Semester One Examination 2016
Question/Answer Booklet

PHYSICS
UNIT 1

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 provides by the supervisor
This Question/Answer Booklet
Formulae and Data Booklet

To be provided by the candidate
Standard items: pens, pencils (including coloured), sharpener, correction fluid, eraser, ruler, highlighters.
Special items: up to three non-programmable calculators approved for use in the WACE examinations, drawing templates, drawing compass and a protractor.

STRUCTURE OF THIS PAPER

Section	No. of Questions	No. of questions to be attempted	Suggested working time (minutes)	Marks available	Percentage of exam
1: Short response	13	ALL	50	54	30
2: Problem-solving	7	ALL	90	90	50
3: Comprehension	2	ALL	40	36	20
			Total	**180**	**100**

INSTRUCTIONS TO CANDIDATES

Write your answers in the spaces provided beneath each question. The value of each question (out of 180) 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. The calculator **cannot** be a "**graphics"** calculator.

Answers to questions involving calculations should be evaluated and given in decimal form. Final answers should be given up to three significant figures and include appropriate units where appropriate. Despite an incorrect final result, credit may be obtained for method and working providing these are 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. 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 response **30% (54 marks)**

This section has 13 questions. Answer **all** questions. Answer the questions in the spaces provided.
Suggested working time: 50 minutes.

Question 1 **(4 marks)**

(a) List two assumptions of the kinetic particle model. (2 marks)

Any two of the following:

- Matter consists of (small) particles
- The Particles are in constant motion
- All substances have internal energy due to the motion and separation of their particles
- Collisions between the particles are elastic (i.e., no kinetic energy is lost in these collisions)
- The particles don't exert forces on one another
- The distance between particles is large (compared to their size)

(b) Dry ovens cook food by circulating hot air around it. Steam ovens cook food by circulating steam. If both types of oven are set to 100 °C, a carrot cooks in a few minutes in a steam oven, but takes hours to cook in a dry oven. Suggest a reason why. (2 marks)

Although the particles in each oven have the same average kinetic energy, the steam oven has the advantage wherein the steam condenses on the carrot, releasing latent heat – i.e., providing an additional 2.26 MJ kg^{-1} of condensed water.

Question 2 **(4 marks)**

(a) Explain why heat transfer by conduction is more effective in liquids than in gases. (2 marks)

Conduction relies on particles passing on energy via collisions. The particles of a liquid are closer together, thereby facilitating more effective heat transfer between liquid particles compared to gas particles.

(b) Explain why aluminium is a better conductor of heat than phosphorus, despite the fact that both are solids at room temperature and they have similar atomic masses. (2 marks)

Metals (aluminium in this case) have free electrons that are able to transfer heat to neighbouring atoms. In non-metals (phosphorus in this case), heat is transferred by lattice vibrations => much less effective transfer of energy

Question 3 **(4 marks)**

(a) Recent advances have increased the efficiency of some petrol engines to 35%. Explain what happens to the other 65% of the energy.

(2 marks)

The other 65% is converted into energy that is not doing useful work – either as heat created as a result of combustion (which may be carried from the car by the exhaust gases or by the engine cooling system), or due to friction, noise etc. of engine components or the drivetrain/axle/wheels

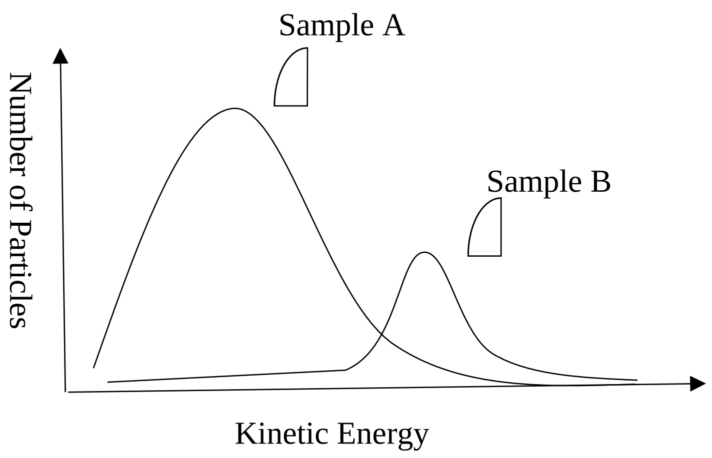
(b) Describe two ways that a car engine can be cooled.

(2 marks)

- A car engine can be cooled by a fluid, e.g., a liquid coolant that removes heat from the engine and is passed through the radiator where the fluid is cooled by air
- Air that is taken into the engine in the intake stroke can cool the combustion chamber
- Lubricants can cool moving parts of the engine
- Parts of the engine that are not directly cooled by the fluid cooling system can Heat can be transferred by conduction to parts of the engine that are directly cooled by the fluid cooling system

Question 4 **(4 marks)**

Below is a graph showing the distribution of kinetic energy of particles for two different samples of zinc that are at two different temperatures.



(a) Which of the two samples of zinc would have the higher temperature? Explain your choice.
(2 marks)

Although sample A has a higher peak, its average kinetic energy is lower than that of sample B – since temperature is a measure of the average kinetic energy of an object, the sample B has a higher temperature.

(b) Which is likely to have greater internal energy – an indoor swimming pool that has been heated to 28 °C or a stainless steel paper clip heated to 1,100 °C? Explain your answer.
(2 marks)

The pool – although it has a far lower temperature, it has a much greater internal energy as the total internal energy is the sum of the energy of each of the particles. The larger number of particles in the pool will contribute more to the total internal energy than the far smaller number of particles of the paper clip object.

