ATAR Physics Year 11

Semester One Examination, 2017

Question/Answer Booklet

Student Name: ___________SOLUTIONS________________

Time allowed for this paper

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

Materials required/recommended for this paper

To be provided by the supervisor

This Question/Answer Booklet and the Formulae and Constants Sheet

To be provided by the candidate

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

Special items: non-programmable calculators approved for use in the WACE examinations, 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 notes or other items of a non-personal nature in the examination room. If you have any unauthorised material with you, hand it to the supervisor before reading any further.

Structure of this paper

Section	Number of questions available	Number of questions to be answered	Suggested working time (minutes)	Marks available	**Marks Attained**
Section One: Short answers	13	13	54	54 (30%)	/54
Section Two: Problem-solving	7	7	90	90 (50%)	/90
Section Three: Comprehension	2	2	36	36 (20%)	/36
				180 (100%)	/180

Instructions to candidates

Write your answers in the spaces provided beneath each question. The value of each question (out of 150) is shown following each question.

The enclosed Physics: Formulae and Constants Sheet may be removed from the booklet and used as required.

Calculators satisfying conditions set by the School Curriculum and Standards Authority may be used to evaluate numerical answers.

Answers to questions involving calculations should be evaluated and given in decimal form. Give final answers to three significant figures and include appropriate units where applicable.

When calculating numerical answers, show your working or reasoning clearly. Despite an incorrect final answer, credit may be obtained for method and working, providing this is clearly and legibly set out.

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.

Questions containing the instruction **estimate** may give insufficient numerical data for their solution. Students should provide appropriate figures to enable an approximate solution to be obtained. 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.

Section One: Short answers (54 Marks)

This section has **thirteen (13)** 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.

Spare pages are included at the end of this booklet. They can be used for planning your responses and/or as additional space if required to continue an answer. If you need to use the space to continue an answer, indicate in the original answer space where the answer is continued, i.e. give the page number. Fill in the number of the question that you are continuing to answer at the top of the page.

Suggested working time: 54 minutes.

Question 1 **(4 marks)**

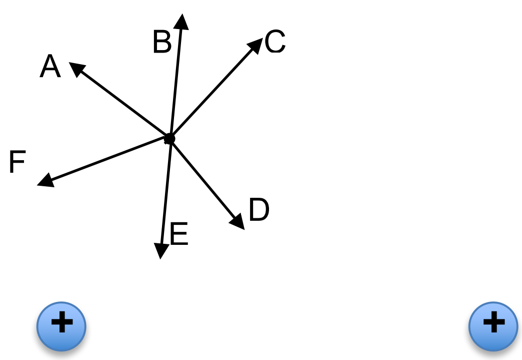
Two table tennis balls are rubbed vigorously with a woollen cloth so that they receive equal size positive charges.

(a) Briefly explain how each ball acquires a positive charge when rubbed. (2 marks)

When rubbed, friction between the cloth and ball causes electrons to be transferred from the ball to the cloth (✔) , leaving the ball with a deficiency of electrons and hence a positive charge. (✔)

(b) The two positively charged balls are placed a fixed distance apart. A small test charge is placed at the position indicated by the black dot in the diagram below. Which direction, as indicated by the arrows labelled A to F, shows the direction of the electrostatic force on the test charge due to the two balls if it was. (2 marks)

(i) positively charged ____**B**____ (ii) negatively charged ____**E**____



Question 2 **(4 marks)**

A 75 kg nuclear laboratory worker accidently receives a radiation dose from fast neutrons, which are highly penetrating but of moderate ionising ability.

(a) Describe the difference between penetrating ability and ionising ability for a particular type of radiation. (2 marks)

Penetrating ability refers to how far a particular type of radiation will travel through a substance before being stopped. (✔)

Ionising ability refers to how readily a particular type of radiation will ionise atoms/molecules when moving through a substance. (✔)

(b) Given the worker received a total of 27 mJ of energy from the fast neutron radiation dose, calculate the dose equivalent absorbed by the worker. (2 marks)

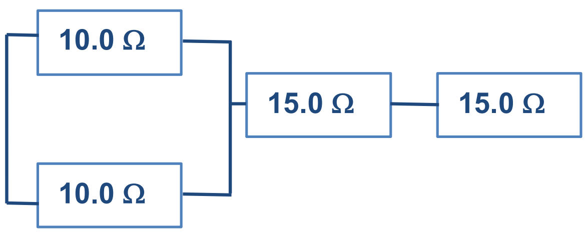
DE = E/m x QF (✔)

= (27 x 10^{-3} J)/75 kg x 10 = 3.6 mSv (✔)

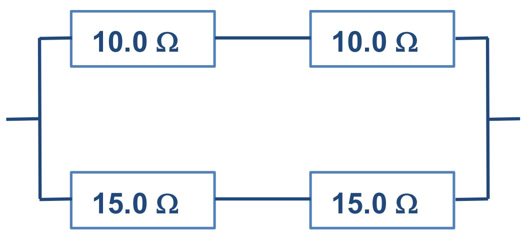
Question 3 **(4 marks)**

You have been provided with two 10.0 Ω and two 15.0 Ω resistors. Draw simple circuit diagrams to show how you could connect these resistors to create the following combined resistances.

(a) 35.0 Ω (2 marks)



(b) 12.0 Ω (2 marks)



Question 4 **(5 marks)**

A 1.8 kW electric kettle contains 600 mL of water at room temperature of 16°C. When electrical energy is supplied to the kettle, 95% goes into heating the water.

(a) Calculate the amount of heat needed to be absorbed by the water to reach boiling point (100°C). (2 marks)

$Q = m\,c\,\Delta T$

= 0.6 kg x 4180 J/kg/K x (100 – 16) K (✔)

= 211 kJ (✔)

(b) Calculate the amount of heat that the kettle transfers to the water each second, and hence how long it will take for the water to reach boiling point. (3 marks)

Q(transferred by kettle) = 95% x 1800 W = 1710 W (✔)

So P = Q/t t = Q/P (✔)

= 211000J/1710W

= 123 s (✔)

Question 5 **(4 marks)**

The manufacturer the kettle gave it the following features to maximise its efficiency. Briefly explain the benefit of each feature.

(a) The surface of the kettle is highly polished metal. (2 marks)

A shiny polished surface is a poor emitter of radiation (✔), so this minimizes heat loss from the kettle by radiation. (✔)

(b) The heating element inside the kettle is placed at the bottom of the kettle. (2 marks)

Water heated by the element will rise within the kettle (✔), to be replaced by colder water, so convection currents will be set up (✔) that cause the water to be heated evenly throughout.

Question 6 **(3 marks)**

Complete the following nuclear equations by writing in the missing symbol.

(a) $^{32}_{15}\mathrm{P} \rightarrow {}^{0}_{-1}\mathbf{e} + {}^{32}_{16}\mathrm{S}$ (1 mark)

(b) $^{4}_{2}\mathbf{He} + {}^{23}_{11}\mathrm{Na} \rightarrow {}^{26}_{12}\mathrm{Mg} + {}^{1}_{1}\mathrm{H}$ (1 mark)

(c) $^{1}_{0}\mathrm{n} + {}^{10}_{5}\mathbf{B} \rightarrow {}^{7}_{3}\mathrm{Li} + {}^{4}_{2}\mathrm{He}$ (1 mark)

Question 7 **(4 marks)**

Explain the following observations, using appropriate physics terminology.

