

Year 11 ATAR course examination 2022 semester 1

Question/Answer

PHYSICS

Student number: In figures:

2	9	4	1	5	3	5	1
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In words:

two nine four one four three five one

Time allowed for this paper

Reading time before commencing work: ten minutes

Working time: three hours

Number of pages: 45 pages

Materials required/recommended for this paper**To be provided by the supervisor**

This Question/Answer booklet

Formulae and Data 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: non-programmable calculators approved for use in this 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	Questions	Questions to be attempted	Suggested working time (mins)	Marks available	Percentage of exam
Section One: Short Response	10	10	50	54	30%
Section Two: Problem Solving	6	6	90	90	50%
Section Three: Comprehension	2	2	40	36	20%
Total				180	100

Instructions to candidates

1. The rules for the conduct of the Saigon International College examinations are detailed in the *SIC Assessment Policy 2022*. Sitting this examination implies that you agree to abide by these rules.
2. Write your 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 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 at the original answer where the answer is continued, i.e. give the page number.

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 **ten (10)** 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 1.00×10^3 W electric water heater has an efficiency, $\eta = 55.0\%$. The heater raises the temperature of 10.0 kg of water from 20.0°C to 75.0°C . Calculate the time (in seconds) taken for the electric water heater to complete this task.

SEE NEXT PAGE

Question 2**(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 becquerel's (Bq).
[Note: 1 Bq = 1 decay per second]

(2)

Bq

- b) Calculate:

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

(2)

Gy

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

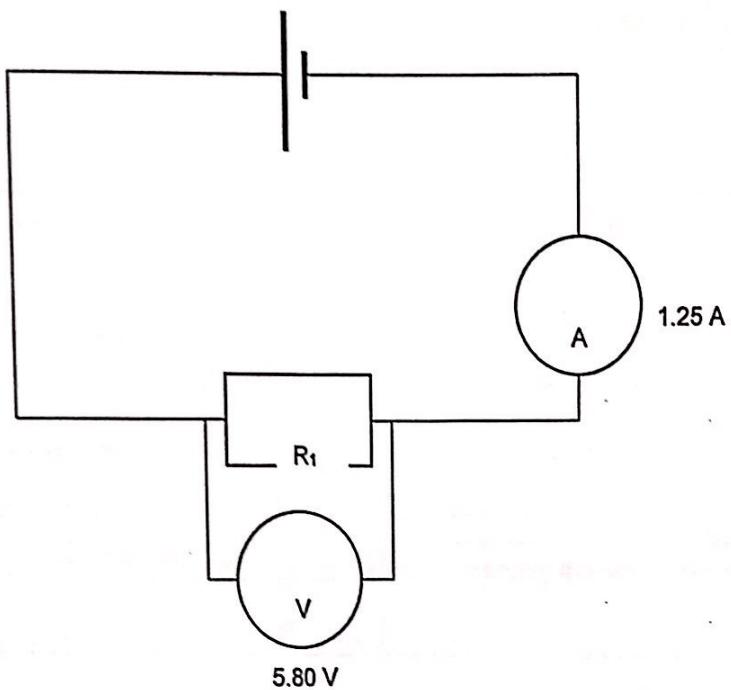
(2)

Sv

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Question 3**(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)

 Ω

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

(3)

