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**PHYSICS**

**UNIT 1**

**2022**



MARKING KEY

***TIME ALLOWED FOR THIS PAPER***

Reading time before commencing work: Ten minutes

Working time for the paper: Three hours

***MATERIALS REQUIRED/RECOMMENDED FOR THIS PAPER***

**To be provided by the supervisor:**

* This Question/Answer Booklet
* Formula and Data Booklet

**To be provided by the candidate:**

* Standard items: pens (blue and black preferred), pencils (including coloured), sharpener, correction fluid/tape, eraser, ruler, highlighters.
* Special items: up to three calculators, which do not have the capacity to store programmes or text, are permitted in this ATAR course examination, drawing templates, drawing compass and a protractor.

***IMPORTANT NOTE TO CANDIDATES***

No other items may be taken into the examination room. It is **your** responsibility to ensure that you do not have any unauthorised material. If you have any unauthorised material with you, hand it to the supervisor **before** reading any further.

**Structure of this paper**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Section | Number of questions available | Number of questions to be answered | Suggested working time  (minutes) | Marks available | Percentage of exam |
| Section One:  Short answer | 11 | 11 | 50 | 54 | 30 |
| Section Two:  Extended answer | 6 | 6 | 90 | 90 | 50 |
| Section Three:  Comprehension  and data analysis | 2 | 2 | 40 | 36 | 20 |
|  |  |  | **Total** | 180 | 100 |

**Instructions to candidates**

1. The rules for the conduct of Western Australian external examinations are detailed in the *Year 11 Information Handbook 2022: Part II Examinations.* Sitting this examination implies that you agree to abide by these rules.
2. Write your answers in this Question/Answer booklet preferably using a black/blue pen. Do not use erasable or gel pens.
3. You must be careful to confine your answers to the specific questions asked and 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.

1. 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 in the original answer where the answer is continued, ie – give the page number.
2. 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 **eleven (11)** 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 balloon contains helium gas and nitrogen gas. The gases are at a common temperature of 25°C.

1. Describe the relative speeds of the gas particles. Explain your answer.

(3 marks)

|  |  |
| --- | --- |
| The particles in each gas will possess the same average kinetic energy (same temperature). | 1 mark |
| Mass of nitrogen particles > mass of helium particles. | 1 mark |
| Hence, average speed of nitrogen particles < average speed of helium particles. | 1 mark |

1. The gases are heated to 50°C. Describe any change you would expect to notice in the balloon. Explain your answer using the Kinetic Theory.

(3 marks)

|  |  |
| --- | --- |
| The balloon will expand. | 1 mark |
| Increase in temperature of gases mean particles will travel faster. | 1 mark |
| Particles collide more frequently and with more force with the walls of the balloon. | 1 mark |

**Question 2 (6 marks)**

A worker in a uranium mine is exposed to three different types of radiation: alpha, beta and gamma. The worker has a mass of 95.5 kg and absorbs 10.7 J of ionising radiation. The worker estimates that 25.0% of this is due to alpha radiation; 30.0% due to beta radiation; and 45.0% due to gamma radiation. It is assumed that this is a full-body exposure.

1. Calculate the dose equivalent the worker received.

(4 marks)

|  |  |
| --- | --- |
|  | 1 mark |
|  | 1 mark |
|  | 1 mark |
|  | 1 mark |

1. During their line of work, workers in uranium mines have dust from minerals landing on their clothing that emit all three types of radiation: alpha, beta and gamma. Which of these emissions do they need most protection from? Explain.

(2 marks)

|  |  |
| --- | --- |
| Gamma radiation. | 1 mark |
| This type of radiation is able to penetrate through the workers’ clothing and skin to the interior of their body. | 1 mark |

**Question 3 (4 marks)**

A flashlight operates with a 3.00 V DC battery and draws a current of 0.500 A when it is operating.

1. Calculate the maximum amount of energy in Joules (J) supplied to each electron in the filament’s circuit.

(2 marks)

|  |  |
| --- | --- |
|  | 1 mark |
|  | 1 mark |

1. Calculate the number of electrons that pass through the flashlight’s filament during a 10.0 second operation.

(2 marks)

|  |  |
| --- | --- |
|  | 1 mark |
|  | 1 mark |

**Question 4 (6 marks)**

An aluminium kettle of mass 1.05 kg contains a quantity of water at a room temperature of 23.0 °C. The kettle has a power rating of 1.80 x 103 W and it takes 2.00 minutes to raise the temperature of the water to 75.0 °C. Assuming no heat is lost to the surroundings, calculate the mass of the water in the kettle.