(a) Drawing the curtain across a window at night greatly reduces heat loss. (2 marks)

The curtain traps a layer of air between itself and the windowpane. (✔)

Since air is a very poor conductor, this trapped air reduces heat loss by conduction (✔) (and by preventing convection currents near the window).

(b) Evaporative air-conditioners are ineffective in humid weather. (2 marks)

Evaporative air-conditioners blow air over a moist filter, causing evaporation of water with the latent heat of evaporation being absorbed from the air. (✔)

Humid air is saturated with water vapour, so little evaporation of water occurs and there is minimal cooling of the air blown through the air-con. (✔)

Question 8 **(3 marks)**

Convert each of the following values as indicated:

0.0168 μm = ____**16.8**____ nm

145 MeV = ____**2.32×10^{-11}**____ J

472 K = ____**199**____ °C

Question 9 **(4 marks)**

(a) Explain the difference between the active wire and the neutral wire in a typical household circuit. (2 marks)

The active wire connects the circuit to the power source, and carries the full oscillating voltage. (✔)

The neutral wire connects the circuit to the ground, thereby completing the circuit and enabling current to flow. (✔)

(b) What is a “double insulated” appliance and why does it not need an earth wire? (2 marks)

A double insulated appliance has an outer casing made of plastic (or some other insulating material), in addition to the internal wiring being insulated. (✔)

This prevents the outer casing from becoming live and conducting current, so an earth wire is not needed. (✔)

Question 10 **(5 marks)**

The radiator of a car has several features which help it to maximise the transfer of heat from the coolant (water) flowing through it into the surrounding air, in order to remove heat as quickly as possible from the car engine. Describe how each of the following features of a radiator helps maximise the transfer of heat, with reference to the three methods of heat transfer.

(a) Being made of metal (1 mark)

Metals are good conductors of heat, so transfer thermal energy rapidly from the hot coolant. (✔)

(b) Having air vents and a fan behind it (2 marks)

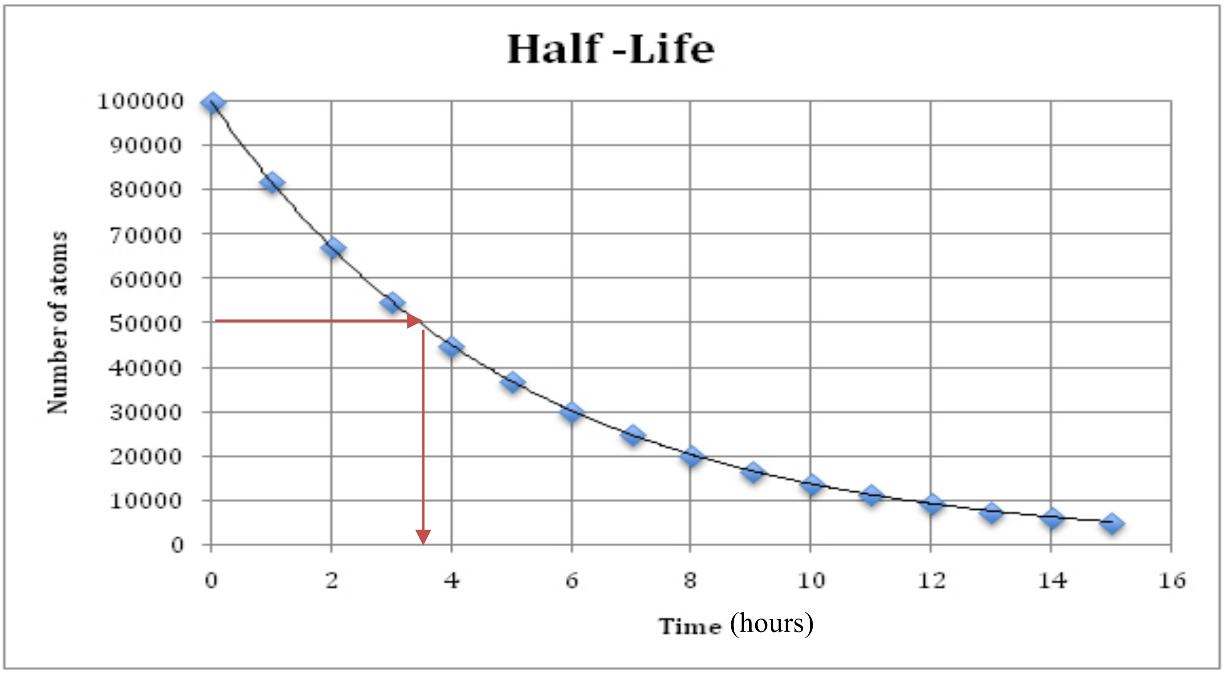
The air vents and the fan increase air flow over and through the radiator (✔), so heat transfer by convection is increased. (✔)

(c) Being painted black (2 marks)

Black and other dark colours emit more infrared radiation than light colours (✔), so heat transfer by radiation is increased. (✔)

Question 11 **(5 marks)**

The graph below shows the decay of a sample of a radioisotope over a 15 hour time period.



(a) Estimate the half-life of the radio-isotope, using the graph to show your working. (2 marks)

Number of atoms halves from 100 000 to 50 000 in a time of <u>3.5 hours</u> (✔)
(working shown on graph (✔))

(b) Determine the number of atoms of the radioisotope remaining in the sample after 20 hours, using your estimated value of the half-life. (3 marks)

$N = N_o (1/2)^x$, where x = (20 h/3.5 h) = 5.71 half-lives (✔)

So $N = N_o (1/2)^x$ = $100\,000\,(1/2)^{5.71}$ (✔)

= <u>1900 atoms</u> (✔)

Question 12 **(3 marks)**

Bill compares a hot summer day of 40°C to a cold winter night of 4°C, and mistakenly declares that the hot summer day is 10 times as hot as the cold winter night. Calculate, to the nearest percent, how much hotter it really is on the hot summer day compared to the cold winter night.

In Kelvin the two temps are (✔)

summer day: 40°C = 40 + 273 = 313 K

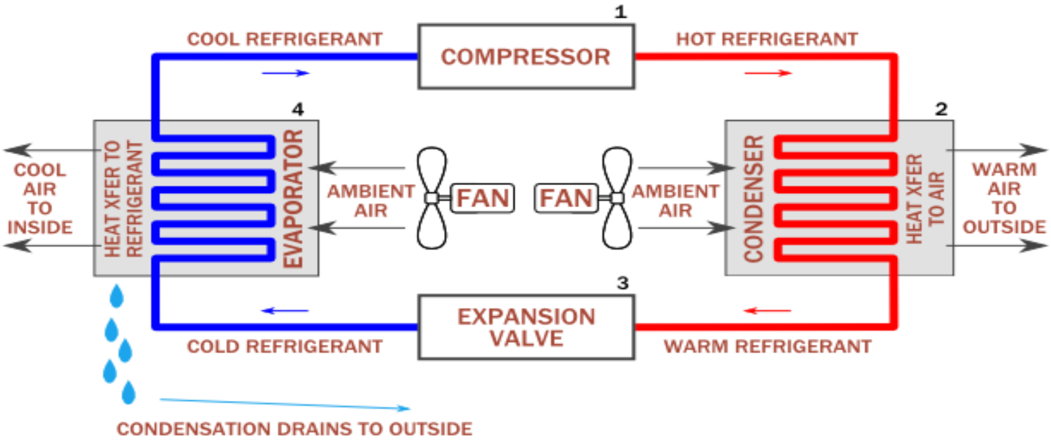
winter night: 4°C = 4 + 273 = 277 K

ratio = 313/277 = 1.13 (✔)

So it is <u>13% hotter</u> (✔) on the summer day compared to the winter night.

