes	1
Caesium-134	Beta	2 years	Yes	1
Xe-133	Beta	5.2 days	No	1

Table 1: Radiation from damaged nuclear power stations in Fukushima.

(a) Which of the radioisotopes in the table is/are most likely to be present in 100 years from now? Explain your answer with reference to the data from table. (2 marks)

Cs-137 ✓
It has the longest half life. ✓

(b) Which radioisotopes is/are most likely to be found in marine biological samples? Briefly explain. (2 marks)

Cs-137 and Cs-134 ✓
They are soluble in water. ✓

(c) It is estimated that a safe level of radiation for Cs-137 is about 5% of the initial radiation. How long does it take for the radiation from Cs-137 to drop below 5% of initial radiation? (4 marks)

100
1 50
2 25 ✓
3 12.5
4 6.25
5 3.125

5% activity occurs between 4 and 5 half lives ✓
∴ It will take between 120 and 150 years ✓
(129.7 years) ✓

120 - 150 years

(d) After the accident, a group of volunteers called "Fukushima 50" attempted to assess and fix the radiation problem. The workers worked in short 15 minute shifts.
Explain why the workers were only allowed to work in 15 minute shifts. (2 marks)

To reduce exposure to radiation ✓

less exposure → less absorbed dose. ✓

(e) Figure 2 below shows workers were dressed in protective clothing and wearing masks as they worked in the reactor area. What type of radiation(s) is/are stopped by the protective clothes, shoes, thick gloves and mask? Explain. (3 marks)

Figure 2: Some of the workers at the damaged reactor.

α + β - weak penetrating ability ✓
α easily stopped by surface of protection. ✓
β more penetrating but still substantially stopped by thick protection. ✓

(f) One of the workers worked for six (6) 15-minute shifts. He was exposed to radiation with a dose of about 300 mSv/h (300 mSv/h means 300 mSv is absorbed every hour). Given that his mass was 70 kg, how much radiation energy did he absorb? (4 marks)

$t = 6 \times 15 = 90$ minutes $= 1.5$ hours ✓

$D.E. = 300\ mSv/hr \times 1.5\ hr$ ✓
$= 450\ mSv$

$Q.F. = 1$ because α does not penetrate. ✓

$A.D. = \frac{E}{m}$

$E = A.D. \times m$
$= 0.45 \times 70$

31.5 ✓ J

17

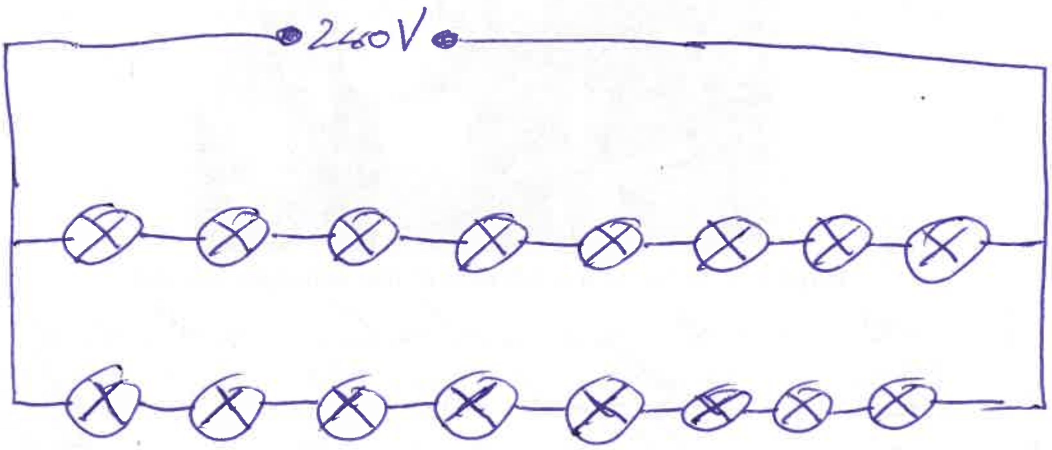
Question 14 **(15 marks)**

A set of 16 party lights is purchased to decorate the back patio of a house for a birthday party. The entire circuit draws 3.20 A and is supplied with 240 volts. When one of the globes is removed, only half of the lights continue to work. When one of the remaining working globes is removed, the rest go out.