[Specific heat capacity of aluminium = 904 J kg-1° C-1]

|  |  |
| --- | --- |
|  | 1 mark |
|  | 1 mark |
|  | 1 mark |
|  | 1 mark |
|  | 1 mark |
|  | 1 mark |

**Question 5 (4 marks)**

Cosmic radiation consists of high-speed protons (50%) and alpha particles (50%). Both of these ionising radiation sources are extremely dangerous to humans and astronauts must be protected from them. Their quality factors are shown below:

|  |  |
| --- | --- |
| **TYPES OF COSMIC RADIATION** | **QUALITY FACTORS** |
| **High-speed protons** | **10** |
| **Alpha particles** | **20** |

During a typical 8-day Space Shuttle Mission, a 78.5 kg astronaut can expect the following dose equivalents (in mSv) for their cosmic ray exposure:

|  |  |
| --- | --- |
| **TYPES OF COSMIC RADIATION** | **DOSE EQUIVALENT (mSv)** |
| **High-speed protons** | **3.60** |
| **Alpha particles** | **2.00** |

In the space below, calculate the total quantity of ionising radiation (in Joules, J) absorbed by the astronaut during this Space Shuttle mission.

|  |  |
| --- | --- |
|  |  |
|  | 1 mark |
|  | 1 mark |
|  | 1 mark |
|  | 1 mark |

**Question 6 (4 marks)**

A Physics student is examining the safety features associated with a toaster. They are able to identify the following protections:

RESIDUAL CURRENT DEVICE (RCD); CIRCUIT BREAKERS; EARTH WIRE

The student considers the following scenario:

The toaster malfunctions and does not eject the bread. The user decides to get the toast out with a metal knife.

1. Describe why this action is potentially dangerous.

(2 marks)

|  |  |
| --- | --- |
| The metal knife is a conductor and could cause a live connection with the heating element which will be at 240 V. | 1 mark |
| This could cause an electric current to flow from the user’s hand to their feet to the earth; ie - electrocution. | 1 mark |

1. Explain how one of the safety features on the list above will protect the user in this situation.

(2 marks)

|  |  |
| --- | --- |
| The current flowing through the user will mean that the current in the active wire will often be different to the current in the neutral wire. | 1 mark |
| This will cause the RCD to open and cut off current flow to the toaster and the user. | 1 mark |

**Question 7 (4 marks)**

Jenny loves a cup of iced tea - and she likes it being ice cold. On a particular day, she brews a pot of tea which contains 0.255 kg of water at 90.0°C. She keeps adding ice at 0.00°C until the water reaches 2.00°C. The pot can be assumed to have no thermal properties and no heat is lost to the surroundings. Calculate the mass of ice that must be added to the water to achieve this.

|  |  |
| --- | --- |
|  | 1 mark |
|  | 1 mark |
|  | 1 mark |
|  | 1 mark |

**Question 8 (5 marks)**

Polonium-218 is an alpha emitter. During this transmutation, it produces the isotope lead-214.

The atomic masses of the particles involved in this decay are:

Po-218: 218.008966 u

Pb-214: 213.999805 u

He-4: 4.002603 u

1. Write a balanced nuclear equation for this alpha decay.

(2 marks)

|  |  |
| --- | --- |
|  |  |
| Correct species | 1 mark |
| Atomic numbers and mass numbers balanced | 1 mark |

1. Calculate the energy released (in MeV) during this decay.

(3 marks)

|  |  |
| --- | --- |
|  | 1 mark |
|  | 1 mark |
|  | 1 mark |

**Question 9 (4 marks)**

A filament lamp or incandescent light globe is a good example of a non-ohmic resistor. Its resistance is low for low potential differences. The resistance rises as the potential difference increases and the temperature of the filament rises.

1. Using the information provided, sketch a ‘Current (I)’ vs ‘Voltage (V)’ graph for a filament in an incandescent light globe on the axes below. No values are required.

(2 marks)

VOLTAGE

CURRENT

|  |  |
| --- | --- |
| Curved graph (not linear). | 1 mark |
| Correct shape (see above). | 1 mark |

1. Explain why the temperature of the filament of an incandescent light globe increases over time once current begins to flow through it. In your answer, consider the collisions that electrons undergo as they flow through the filament.

(2 marks)

|  |  |
| --- | --- |
| The electrons collide with atoms in the filament which impede their motion. | 1 mark |
| Each collision cause energy loss from the electrons in the form of heat. | 1 mark |

**Question 10 (6 marks)**

Water is being heated in a metal pan on an electric heating element as shown below. The handle for the pan is covered in hard plastic.

