Section one: Short answer

This section has **fourteen (14)** questions. Answer all questions in the spaces provided.

Question 1 **[3 marks]**

A man going for a hike along a bush trail walks 12 km east, then turns around and heads back home, walking 3 km west, before stopping to have a rest. State the distance covered by the man, and his displacement, when he stops to have his rest.

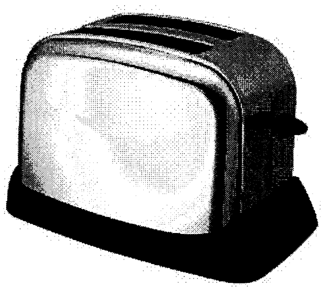
Distance covered = 15 km [1 mark]

Displacement = 9 km east [2 marks]

1 1

Question 2 **[4 marks]**

When a toaster is switched on, current flows through the heating element causing it to become red hot and toast the bread placed inside it.



(a) Calculate the resistance of the element when red hot, given it draws a current of 5.00 A at the standard domestic voltage of 240 V. [2 marks]

$$R = \frac{V}{I} = \frac{240\,V}{5.00\,A} = 48\,\Omega$$

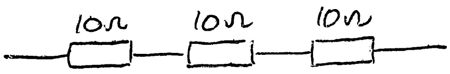
1 1

(b) Describe how and explain why the current through the heating element changes as the element heats up. [2 marks]

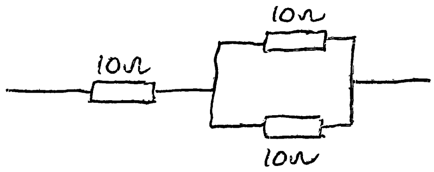
As the element heats up, the current flowing through it decreases 1 because the resistance of the element increases with temperature 1

Question 3 **[4 marks]**

Three 10 Ω resistors can be connected together in four different ways to give four different effective resistance values. **Sketch** the four different ways that the resistors can be arranged and **state** the effective resistance for each case.

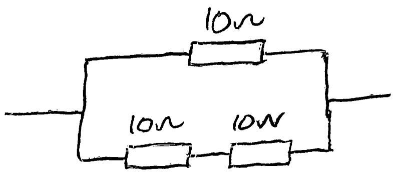


$R = 30\Omega$

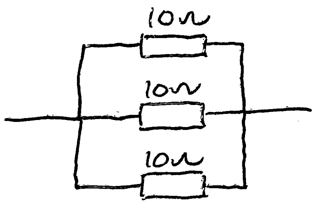


$R = 15\Omega$

(1) each



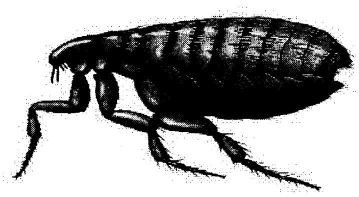
$R = 6.7\Omega$



$R = 3.3\Omega$

Question 4 **[4 marks]**

A flea jump results in one of the most impressive examples of acceleration in the animal kingdom. By pushing its legs against the ground, the flea can attain an initial upward velocity of 1.00 m/s in a time of 1.00 millisecond.



(a) What is the flea's average acceleration when pushing off the ground? [1 mark]

$$a = \frac{1.00 \text{ m/s}}{0.001 \text{ s}} = 1000 \text{ m/s}^2 \quad (1)$$

(b) Calculate how high the flea manages to jump off the ground. [3 marks]

$u = 1.00 \text{ m/s}$, $v = 0$, $a = -9.80 \text{ m/s}^2$ (1)

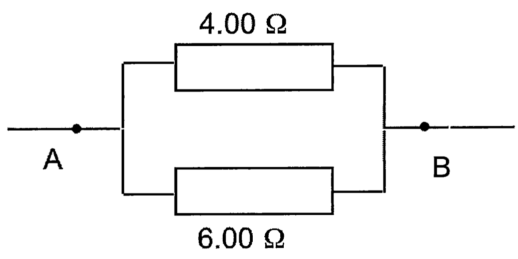
$v^2 = u^2 + 2as$ (1) $0 = (1.00)^2 + 2(-9.8)s$

$$\therefore s = \frac{(1.00)^2}{19.6} = 0.051 \text{ m} \quad (1)$$

$(\cong 5 \text{ cm})$

Question 5 **[3 marks]**

Two resistors are connected as shown in the diagram at right. A potential difference of 12.0 V is applied between points A and B.



(a) State the voltage drop across each resistor.

4.00 Ω resistor: 12.0 V

6.00 Ω resistor: 12.0 V 1

(b) Give the current flowing through each of the resistors.