Question 13 **(6 marks)**

Answer the following questions regarding the refrigerative air conditioner shown in the sketch below.



(a) Describe the nature of the fluid found in the condenser pipes just after it has passed through the compressor. (1 mark)

hot liquid (✔)

(b) Explain how the fluid passing through the evaporator pipes inside the house produces a cooling effect on the air blown over them. (2 marks)

As the fluid passes through the evaporator pipes inside the house it undergoes the phase change from liquid to gas. (✔)

This phase change is endothermic, so the latent heat needed for the fluid to evaporate is absorbed from the evaporator pipes, cooling them down. (✔)

(c) State another effect on the air blown over the evaporator pipes inside the house, as well as being cooled down, that can be inferred from the sketch above. (1 mark)

The air becomes drier (less humid) (✔), as water condenses from the air as it is blown over the evaporator pipes and cools.

(d) When used in reverse cycle mode in winter this air-conditioner produces 200 J of heat for every 100 J of electrical energy consumed. Explain how it can produce more heat than the electrical energy it consumes. (2 marks)

The air-conditioner does not transform the 100 J of electrical energy into 200 J of thermal energy (✔), but rather the air-conditioner uses the 100 J of electrical energy to pump 200 J of thermal energy from the air outside to the air inside the house. (✔)

END OF SECTION ONE

Section Two: Problem Solving (90 Marks)

This section has **seven (7)** 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.

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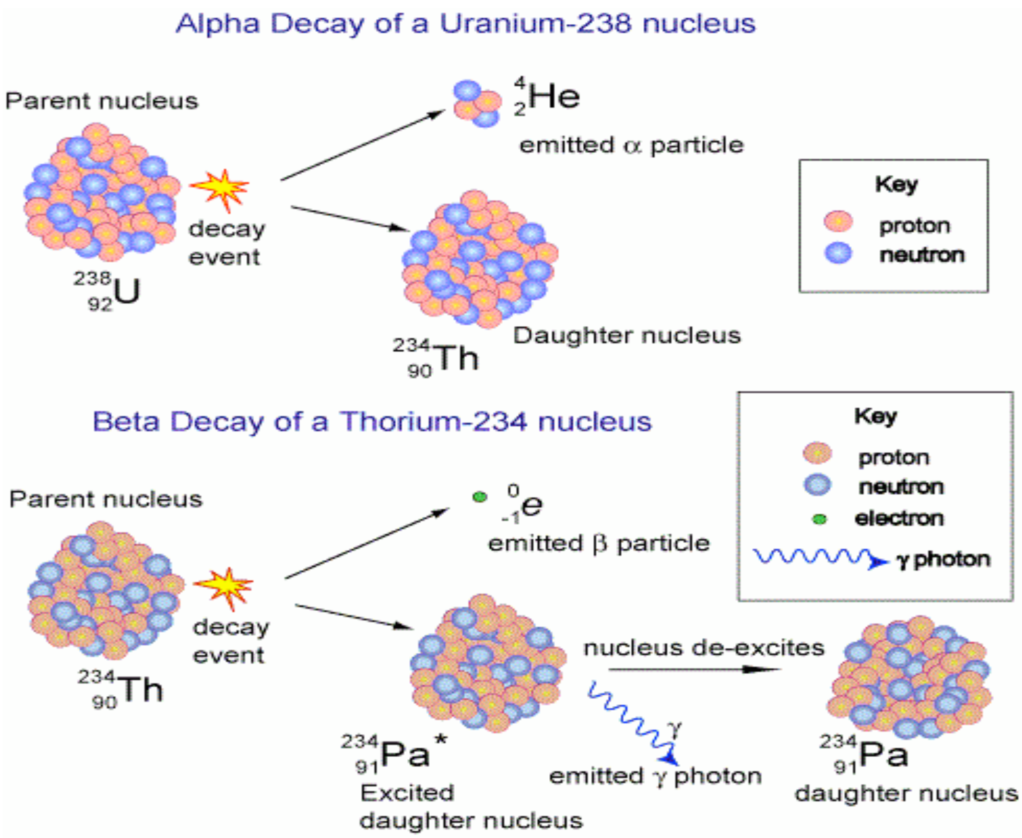
Suggested working time: 90 minutes.

Question 14 **(10 marks)**

All isotopes of all elements past bismuth (Z = 83) in the periodic table are radioactive; there are no stable nuclei past bismuth. One of the most stable isotopes past bismuth is uranium-238 ($^{238}_{92}U$), which has an extremely long half-life of 4.5 billion years. Uranium-238 nuclei eventually decay into thorium-234 nuclei, as shown in the diagram below. Thorium-234 itself undergoes radioactive decay into protactinium-234 via a two-step process also illustrated below.



(a) What is an isotope? (1 mark)

An isotope is a particular variety of nucleus of an element with a certain number of neutrons. (✔)

(b) The half-life of thorium-234 is 24.1 days, while protactinium-234* and protactinium-234 have half-lives of 1.17 minutes and 6.75 hours respectively. Predict the relative abundance of these three radioisotopes (Th-234, Pa-234* and Pa-234) in a sample of uranium ore, from most abundant to least abundant. (1 mark)

Most abundant **Th-234** > **Pa-234** > **Pa-234*** Least abundant
(longest half-life to shortest)

(c) State which of the types of nuclear radiation shown above (3 marks)

(i) is the most penetrating. ____**gamma**____**(✔)**

(ii) is the most ionizing. ______**alpha**______**(✔)**

(iii) leaves the nucleon composition of the nucleus unchanged. _____**gamma**____**(✔)**

(d) Briefly describe the nucleon change that occurs inside the thorium-234 nucleus that results in the emission of a β particle. (1 mark)

A neutron decays into a proton (✔), emitting the β particle

(e) In terms of the balance of forces within the nucleus, explain why there is a limit to the size of stable nuclei. (4 marks)

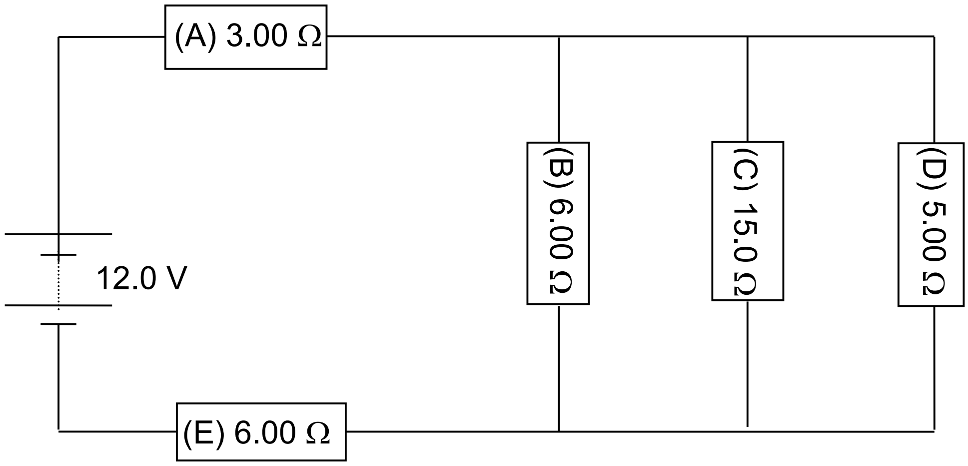
The two main forces which act within the nucleus are the (✔)

- **electrostatic repulsion forces between all the protons**
- **strong nuclear forces between neighbouring nucleons**

As nuclei become larger, the electrostatic repulsion forces between all the protons increase with atomic number (✔), while the strong nuclear forces remain of similar strength (✔), and so eventually, for large enough nuclei, the electrostatic repulsion forces overcome the strong nuclear forces and the nucleus is unstable. (✔)

Question 15 **(16 marks)**

Consider the circuit shown below.