Water

Metal pan

Handle

Electric heating element

1. State the form of heat transfer that is primarily responsible for the electric heating element initially heating the water.

(1 mark)

|  |  |
| --- | --- |
| Conduction | 1 mark |

1. In terms of heat transfer, explain why the handle of the pan is made of plastic.

(2 marks)

|  |  |
| --- | --- |
| Plastic is a poor conductor. | 1 mark |
| This prevents conduction of heat from the pan to the hand of a user, this preventing burns. | 1 mark |

1. It is found that placing a lid over the pan allows the temperature of the water to rise more quickly. In terms of heat transfer, explain why this is the case.

(3 marks)

|  |  |
| --- | --- |
| Heat is transferred to the air above the water via conduction. | 1 mark |
| The hotter air just above the water rises and transfers heat away from the water via convection. | 1 mark |
| The lid prevents this air from rising and halts the convection of heat from the pan. | 1 mark |

**Question 11 (5 marks)**

A firm that produces thin sheets of plastic (less than one millimetre thickness) for laminating monitors the thickness of these to ensure that they are within a given tolerance. The sheets are passed between two rollers whose distance apart matches this required thickness. This distance can gradually vary over time. So, a detection system is used to monitor the thickness of the plastic sheets which, in turn, controls the distance between the rollers. This monitoring system consists of a radioactive source and a detector. See diagram below.

Radiation detector

Roller

Radiation source

Plastic sheet

Roller

Describe how this monitoring system works using concepts you have learned in nuclear science. As part of your answer, explain which type of nuclear radiation emitter the source would need to be as shown in the diagram.

|  |  |
| --- | --- |
| The radiation source would need to be a beta emitter. | 1 mark |
| Alpha radiation would be completely absorbed by the sheets; gamma radiation would completely penetrate through the sheets. | 1 mark |
| When the sheets are at the required thickness, the detector will obtain a particular reading. | 1 mark |
| If the sheet is too thick, more beta radiation is absorbed and the reading will decrease below the required reading. Vice versa if the sheet is too thin. | 1 mark |
| When the reading is too low, the rollers are moved closer together. Vice versa if reading is too high. | 1 mark |

**End of Section One**

**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 12 (16 marks)**

A group of students conduct an investigation to identify a metal by determining its unique resistivity measurement. The resistivity of a material is a measure of the opposition to flow of electric charge through that material. It is unique to each material and, like resistance, is also dependent on temperature – especially in materials that are non-ohmic conductors.

Resistivity values for some materials are shown below. The students know that their unknown material is on this list.

|  |  |
| --- | --- |
| MATERIAL | RESISTIVITY (x10-8 Ωm) |
| copper | 1.59 |
| aluminium | 2.65 |
| tungsten | 5.60 |
| iron | 9.71 |

The students know that the overall resistance of a conductor (measured in Ohms, Ω) can be calculated using the following formula:

**Where:**

**R = resistance of conductor (Ω)**

**ρ = resistivity of conductor (Ωm)**

**L = length of conductor (m)**

**A = cross-sectional area (m2)**

**L = length**

**A = area**

The students decide to build a circuit that allows them to measure the potential difference across - and current flowing through - a wire made of the unknown material. The circuit will be built in such a way that it allows the length of the wire in the circuit to be varied. The students have the following pieces of equipment at their disposal:

One (1) metre of the wire made of the unknown material; 1 x voltmeter; 1 x ammeter; 1 x battery; 1 x switch; 1 x rheostat; 1 x one metre ruler; as many wires and alligator clips as required.

1. In the space below, the wire is shown. Complete a circuit diagram using the relevant symbols to illustrate the circuit that the students will build in their experiment.

(3 marks)

V

A

|  |  |
| --- | --- |
| See circuit diagram above. |  |
| Ammeter in series with wire; voltmeter in parallel with wire. | 1 mark |
| All other components (rheostat, switch, power supply) in series with the wire. | 1 mark |
| All circuit symbols correct. | 1 mark |

The students conduct their experiment and gather the data shown below:

**Cross-sectional area ‘A’ = 2.00 x 10-7 m2**

|  |  |  |  |
| --- | --- | --- | --- |
| **L (m)** | **V (V)** | **I (A)** | **R (Ω)** |
| **0.200** | **0.10** | **3.70** | **0.0270** |
| **0.400** | **0.21** | **3.79** | **0.0554** |
| **0.600** | **0.37** | **4.41** | **0.0839** |
| **0.800** | **0.51** | **4.60** | **0.111** |
| **1.00** | **0.72** | **5.25** | **0.137** |

1. There is one value missing in the ‘R’ column in the table. Calculate this value and place it in the table. Shown clearly how you did this calculation in the space below.