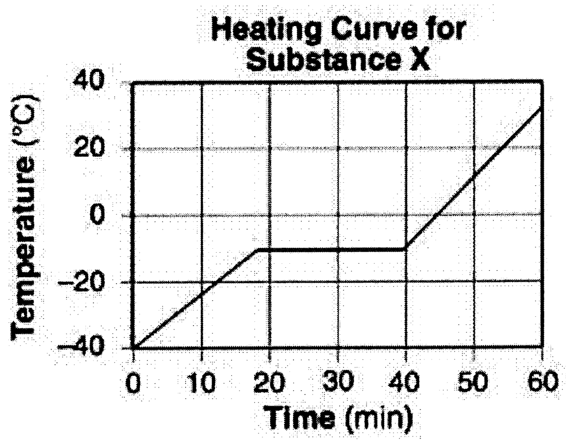
4.00 Ω resistor: 3.00 A 1

6.00 Ω resistor: 2.00 A 1

(don't worry about sig figs)

Question 6 **[6 marks]**

The graph at right shows how the temperature of 1.00 kg of substance X varies as it is steadily heated by a 50.0 W element. Substance X is initially in the solid phase. From the graph determine substance X's



(a) melting point. [1 mark]

$-10\,°C$

(b) latent heat of fusion. [2 marks]

time to completely melt = 40 min − 18 min = 22 m

$\therefore Q = (22 \times 60\,s)(50\,W) = 66\,000\,J$ 1 $\rightarrow L = 66\,kJ/kg$ 1

(c) specific heat when in the liquid phase. [3 marks]

$Q = (60\,min - 40\,min)(60\,s)(50\,W) = 60\,000\,J$ 1

$\Delta T = 30\,°C - (-10\,°C) = 40\,K$ 1

$Q = mc\Delta T \rightarrow c = \dfrac{Q}{m\Delta T} = \dfrac{60\,000\,J}{(1\,kg)(40\,K)} = 1500\,J\,kg^{-1}\,K^{-1}$ 1

Question 7 **[4 marks]**

Indicate whether each of the following statements is true (T) or false (F).

(a) Work is the rate of transfer of energy. F (Power is the rate...)

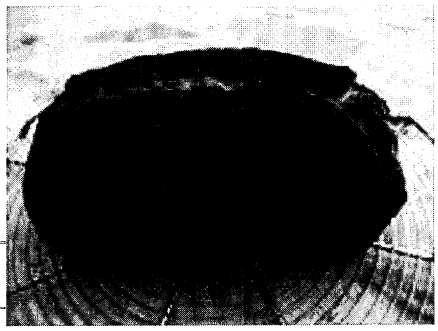
(b) Heat can travel through a vacuum. T (radiation)

(c) An ammeter should be connected in parallel. F (ammeter must be in series)

(d) Alpha particles have a very high ionising ability. T (+2e charge, high mass)

Question 8 **[3 marks]**

A cake you have finished baking is removed from the oven and placed on a metal rack on a nearby benchtop to cool down before icing. With reference to the three methods of heat transfer, briefly describe how the cake loses heat energy during the cooling process.



The cake loses heat through conduction into the metal rack it is standing on. 1

The cake heats the air around it, which rises and is replaced by cooler air, so convection currents carry heat away from the cake. 1

The cake radiates infrared as it is hotter than its surroundings, so loses heat by radiation 1

Question 9 **[4 marks]**

Most naturally occurring nuclei are stable despite the fact that their protons mutually repel one another.

(a) Explain how nuclei remain stable. [2 marks]

The strong nuclear force is a very strong, short range force that binds nucleons together. (1)
It is strong enough to overcome the repulsion experienced by the positively charged protons (1)

(b) Why do very large nuclei tend to be unstable? [2 marks]

Very large nuclei have a large number of protons (1) so the electrostatic repulsion experienced by each (1) proton balances the attractive forces from nearby nucleons due to the SNF, making it much easier for the nucleus to fragment (decay)

Question 10 **[5 marks]**

A golfer swings a golf club and drives a golf ball from the tee. The effective mass of the head of the golf club is 1.20 kg. The initially stationary golf ball of mass 50.0 g leaves the face of the golf club with a speed of 60.0 ms^{-1}.

(a) Determine the impulse experienced by the golf ball [2 marks]

$$\text{impulse} = \Delta p = m\,\Delta v = (0.05\text{ kg})(60\text{ m/s}) = 3.00\text{ kg m/s}$$
(1) (1)

(b) Will the golf club experience the same impulse as the golf ball? Explain. [2 marks]

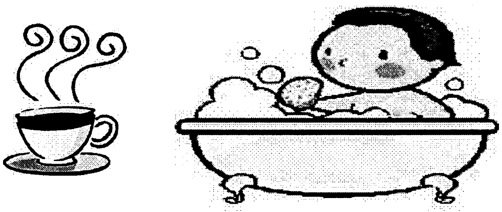
Since impulse $= F \times t$, and the club and ball (1) experience equal size forces in opposite directions during impact, the club experiences the same size impulse as the ball but in the opposite direction (1)

(c) How much does the golf club slow down after striking the ball? [1 mark]

$$\Delta v = \frac{3.00\text{ kg m/s}}{1.20\text{ kg}} = 2.50\text{ m/s}$$ (1)

Question 11 **[4 marks]**

A cup of coffee is hotter than a warm bath, but the bath water can transfer more heat to its surroundings than the cup of coffee. Using the terms temperature, heat and internal energy, explain why this statement is true.