(a) Without doing any calculations, explain which of the two 6.00 Ω resistors (B or E) must have the larger potential difference across it. (3 marks)

Resistor E (✔) must have the larger potential difference, as pot. diff. V = I R , and all the circuit current flows through resistor E (✔), while resistor B only has a share of the circuit current as it is in parallel with resistors C and D. (✔)

(b) Hence which resistor in the whole circuit (A, B, C, D or E) has the largest potential difference across it? Briefly explain. (3 marks)

Resistor E (✔) must have the largest potential difference, as

- **resistors C and D have the same potential difference as resistor B, which is smaller than that of resistor E (✔)**
- **resistor A has the same current flowing through it as resistor E but has only half the resistance, so must have half the potential difference (✔)**

(c) Calculate the current through the 3.00 Ω resistor (A). (4 marks)

For the three parallel resistors

$1/R = 1/6 + 1/15 + 1/5 = 0.433$

$R = 2.31\ \Omega$ (✔)

Hence total resistance of the circuit is

$R_{tot} = 3.00\ \Omega + 2.31\ \Omega + 6.00\ \Omega = 11.3\ \Omega$ (✔)

Current through the 3.00 Ω resistor is the current from the battery

$I = {}^{\varepsilon}/_{R} = {}^{12.0\ V}/_{11.3\ \Omega} = \underline{1.06\ A}$ (✔)
(✔)

(d) Find the voltage drop across the 15.0 Ω resistor (C). (2 marks)

Voltage drop across 15.0 Ω resistor = voltage drop across parallel resistors (✔)

$V = IR = (1.06\ A)(2.31\ \Omega) = \underline{2.45\ V}$ (✔)

(e) Hence determine the current flowing through the 5.00 Ω resistor (D). (2 marks)

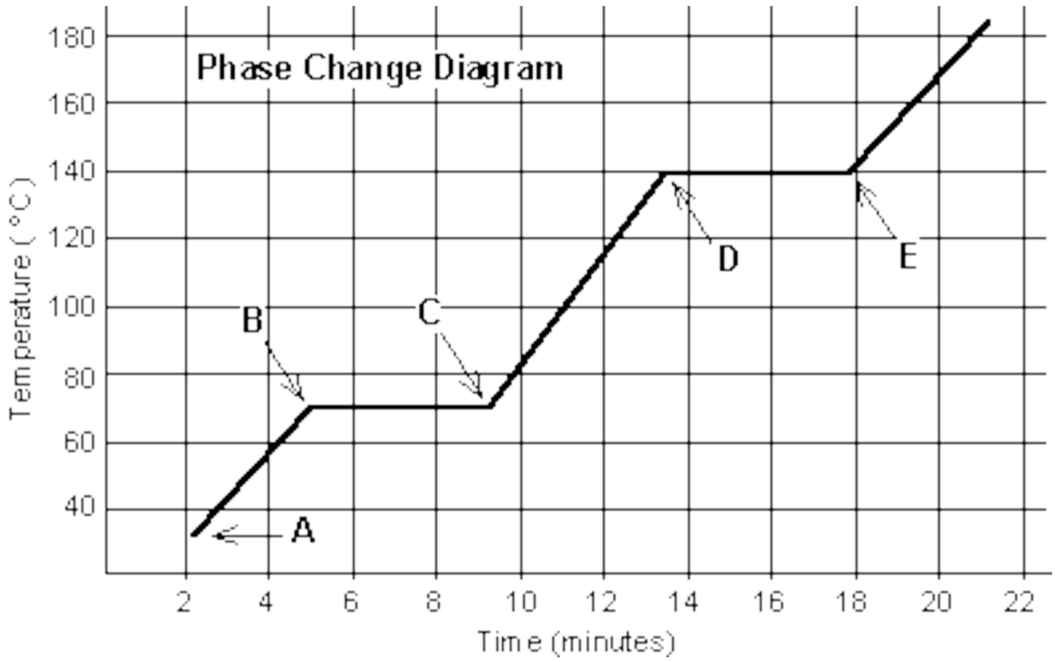
$I = {}^{V}/_{R} = {}^{2.45\ V}/_{5.00\ \Omega} = \underline{0.490\ A}$ (✔)
(✔)

(f) At what rate is electrical energy converted into heat by this circuit? (2 marks)

$P = VI = (12.0\ V)(1.06\ A) = \underline{12.7\ W}$ (✔)
(✔)

Question 16 **(13 marks)**

The heating curve for an organic compound was obtained by steadily heating a 2.50 kg sample of the substance and continuously recording its temperature, as shown in the graph below. The compound was initially in the solid state but after continuous heating for more than 20 minutes finished as a gas.



(a) Give the melting point of the compound. ______**70°C**________ (1 mark)

(b) Explain, in terms of kinetic theory, what is happening to the molecules of the compound during each of the following stages of heating

(i) from A to B. (2 marks)

The compound is in the solid state (✔) and the molecules are <u>gaining kinetic energy</u> (✔), moving around more vigorously on average, as the compound heats up.

(ii) from B to C. (2 marks)

The compound is changing phase from solid to liquid (✔) and the molecules are <u>gaining potential energy</u> (✔), moving further apart from one another, as the compound heats up.

(c) The latent heat of vaporisation of the compound is 170 kJ/kg. Calculate the heat absorbed by the compound during vaporization. (2 marks)

$Q = mL = (2.50\text{ kg})(170\text{ kJ/kg}) = 425\text{ kJ}$ (✔)
(✔)

(d) Hence, use the graph to estimate the power of the heater. (2 marks)

Time to completely vaporize compound = 18 min - 13 min = 5 min = 300 s (✔)

Hence power $P = Q/t = 425\,000\text{ J}/300\text{ s} = \underline{1420\text{ W}}$ (✔)

(e) Now use the graph to estimate the specific heat capacity of the compound when in the liquid phase. (4 marks)

The liquid phase is from C to D on the graph, where

temp change $\Delta T = 140°C - 70°C = 70°C$

(✔)