Question 5 **(4 marks)**

State whether each of the following statements is true or false:

(a) The nucleons in an atom are held together due to the attraction between positively charged protons and negatively charged electrons.

True / False (1 mark)

False – protons and neutrons are held together by the strong nuclear force, which overcomes the electrostatic repulsion between the positively charged protons

(b) Nuclear fusion reactions release more energy than fission reactions in total, however fission reactions release more energy per nucleon.

True / False (1 mark)

False – more energy per nucleon is released in fusion reactions

(c) Alpha particles have a relatively poor penetrating power, but they have a relatively high ionising ability.

True / False (1 mark)

True

(d) Alpha, beta and gamma radiation will be deflected near a charged plate.

True / False (1 mark)

False – gamma radiation is uncharged and will therefore not be deflected near a charged plate (i.e., will not be attracted to or repelled by the charged plate).

Question 6 **(4 marks)**

The activity of an unknown radioactive source was measured for a period of 5 minutes and 50.0 seconds. At the end of this time, its activity was measured to be 15.0 Bq. If the half-life of the material is 70.0 s, calculate its activity at the start of the measurement period (i.e., when t = 0 s)?

$t = (5 \times 60) + 50 = 350$ s
number half-lives $n = 350 / 70 = 5$
$N = N_0 (1/2)^n$
$15 = N_0 (1/2)^5$
$N_0 = 15 / (1/2)^5$
$N_0 = 480$ Bq $= 4.80 \times 10^2$ Bq

OR: Can work backwards by doubling 15.0 Bq 5 times
i.e., $N_0 = 15 \times 2^5 = 4.80 \times 10^2$ Bq

Question 7 **(4 marks)**

Complete the following sentences by inserting either: alpha radiation, beta radiation, or gamma radiation:

(a) Gamma radiation is the least ionising type of radiation (1 mark)

(b) The radiation that comprises particles of the greatest charge is alpha radiation. (1 mark)

(c) Gamma radiation has the highest penetrating power (1 mark)

(d) The radiation that has the lowest emission velocity is alpha radiation. (1 mark)

Question 8 **(4 marks)**

A 65.0 kg technician accidentally ingested a source of alpha radiation. Over the next 4.00 hours he absorbed 3.18 J of energy before removing the radioactive materials from his body by vomiting.

(a) Calculate the technician's absorbed dose over the four-hour period (1 mark)

Absorbed dose = energy absorbed / mass = 3.18 / 65 = 48.9 mGy.

(b) Calculate the technician's dose equivalent over the four-hour period. (1 mark)

Dose equivalent = absorbed dose x quality factor
Dose equivalent = $48.9 \times 10^{-3} \times 20 = 0.978$ Sv

(c) Should the technician be concerned about his radiation exposure? (2 mark)

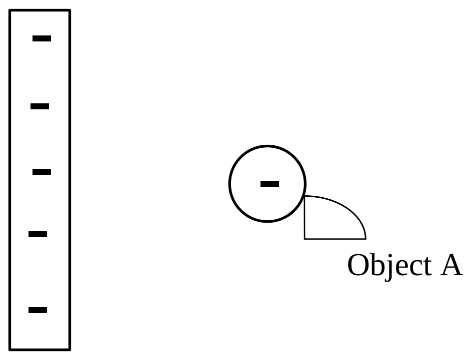
Yes – he has received a dose equivalent of almost 1 Sv. He will likely suffer from radiation sickness, possibly within days, and a have very high chance of fatal cancers developing later.

Yes – he ingested an alpha source, it has a high ionising ability and could cause damage to living tissue inside the body

Question 9 **(4 marks)**

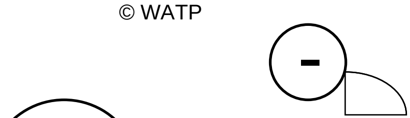
Draw an arrow on each of the following diagrams to indicate the direction in which a net force would be exerted on object A. If you decide that no net force is present, explain your answer.

(a) A negatively charged plate is close to object A, which is also negatively charged. (1 mark)



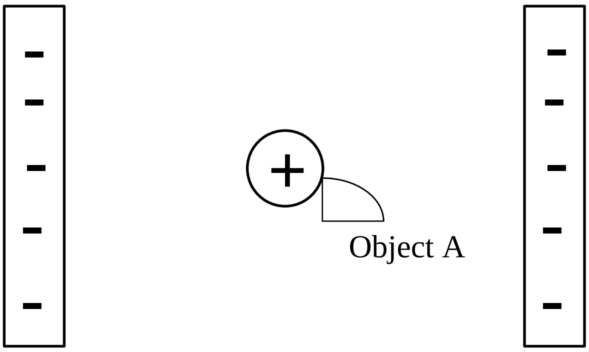
Force would act directly away from the centre of the plate

(b) A positively charged sphere is close to object A, which is negatively charged. (1 mark)



Force would be directed to the centre of the sphere.

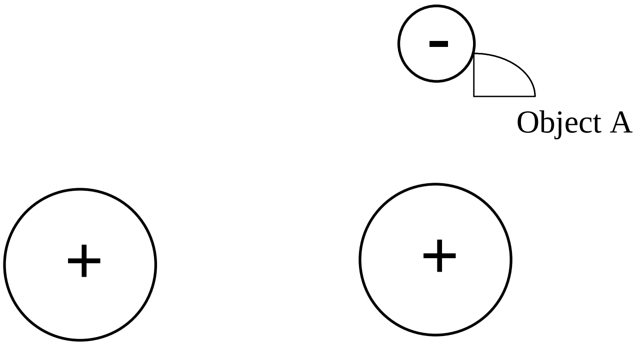
(c) Positively charged object A is between two plates with *equal* negative charges. (1 mark)



No net force should be present (forces cancel out from all directions) – accept two arrows cancelling each other out to show that there is no net force.