(a) Explain why the other seven globes went out when the second globe was removed, but not when the first globe was removed (2 marks).

Circuit has 2 // sections each with 8 globes in series.
If one // section stops working, the other section can still work.
In one series section, if any globe removed, all others stop.

(b) Draw a simple circuit diagram to show how to wire all 16 globes to the 24.0V power supply. (2 marks)



(c) Determine the voltage across each globe (2 marks).

24/8 = 3 V

3 (or 30) V

(d) Determine the current through each globe. (2 marks).

V = IR 3.2/2

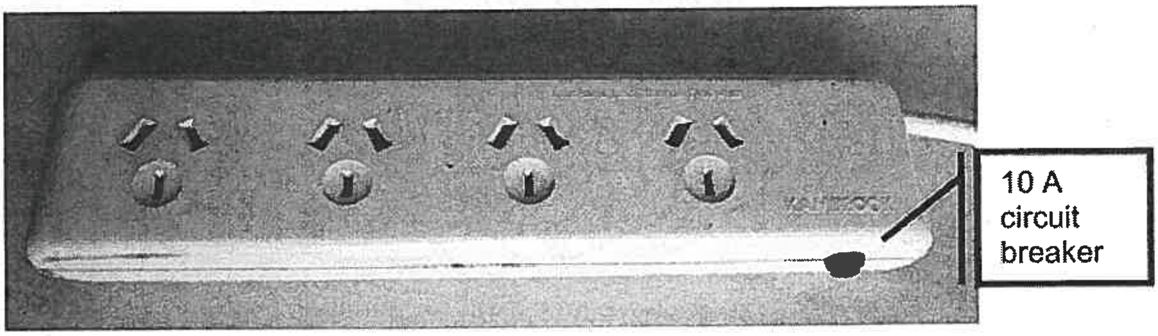
1.6 A

(e) Calculate the power consumed by each globe (2 marks).

$P = VI$
$= 3 \times 1.6$
$= 4.8$

4.8 (48) W

(f) If you wanted more than one set of lights, you might use a power board similar to the one below. This power board has a 10.0A circuit breaker built into it as shown in the picture.



(i) How many sets of these party lights can be operated from the power board before the circuit breaker is overloaded? (2 marks)

$10/3.2 = 3.125$

∴ 3 sets

3

(ii) Explain the purpose of the circuit breaker. (2 marks)

When too much current passes through a circuit breaker, the switch is opened breaking the circuit.
It limits the current that can flow.

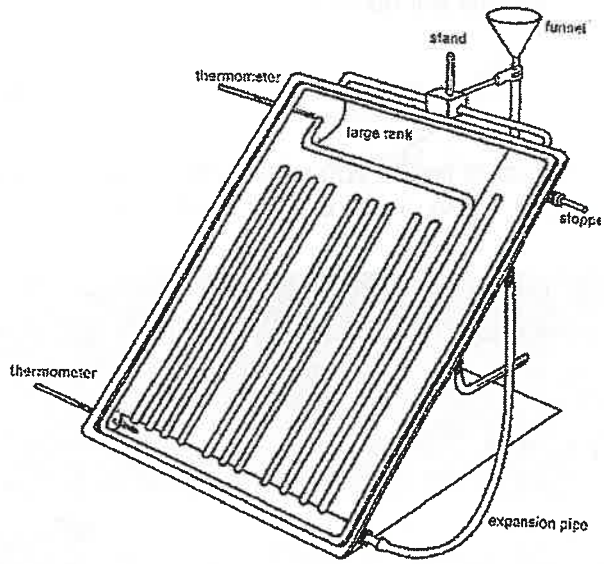
(iii) Is the circuit breaker connected to the power circuit in series or parallel? (1 mark)

SERIES

15

Question 15 **(16 marks)**

A student has set up an experiment designed on building a passive solar hot water heater. She designs the apparatus as shown, places it in a sunny area and records the temperatures. After an hour, the temperatures are recorded again. The thermometers are digital, with readings in whole numbers only (no decimals). The table has begun to be filled in.