 electrons

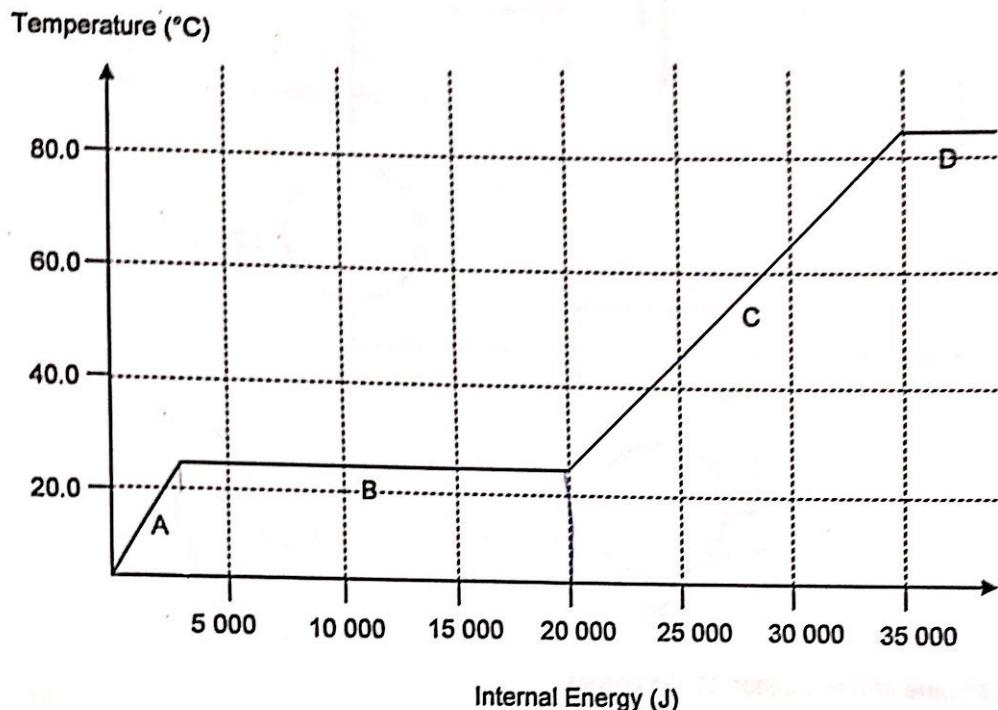
- c) Calculate the work done on the electrons in this circuit during this time.

(2)

 J

 SEE NEXT PAGE

The graph below shows how the temperature of 0.500 kg of an unknown substance 'X' increases as thermal energy is added to it.



- a) Circle the region where the particles in substance 'X' are moving the slowest.

A B C D

(1)

- b) Circle the region(s) where the kinetic energy of the particles in substance 'X' is increasing.

A B C D

(1)

- c) Calculate the latent heat of fusion for substance 'X'. Show working.

(3)

$\text{J kg}^{-1} \text{ }^{\circ}\text{C}^{-1}$

- d) Using the particle model, describe one (1) difference between the arrangement of the particles in regions 'A' and 'C'.

(2)

Question 5**(5 marks)**

A worker is operating two identical work lights from a single power source. The two lights have to operate at a large distance from each other, so the worker uses a very long extension cord for one of the lights. When both globes are operating, the worker notices that the globe that is closer to the power supply (Globe 1) is slightly brighter than the globe that is further away (Globe 2). Using physical principles, explain why this has occurred.

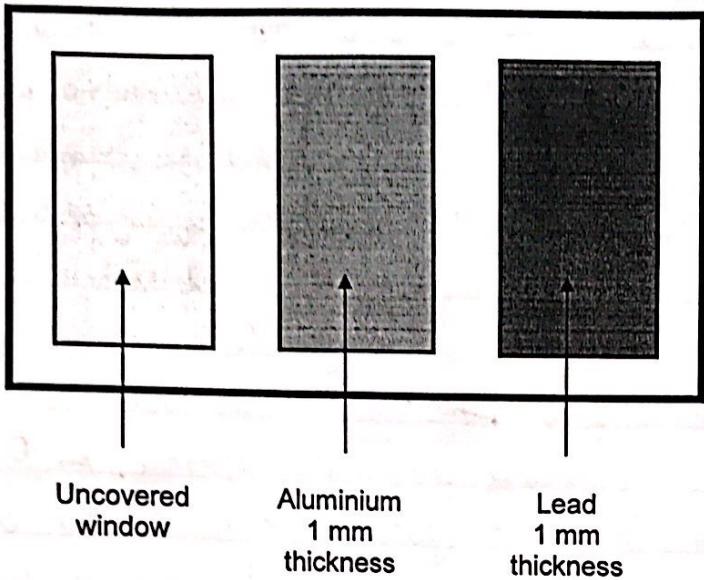
The worker is using two identical work lights from a single power source. The two lights have to operate at a large distance from each other, so the worker uses a very long extension cord for one of the lights. When both globes are operating, the worker notices that the globe that is closer to the power supply (Globe 1) is slightly brighter than the globe that is further away (Globe 2). Using physical principles, explain why this has occurred.