(d) Two positively charged spheres are in the same horizontal plane. Point A, which is negatively charged, is directly above one of the spheres. (1 mark)

Force should be at an angle between each of the two balls, but closer to the nearest ball (i..e, the one



directly vertically below A). Two component force arrows is also acceptable.

Question 10 **(4 marks)**

In a Van de Graaff generator a rubber belt rubs against an acrylic plate transferring electrons from the plate to the belt. Calculate the electric current generated when 2.70×10^{18} electrons are transferred to the rubber belt over a period of 5 minutes and 30.0 seconds.

$I = q / t$

$q = 2.70 \times 10^{18} \times 1.6 \times 10^{-19}$ (charge on 1 e^-) = 0.432 C

$t = 5.5 \times 60 = 330$

$I = 0.432 / 330 = 1.31 \times 10^{-3}$ A or 1.31 mA

Question 11 **(4 marks)**

Capacitors store electrical energy by keeping opposite charges separated on parallel metal plates. An insulator between the plates maintains the charge separation.

(a) Briefly explain why charge separation would result in energy being stored. (2 marks)

Work is done in separating the opposite charges – the work that is done is stored as potential energy, which can be released when the charges are allowed to flow towards one another again and convert the potential energy into work.

(b) A battery has some similarities with a capacitor in that there is a separation of charges. The charge separation is achieved by a chemical reaction. If the chemical reaction does 4.50 J of work for each 3.13×10^{18} electrons, what is the voltage of the battery? (2 marks)

$V = W / q$
$W = 4.5$ J
$q = 3.13 \times 10^{18} \times 1.6 \times 10^{-19} = 0.5008$
$V = 4.5 / 0.5008 = 8.99$ V

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

This section contains 7 questions. Answer **all** questions. Answer the questions in the spaces provided. Suggested working time 90 minutes.

Question 12 **(13 marks)**

A 45.5 g block of ice is heated from a temperature of -30.4 °C until it melts completely at 0.00 °C. Heat continues to be applied until the resulting liquid begins to boil at 1.00×10^{2} °C.

(a) Calculate the amount of energy required to heat the block of ice from -30.4 °C until it begins to melt. (2 marks)

$\Delta Q = cm\Delta T$

$\Delta Q = (2100)(0.0455)(0 - (-30.4)) = 2904.72$ J $= 2.90$ kJ

(b) Calculate the amount of energy required to melt the ice. (2 marks)

$\Delta Q = mL$

$\Delta Q = (0.0455)(334 \times 10^3) = 15197$ J = 15.2 kJ

(c) Calculate the amount of energy required to heat the liquid from 0.00 °C to 1.00 x 10^2 °C. (2 marks)

$\Delta Q = mc\Delta T$

$\Delta Q = (0.0455)(4180)(100 - 0) = 19019$ J = 19.0 kJ

(d) Once the liquid had reached its boiling point, calculate the amount of energy required to boil it all off. (2 marks)

$\Delta Q = mL$

$\Delta Q = (0.0455)(2260 \times 10^3) = 102830$ J = 103 kJ

(e) A Bunsen burner supplied all of the heat in this example. Briefly describe how you could estimate the power output of the Bunsen burner, indicating any additional measurements that may be required to make this estimation. (2 marks)

The amount of energy to perform any one of the stages of the experiment has been calculated in the previous questions. If the amount of time was measured for at least one of these stages, the power of the Bunsen can be estimated using: $P = E / t$

(f) If it was determined that the Bunsen burner had a power output of 1.24 kW, calculate the amount of time taken for the solid ice (which was initially at -30.4 °C) to be completely boiled off using this Bunsen burner. (3 marks)

Calculate total energy needed to heat the solid (part (a)), melt the solid (part (b)), heat the liquid (part (c)), and boil off all the liquid (part (d)):

Q_{total} = (a) + (b) + (c) + (d)

$Q_{total} = 2.90 \times 10^3 + 15.2 \times 10^3 + 19.0 \times 10^3 + 103 \times 10^3 = 140.1$ kJ or 1.40×10^5 J

P = E / t => t = E / P

$t = 140.1 \times 10^3 / 1.24 \times 10^3$

t = 112.98 s

t = 113 s or 1 minute 53 seconds

Question 13 **(13 marks)**

A Styrofoam cup has a mass of 48.7 g. After water was added, the combined mass of the cup and the water was 167.3 g. The water had an initial temperature of 25.5 °C. A 23.2 g mass of a metal was heated to a temperature of 99.0 °C and added to the water in the cup. The water and the metal reached thermal equilibrium at a temperature of 26.8 °C.

(a) Calculate the specific heat of the metal. (5 marks)

Mass of water = 167.3 - 48.7 = 118.6 g
Heat gained by the water = heat lost by the metal
$m_{water}c_{water}\Delta T_{water} = m_{metal}c_{metal}\Delta T_{metal}$
$(0.1186)(4180)(26.8 - 25.5) = -(0.0232)(c_{metal})(26.8 - 99)$
$644.472 = c_{metal}(1.67504)$
$c_{metal} = 644.472 / 1.67504 = 384.750$ J kg^{-1} K^{-1} (which roughly corresponds to the specific heat of zinc)
$c_{metal} = 385$ J kg^{-1} K^{-1}

(b) After the metal and water had reached thermal equilibrium, the metal was removed from the water and the metal and the water were both heated separately such that they each received an additional 555 J of heat energy. Assuming no heat energy is lost to the environment, when the metal is placed back in the water, will the metal and the water still be in thermal equilibrium? Explain your answer by including a calculation (if you did not determine the specific heat of the metal in part (a), use a value of 4.00×10^{2} J kg^{-1} K^{-1}). (4 marks)

The change in temperature is inversely proportional to the product of specific heat and the mass of the substance (i.e., $\Delta T = \Delta Q / mc$). Given that both the mass and the specific heat of the metal are smaller than that of the water, the temperature of the metal will increase more than the water if the same amount of energy is applied.