(a) Complete the table below. (2 marks)

	Initial Temperature	Final Temperature	Temperature Difference	Absolute Uncertainty
Top	20 °C	75 °C	55°C	ACCEPT ~~±0.5°C~~ or ±1°C ±2°C
Bottom	20 °C	31 °C	11°C ✓	~~0.5°C~~ or 1°C ±2°C ✓

of WHAT?

(b) Explain why the water is warmer at the top of the apparatus than at the bottom at the end of the experiment. (Include the kinetic theory of matter in your answer) (3 marks)

- Particles in bottom water are moving with greater E_K ✓
- This causes them to spread apart from each other ✓
- The water becomes less dense and so rises to the top. ✓

(c) The student has chosen to paint the apparatus black, explain why she has made this choice. (2 marks)

Black will absorb more light than other colours
∴ More heat absorbed means higher temperature

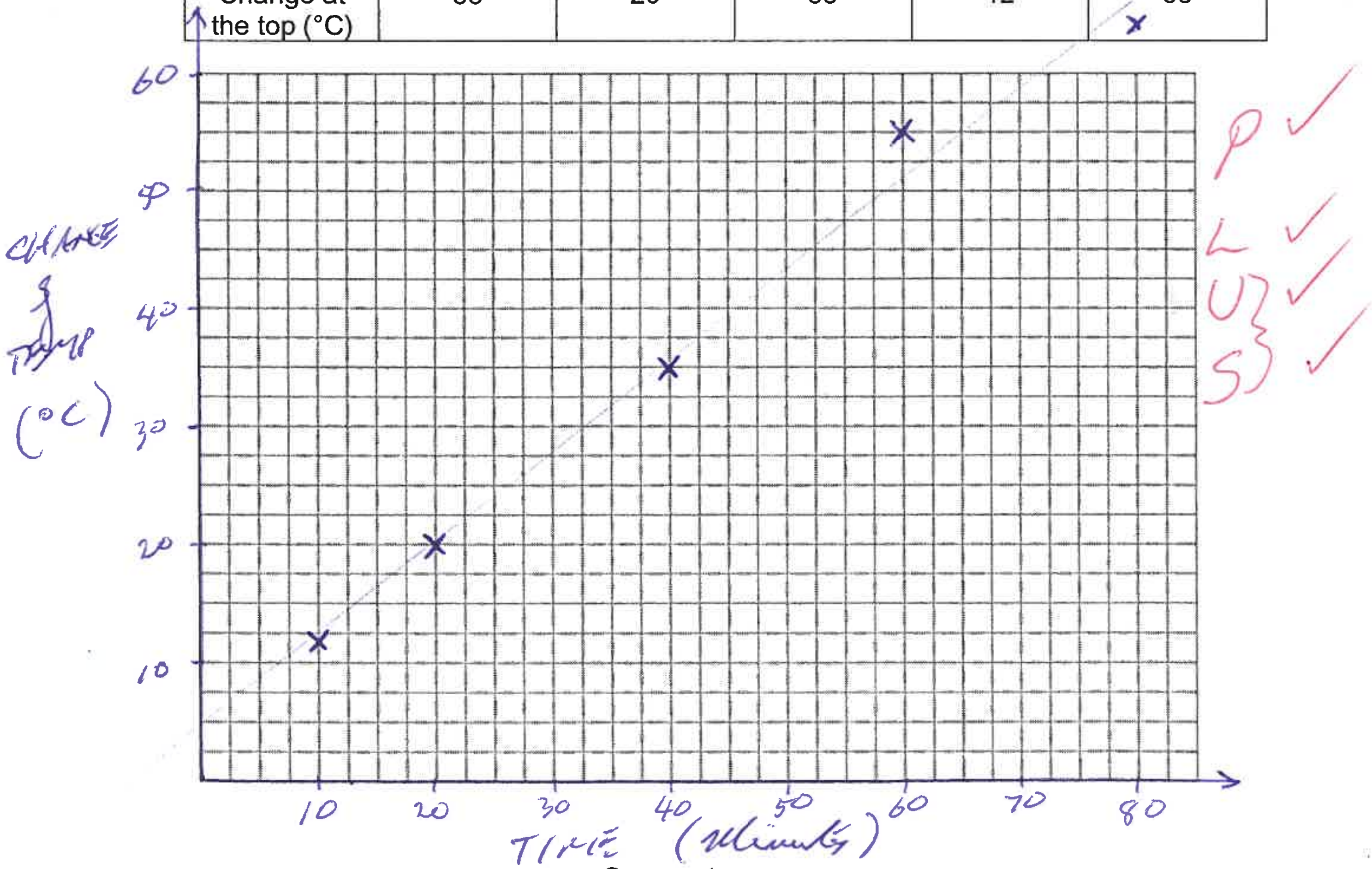
(d) The student attempts to repeat the experiment the next day. What is a source of uncertainty that might occur when trying to repeat the experiment and what likely effect would it have? (2 marks)