heating time $t = 13\text{ min} - 9\text{ min} = 4\text{ min} = 240\text{ s}$

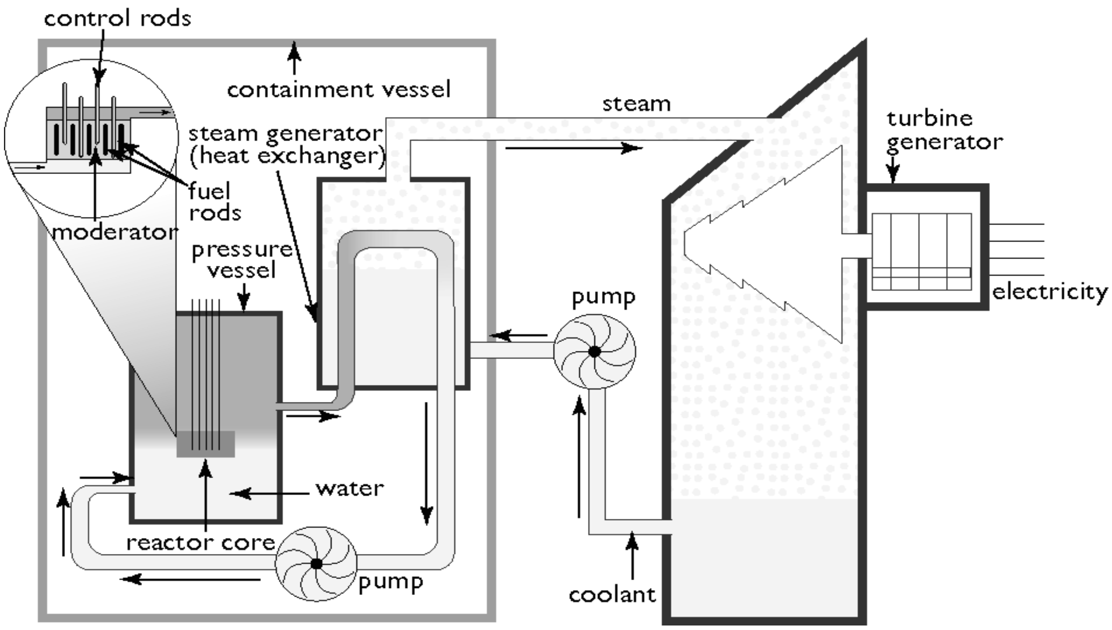
So heat absorbed $Q = Pt = (1420\text{ W})(240\text{ s})$ 340 000 J (✔)

$Q = mc\Delta T \rightarrow 340\,000\text{ J} = (2.50\text{ kg})\, c\, (70°C)$ (✔)

Hence specific heat $c = \underline{1940\text{ J/kg/K}}$ (✔)

Question 17 **(10 marks)**

The fuel rods in a nuclear reactor, as shown in the diagram below, contain the fissile isotope of uranium, U-235, which releases large amounts of energy when it undergoes fission.



(a) Write a **balanced** nuclear equation for the fission of a U-235 nucleus, initiated by the nucleus absorbing a neutron, into daughter nuclei Kr-86 and Ba-147. (2 marks)

$$^{235}_{92}\mathrm{U} + ^{1}_{0}\mathrm{n} \rightarrow ^{86}_{36}\mathrm{Kr} + ^{147}_{56}\mathrm{Ba} + 3\,^{1}_{0}\mathrm{n}$$

balanced equation (✔) **correct no of neutrons each side (✔)**

(b) Explain why an uncontrolled chain reaction cannot occur in the fuel rods in the reactor core, even though they contain fissile uranium-235. (2 marks)

Fissile uranium-235 would only undergo an uncontrolled chain reaction (a nuclear explosion) if the concentration of U-235 in the fuel rods was to exceed 90% (✔), whereas the concentration of U-235 in the fuel rods is typically around 5% - 10% (✔)

(c) The moderator in a nuclear reactor is a substance (e.g. graphite) that slows down neutrons, while the control rods are made of a substance (e.g. boron-steel) that absorbs neutrons. Explain how these two components of a reactor enable a stable chain reaction to occur in the fuel rods. (4 marks)

The moderator slows down neutrons to increase the probability that they will be captured by U-235 nuclei and initiate further fissions. (✔) This enables the fission reaction to proceed at an acceptable (fast enough) rate. (✔)

The control rods absorb neutrons, and by raising them from or lowering them into the reactor core (✔) the fission reaction rate can be controlled and adjusted as required. (✔)

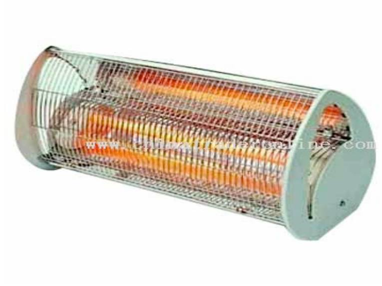
(d) The coolant flowing through the reactor core has two main functions. State these two functions (hint: they are related to one another) (2 marks)

The functions of the coolant are to

- **remove heat from the reactor core to prevent it from overheating (✔)**
- **transfer heat to the heat exchanger to produce steam and drive the turbines, and ultimately generate electricity (✔)**

Question 18 **(15 marks)**

A 1.8 kW electric heater operates on the domestic electricity supply (240V) for a period of three hours.



(a) What current does the heater draw? (2 marks)

$I = {}^{P}/_{V} = {}^{1800\ W}/_{240\ V} = \underline{7.50\ A}$ (✔)
(✔)

(b) What is the resistance of the heater when operating? (2 marks)

$R = {}^{V}/_{I} = {}^{240\ V}/_{7.50\ A} = \underline{32\ \Omega}$ (✔)
(✔)

(c) When first switched on, the heater draws a larger current than that calculated in part (a) above. How do you explain this? (3 marks)

When first switched on, the element of the heater is <u>cold</u> (✔), and so its <u>resistance is lower</u> (✔) than its operating resistance when warmed up.

Since $I = {}^{V}/_{R}$, a lower resistance means a larger current is drawn. (✔)

(d) Given that electricity costs 25 cents per kilowatt-hour, find the cost (to the nearest cent) of using the heater for the three hour period. (2 marks)

Cost = P(in kW) x t(in hours) x unit cost (✔)

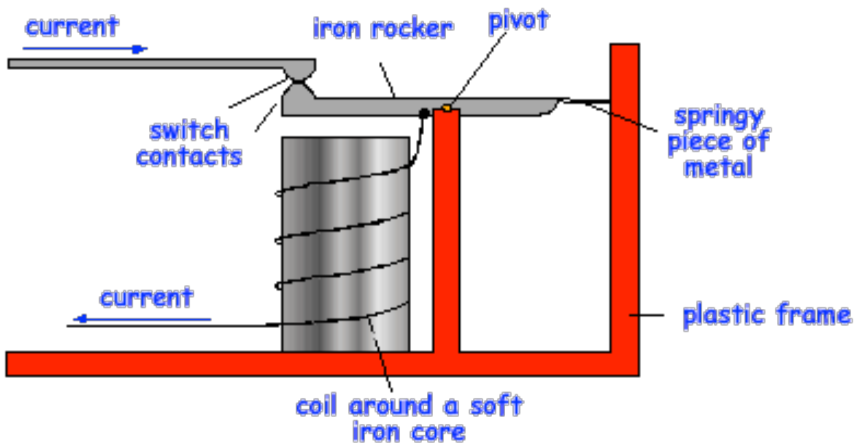
= 1.8 kW x 3 h x 25c = <u>135c</u> ($1.35) (✔)

(e) The heater has an outer casing made of steel. Briefly describe how the earth wire would protect against electric shock if the metal casing was to become live. (3 marks)

If a live wire inside the appliance touches the metal casing, then the earth wire provides a low resistance path to the ground. (✔)

As a result a large current will be drawn from the power supply (✔), and the circuit breaker (or fuse) will cut the power (✔), protecting against the danger of electric shock.