Specifically: For water: $\Delta Q = mc\Delta T \Rightarrow$

$$\Delta T = \Delta Q / mc$$
$$\Delta T = 555 / (0.1186)(4180)$$
$$\Delta T = 1.12\ °C$$

For metal: $\Delta Q = mc\Delta T \Rightarrow$

$$\Delta T = \Delta Q / mc$$
$$\Delta T = 555 / (0.0232)(385)$$
$$\Delta T = 62.1\ °C$$

(or $\Delta T = 59.8$ °C if the 4.00×10^{2} J kg^{-1} K^{-1} value was used)

Therefore, if the same amount of heat energy is applied to each of the water and the metal, the metal will increase in temperature by a larger amount. The metal and the water will therefore not be in thermal equilibrium any longer.

(c) If the Styrofoam cup was not a perfect insulator, how would this affect the determination of the specific heat capacity of the metal (assuming the temperature of the room was lower than that of any of the materials being used)? Explain your answer. (4 marks)

If the Styrofoam cup was not a perfect insulator, some heat energy will be lost to the environment and the equilibrium temperature (T_{final}) will not be as high.

From $m_{water}c_{water}\Delta T_{water} = m_{metal}c_{metal}\Delta T_{metal} \Rightarrow c_{metal} = m_{water}c_{water}\Delta T_{water} / m_{metal}\Delta T_{metal}$

Reduction in equilibrium temperature (i.e., T_{final}) means that ΔT_{water} will be smaller, and ΔT_{metal} will be greater $\Rightarrow c_{metal}$ will appear to be smaller than it really is.

Question 14 **(11 marks)**

Many homes use solar energy to heat water. One design uses solar collectors to directly heat water by the sun. The heated water is then stored for later use. There are two main components to these types of solar hot water systems:

- A solar collector, through which water passes and absorbs thermal energy from the sun. The water typically runs through copper tubes, which transfer the sun's energy; and
- A storage tank that stores hot water from the solar collector.

(a) In one design, the storage tank is located above the solar collector. Water circulates from the collector to the storage tank without the use of a pump. Explain how this happens.

(3 marks)

The warmer water will be less dense as the particles have moved further apart from each other due to thermal expansion. This warmer water will be displaced by the denser colder water and will therefore be pushed upwards to the storage tank

(b) Calculate the internal energy of the water in the system if, over a period of an hour, the sun adds an amount of energy equal to 3.65 MJ to the water, but the system loses 1.40 MJ of its energy to the surroundings. (2 marks)

$\Delta Q_{internal} = W_{work\ done} - \Delta Q_{lost}$

$\Delta Q_{internal} = 3.65 \times 10^6 - 1.40 \times 10^6 = 2.25$ MJ

(c) Calculate the efficiency of the energy storage system from part (b). (2 marks)

Efficiency = useful work done (i.e., energy stored) / energy input x 100%

Efficiency = $2.25 \times 10^6 / 3.65 \times 10^6 \times 100\% = 61.6\%$

(d) If the hot water system holds 3.00×10^2 L of water, calculate the increase in temperature of the water in one hour if the system absorbs 3.45 kW of solar energy (assuming all efficiency losses have been taken into account).

(2 marks)

$m_{water} = 300$ kg (1 L = 1 kg of water)

$E = Pt = 3.45 \times 10^3 \times (60 \times 60) = 12.42$ MJ

$\Delta Q = mc\Delta T \Rightarrow \Delta T = \Delta Q / mc = 12.42 \times 10^6 / (300)(4180) = 9.90$ °C

(e) Heating the water using an electrical heating element would consume 22.0 MJ of energy. If it costs 25.7c per kWhr, how much would it cost for the water to be heated to the same temperature using an electrical heating element. (2 marks)

1 kWhr = 1000 x (60)(60) = 3.6 MJ
Cost = (22 / 3.6) x $0.257 = $1.57

Or
P = Q/t = 22 x 10^6 / 3600 = 6.11 kW in one hour
Cost = 6.11 kWhr x 25.7 c = $1.57

Question 15 **(13 marks)**

Thorium-based nuclear power plants take advantage of the fission of uranium-233, which is produced from thorium decay. The thorium fuel cycle can be represented using the following equations:

$$n + {}^{232}_{90}Th \rightarrow {}^{233}_{90}Th \rightarrow {}^{233}_{91}Pa \rightarrow {}^{233}_{92}U$$

(a) What type of decay does the thorium-233 undergo to form protactinium-233? (1 mark)

β^- decay

(b) What type of decay does the protactinium-233 undergo to form uranium-233? (1 mark)

β^- decay

When used as a fuel, a uranium-233 nucleus can absorb a neutron to form an unstable uranium-234 nucleus, which later decays into zirconium and tellurium:

$$n + {}^{233}_{92}U \rightarrow {}^{93}_{40}Zr + {}^{138}_{52}Te + 3n$$

The masses for the above nuclei, along with a more precise mass for a neutron, are shown below:

mass of a neutron = 1.674929445 x 10^{-27} kg
mass of U-233 = 3.869716824 x 10^{-25} kg
mass of Zr-93 = 1.542749382 x 10^{-25} kg
mass of Te-138 = 2.290370146 x 10^{-25} kg