- Different ambient temp
- Presence / Absence of clouds/sun
- Time of day

} Reasonable likely effect.

(e) Over the next few days, she completed the experiment four more times. The results are shown on the table. Graph the results below: (4 marks)

Experiment	1	2	3	4	5
Time (minutes)	60	20	40	10	80
Temperature Change at the top (°C)	55	20	35	12	65



See next page

(f) What conclusion can be made about the relationship in the graph on the previous page? (1 mark)

As time increases, the change in temperature increases ✓

(g) If the initial temperature of the water was 17 °C, what would you expect the final temperature of the water to be after 50 minutes? (2 marks)

$\Delta T \approx 40\text{-}45\,K$ ✓

$\therefore T_f = \sim 60°C$

~60° °C ✓

16

End of Section Two

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Section Three: Comprehension 20% (30 marks)

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

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

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

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 answer is continued, i.e. give the page number.

Suggested working time: 30 minutes.

Question 16 **(16 marks)**

Nuclear Astrophysics: Nucleosynthesis in the Universe

From Lepine-Szily and Descouvement (2012)

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

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

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

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

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

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

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

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

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

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

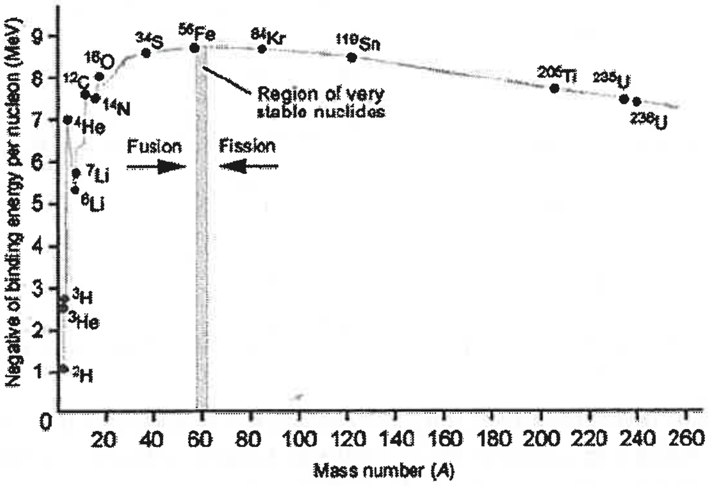

Figure 1

(a) According to the graph in Figure 1, the isotope with the greatest binding energy per nucleon is Fe-56. Use the data in the table below (and information from your Data Booklet) to show that the binding energy per nucleon for Fe-56 is about 8.6 MeV. Show all working. (4 marks)

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

$26p + 30n = 26 \times 1.00727647 + 30 \times 1.008665$
$= 56.44913822$ u

Mass defect $= 56.44913822 - 55.9349375$
$= 0.51420072$ u

$\therefore$ B.E. $= 0.51420072 \times 931 = 478.721$ MeV

B.E./number : $\frac{478.721}{56} = 8.548$ MeV

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

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

7.5 (± 0.2) MeV ✓

(ii) Compare the binding energy per nucleon values for both U-235 and Fe-56. Use this comparison to explain why Fe-56 can be called a 'stable nuclide', while U-235 cannot be called this. (3 marks)

BE/n (Fe-56) > BE/n (U-235) ✓
BE/nucleon for Fe-56 means work must be done to overcome the Strong Force holding the nucleons together → stable. ✓
Isotopes like U-235 have lower BE/nucleon → less stable → more likely to decay. ✓

(c) Use the information in the article to briefly describe why isotopes in the region with mass numbers such that A<56 are more likely to undergo fusion, while those isotopes with mass numbers such that A>200 are more likely to undergo fission. (2 marks)