(f) The diagram below shows the basic design of a circuit breaker. Briefly explain the purpose of a circuit breaker and describe how it works. (3 marks)



The purpose of a circuit breaker is to cut the power when the current drawn exceeds a certain pre-determined value. (✔)

It wraps the active wire around a soft iron core, creating an electromagnet. (✔)

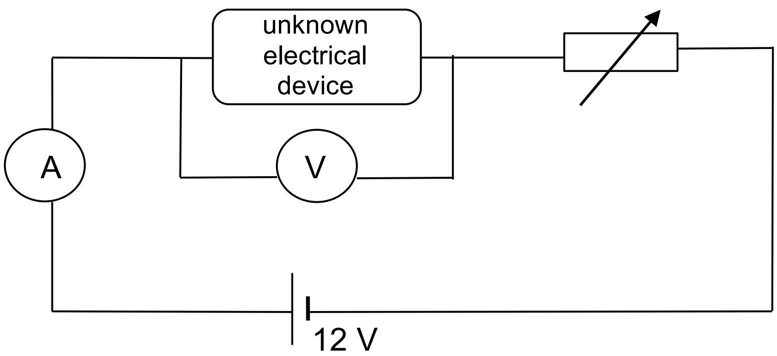
If the current becomes too large, the magnetic field of the electromagnet becomes strong enough to pull the iron rocker towards itself, opening the switch. (✔)

Question 19 **(14 marks)**

A student set up a circuit using multimeters to measure the voltage across, and the current through, an unknown electrical device. The potential difference across the device was varied by using a rheostat (variable resistor) and a 12.0 V battery in series with the unknown device. The measurements obtained by the student over half a dozen trials are given in the table below.

Voltage(V)	1.5	3.2	5.3	6.8	8.1	9.5
Current(A)	0.24	0.46	0.67	0.79	0.88	0.96

(a) Draw a diagram of the circuit that the student used to enable these measurements to be made. (3 marks)



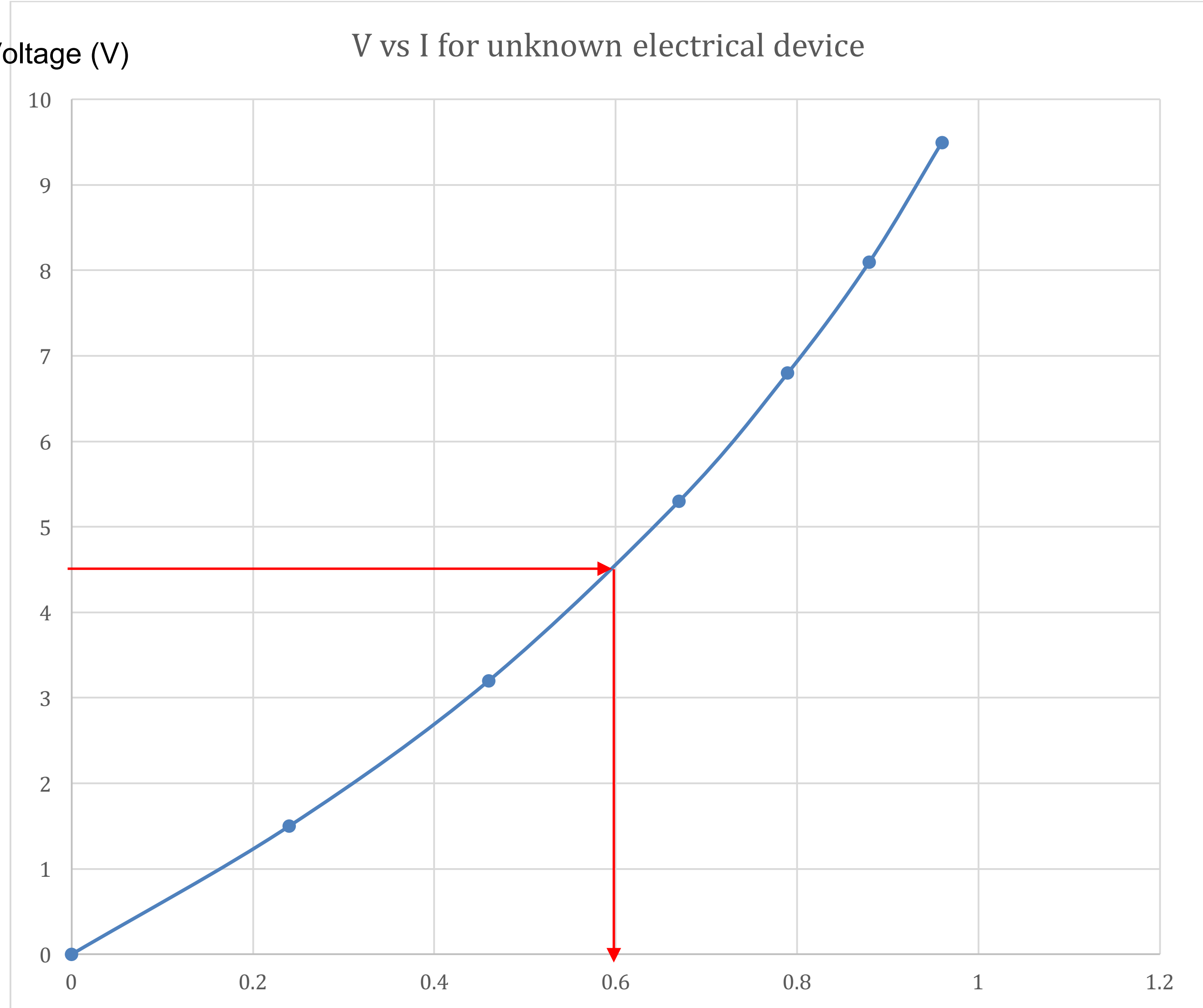
device, rheostat, battery in series (✔)
ammeter in series (✔)
voltmeter in parallel (✔)

(b) Sketch a voltage versus current graph for the unknown electrical device, on the graph paper on the next page, using the data above. (4 marks)

(c) Give a plausible explanation for the behaviour of the unknown electrical device. (3 marks)

As the voltage across the device increased, the current increased (✔)
This caused the device to heat up, so its resistance went up (✔)
As the resistance increased, the device became non-ohmic and produced a nonlinear graph (✔)

Voltage (V)



Current (A)

labelled

(d) When the voltage across the unknown electrical device is 4.5 V, use the graph to find

(i) the resistance of the unknown electrical device (2 marks)

When voltage V = 4.5 V, current I = 0.6 A (✔)

So R = $^V/_I$ = $^{4.5\ V}/_{0.60\ A}$ = <u>7.5 Ω</u> (✔)

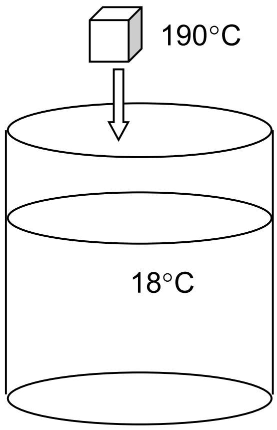
(ii) the resistance of the rheostat (variable resistor) (2 marks)

Rheostat is in series with the unknown electrical device so its voltage drop V = 12.0 V – 4.5 V = 7.5 V and its current I = 0.6 A (✔)

So R = $^V/_I$ = $^{7.5\ V}/_{0.60\ A}$ = <u>12.5 Ω</u> (✔)

Question 20 **(12 Marks)**

A piece of metal of mass 34.6 g is heated to a temperature of 190°C in an oven, then cooled by being dropped into a beaker containing 120 mL of water at an initial temperature of 18°C.



(a) Explain how the heated piece of metal can be at a higher temperature than the cold water in the beaker, yet have less internal energy. (3 marks)

The atoms of the heated piece of metal have more kinetic energy on average than the molecules of water (✔), but the mass of the water is much greater than the metal (✔) and so the total of all the KE and PE of the molecules of water (i.e. the internal energy) is larger than that of the atoms of the metal. (✔)

(b) Describe what happens at the molecular level as the piece of metal cools down after being dropped into the water (the water warms up slightly). (3 marks)

The fast moving (on average) atoms of the metal collide with the slower moving molecules of water (✔), and because of these collisions kinetic energy is transferred and shared among the particles (✔). This continues until all particles have about the same kinetic energy (✔), so the metal cools down and the water heats up slightly.