(2 marks)

|  |  |
| --- | --- |
|  | 1 mark |
|  | 1 mark |

1. On the grid provided on the next page, draw a graph of ‘Length’ versus ‘Resistance’. Plot ‘Length’ on the horizontal axis. Draw a line if best fit for the data.

(4 marks)

L (m)

R (Ω)

|  |  |
| --- | --- |
| Axes labelled correctly (‘L’ on horizontal axis). | 1 mark |
| Correct units supplied on both axes. | 1 mark |
| Points plotted correctly. | 1 mark |
| Line of best fit plotted correctly. | 1 mark |

1. Calculate the gradient of the line of best fit you have drawn. Show clearly how you did this. Include units in your answer.

(3 marks)

|  |  |
| --- | --- |
| Uses point from the line of best fit: (1.00, 0.14) and (0.150, 0.020) | 1 mark |
|  | 1 mark |
| Units: Ω m-1 (ohms per metre) | 1 mark |

1. Use the gradient in part d) to calculate the resistivity (ρ) of the unknown material.

(3 marks)

|  |  |
| --- | --- |
|  | 1 mark |
|  | 1 mark |
|  | 1 mark |

1. Hence, identify the unknown material.

(1 mark)

|  |  |
| --- | --- |
| Aluminium | 1 mark |

**Question 13 (14 marks)**

Whilst making a cup of coffee, 355 mL of hot water is added to a 320.0 g ceramic coffee mug. Both reach a common temperature of 90.0°C.

It is known that water at this temperature can cause third degree burns – so a decision is made to cool it down to 55.0 °C. This is achieved by adding ice at -8.50 °C until this final cooler temperature is achieved.

Assume no heat is transferred to the surroundings.

1. Show that the heat energy lost by the water and the ceramic mug as their temperature drops to 55.0 °C is approximately 7.00 x 104 J. The specific heat capacity of ceramic is 1.49 x 103 J kg-1 °C-1.

(3 marks)

|  |  |
| --- | --- |
|  | 1 mark |
|  | 1 mark |
|  | 1 mark |

1. The mass ‘m’ of the ice added is unknown. In terms of ‘m’, calculate the thermal energy gained by the ice as it is heated to 55.0 °C.

(5 marks)

|  |  |
| --- | --- |
|  | 2 marks |
|  | 2 marks |
|  | 1 mark |

1. Hence, use the answers form parts a) and b) to calculate ‘m’ - the unknown mass of ice added.

[Note: if you were unable to calculate and answer for part a), use 7.00 x 104 J. If you were unable to get an answer for part b), use m x 6.00 x 105 J]

(3 marks)

|  |  |
| --- | --- |
|  |  |
|  | 1 mark |
|  | 1 mark |
|  | 1 mark |

1. Instead of a ceramic mug, a Styrofoam cup (which is an effective thermal insulator) is used. State and explain the effect on the amount of ice that would have to be used to cool the coffee to 55.0 °C when compared to using a ceramic cup. Assume no heat is lost to the surroundings.

(3 marks)

|  |  |
| --- | --- |
| The Styrofoam cup will not absorb or release any thermal energy. | 1 mark |
| Hence, the only substance that needs to be cooled to 55.0 °C is the hot water. | 1 mark |
| Hence, less ice is required. | 1 mark |

**Question 14 (14 marks)**

One possible nuclear fission reaction is shown below:

The atomic masses of the isotopes and neutrons that take part in this fission reaction are listed below:

|  |  |
| --- | --- |
| **m(U-235)** | **235.043928 u** |
| **m(neutron)** | **1.00867 u** |
| **m(Zr-94)** | **93.906313 u** |
| **m(Te-139)** | **138.93473 u** |

* 1. (i) Calculate the mass defect for the fission reaction.

(3 marks)

|  |  |
| --- | --- |
| Mass of reactants = 235.043928 + 1.00867 = 236.052598 u | 1 mark |
| Mass of products = 93.906313 + 138.93473 + 3 x 1.00867 = 235.867053 u | 1 mark |
| Mass defect = 236.052598 - 235.867053 = 0.186 u | 1 mark |

(ii) Hence, calculate the energy released by one fission reaction (in MeV).