SEE NEXT PAGE

Question 6**(4 marks)**

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

The structure of the badge is below:



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

Question 7**(5 marks)**

Water is used as a coolant in car engines. Car engines are mostly made of iron. The specific heat capacities of iron and water are shown in the table below.

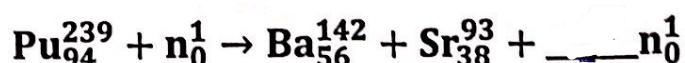
SUBSTANCES	SPECIFIC HEAT CAPACITY (J kg ⁻¹ °C ⁻¹)
Water	4180
Iron	450

Explain why a water coolant is required in car engines. In your answer, refer to the specific heat capacities of both water and iron.

Question 8

(6 marks)

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



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

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

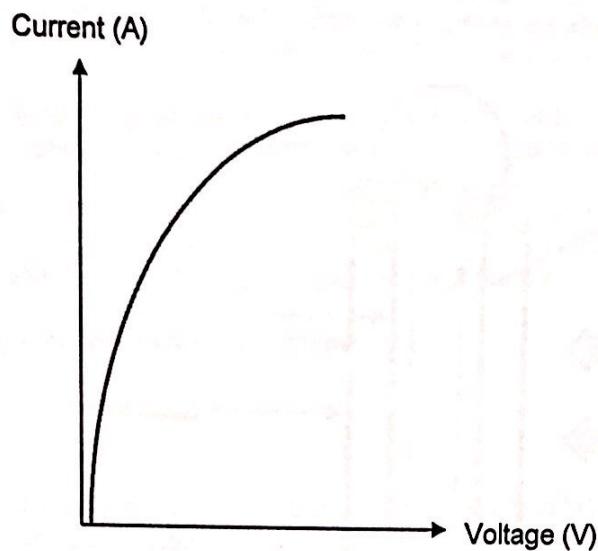
Pu-239	239.052163 u
neutron	1.00866 u
Ba-142	141.916343 u
Sr-93	92.91403 u

- b) Calculate the energy released (in Joules) by this fission reaction. (5)

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Question 9**(4 marks)**

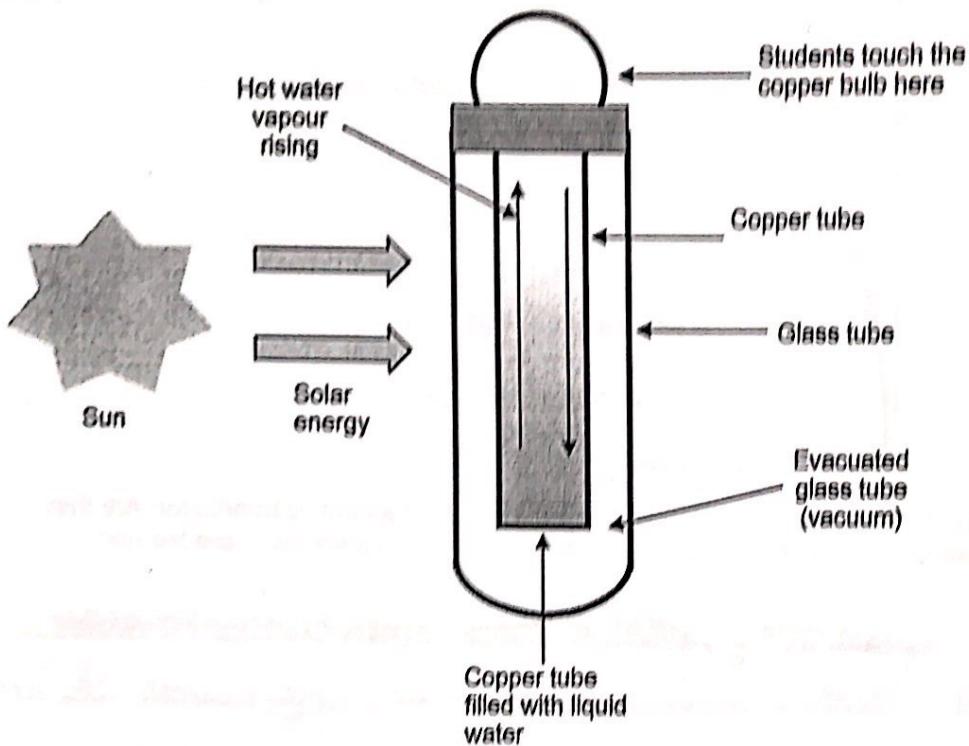
Some students gathered corresponding voltage and current data for an electrical conductor and plotted the results on a graph. This graph is below.