The coffee is at a higher temperature than the bath water, so its molecules have a higher average KE than those in the bathwater. 1
However, there are many more molecules in the bath water compared to the coffee, so the total internal energy of the bath water is much higher. 1 1
Hence the bathwater can transfer much more heat to its surroundings as it cools to room temperature compared to the much smaller cup of coffee 1

Question 12 **[3 marks]**

Convert each of the following values as indicated:

225 K = -48 °C

40 ms^{-1} = 144 km h^{-1}

3.0 μC = 3000 nC

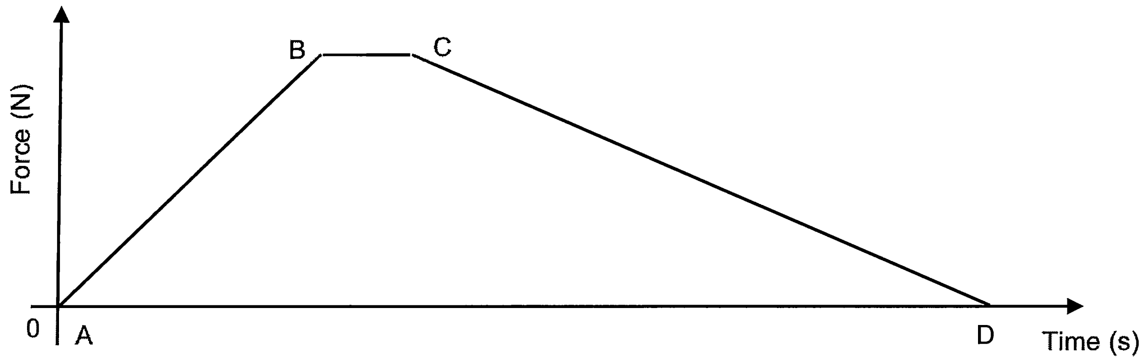
Question 13 **[2 marks]**

Explain why it is not possible to cool a substance below 0 K (absolute zero).

As a substance is cooled, its particles move more slowly. 0 K is the lowest possible temperature as at that temperature the particles of a substance stop moving

Question 14 **[5 marks]**

A cyclist accelerates from rest on a smooth horizontal road. The graph below shows how the force applied to the bicycle by the cyclist changed over this period of acceleration.



(a) During which stage of the motion as represented in the graph was the acceleration of the cyclist greatest? (Circle your choice) [2 marks]

AB **BC** (1) **CD**

Explain your answer: Since F = ma, the acceleration of the cyclist was greatest when the force he applied was greatest (1)

(b) The change in momentum of the cyclist can be calculated by finding which of the following quantities? (Circle your choice) [3 marks]

the gradient of AB

the average gradient from A to D

the area under the graph (1)

Explain your answer: the area under the force-time graph is the impulse experienced by the cyclist, which is equivalent to his change in momentum (1) (1)

END OF SECTION ONE

Section two: Problem-solving **90 marks**

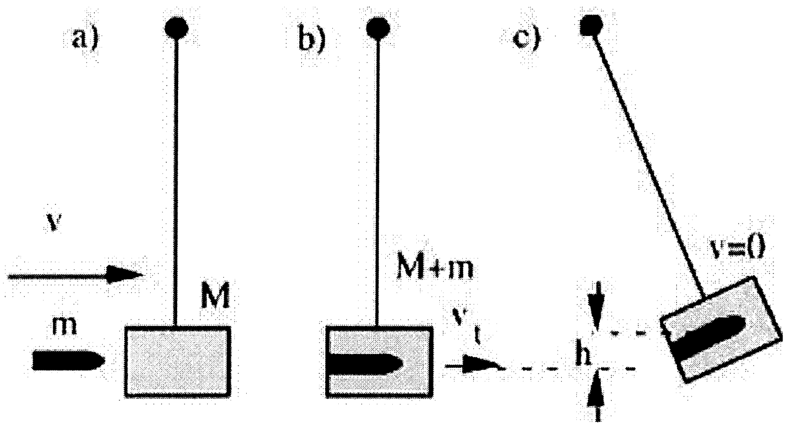
This section has **six (6)** questions. Answer all questions in the spaces provided.

Question 15 **[14 marks]**

A ballistic pendulum is a device that can be used by forensic scientists to determine the speed of a bullet.

The pendulum consists of a large wooden block hanging vertically, as shown in diagram a) at right, at which a bullet is fired horizontally.

The bullet hits the wooden block and remains embedded in it, transferring most of its momentum to the block (diagram b).



The speed of the system after collision can be determined by measuring the maximum height to which the block swings (diagram c).