(c) Calculate the amount of energy in eV released in the above nuclear reaction. (7 marks)

Mass defect is:
n + U-233 – (Zr-93 + Te-138 + 3n)

= 1.674929445 x 10^{-27} + 3.869716824 x 10^{-25} – (1.542749382 x 10^{-25} + 2.290370146 x 10^{-25} + (3 x 1.674929445 x 10^{-27})

$= 3.886466118 \times 10^{-25} - (3.883367411 \times 10^{-25})$

$= 3.098707 \times 10^{-28}$ kg

From $E = mc^2 \Rightarrow E = 3.098707 \times 10^{-28} \times (3.00 \times 10^8)^2 = 2.7888363 \times 10^{-11}$ J

Convert to eV: $2.7888363 \times 10^{-11} / 1.6 \times 10^{-19}$ = 174 302 269 = 174 MeV

Although there are no existing commercial thorium-based reactors, they may prove to be safer than present reactors by enabling greater control over the rate of fission and reducing the chance of nuclear meltdown.

Two features of current nuclear reactors that allow us to control nuclear reaction rates are the *moderator* and the *control rods*.

(d) Briefly describe the function of:

(i) the moderator (2 marks)

The moderator is able to slow down neutrons, which facilitates absorption by the fissile material (e.g., U-235) to allow fission to occur.

(ii) the control rods (2 marks)

Control rods can absorb neutrons, so their presence can slow down the cascading reaction that would otherwise occur of the rods were not present. Lowering more of the control rods into the reactor core will absorb more neutrons and slow the reaction down. Lifting the control rods further out of the core will reduce the amount of neutron absorption, allowing more to be absorbed by the fissile material, effectively speeding the reaction up.

(ii) the radiation shield (2 marks)

So that alpha, beta, gamma cannot penetrate the shield and escape into the environment which protects the workers at the plant.

Question 16 **(11 marks)**

The first nuclear weapon used in warfare was the 'Little Boy' atomic bomb, which was dropped on the Japanese city of Hiroshima on 6 August 1945 during World War II.

The bomb had an estimated blast yield that was equivalent to 15.0 kilotons of TNT being detonated.

(a) Given that one ton of TNT is equivalent to about 4.18 GJ of energy, calculate the mass of fissile material that would have been converted into energy in the explosion. (3 marks)

Total energy given off = $15.0 \times 10^{3} \times 4.18 \times 10^{9} = 6.27 \times 10^{13}$ J

From $\Delta E = \Delta mc^2 \Rightarrow \Delta m = \Delta E / c^2 = 6.27 \times 10^{13} / (3.0 \times 10^{8})^2 = 6.97 \times 10^{-4}$ kg = 0.697 g

The Little Boy atomic bomb contained 64.1 kg of enriched uranium-235.

(b) Calculate the percentage of the mass of the Little Boy's fissile material that was converted into energy (1 mark)

% = mass converted / total mass x 100% = $0.697 \times 10^{-3} / 64.1 \times 100\% = 0.00109\%$

The Little Boy atomic bomb was a 'gun-type' fission weapon. When the bomb was detonated, a 38.5 kg 'bullet' of uranium-235 was fired towards a 25.6 kg 'target' of uranium-235. The combined uranium-235 then began nuclear fission and energy equivalent to 15.0 kT of TNT was released.

(c) Suggest why the atomic bomb didn't undergo a fission reaction prior to the 'bullet' of U-235 combining with the 'target' of U-235. (4 marks)

The two separate masses of U-235 are sub-critical – i.e., their mass and/or shape are such that an uncontrolled chain reaction will not occur as a result of neutrons being produced by the fission of U-235 atoms. When the masses combine, they reach a critical mass at which neutrons produced by fission are absorbed by other U-235 atoms, which in turn produce neutrons and a cascading fission reaction occurs, releasing enormous amounts of energy in a fraction of a second.

(d) Today's most powerful nuclear weapons use a fission reaction to start a fusion reaction. Suggest reasons why nuclear weapons that use a fusion reaction are more powerful than those that only use fission reactions. (3 marks)

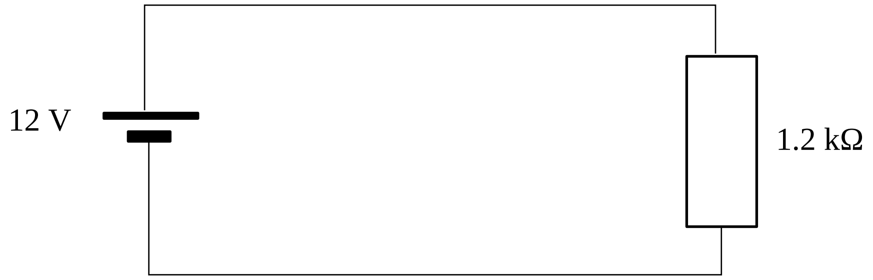
More energy is released per nucleon in nuclear fusion than in nuclear fission. This is due to a larger percentage of the mass being transformed into energy in fusion reactions.

Question 17 **(14 marks)**

A resistor is connected to a 12.0 V battery via conductive wires as shown in the following circuit diagram. The resistor has a value of 1.20 kΩ.

(a) Draw a voltmeter and ammeter on the circuit diagram to show how they would be connected to measure the current and voltage in the circuit. (2 marks)

Connect the ammeter in series with the resistor, and the voltmeter in parallel with the resistor.