The students decide that this electrical conductor is an example of an ohmic conductor. Are they correct? Explain using the data from the graph and any Physics principles you have learned.

Question 10**(4 marks)**

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



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

SEE NEXT PAGE

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.

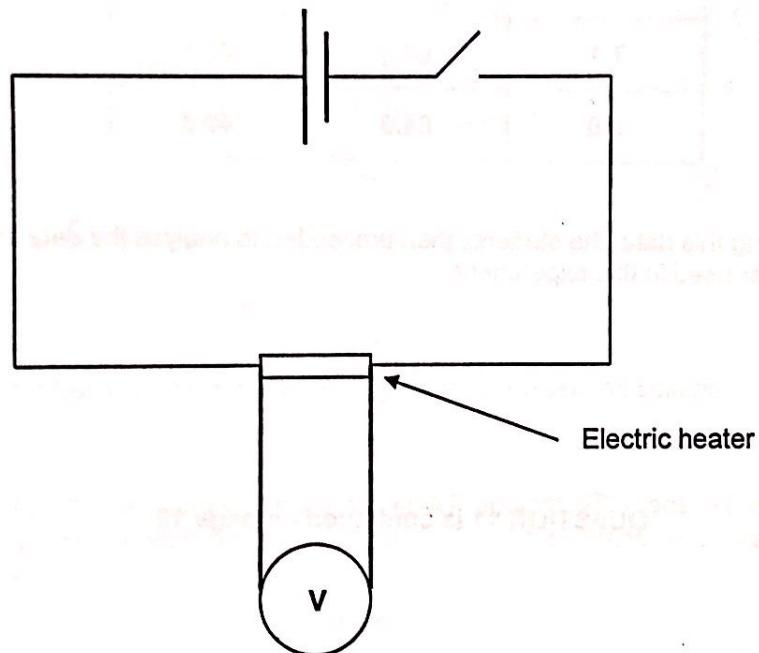
When estimating numerical answers, show your working and reasoning clearly. Give final answers to a maximum of **two significant figures** and include appropriate units where applicable.

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 11**(14 marks)**

A group of Year 11 Physics students conducted an experiment to find the mass of some water. They set up some electrical equipment as shown below:



During the experiment, the students used the electric heater to heat up a known mass of water for 100.0 seconds in the calorimeter. They gradually increased the voltage (V) supplied to the electric heater (measured by the voltmeter) and then measured the change in temperature of the water (ΔT) after this time using the thermometer.

The calorimeter is a perfect insulator. The resistance of the connecting wires, voltage supply and the switch are negligible. The heater is an ohmic conductor and has an efficiency of 100%.

Physics Units 1 & 2

Some important measurements are displayed in the tables below.

Resistance of the electric heater	1.50 Ω
Specific heat capacity	4180 J kg⁻¹°C⁻¹
Heating time	100.0 s

V (V)	V ² (V ²)	ΔT (°C)
2.0	8.4	5.4
4.2	17.6	11.2
6.0	25.0	15.0
6.9		22.2
7.1	50.4	32.1
8.0	64.0	40.8

After collecting this data, the students then proceeded to analyse the data and find the mass of water used in this experiment.

QUESTION 11 is continued on page 15

SEE NEXT PAGE

- a) The students know that rate at which electrical energy is supplied to the electric heater can be calculated using the following formulae:

$$P = VI = I^2R = \frac{V^2}{R} = \frac{Q}{t}$$

The students also know that the electrical energy supplied (Q) to the water is converted into thermal energy that increases its temperature.

By combining appropriate formulae for electric power (see above), another formula you have learned in the Heating Processes topic and information from the first data table, derive the following equation.

This equation displays the relationship between the voltage supplied to the electric heater (V) and the resultant change in temperature (ΔT).

$$\Delta T = \frac{V^2}{m \times 62.7}$$

where 'm' equals the unknown mass of the water.