The mass of the bullet is 20.0 g and the mass of the block is 2.30 kg. → total $m = 2.32\,kg$

(a) State the energy transformation that occurs after collision as the block swings to its maximum height (diagram c). [1 mark]

kinetic energy → gravitational potential energy

(b) The block (plus embedded bullet) swings upwards to a maximum height of 26.0 cm. Calculate their increase in gravitational potential energy. [2 marks]

$\Delta PE = mgh = (2.32\,kg)(9.8\,m/s^2)(0.26\,m) = \underline{5.91\,J}$

(1) (1)

(c) Determine the initial speed of the block as it first begins to swing upwards, immediately after the bullet is embedded in it. [3 marks]

Initial KE = final PE = 5.91 J (1)

$KE = \frac{1}{2}mv^2 \rightarrow 5.91 = \frac{1}{2}(2.32)\,v^2$ (1)

$v^2 = 5.096 \rightarrow v = \underline{2.26\,m/s}$

(1)

(d) What is the relationship between the initial momentum of the bullet, before hitting the block, and the momentum of the block plus embedded bullet immediately afterwards (diagram b)? [1 mark]

momentum of bullet before collision = momentum of block + bullet after collision

(e) Hence calculate the speed of the bullet before hitting the block. [3 marks]

$$m_{bullet}\, u = (m_{block} + m_{bullet})\, v \quad ①$$

$$(0.02\,kg)\, u = (2.32\,kg)(2.26\,m/s) \quad ①$$

$$\therefore u = \frac{(2.32)(2.26)}{0.02} = 262\,m/s \quad ①$$

(f) Determine the kinetic energy of the bullet before collision, and compare it to the kinetic energy of the block (plus bullet) after collision. [2 marks]

$$KE\,(bullet) = \tfrac{1}{2}(0.02)(262)^2 = 686\,J \quad ①$$

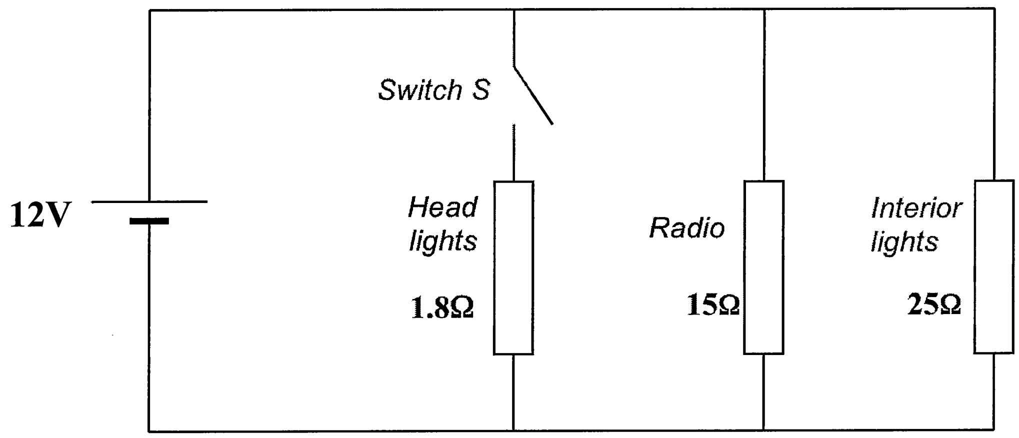
$$KE\,(block + bullet) = \tfrac{1}{2}(2.32)(2.26)^2 = 5.91\,J \quad ①$$

(g) How do you explain any difference between the kinetic energy of the bullet before collision and the kinetic energy of the block (plus bullet) after collision? [2 marks]

Most of the KE of the bullet before collision is transformed into heat and sound as it strikes the block and embeds itself into the block, leaving less than 1% of the original energy as KE

Question 16 **[15 marks]**

The circuit shown below is a simplified version of part of the electrical system in a typical car.



(a) Determine the effective resistance of the circuit when the headlights are turned off (switch S is open). [2 marks]

$$1/R = 1/15 + 1/25 = 0.107 \quad (1)$$

$$\therefore R = \underline{9.4\,\Omega} \quad (1)$$

(b) Calculate the size of the current flowing from the battery when the headlights are turned off. [2 marks]

$$I = \frac{V}{R} = \frac{12\text{V}}{9.4\,\Omega} = \underline{1.28\text{ A}} \quad (1)$$

(1)

(c) What is the size of the total current from the battery if switch S is closed so that the headlights are now turned on? [3 marks]

When S is closed, additional current of

$$I = \frac{12\text{V}}{1.8\,\Omega} = 6.67\text{ A}$$ flows through headlights

(1) (1)

$$\therefore \text{total current} = 6.67\text{A} + 1.28\text{A} = \underline{7.95\text{ A}} \quad (1)$$

(d) Calculate the power produced by the headlights when switched on. [2 marks]

$$P(\text{headlights}) = \frac{V^2}{R} = \frac{(12V)^2}{1.8\Omega} = \underline{80W}$$

(1) (1)

$$(\text{or } P = VI \text{ or } P = I^2R)$$

After many years the contacts on switch S become corroded, which gives the switch a small resistance of 0.45 Ω when closed. It is noticed that the headlights seem dimmer when in use.