(b) Calculate the current flowing through the 1.20 kΩ resistor. (1 mark)

$I = V / R = 12 / 1.2 \times 10^3 = 1.00 \times 10^{-2}$ A or 10.0 mA

(f) Calculate the power that is consumed by the 1.20 kΩ resistor. (2 marks)

$P = VI = 12 \times 1.00 \times 10^{-2} = 1.20 \times 10^{-2}$ W

In the above calculations we have ignored any resistance that the electrical conductors may have.

(g) If the resistance of the electrical conductors was high enough that it had an effect on the circuit, would more or less power be consumed by the 2.20 kΩ resistor? (1 mark)

Less power would be consumed – the additional resistance of the conductors would increase the overall resistance of the circuit, thereby reducing the current flowing through each of the circuit elements. The resistance of the 2.2 kΩ resistor remains the same, so the $P = I^2R$ value would be reduced.

(h) If the electrical conductors were all made of the same conductive material, what would be the effect of the following changes on the overall resistance of the circuit?

(i) longer wires were used (1 mark)

R would increase as there is more 'material' in the way of the electron flow.

(ii) thicker wires were used (1 mark)

R would decrease as there are more 'pathways' for the electrons to flow along.

(iii) the temperature of the wires was increased (1 mark)

R would increase as the particles in the conductor are vibrating faster, increasing the number of 'interactions' with electrons flowing therethrough, thereby providing greater resistance

Section Three: Comprehension **20% (36 marks)**

This section has two questions. Answer **both** questions. Answer the questions in the spaces provided. Suggested working time: 40 minutes.

Question 18 **(15 marks)**

Star Fuel

Two features of a star can be used for classification purposes: its colour and its brightness. By plotting each star's colour against its brightness, they tend to form distinct groups. One of these groups is called the 'main sequence' which corresponds to stars that generate thermal energy by the nuclear fusion of hydrogen atoms into helium. The Sun is an example of a star that is in the main sequence.

The main sequence is typically divided into two parts – upper and lower. Stars that are less than about one and a half times the mass of the Sun are classed in the lower part of the main sequence. Stars in this part generate thermal energy primarily by the fusion of hydrogen atoms into helium in a process known as the proton-proton chain reaction. Stars that have a mass greater than this are classed in the upper part of the main sequence in which hydrogen fusion occurs as part of a set of reactions known as the CNO cycle.

The proton-proton chain reaction involves a number of reactions that occur in sequence. The first of the reactions involves two hydrogen atoms fusing to form a diproton:

$${}^{1}_{1}H + {}^{1}_{1}H \rightarrow {}^{2}_{2}He + \gamma$$

Diprotons are very unstable and can either decay back into two protons, or undergo beta decay to produce deuterium, a positron and an electron neutrino (ν_e), as shown in the following reaction:

$$ {}^{2}_{2}He \rightarrow {}^{2}_{1}H + \beta^{+¿+\nu_e¿} $$

The deuterium can then undergo fusion with a further proton to produce helium-3:

$$ {}^{2}_{1}H + {}^{1}_{1}H \rightarrow {}^{3}_{2}He + \gamma $$

After helium-3 has been produced a number of different reactions can occur to produce helium-4. The main type of fusion reaction that results in the formation of helium-4 is called the ‘pp I’ branch reaction in which two helium-3 nuclei can fuse to form helium-4 and hydrogen.

The pp I branch reaction can be represented as follows:

$$ {}^{3}_{2}He + {}^{3}_{2}He \rightarrow {}^{4}_{2}He + 2\,{}^{1}_{1}H $$

The CNO cycle starts at higher temperatures than the proton-proton chain reaction, and involves four hydrogen nuclei fusing to form helium-4, two positrons and two electron neutrinos. The manner in which the hydrogen nuclei fuse can vary, but typically involve carbon, nitrogen and oxygen atoms acting as catalysts.

Stars in the main sequence rely on a core of hydrogen to provide the fuel for the fusion processes. After a star’s hydrogen has been consumed, it will evolve into a white dwarf directly if its mass is less than about 0.3 times the mass of the Sun, or indirectly by way of first becoming a red giant if its mass is between about 0.3 to 10 times that of the Sun. If the star is super-massive, it may become a supergiant, with the potential of exploding as a supernova.

Regarding the future of our Sun, it is estimated that there was initially enough hydrogen in its core that it would take in the order of ten billion years to be consumed. Over this time, 3.6 x 10^{38} protons are being converted into helium every second, releasing energy at a rate of 3.86 x 10^{26} W. It is about half way through its life as a stable star and is estimated to remain stable for about the next four billion years. The Sun is not massive enough to end its life as a supernova – it will instead become a red giant in about 5.4 billion years.

(a) What does the abbreviation CNO stand for? (1 mark)

Carbon-nitrogen-oxygen

(b) What is a diproton? (1 mark)

A helium atom that comprises only protons

(c) What is deuterium? (1 mark)

Deuterium is Hydrogen-2, i.e., hydrogen that comprises one proton and one neutron

(d) What feature of stars in the upper main sequence facilitates the CNO cycle being the dominant energy production mechanism? (1 marks)

Higher temperatures, which is a result of the star having a mass that is greater than one and a half that of the Sun

(e) Determine the amount of energy released in the pp I branch reaction given the following information: (4 marks)

mass of a proton = $1.67262178 \times 10^{-27}$ kg
mass of a helium-3 nucleus = $5.008237929 \times 10^{-27}$ kg
mass of a helium-4 nucleus = $6.646483608 \times 10^{-27}$ kg

$$^{3}_{2}He + ^{3}_{2}He \rightarrow ^{4}_{2}He + 2\,^{1}_{1}H$$

Mass of reactants = $2 \times 5.008237929 \times 10^{-27}$ kg = $10.01647586 \times 10^{-27}$
Mass of products = $1 \times 6.646483608 \times 10^{-27}$ kg + ($2 \times 1.67262178 \times 10^{-27}$) = $9.991727168 \times 10^{-27}$