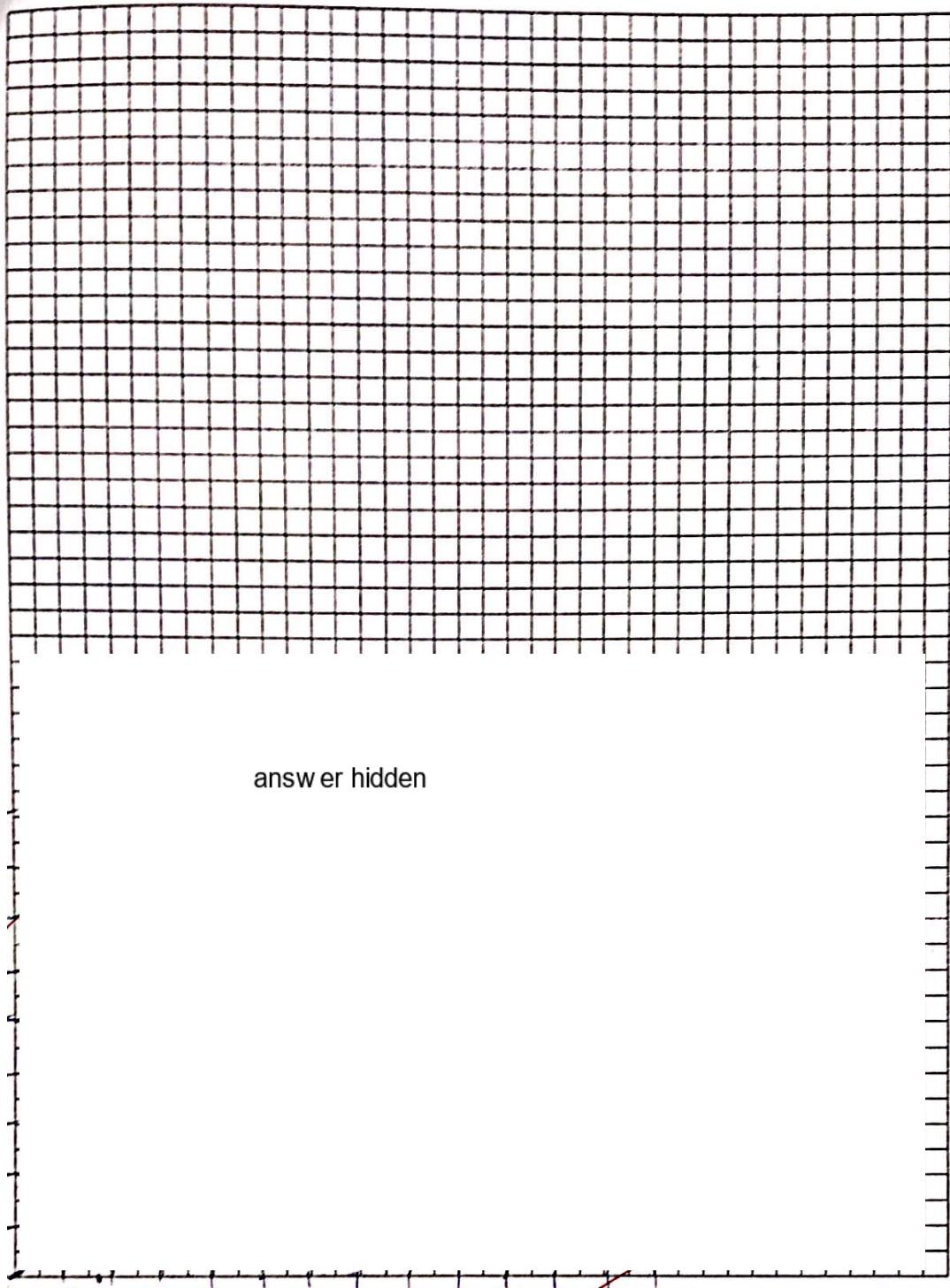
(3)