(e) Find the voltage drop across the headlights in this situation. [3 marks]

Total resistance in headlight branch $= 1.8 + 0.45 = 2.25\Omega$ (1)

$$\therefore I = \frac{V}{R} = \frac{12V}{2.25\Omega} = 5.33A \quad (1)$$

$$\therefore V(\text{headlights}) = IR = (5.33)(1.8) = \underline{9.6V} \quad (1)$$

(f) Calculate the power of the headlights in this situation, and the percentage by which they have dimmed over the years. [3 marks]

$$P = \frac{V^2}{R} = \frac{(9.6V)^2}{1.8\Omega} = \underline{51.2W}$$

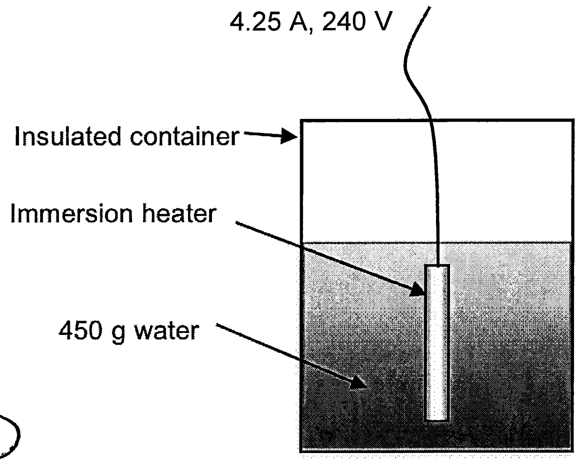
(1) (1)

$$\frac{51.2W}{80W} = \underline{64\%} \text{ (of original power)}$$

(1)

Question 17 **[16 marks]**

Ali measured 450 grams of cold water, at room temperature of 18°C, into an insulated container of negligible heat capacity. Ali then heated the water using an electrical immersion heater that drew 4.25 A of current from the 240 V supply.



(a) Calculate the quantity of heat needed to bring the water in the insulated container to the boil. [3 marks]

$\Delta T = 100 - 18 = 82\,K$ (1)

$Q = mc\Delta T$

$= (0.45\,kg)(4180\,J\,kg^{-1}K^{-1})(82\,K) = \underline{1.54 \times 10^5\,J}$ (1)

(1)

(b) Describe, in terms of the kinetic theory, what is happening to the water molecules as the temperature of the water in the container increases. [2 marks]

As the temperature of the water increases the average KE of the water molecules (1) increases, and the water molecules move (1) faster (on average)

(c) Determine the power of the heating element, and use this value to find the time taken for the water in the container to reach boiling point. [3 marks]

$P = VI = (240\,V)(4.25\,A) = \underline{1020\,W}$ (1)

$P = \frac{Q}{t} \rightarrow t = \frac{Q}{P} = \frac{1.54 \times 10^5\,J}{1020\,W} = \underline{151\,s}$

(1) (1)

The immersion heater does not switch off immediately when the water begins to boil, but rather continues to heat the water for an extra 20 seconds after it reaches boiling point.

(d) What temperature will the water be after the extra 20 s of heating? [1 mark]

$100°C$

(e) Describe, in terms of the kinetic theory, how the heat absorbed during the extra 20s of heating affects the molecules of water. [2 marks]

During the extra 20s of heating some of the water molecules increase their PE greatly and leave the liquid phase and enter the gaseous phase. The avrage KE of the molecules does not change. (1) (1)

(f) Calculate the mass of water in the container that boils away during this extra 20 s of heating. [3 marks]

Heat absorbed $Q = P \times t = (1020W)(20s) = 20400J$ (1)

$Q = mL \rightarrow m = \frac{Q}{L} = \frac{20400J}{2.26 \times 10^6 J/kg} = \underline{9.03 \times 10^{-3} kg}$ (1) (1)

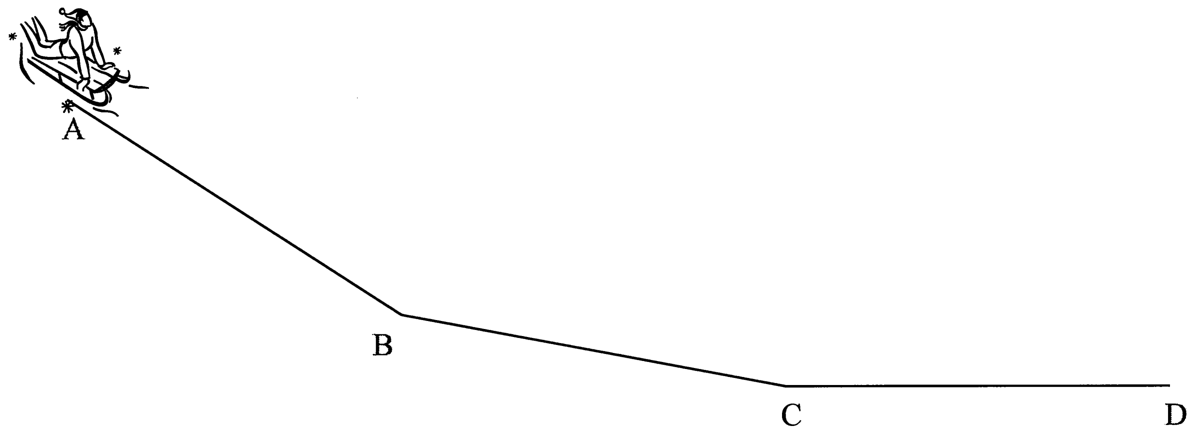
$(\cong 9 \text{ grams})$

(g) Explain why it is preferable to place the heating element in the container near the bottom of the vessel. [2 marks]