[If you were unable to calculate a value for part (i), use 0.20000 u]

(2 marks)

|  |  |
| --- | --- |
| Energy released = 0.185545 x 931 | 1 mark |
| = 173 MeV (186 MeV) | 1 mark |

Nuclear reactors typically use ‘low-enriched uranium’ as the fuel for power generation. This fuel consists mostly of two isotopes of Uranium – Uranium-235 (which is fissile) and Uranium-238 (which is not fissile).

The concentration of U-235 in low-enriched uranium by mass is 5.00%; the concentration of U-238 is 95.0%.

* 1. Calculate the maximum total energy that could be released by this 10.0 kg sample of low-enriched Uranium (in Joules). Assume that the energy is released exclusively by the nuclear fission reaction above.

(5 marks)

|  |  |
| --- | --- |
|  | 1 mark |
|  | 1 mark |
|  | 1 mark |
|  | 1 mark |
|  | 1 mark |

Whilst nuclear fission reactors generate a sizable proportion of the world’s electricity, it hoped that nuclear fusion will replace these reactors in the future.

* 1. In the table below, state four (4) differences between nuclear fission and nuclear fusion.

(4 marks)

|  |  |
| --- | --- |
| Any four (4) of the following – one (1) mark each to a maximum total of four (4) marks: |  |
| Fuel for fusion is hydrogen; fuel for fission is uranium. | 1 mark |
| Fuel for fusion is light nuclei; fuel for fission is heavy nuclei. | 1 mark |
| Fuel for fusion is a very common element; fuel for fission is a very rare isotope. | 1 mark |
| Fusion – joining of two nuclei; fission – splitting of one nuclei. | 1 mark |
| Fusion power has a higher energy yield than fission power. | 1 mark |
| Fusion power not yet commercially viable; fission power is commercially viable. | 1 mark |
| Fusion power does not produce long-term radioactive waste; fission power produces long-term radioactive waste. | 1 mark |
| Any other reasonable responses. | 1 mark |

**Question 15 (15 marks)**

A student constructs the circuit below to investigate current, voltage and electric power. Note the positions of the ammeter and voltmeter. In the questions that follow, the resistance of the connecting wires and the power source are equal to zero.

**R4 = 5.00 Ω**

**R3 = 5.00 Ω**

**R2 = 5.00 Ω**

**R1 = 10.0 Ω**

**24.0 V**

**J**

**H**

**G**

**F**

**E**

**D**

**C**

**B**

**A**

**A**

**V**

1. Show with a calculation that the combined resistance between ‘C’ and ‘J’ is about 3 Ω.

(3 marks)

|  |  |
| --- | --- |
|  | 1 mark |
|  | 1 mark |
|  | 1 mark |

1. Hence, show with a calculation that reading on the ammeter is 1.80 A.

(2 marks)

|  |  |
| --- | --- |
|  | 1 mark |
|  | 1 mark |
|  | 1 mark |

1. Hence, calculate the reading on the voltmeter.

(3 marks)

|  |  |
| --- | --- |
|  | 1 mark |
| dd | 1 mark |
|  | 1 mark |

1. Calculate the power generated in R4.

(3 marks)

|  |  |
| --- | --- |
|  | 1 mark |
|  | 1 mark |
|  | 1 mark |

1. During the experiment, a break in the circuit occurs between ‘C’ and ‘D’. Without performing any calculations, explain how the readings in the ammeter and voltmeter changed compared to before the break occurred.

(4 marks)

|  |  |
| --- | --- |
| The break between ‘C’ and ‘D’ removes R3 and R4 from the circuit. | 1 mark |
| This creates an increase in the overall resistance of the circuit. | 1 mark |
| Overall circuit voltage remains constant; hence, the overall current through both R1 and R2 and the ammeter decreases. | 1 mark |
| Voltmeter reading increases since resistance of that part of the network increases relative to R1. | 1 mark |

**Question 16 (17 marks)**

Radiocarbon dating is a process that is used to determine the age of fossilised bones. All living cells contain the element carbon – the vast majority of which is the stable isotope carbon-12 and the radioisotope carbon-14 (which is a beta emitter (β-) and has a half-life of 5730 years).

In a living organism, the ratio of carbon-14 : carbon-12 nuclei is a constant value of about 1:100 000. After an organism dies, this ratio decreases.