For A<56, BE/nucleon increases as mass of isotope increases → particle capture more likely (Fusion is exothermic). ✓ For A>200, as mass increases, BE/nucleon decreases → Fission is exothermic. ✓

(d) Like many isotopes in the region A>56, the radioisotope Rn-222 is an α-emitter. Write a balanced nuclear equation for this nuclear decay. (3 marks)

$${}^{222}_{86}Rn \rightarrow {}^{218}_{84}Po + {}^{4}_{2}He$$

PARTICLES ✓
A ✓
Z ✓

(e) The article describes the process whereby the important isotope of Carbon, C-12, is produced by a "triple-α" process (ie, three α-particles combining in two steps to form C-12).

In the space below, write two (2) balanced nuclear equations illustrating the "triple-α" process.
(3 marks)

$${}^{4}_{2}\alpha + {}^{4}_{2}\alpha \rightarrow {}^{8}_{4}Be$$

$${}^{8}_{4}Be + {}^{4}_{2}\alpha \rightarrow {}^{12}_{6}C$$

PARTICLES ✓
Z ✓
A ✓

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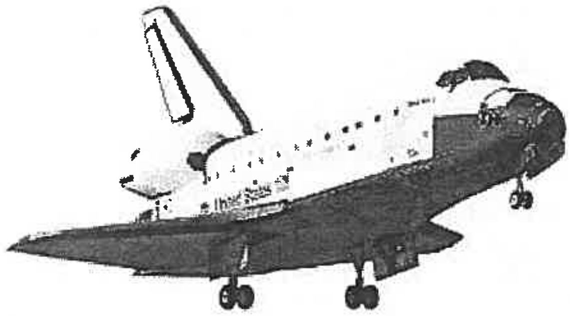
Question 17 **(14 marks)**

The Space Shuttle's Thermal Protection System



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

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

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

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

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

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

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

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

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

	ALUMINIUM	SILICON DIOXIDE
MELTING POINT	660 °C	1710 °C
SPECIFIC HEAT CAPACITY	900 J kg^{-1} °C^{-1}	628 J kg^{-1} °C^{-1}
THERMAL CONDUCTIVITY	180 W m^{-1} °C^{-1}	0.0485 W m^{-1} °C^{-1}

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

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

where:
k = thermal conductivity (W m^{-1} °C^{-1})
Q/t = rate of flow of thermal energy (W)
L = length or thickness of the conducting material (m)
A = surface area of the material (m^2)
$T_2 - T_1$ = temperature difference across the length of the material (°C)

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

- High melting point
- High specific heat capacity
- ~~Low thermal conducto~~

A typical HRSI tile has the following specifications:

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

(b) (i) Calculate the energy required to raise the temperature of an HRSI tile from 650 °C to 1260 °C. (3 marks)

$Q = mc\Delta T$

$= 1.02 \times 628 \times (1260 - 650)$

3.91×10^5 J

(ii) During re-entry, an HRSI tile will typically experience a temperature gradient of 1260 °C on its exterior to about 170 °C on its interior. Using equation (1), determine how much heat energy is passed through the tile every second during re-entry. (4 marks)

$k = 0.0485 \ W m^{-1} {}^\circ C^{-1}$

$L = 0.0254$ m

$A = 0.15 \times 0.15 = 2.25 \times 10^{-2} m^2$

$T_2 - T_1 = 1260 - 170 = 1090 {}^\circ C$

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

$0.0485 = \frac{Q}{t} \times \frac{0.0254}{2.25 \times 10^{-2} \times 1090}$

$\frac{Q}{t} = \frac{0.0485 \times 24.5}{0.0254}$

$= 46.8$ W

46.8 J

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

SiO_2 low thermal conductivity means that the rate it conducts thermal energy is very slow and would not burn.

Al has thermal conductivity ~3700 times higher

∴ Al would conduct much more and burn.

(c) The HRSI tiles are black in colour. Explain why this colour also assists with protecting the aluminium Orbiter body from absorbing excessive amounts of heat. (2 marks)

Black objects are very good absorbers and emitters of thermal radiation. ✓

The tiles will, therefore, absorb much more radiant energy than that absorbed by the aluminium. ✓

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End of questions