Placing the element near the bottom of the container enables the heated water to rise away from the element and be replaced by cool water, setting up a <u>convection current</u> that allows all the water to be heated (1) (1)

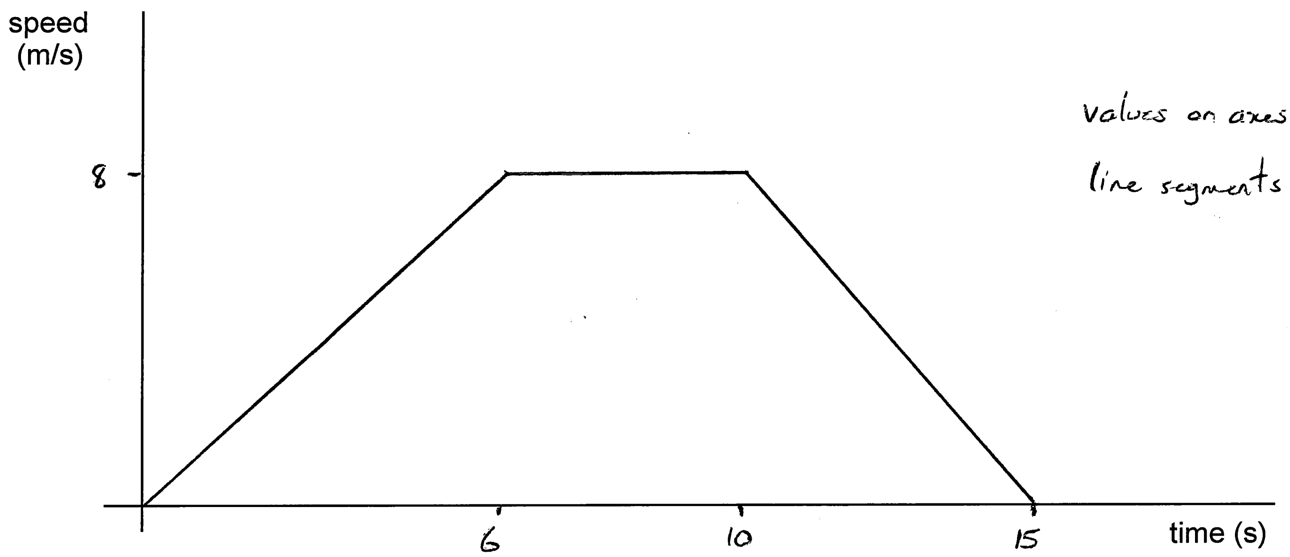
Question 18 **[15 marks]**

A girl on a sledge slides down a slope at the snowfields. The total mass of the girl and the sledge is 105 kg. The record of her journey from A to D is recorded on a combined stopwatch-speedometer attached to the sledge. The readings of this instrument at positions A , B , C and D are shown in the table below.



Position	A	B	C	D
Time (s)	0	6.0	10.0	15.0
Speed (m/s)	0	8.0	8.0	0

(a) Sketch a speed versus time graph for the sledges journey from A to D on the axes provided below. [2 marks]



values on axes (1)
line segments (1)

(b) Calculate the average deceleration and hence retarding force acting on the sledge during stage CD. [3 marks]

$$a = \frac{v-u}{t} = \frac{0 - 8\,m/s}{5\,s} = -1.6\,m/s^2 \quad 1$$

$$\therefore F = ma = (105\,kg)(-1.6\,m/s^2) = \underline{-168\,N} \quad 1$$

1

(c) Use the graph to calculate the distance travelled from A to D. [3 marks]

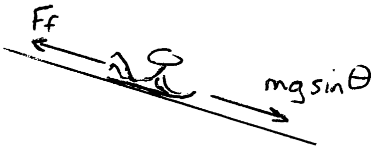
distance travelled = area under graph 1

$$= \tfrac{1}{2}(6)(8) + (4)(8) + \tfrac{1}{2}(5)(8) \quad 1$$

$$= \underline{76\,m} \quad 1$$

(d) If stage BC is at an angle of 12° to the horizontal, calculate the frictional force acting on the sledge during that stage. [3 marks]

constant speed during stage BC $\Rightarrow$ net force = 0 1



$\therefore$ friction $F_f = mg\sin\theta$ 1

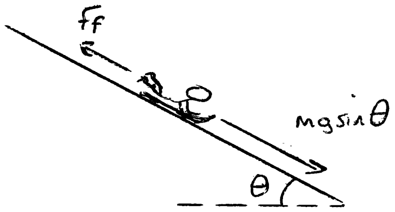
$$= (105)(9.8)\sin 12°$$

$$= \underline{214\,N} \quad 1$$

(e) If the frictional force acting on the sledge during stage AB is the same as that during stage BC, calculate the angle to the horizontal of the slope in stage AB (use a value of 200 N for the frictional force if you have no answer from above). [4 marks]