1. Write a nuclear equation for the beta decay (β-) of carbon-14.

(3 marks)

|  |  |
| --- | --- |
|  |  |
| Correct symbols used | 1 mark |
| Atomic numbers balanced. | 1 mark |
| Mass numbers balanced. | 1 mark |

1. Explain why the carbon-14 : carbon-12 nuclei ratio decreases after an organism dies.

(3 marks)

|  |  |
| --- | --- |
| When an organism dies, it stops ingesting carbon/maintaining its carbon levels via eating, etc. | 1 mark |
| The carbon-12 level remains stable – its quantity does not change after the organism dies. | 1 mark |
| Carbon-14 is an unstable radioisotope – it decays and its quantity, therefore, reduces after the organism dies. | 1 mark |

1. A carbon-14 nucleus has a mass of 14.00324 u. A proton has a mass of 1.00727 u; a neutron has a mass of 1.00867 u. Use this data to calculate the binding energy per nucleon of carbon-14.

(4 marks)

|  |  |
| --- | --- |
|  | 1 mark |
|  | 1 mark |
|  | 1 mark |
|  | 1 mark |

d) Compare and explain the difference in the binding energy per nucleon between a carbon-12 and a carbon-14 nucleus.

(3 marks)

|  |  |
| --- | --- |
| BE/nucleon (C-12) > BE/nucleon (C-14) | 1 mark |
| C-12 atoms are stable; C-14 atoms are unstable. | 1 mark |
| Hence, C-14 atoms have inadequate BE/nucleon to hold the nucleons together in a stable formation. | 1 mark |

e) A fossilised bone is analysed and it is found that the carbon-14 : carbon-12 ratio has decreased to 15.0% of its value for a living organism. Using the half-life of carbon-14, estimate a value for the age of the fossilised bone.

(4 marks)

|  |  |
| --- | --- |
|  | 1 mark |
|  | 1 mark |
|  | 1 mark |
| 1 or 2 significant figures | 1 mark |

**Question 17 (14 marks)**

The diagram below shows the structure of an old-fashioned incandescent light globe mounted on a wall. The light operates for 4.50 hours every day.

The structure of the globe is as follows:

* Glass bulb enclosing a vacuum.
* Metal filament located inside the glass bulb; connected to the 240 V mains supply - this produces the light and excess heat.

filament

vacuum

glass bulb

The light globe has a power rating of 60.0 W.

1. Calculate the resistance of the light globe’s filament.

(3 marks)

|  |  |
| --- | --- |
|  | 1 mark |
|  | 1 mark |
|  | 1 mark |

1. If electrical energy costs 28.5 cents per kilowatt hour, calculate the cost of operating this light globe for 4.50 hours.

(3 marks)

|  |  |
| --- | --- |
|  | 1 mark |
|  | 1 mark |
|  | 1 mark |

Incandescent light globes are only 10.0% efficient. The wasted energy is given off as heat.

1. Calculate the quantity of heat energy generated by the light globe in 4.50 hours.

(3 marks)

|  |  |
| --- | --- |
|  | 1 mark |
|  | 1 mark |
|  | 1 mark |

1. The light globe is switched on and, after one minute, an observer notices that if they touch the glass bulb – or even hold their hand next to the globe – their hand feels hot.

Explain how the glass bulb gets so hot, even though the bulb contains a vacuum.

(3 marks)

|  |  |
| --- | --- |
| Thermal energy is being transferred to the glass bulb via absorption of thermal radiation. | 1 mark |
| Radiation is a method of heat transfer that requires no medium for its transfer. | 1 mark |
| The glass bulb then conducts heat to the cooler fingers of the observer and the air surrounding it. | 1 mark |

1. The observer notices that if they hold their hand above the light globe it feels hotter than if they hold it underneath. Explain.

(2 marks)

|  |  |
| --- | --- |
| The hot air above the globe will rise to the person’s hand due to convection. | 1 mark |
| The hot air below the globe will rise away from the person’s hand. | 1 mark |

**End of Section Two**

**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.

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 40 minutes.

**Question 1 (18 marks)**

**Racing toward Absolute Zero**

The coldest theoretical temperature allowed by thermodynamics is called ‘absolute zero’ – a temperature that is colder than outer space. This temperature is assigned a value of zero degrees kelvin and is equal to −273.15 degrees Celsius or -459.67 degrees Fahrenheit. This is technically the temperature when a ‘system’ (such as a thermometer) reaches its lowest possible energy.

Humans have an intuitive understanding of temperature due to their experience with the sensations of feeling ‘hot’ and ‘cold’. However, what humans are really experiencing in situations where they are distinguishing between hot and cold objects is the amount of internal energy that these objects contain. Internal energy is partly defined by the amount of movement the particles in an object have (ie – their ‘thermal motion’). An ice cube, for example, contains less internal energy than a cup of hot water because its particles are not moving as much as in the water. At absolute zero, the thermal motion of the particles would be at their minimum.