- b) Complete the table by filling in the missing value in the second column. (1)
- c) On the grid on the next page, plot a graph of ' ΔT ' against ' V^2 '. Place ' ΔT ' on the vertical axis. Draw a line of best fit for the data. Place ' ΔT ' on the vertical axis. Draw a line of best fit for the data. (4)
- d) Calculate the gradient of the line of best fit. Show clearly how you did this. State the units. (3)

Physics Units 1 & 2

- e) Use the gradient you calculated in part d) to calculate the unknown mass 'm' of the water in the experiment. (3)

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Question 12

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

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

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

Specific heat capacity of lead	$130.0 \text{ J kg}^{-1} \text{ }^{\circ}\text{C}^{-1}$
Latent heat of fusion of lead	$22\ 900 \text{ J kg}^{-1}$
Specific heat capacity of the plastic bucket	$900.0 \text{ J kg}^{-1} \text{ }^{\circ}\text{C}^{-1}$
Mass of one (1) litre of water	1.00 kg

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

- a) Show that the quantity of internal energy lost by the lead as it freezes at its melting point is equal to 2290 J. (2)

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

(3)

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

(4)

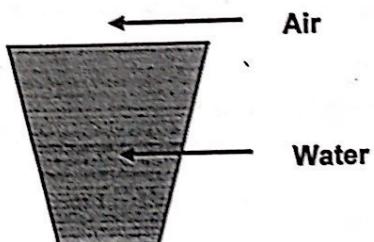
- d) Hence, use the expressions you derived in parts b) and c) to show that the final temperature 'T' is approximately 25 °C.

(3)

Physics Units 1 & 2

In reality, some thermal energy is lost to the atmosphere by the lead/water/plastic bucket system.

- e) Describe the roles that conduction and convection play in transferring heat from the bucket of water to the air above. (3)



- f) When calculating the final temperature in part d), heat lost to the atmosphere and surroundings was not included. In words, explain the effect that including this energy loss would have had on this final temperature. (3)

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Question 13

(14 marks)

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

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

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

- a) As stated, Tc-99 is gained from the decay of Mo-99 atoms. Identify the type of decay that occurs in Mo-99 by writing a balanced nuclear equation for this transmutation. (3)

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

- c) Explain why the half-life of Tc-99 makes it an ideal radioisotope to use for a medical scan. (2)

Physics Units 1 & 2

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

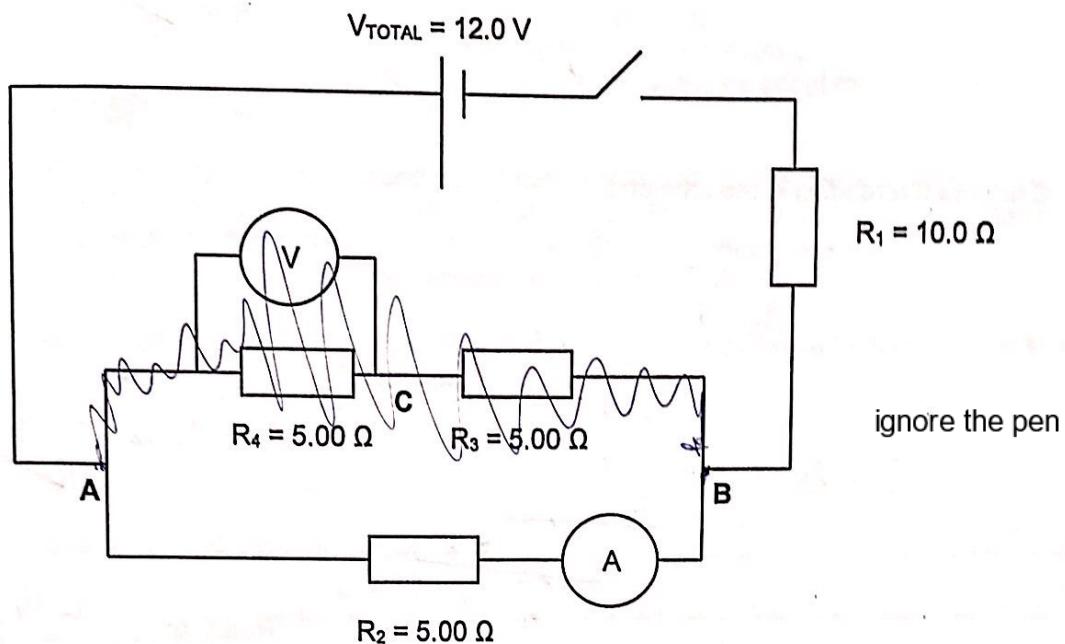
- d) (i) Calculate the mass of solid, radioactive Tc-99 that remains after 15 hours. Show working. (3)