Therefore mass defect = $10.01647586 \times 10^{-27} - 9.991727168 \times 10^{-27} = 2.4748692 \times 10^{-29}$ kg

From $E = mc^2$ => $E = 2.4748692 \times 10^{-29} \times (3.00 \times 10^{8})^2 = 2.22738228 \times 10^{-12}$ J

(if answered in eV: $2.22738228 \times 10^{-12} / 1.6 \times 10^{-19}$ = 13 921 139 eV = 13.9 MeV)

(f) Write a reaction equation for the fusion of the four protons to form helium-4. (3 marks)

The text states that "four hydrogen nuclei fus(e) to form helium-4, two positrons and two electron neutrinos". This could be represented with the following equation:

$$4\,^{1}_{1}H \rightarrow ^{4}_{2}He + +2\,^{0}_{1}\beta + 2\nu_e$$

or $4\,^{1}_{1}H \rightarrow He + +2\,^{40}_{21}e^{+¿+2\nu_e}¿$

(g) Consider the following statement: "A star that has a mass that is 6.7 times that of the sun will not become a white dwarf, and will instead become a red giant". Is this statement true or false? Justify your answer. (1 marks)

False – although the star will become a red giant, it will eventually form into a white dwarf.

(h) Given that the total number of protons that fuse to form helium over the life of the Sun represents 10% of the mass of the Sun, provide an estimate for the total mass of the Sun. (3 marks)

SEE NEXT PAGE

The text states that 3.6 x 10^{38} protons are fusing each second over a time of 10 billion years. This amount represents 10 % of the mass of the Sun. Therefore:

Mass of Sun = (number of protons going through fusion x mass of proton) / 0.1

Mass of Sun = (3.6 x 10^{38} x (10 x 10^{9} x 365 x 24 x 60 x 60) x 1.67 x 10^{-27}) / 0.1

Mass of Sun = 1.89 x 10^{30} kg = 1.9 x 10^{30} kg

It is acceptable if the student interpreted the text to imply that the Sun is halfway through its life with 4 billion years left to go – i.e., the total time is 8 billion years

Using 8 billion years gives: Mass of Sun = 1.5 x 10^{30} kg

Question 19 **(21 marks)**

Conductance

The ‘specific conductance’ of a material provides an indication as to its ability to conduct electricity. Specific conductance is represented by the symbol σ, and is measured in siemens per metre (S m^{-1}). The conductance of a material will increase as the material’s cross-sectional area increases, and decrease with the length of the material. This leads to the general expression:

$$G=\sigma\frac{A}{l}$$

where:

G is the electrical conductance of the material (S);

A is cross-sectional area of the material (m^2);

l is length of the material (m); and

σ is the specific conductance of the material (S m^{-1}).

Electrical conductance, G, can also be defined by its relationship to current and voltage. In particular, electrical conductance is defined as:

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

where:

I is the current flowing through the material (A); and

V is the voltage across the material (V).

The specific conductance of some materials is shown in the table below:

Material	**Specific Conductance (S m^{-1})**
Carbon (graphene)	1.00×10^8
Copper	5.96×10^7
Aluminium	3.50×10^7
Platinum	9.43×10^6
Lead	4.55×10^6

An experiment was conducted to determine the specific conductance of a particular type of metal. The metal was formed into a series of wires that all had the same length, but different diameters. Each of the metal wires was connected to a DC voltage source, and both the current flowing through and the voltage drop across the material was measured to determine the electrical conductance of the material. A 100 Ω resistor was connected in series with the metal wire to reduce the maximum current flowing through the circuit. The following results were obtained as a result of the experiment:

Length of the metal wire (m)	Diameter of the metal wire (mm)	Area of the metal wire (m^2)	Voltage drop across the metal wire (V)	Current flowing through the metal wire (A)	Conductance (S)
0.100	0.100	0.785×10^{-8}	0.260	1.175	4.52
0.100	0.150	1.77×10^{-8}	0.120	1.189	9.91
0.100	0.200	3.14×10^{-8}	0.0640	1.194	18.7
0.100	0.250	4.91×10^{-8}	0.0420	1.196	28.5
0.100	0.300	7.07×10^{-8}	0.0284	1.198	42.2

(a) Complete the table by filling out the values for electrical conductance of the wire, and the missing values for the cross-sectional area (some of the values for the area have been filled in for you). (3 marks)

(b) State the independent variable in the above experiment (1 mark)

The diameter of the wire or the area of the wire

(c) State the dependent variable in the above experiment. (1 mark)

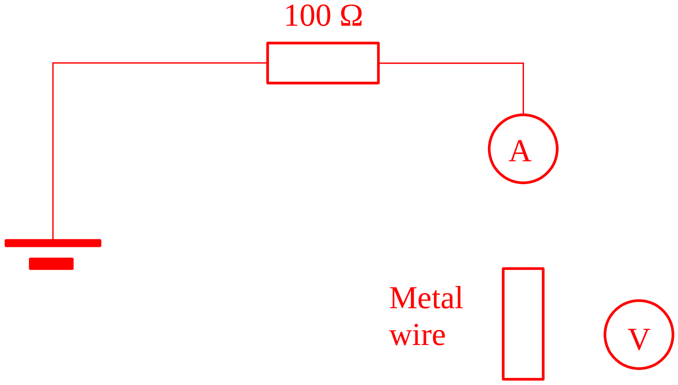
The electrical conductance of the wire (or voltage and current of the wire, which are used to derive the electrical conductance of the metal wire)