The concept of ‘absolute zero’ first emerged in the early 1700’s when a French physicist and inventor called Guillaume Amontons related temperature to the amount of heat in a system. Amontons hypothesised that there would be a minimum amount of heat a system could possess and that this would correspond to a minimum temperature.

In the early 1900’s, the Dutch physicist, Heike Onnes, used several precooling stages and a process called the Hampson-Linde Cycle to liquefy helium gas for the first time. In this experiment, he lowered the helium gas to a temperature just below its boiling point: -269 °C.

Onnes’ high-powered cooling system has been adopted by refrigeration systems used in physics laboratories around the world. The cooling process is like that which occurs when you blow on a hot beverage.

The latest step in the quest to achieving absolute zero is being pursued by the Quantum Matter Team at the University of Cambridge’s Cavendish Laboratory. As they lower the temperature of materials to super-cold levels, they are discovering exotic quantum properties that only emerge at these temperatures – some of which are extremely useful. Advances in technology enables this team to measure and observe energies at evermore extreme scales and at lower temperatures that are getting closer and closer to zero kelvin.

The Quantum Matter Team know, however, that achieving absolute zero is theoretically impossible. The refrigeration systems needed to achieve this consume energy as they operate. The work done by these systems increases exponentially as the temperature gets closer and closer to absolute zero. In theory, to achieve this temperature an *infinite* amount of work needs to be done. In addition, quantum mechanics dictates that even at absolute zero the particles’ thermal motion would not be at a minimum: they would still have some form of *irreducible* motion.

Nonetheless, the best refrigeration systems - based on Onnes’ original designs – are getting closer to this lowest temperature and are now able to reach a few millikelvins.

1. Define ‘heat energy’. As part of your answer, define ‘internal energy’ and describe the energy possessed by particles in a substance.

(4)

|  |  |
| --- | --- |
| Internal energy is equal to the sum of the kinetic and potential energies of the particles in a substance. | 1 mark |
| Internal energy consists of the kinetic energy of the particles and | 1 mark |
| the potential energy of the particles. | 1 mark |
| Heat energy is the flow of internal energy from a higher temperature object to a lower temperature object. | 1 mark |

1. Explain three (3) reasons why a small block of ice has less internal energy than a large cup of hot water.

(5)

|  |  |
| --- | --- |
| A bowl of soup consists of more particles than ice cream in a cone. | 1 mark |
| The strength of attraction between the particles in a liquid are generally less than that in a solid. | 1 mark |
| Therefore, a liquid’s particles generally have a higher potential energy than a solid. | 1 mark |
| The ice cream’s temperature is lower than that of the bowl of soup. | 1 mark |
| Therefore, the average kinetic energy of the particles in the ice cream is less than that in a bowl of soup. | 1 mark |

1. The Celsius and the Kelvin scales are both the same – they just have different origins. Complete the table below converting the temperatures shown between degrees Celsius and Kelvin. Round your answers for ‘Temperature (°C)’ to the nearest 0.01 of a degree.

(2)

|  |  |
| --- | --- |
| Temperature (°C) | Temperature (K) |
| -273.15 | 0 |
| -173.15 | 100 |
| -269 | 4.15 |

|  |  |
| --- | --- |
| T = -173.15 = 100 K | 1 mark |
| T = -269 = 4.15 K | 1 mark |

1. The article states that a temperature of ‘absolute zero’ would be impossible to reach experimentally.

(i) Explain what should theoretically happen to an object’s particles at a temperature of zero Kelvin.

(2)

|  |  |
| --- | --- |
| A temperature of absolute zero should mean an average kinetic energy of the particles equal to zero. | 1 mark |
| Hence, the particles should stop moving completely (ie – become stationary). | 1 mark |

(ii) Hence, explain why scientists believe that is impossible to reach absolute zero.

(2)

|  |  |
| --- | --- |
| Quantum physics implies that particles would always have some irreducible motion. | 1 mark |
| Hence, the particles will always have some kinetic energy (ie - the kinetic energy of the particles can never be zero). | 1 mark |

e) Explain how blowing on a cup of coffee can cause it to cool down.