(ii) Once the mass of a sample of Tc-99 drops below 5.00 g, a new sample of Tc-99 needs to be brought in to the hospital. Calculate how long it will take for this sample of Tc-99 to drop below this mass. (4)

Question 14

(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)

_____ Ω

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

(2)

_____ Ω

Physics Units 1 & 2

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


A

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

Reading: _____

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

Reading: _____

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

Question 15**(16 marks)**

A **fast breeder reactor** - unlike other 'conventional' reactors - is a nuclear fission reactor that generates more fissile material than it consumes. Breeder reactors achieve this by irradiation of a 'fertile material' (ie – a radioisotope that can be turned into a fissile material by capturing bombarding neutrons). An example of a 'fertile material' is uranium-238 and this is loaded into the reactor along with fissile fuel (eg – U-235). Modern nuclear weapons adopt the same 'fast-breeding' principle.

The extra fissile material that is produced by irradiation of U-238 with neutrons is an isotope of Plutonium, Pu-239. The initial neutron bombardment of U-238 produces U-239. This radioisotope of Uranium is a beta emitter and transmutes into fissile Pu-239. The extra fissile Neutron capture in a nuclear reactor or weapon can only occur with slow-moving neutrons.

- a) Name the feature within a nuclear fission reactor that is responsible for reducing the speed of fast-moving neutrons. Explain how this material works. (3)

The chain reaction that occurs in the fast breeder reactor is a 'controlled' chain reaction. This contrasts with the 'uncontrolled' chain reaction which occurs when a nuclear weapon is detonated.

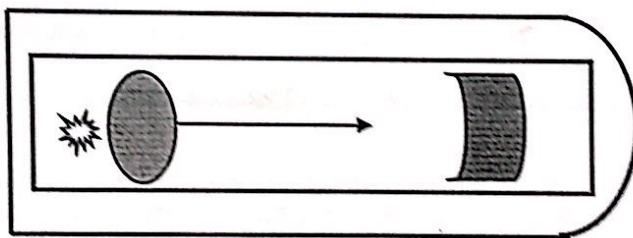
- b) (i) Name the structure in the nuclear fission reactor that is responsible for 'controlling' the chain reaction. Explain how this structure achieves this. (3)

- (ii) Explain why the chain reaction in a nuclear reactor must be 'controlled' – but is not 'controlled' in the same way in a nuclear weapon.

(3)

In a nuclear bomb, prior to detonation, two sub-critical samples of the fissile material are separated at either end of a long tube inside the bomb (see below).

The bomb is carried on a long-range missile and is detonated at a high altitude above the target. Upon detonation, conventional explosives force the two sub-critical samples together and a massive explosion results.



- c) Define the terms 'critical mass' and 'sub-critical mass' and use them to explain the operation of the nuclear bomb described earlier in the question.

(4)

SEE NEXT PAGE

- d) In the introduction to this question, a comparison was made between fast breeder reactors and 'conventional' reactors. Briefly explain how a fast breeder reactor increases the overall power output of a fission reactor compared to that produced by other 'conventional' reactors.

(3)

In a fast reactor, the neutron energy spectrum is different from that of a conventional reactor. In a conventional reactor, the neutron energy spectrum is thermal, meaning that most neutrons have low energy. In a fast reactor, the neutron energy spectrum is non-thermal, meaning that most neutrons have high energy. This is achieved by using a moderator that has a low atomic mass, such as lithium or beryllium, which slows down the neutrons through elastic scattering. The high-energy neutrons are more effective at causing fission in fissile fuel rods, such as plutonium-239, because they have a higher probability of interacting with the nucleus. This results in a higher overall power output for a given amount of fissile fuel.