The temperature reached by the water once thermal equilibrium is achieved is 28°C.

(c) What is meant by the expression "thermal equilibrium is achieved"? (2 marks)

Thermal equilibrium is achieved when the transfer of thermal energy from the metal to the water is complete (✔) and has resulted in both substances reaching a common, intermediate temperature. (✔)

(d) Assuming that heat transfer only occurs between the metal and the water, and that any evaporation of water is negligible, calculate the specific heat content of the metal. (4 marks)

Q (lost by metal) = Q (gained by water)

$(m\ c\ \Delta T)_{metal} = (m\ c\ \Delta T)_{water}$ **(✔)**

$(0.0346\ kg)\ c\ (190°C - 28°C) = (0.120\ kg)\ (4180\ J/kg/K)\ (28°C - 18°C)$
(✔) (✔)

$\rightarrow \quad c = \frac{5016\ J}{(0.0346\ kg)(162°C)} = \underline{895\ J/kg/K}$ **(✔)**

END OF SECTION TWO

Section Three: Comprehension (36 Marks)

This section has **two (2)** 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.

Spare pages are included at the end of this booklet. They can be used for planning your responses and/or as additional space if required to continue an answer. If you need to use the space to continue an answer, indicate in the original answer space where the answer is continued, i.e. give the page number. Fill in the number of the question that you are continuing to answer at the top of the page.

Suggested working time: 36 minutes.

Question 21 STELLAR ENERGY PRODUCTION & TRANSFER (17 marks)

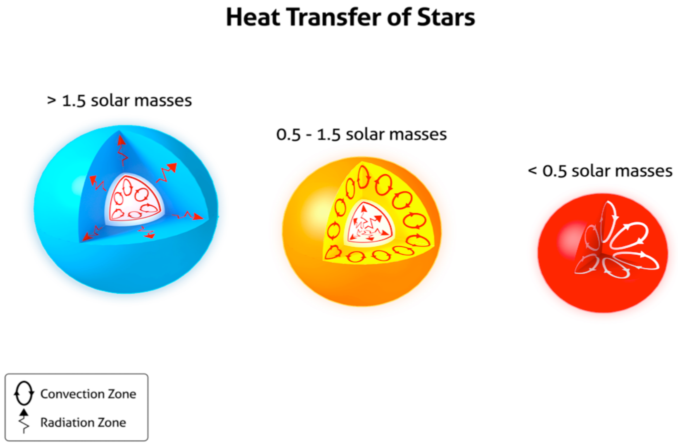
(Paragraph 1)
The Sun produces vast amounts of energy through thermonuclear fusion deep in its core. The main nuclear reaction involves four hydrogen nuclei (protons) being fused together to form a helium-4 nucleus plus two positrons (via some intermediate reactions) as shown below

$$4\ {}^{1}_{1}\mathrm{H} \rightarrow {}^{4}_{2}\mathrm{He} + 2\ {}^{0}_{+1}\mathrm{e}$$

Comparing the mass of the final helium-4 atom (and the two positrons) with the masses of the four protons reveals that some of the mass of the original protons has been lost. This mass has been converted into energy, in the form of gamma rays and kinetic energy of the fusion products. The total energy yield of one complete reaction is around 25 MeV. Energy released as gamma rays interacts with electrons and protons and heats the interior of the Sun, increasing the temperature of the plasma in the Sun. This heating supports the Sun and prevents it from collapsing under its own weight.

(Paragraph 2)
Different layers of a star transport heat up and outwards in different ways, primarily through convection and radiative transfer, although thermal conduction is important in small collapsed stars. Convection is the dominant mode of energy transport when the temperature difference between layers is high. This enables a hot parcel of gas within the star to be buoyant and to rise if it is warmer than the surrounding gas; when it cools, it will fall back to its original height, and so a convection current is set up. In regions with a low temperature difference between layers, that are transparent enough to allow energy transport via radiation, radiation is the dominant mode of energy transfer.

(Paragraph 3)
The internal structure of a typical star depends upon the mass of the star. In stars with masses of 0.5–1.5 solar masses, including the Sun, hydrogen-to-helium fusion in the core does not establish a large temperature difference between layers. Thus, radiation dominates in the inner portion of solar mass stars. The outer portion of solar mass stars cools down rapidly towards the surface, so convection dominates. Therefore, solar mass stars have radiative cores with convective envelopes in the outer portion of the star.



(Paragraph 4)
In large stars (greater than about 1.5 solar masses), the central core temperature is above 18×10^6 K, so the temperature differences within the inner portion of the star are high enough to make the core convective. In the outer portion of the star, the temperature differences between layers are smaller and so large stars have a radiative envelope. Small stars (less than about 0.5 solar masses) have no radiation zone; the dominant energy transport mechanism throughout the star is convection.

(a) Calculate the mass difference between the reactants and products in the thermonuclear fusion reaction shown in paragraph 1, given the particle masses listed below. (2 marks)

$m(e) = 9.1094 \times 10^{-31}$ kg $m(H) = 1.67262 \times 10^{-27}$ kg $m(He\text{-}4) = 6.64466 \times 10^{-27}$ kg

$\Delta m = 4 \times m(H) - (m(He\text{-}4) + 2 \times m(e))$ (✔)

$= 4 \times 1.67262 \times 10^{-27}\text{ kg} - (6.64466 \times 10^{-27}\text{ kg} + 2 \times 9.1094 \times 10^{-31}\text{ kg})$

$= \underline{4.3998 \times 10^{-29}\text{ kg}}$ (✔)

(b) Find the energy released (in J) by a single fusion reaction, and hence compare to and confirm the value given for the energy yield of a complete reaction. (paragraph 1) (4 marks)

$E = \Delta mc^2$ (✔)

$= (4.3998 \times 10^{-29}\text{ kg})(3 \times 10^8\text{ m/s})^2$

$= \underline{3.9598 \times 10^{-12}\text{ J}}$ (✔)

$= 3.9598 \times 10^{-12}\text{ J} / 1.6 \times 10^{-13}\text{ J/MeV} = 24.75\text{ MeV}$ (✔)

which is similar to the value of about 25 MeV given for the energy yield of this fusion reaction in paragraph 1 (✔)

(c) What percentage of the original mass of the hydrogen nuclei has been converted into energy during this reaction? (2 marks)

Percentage of mass $= \Delta m / (4 \times m(H)) \times 100\%$ (✔)

$= 4.3998 \times 10^{-29}\text{ kg} / (4 \times 1.67262 \times 10^{-27}\text{ kg}) \times 100\%$

$= \underline{0.658\%}$ (✔)

(d) Find the energy released when 1 kg of hydrogen fuses according to this reaction. (2 marks)

Energy released $E = mc^2$ = 0.658% x 1 kg x $(3 \times 10^8 \text{ m/s})^2$ (✔)

= <u>5.919×10^{14} J</u> (✔)

(e) The total power output of the Sun due to this fusion reaction is a huge 3.6×10^{26} W. Calculate the mass of hydrogen that is fused into helium <u>every second</u> in the Sun. (3 marks)

1 kg of hydrogen fuses to produce 5.919×10^{14} J

x kg of hydrogen fuses to produce 3.6×10^{26} J every second (✔)

So x kg = $(3.6 \times 10^{26}$ J/s) / $(5.919 \times 10^{14}$ J/kg) (✔)