acceleration during stage AB

is $a = \frac{\Delta V}{t} = \frac{8\,m/s}{6\,s} = 1.33\,m/s^2$ 1



$F_{net} = ma \rightarrow mg\sin\theta - F_f = ma$ 1

$$\therefore (105)(9.8)\sin\theta - 214 = (105)(1.33) \quad 1$$

$$\sin\theta = \frac{354}{1029} = 0.344$$

$$\therefore \theta = \underline{20.1°} \quad 1$$

Question 19 **[15 marks]**

In 1986 a nuclear reactor exploded at Chernobyl in the Ukraine, sending a cloud of radioactive material over several European countries, and causing radiation levels to rise above normal background levels. A major part of the radioactive material was iodine-131 with a half-life of 8 days. Also released were caesium-137 and caesium-134, with half-lives of 2 years and 30 years respectively.

(a) What is meant by normal background radiation? [2 marks]

Normal background radiation refers to the typical level of nuclear radiation resulting from (1) naturally occurring sources such as cosmic rays, (1) radioactive isotopes in minerals and in the air, etc

(b) How is the caesium-137 nucleus similar to the caesium-134 nucleus? How are they different? [2 marks]

Cs - 137 and Cs - 134 nuclei are similar in that they both contain 55 protons (1)
They are different in that Cs - 137 contains 3 more neutrons than Cs - 134 (82 vs 79 neutrons) (1)

(c) Calculate the fraction of the original iodine-131 that would remain 4 weeks after the accident. [3 marks]

4 weeks after the accident represents

$$n = \frac{28 \text{ days}}{8 \text{ days}} = 3.5 \text{ half-lives}$$ (1)

The fraction of I - 131 remaining is given by

$$\left(\frac{1}{2}\right)^n = \left(\frac{1}{2}\right)^{3.5} = 0.0884 = \underline{8.84\%}$$

(1) (1)

Iodine-131 undergoes beta decay into xenon (Xe) according to the equation

$$^{131}_{53}I \rightarrow\ ^{131}_{54}Xe +\ ^{0}_{-1}\beta$$

The nuclear masses of the particles involved in this decay are given in the table below, in unified atomic mass units.

Particle	Mass (u)
$^{131}_{53}I$	130.906 125
$^{131}_{54}Xe$	130.904 533
$^{0}_{-1}\beta$	0.000 549

(d) Calculate the mass difference for this reaction and determine the energy released (in MeV) by a single decay of iodine-131 into xenon-131. [3 marks]

$$\Delta m = m(I\text{-}131) - m(Xe\text{-}131) - m(\beta) \quad (1)$$

$$= 130.906125 - 130.904533 - 0.000549$$

$$= 0.001043\ u \quad (1)$$

$$\text{energy released} = 0.001043u \times 931\ MeV/u = 0.971\ MeV \quad (1)$$

(e) Which isotope of caesium causes most concern today and why? [2 mark]

Cs-134 (1) causes most concern today, as it has a much longer half-life (30yrs) than Cs-137 (1) (2yrs) so persists in the environment at hazardous levels

(f) Estimate how long it will take for the activity of the caesium-137 to drop down to one thousandth of its original value. [3 marks]

$$A = A_0 \left(\tfrac{1}{2}\right)^n \qquad \text{When } A = \tfrac{1}{1000} A_0 = 0.001 A_0$$

$$\text{we have } 0.001 A_0 = A_0 \left(\tfrac{1}{2}\right)^n$$

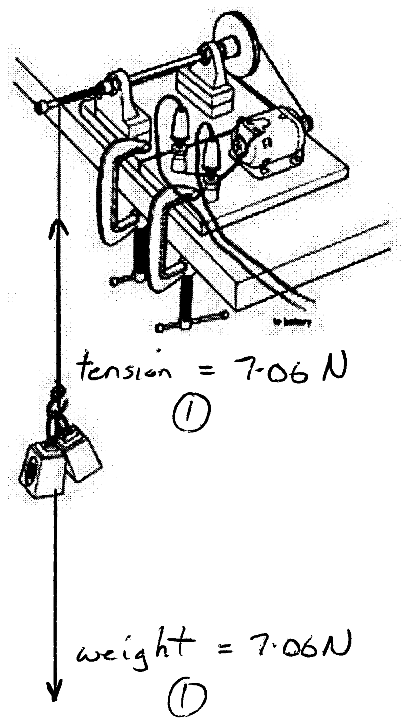
$$\therefore \left(\tfrac{1}{2}\right)^n = 0.001 \ (1) \rightarrow n \cong 10 \ (1) \qquad \text{(use logs or trial and error)}$$

$$\therefore \text{time needed} = 10 \text{ half-lives} \times 2\text{yrs} = 20 \text{ years} \quad (1)$$

Question 20 **[15 marks]**

An electric motor draws a current of 225 mA from a 12.0 V power supply when used to lift a 720 g mass at a steady speed. The mass is lifted from the floor to a maximum height of 1.25 m in a time of 3.90 s.