(3)

|  |  |
| --- | --- |
| The blowing causes high energy water particles to evaporate at a faster rate. | 1 mark |
| Hence, the lower energy particles remain in the coffee which reduces the overall average kinetic energy of the particles. | 1 mark |
| Hence, the temperature of the coffee will reduce. | 1 mark |

**Question 19 (18 marks)**

**The Physics of Lightning**

A lightning storm is essentially a large-scale and powerful electrostatics experiment provided free by nature itself! The mechanics of a lightning strike are still not fully understood; however, there seems to be some agreed steps that lead to their formation.

STATIC BUILD UP IN CLOUDS

The electric polarisation of clouds and the Earth are at the heart of a lighting strike. The first step is the polarisation of positive and negative charges within clouds.

Clouds are essentially collections of water droplets. Evaporated water from the earth’s surface rises and these rising droplets collide with the water droplets in the cloud. A type of ’frictional charging’ occurs – much the same as when you rub a pen in your hair to give it a negative charge.

Through this process, the rising water droplets have electrons ‘ripped off’ them creating an electric dipole in the cloud: positive charge at the top of the cloud; and a negative charge at the bottom. See the diagram below.

EARTH

+ + + + + + + +

Water droplets in cloud

\_ \_ \_ \_ \_ \_ \_ \_

Evaporating water droplets rising from the Earth

The electrical energy stored within a cloud in this way is thought to be enormous. Research has shown that the potential difference between the top and bottom of a cloud can be as high as 1.3 gigavolts. Between the bottom of the cloud and the Earth can be even higher. In total, about 105 Coulombs of excess charge can be stored in an average cloud.

POLARISATION OF THE EARTH AND THE AIR

The electric field around a cloud (ie – the area affected by the charge on the cloud), therefore, is incredibly strong and affects the Earth itself. The top of the Earth’s surface – and objects on it like trees and mountains - becomes charged by the bottom of the cloud leading to further polarisation which is critical in the formation of a lighting strike.

In addition, the cloud’s electric field creates ‘plasma’ in the air – electrically charged particles are produced from the normally neutral gas air particles. This provides a conductive path for charge between the cloud and the Earth that does not normally exist.

The lightning strike consists of two parts: a ‘step leader’ and a ‘streamer’.

The ‘step leader’ travels from the bottom of the cloud towards the Earth (see diagram below). The ‘streamer’ travels from the Earth towards the cloud. The ‘streamer’ meets the ‘step leader’ a short distance above the earth and a continuous conducting part between the cloud and the Earth’s surface is now created. A lightning strike is now possible.

Streamer

Step Leader

EARTH

In an initial lightning strike, about 1021 electrons can traverse this conducting path to the Earth in about one millisecond. This initial strike is normally followed by several secondary strikes. The energy released by these strikes into the air causes it to expand violently and rapidly. The shockwave caused by this rapid expansion is observed as thunder.

1. Describe how ‘frictional charging’ can give a plastic pen a negative charge when it is rubbed with wool.

(4 marks)

|  |  |
| --- | --- |
| The friction created when the plastic pen is rubbed with wool creates the triboelectric effect energy. | 1 mark |
| This effect occurs when certain materials are rubbed together, eg – plastic and wool. | 1 mark |
| Electrons are transferred from the atoms in the wool to the atoms in the plastic pen during this process. | 1 mark |
| This leaves the pen with a net negative charge. | 1 mark |

1. Given the potential difference around the cloud and the quantity of charge stored, estimate the total electrical energy stored in a typical cloud.

(4 marks)

|  |  |
| --- | --- |
|  | 1 mark |
|  | 1 mark |
|  | 1 mark |
| 1 or 2 significant figures | 1 mark |

c) “The top of the earth’s surface – and objects on it like trees and mountains - becomes charged by the bottom of the cloud …”

Describe the type of charge achieved by the earth’s surface in this polarisation process. Explain your answer.

(3 marks)

|  |  |
| --- | --- |
| The earth’s surface achieves a positive charge. | 1 mark |
| The negatively charged bottom of the cloud will repel electrons in the earth’s surface. | 1 mark |
| Hence, the surface is deficient in negatively charged electrons. | 1 mark |

d) Explain why air cannot conduct electricity without plasma being created.

(4 marks)

|  |  |
| --- | --- |
| For a current to flow, there needs to be free charge/electrons. | 1 mark |
| Air particles are neutrally charged. | 1 mark |
| Plasma consists of free electrons and positively charged ions. | 1 mark |
| This free charge can be made to flow and create a conducting path. | 1 mark |

1. Using data from the article, estimate the size of the current in a lightning strike.

(3 marks)

|  |  |
| --- | --- |
|  | 1 mark |
|  | 1 mark |
|  | 1 mark |