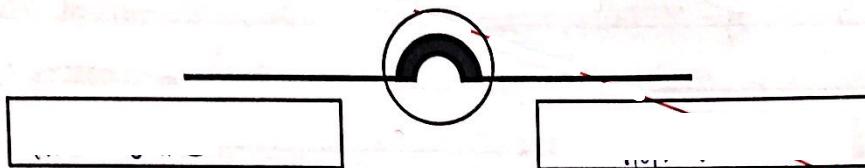
②

With the same initial fissile material, a fast reactor can produce more plutonium-239 than a conventional reactor. This is because the fast reactor's higher neutron flux and higher neutron energy allow it to breed more plutonium-239 from the available fissile fuel. The plutonium-239 can then be extracted and used as fuel in a conventional reactor, which has a higher efficiency than a fast reactor. This makes fast reactors a potentially more efficient way to produce plutonium-239 for nuclear weapons or power generation.

Question 16

Answer the following questions about electrical safety and household wiring in the spaces provided.

- a) The diagram below shows a light globe with the wires that are attached to it in a normal household circuit. In the labels provided, write the names of the wires attached to the light globe. (2)



- b) Switches are placed on a particular wire in the household circuit. Name this wire and explain why switches must be placed on this wire. (3)

- c) Explain the role of 'circuit breakers' in household wiring. (2)

- (d) Certain appliances have an 'earth wire'. Describe the appliances that have an earth wire and explain the role that this wire performs in conjunction with circuit breakers in keeping the occupants of a house safe. (4)

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.

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Suggested working time for this section is 40 minutes.

Question 17**(18 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.

SEE NEXT PAGE

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 ($A > 200$).

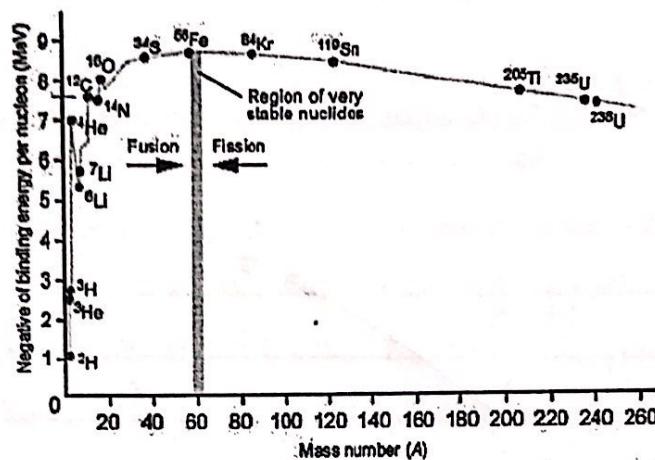


Figure 1

- 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)

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

SEE NEXT PAGE

- b) The isotope Fe-56 is situated in a region on the graph at the beginning of this question called the "Region of very stable nuclides". The radioisotope U-235 is not located in this region.
- (i) Use Figure 1 to estimate the binding energy per nucleon (in MeV) for U-235. (1)

 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)

- 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)

- d) In your own words, describe the process of 'nucleosynthesis'. (2)
-

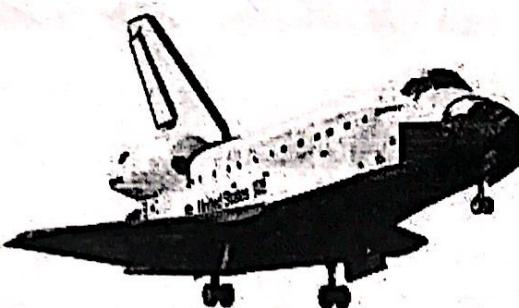
- e) Like many isotopes in the region A>56, the radioisotope Ti-205 is an α -emitter. Write a balanced nuclear equation for this nuclear decay.

(3)

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

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

(3)

Question 18**The Space Shuttle's Thermal Protection System**

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

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

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

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

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

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

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

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

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

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

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

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

where:

k = thermal conductivity ($\text{Wm}^{-1}\text{°C}^{-1}$)

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 ($^{\circ}\text{C}$)

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

(2)

- b) Use the particle model to describe what is occurring to aluminium as its temperature increases from below 175°C to above its melting point of 660°C .

(4)

A typical HRSI tile has the following specifications:

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

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

(3)

- (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)

- (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)

- d) 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)

End of Questions

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