= <u>6.08×10^{11} kg/s</u> (✔) (608 million tonnes per second)

(f) Describe and contrast the transfer of heat within the interior of the Sun to that within the interior of a much larger star. (paragraphs 3 and 4) (4 marks)

Within the Sun temperature differences in the core are small and so heat is transferred mainly by <u>radiation in the core</u> (✔) but in the outer layers of the Sun temperature drops rapidly and heat is transferred by <u>convection currents in the outer envelope</u>. (✔)

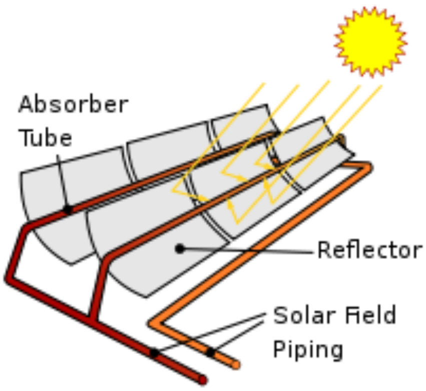
Within a much larger star, temperature differences in the inner portion of the star are high enough to cause heat to be transferred by <u>convection currents in the core</u> (✔) but smaller temperature differences in the outer layers of the star cause heat transfer by <u>radiation in the outer envelope</u>. (✔)

Question 22 **SOLAR THERMAL POWER PLANTS** **(19 marks)**

(Paragraph 1)
The efficiency of any thermal power plant increases with the temperature of the heat source. To achieve high efficiency in solar thermal energy plants, solar radiation is concentrated by mirrors or lenses to obtain higher temperatures – a technique called Concentrated Solar Power (CSP). The practical effect of high efficiency is to reduce a plant's land use per unit power generated, reducing the environmental impacts of a power plant as well as its expense. High temperatures also make heat storage more efficient, because more watt-hours are stored per unit of fluid.

(Paragraph 2)
The principal advantage of CSP is the ability to efficiently add thermal storage. With current technology, storage of heat is much cheaper and more efficient than storage of electricity. Heat storage enables solar thermal plants to produce electricity during hours without sunlight. Heat is transferred to a thermal storage medium in an insulated reservoir during hours with sunlight, and is withdrawn for power generation during hours lacking sunlight. Since peak electricity demand typically occurs at about 5 pm, many CSP power plants use 3 to 5 hours of thermal storage.

(Paragraph 3)
Parabolic trough power plants use a curved, mirrored trough which reflects and concentrates solar radiation onto a glass tube containing a fluid (also called an absorber, receiver, or collector tube). The fluid in the tube becomes very hot, and is transported to a heat engine where about a third of the heat is converted to electricity. Common fluids used are synthetic oil, molten salt and pressurized steam. The absorber tube runs the length of the trough and is positioned at the focal point of the reflectors. The trough is parabolic along one axis and linear along the other axis. As the position of the sun changes during the day, the trough tilts east to west so that the direct radiation remains focused on the absorber tube. However, seasonal changes in the angle of sunlight parallel to the trough does not require adjustment of the mirrors, since the light is simply concentrated elsewhere on the absorber tube. The absorber tube may be enclosed in a glass vacuum chamber, as the vacuum significantly reduces convective heat loss.



(Paragraph 4)
Power towers (also known as 'central tower' power plants or 'heliostat' power plants) capture and focus the sun's thermal energy with thousands of tracking mirrors (called heliostats) in a roughly three square kilometre field. A tower resides in the center of the heliostat field. The heliostats focus concentrated sunlight on a receiver which sits on top of the tower. Within the receiver the concentrated sunlight heats molten salt to over 550°C. The heated molten salt then flows into an insulated thermal storage tank where it can store heat for a week, maintaining 98% thermal efficiency. Tanks that can power a 100-megawatt turbine for four hours would be about 9 m tall and 24 m in diameter. Molten salt is used in solar power tower systems because it is liquid at atmospheric pressure, has operating temperatures compatible with modern steam turbines, is low-cost, and is non-flammable and non-toxic.

(Paragraph 5)
The advantage of this design above the parabolic trough design is the higher temperature. Thermal energy at higher temperatures can be converted to electricity more efficiently and can be more cheaply stored for later use. Furthermore, there is less need to flatten the ground area. In principle a power tower can be built on the side of a hill. Mirrors can be flat and plumbing is concentrated in the tower. The disadvantage is that each mirror must have its own dual-axis control, while in the parabolic trough design single axis tracking can be shared for a large array of mirrors.

(a) Briefly outline two advantages of the high efficiencies achieved by the use of Concentrated Solar Power (CSP). (Paragraph 1) (2 marks)

The two main advantages are

- **reduced area of land needed to generate a certain amount of power (✔)**
- **more thermal energy is stored per unit volume of fluid (✔)**

(b) Explain the main advantage of adding thermal storage to a thermal solar plant. (Paragraph 2) (2 marks)

Adding thermal storage to a thermal solar plant enables it to produce electricity during hours without sunlight (✔), as thermal storage is cheaper and more efficient than storage of electricity. (✔)

(c) Describe how parabolic trough power plants (paragraph 3) deal with the daily and seasonal changes in the position of the Sun in the sky. (3 marks)

The parabolic trough is designed to focus light from the sun onto the absorber tube. As the position of the sun changes during the day, the trough tracks the sun from east to west to keep the light focused on the absorber tube (✔). Seasonal changes in the position of the sun in the sky occur parallel to the trough (✔) and hence do not require adjustment of the mirrors, since the light will be focused further along the absorber tube (✔).

(d) In paragraph 4 the thermal storage tanks for molten salt are described in part as follows: "tanks that can power a 100-megawatt turbine for four hours would be about 9 m tall and 24 m in diameter". Calculate

(i) the thermal energy extracted from molten salt in such a tank, given that the density of the molten salt is 1750 kg/m^3, the specific heat capacity of the salt is about 1500 J/kg/K, and the salt is cooled down to about 150°C in delivering its thermal energy. (5 marks)

Volume of storage tank = $\pi r^2 \times h$ = $\pi(12\ m)^2 \times (9\ m)$ = 4070 m^3 (✔)

Mass of salt stored = density x volume = 1750 kg/m^3 x 4070 m^3

= 7.13 x 10^6 kg (✔)

Temperature change of salt ΔT = 550°C - 150°C = 400 K (✔)

Q = m c ΔT = (7.13 x 10^6 kg)(1500 J/kg/K)(400 K) (✔)

= <u>4.28 x 10^{12} J</u> (✔)

(ii) the output electrical energy of the turbine over that period. (2 marks)

E = P t = (100 x 10^6 W)(4 x 3600 s) (✔)

= <u>1.44 x 10^{12} J</u> (✔)

(iii) the efficiency of the conversion of thermal energy into electrical energy. (2 marks)

Efficiency = electrical energy/thermal energy x 100% (✔)

= 1.44 x 10^{12} J / 4.28 x 10^{12} J x 100%

= <u>33.7%</u> (✔)

(e) State two advantages of power towers over parabolic trough power plants (paragraph 5), and list one disadvantage. (3 marks)

Two advantages of power towers over parabolic trough power plants are

- **Higher temperatures means thermal energy can be converted to electricity more efficiently and can be stored more cheaply (✔)**
- **Can be built on rough or uneven ground (✔)**

The disadvantage is

- **Each mirror must have its own dual-axis control (✔)**

END OF PAPER

EXTRA WORKING SPACE

EXTRA GRAPH PAPER