(d) State two controlled variables in the above experiment. (2 marks)

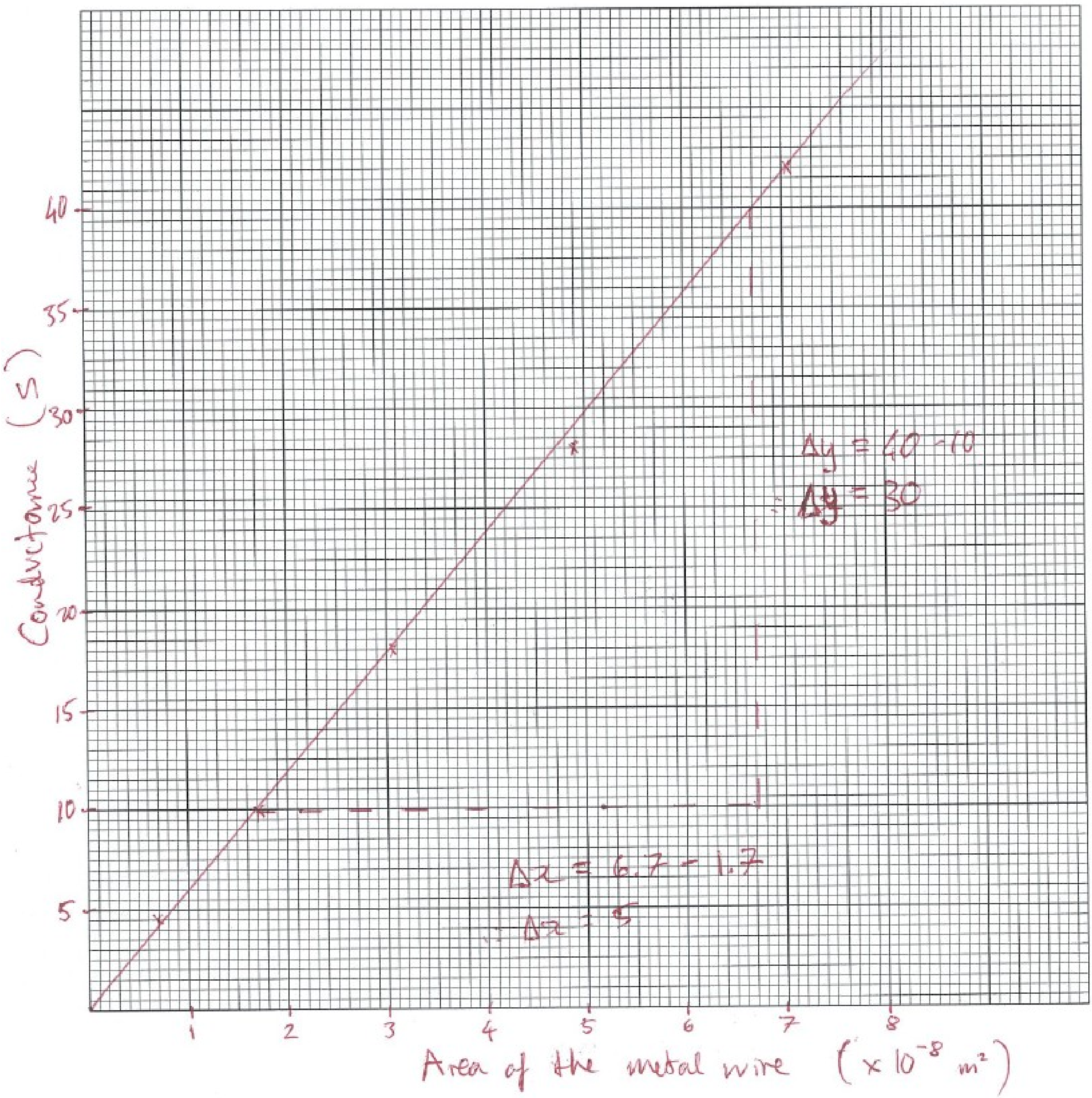
1. The length of the wire
2. The type of metal that the wire is made from

(e) Draw a circuit diagram to show how these results were obtained. Include the ammeter and voltmeter and other circuit elements described in the experimental set-up. (2 marks)

(f) Plot a graph of electrical conductance against the cross-sectional area of the wire. (4 marks)



Electrical conductance vs. cross-sectional area



(g) Determine the gradient of the graph. (3 marks)

Gradient = rise /run = (40 – 10) / ((6.7 – 1.7) x 10^{-8}) = 30 / (5 x 10^{-8}) = 6.00 x 10^{8} S m^{-2}

A range of answers are acceptable here – from about 5.7 to 6.3 10^8 S m^{-2}

(h) Hence calculate the specific conductance of the material (3 marks)

$G = \sigma \frac{A}{l}$ =>

Gradient of the graph = G /A

From the equation: $G = \sigma \frac{A}{l}$ => G/A = σ / l

i.e.: gradient = σ / l

rearranging: σ = gradient x l

$\sigma = 6.00 \times 10^8 \times 0.1 = 6.00 \times 10^7$ S m^{-1}

(i) Use the table of specific conductances to identify the material (2 marks)

$\sigma = 6.00 \times 10^8 \times 0.1 = 6.00 \times 10^7$ S m^{-1} is closest to copper (5.96×10^7 S m^{-1})

END OF SECTION THREE