(a) What is the size of the tension (force) in the cord when the mass moves upwards at constant speed? Use labelled arrows on the diagram at right to indicate the sizes and directions of the forces acting on the mass when it is travelling upwards at steady speed. [3 marks]



$$\text{tension} = mg$$
$$= (0{\cdot}720)(9{\cdot}8)$$
$$= \underline{7{\cdot}06\ N} \quad (1)$$

(b) Calculate the mechanical work done in lifting the mass from the floor to its maximum height. [2 marks]

$$W = \Delta PE = mgh \quad (1)$$
$$= (0{\cdot}720)(9{\cdot}8)(1{\cdot}25)$$
$$= \underline{8{\cdot}82\ J} \quad (1)$$

(c) What is the major energy transformation taking place in this system? [2 marks]

electrical energy (1) is being converted into gravitational potential energy (1)

(d) Calculate the electrical power of the motor. [2 marks]

$$P = VI \overset{(1)}{=} (12V)(0.225A)$$

$$= \underline{2.70 \text{ W}} \quad (1)$$

(e) Determine the total electrical energy transformed by the motor when lifting the mass, and hence find the efficiency of the electric motor in lifting the mass. [4 marks]

Electrical energy transformed lifting mass is

$$E = P \times t \overset{(1)}{=} 2.70\text{W} \times 3.90\text{ s} = \underline{10.5 \text{ J}} \quad (1)$$

The efficiency of the motor is

$$\frac{\text{useful output}}{\text{total input}} = \underset{(1)}{\frac{8.82\text{ J}}{10.5\text{ J}}} = 0.838 = \underset{(1)}{\underline{83.8\%}}$$

(f) Why was it necessary when performing the above calculations to assume that the speed was constant when lifting the mass? [2 marks]

By assuming the speed was constant we can assume the KE of the mass remained constant (1) as it was lifted. Hence all the work done on the mass goes into changing its gravitational (1) PE which we can easily measure.

Question 22

Nuclear Power

(Paragraph 1)
Uranium-235 is one of the few materials that can undergo **nuclear fission**. If a free neutron runs into a U-235 nucleus, the nucleus will absorb the neutron, become unstable and split immediately into two lighter nuclei, throwing off two or three new neutrons (the number of ejected neutrons depends on how the U-235 nucleus happens to split). The two new nuclei then release beta and gamma radiation as they settle into their new states.

(Paragraph 2)
An incredible amount of energy is released, in the form of heat and radiation, when a single U-235 nucleus splits. The energy released comes from the fact that the fission products and the neutrons, together, weigh less than the original U-235 nucleus. The difference in mass is converted directly to energy at a rate governed by Einstein's equation $\mathbf{E = mc^2}$ and is of the order of 200 MeV (million electron volts) per fission.

(Paragraph 3)
To fuel a nuclear reactor, natural uranium must be **enriched** so that it contains 3 percent or more of U-235. Three-percent enrichment is sufficient for use in a civilian nuclear reactor used for power generation The enriched uranium is formed into pellets, which are arranged into long rods, and the rods are collected together into bundles. The bundles are then typically submerged in water inside the reactor core. The uranium bundles act as an extremely high-energy source of heat. They heat the water and turn it into steam, which drives a **steam turbine**, and spins a **generator** to produce power.

(Paragraph 4)
The probability of a U-235 nucleus capturing a neutron depends on the speed of the neutron. A material called the **moderator** (typically water is used, or sometimes graphite) is present in the core of a nuclear reactor to slow down ejected neutrons and increase their probability of subsequent capture.

(Paragraph 5)
Control rods made of a material that absorbs neutrons, such as boron steel, are inserted into the reactor core using a mechanism that can raise or lower the control rods. Raising or lowering the control rods allows operators to control the rate of the nuclear reaction. When an operator wants the uranium core to produce more heat, the rods are raised out of the uranium bundle; to create less heat, the rods are lowered into the uranium bundle. In a reactor working properly (known as the **critical state**), one neutron ejected from each fission causes another fission to occur. The rods can also be lowered completely into the uranium bundle to shut the reactor down in the case of an accident or to change the fuel.

(Paragraph 6)
The reactor core is typically housed inside a concrete liner within a much larger steel containment vessel that is designed to prevent leakage of any radioactive gases or fluids. An outer concrete building that is strong enough to survive impact by crashing jet airliners protects the steel containment vessel. The absence of secondary containment structures in Russian nuclear power plants allowed radioactive material to escape at Chernobyl.

(Paragraph 7)
Uranium-235 is not the only possible fuel for a power plant. Another fissionable material is the artificial isotope **plutonium-239**. Pu-239 can be created easily from U-238 by bombarding it with neutrons - something that happens all the time in a nuclear reactor - in a 3-step process that involves the neutron bombardment of U-238 followed by successive beta decays that convert the uranium nucleus into a plutonium nucleus.

(a) One of the possible fission reactions for a U-235 nucleus is where it absorbs a neutron and splits into a barium-142 nucleus and a krypton-91 nucleus. Write the balanced nuclear equation for this fission reaction. [2 marks]

$$\underbrace{{}^{235}_{92}U + {}^{1}_{0}n \rightarrow {}^{142}_{56}Ba + {}^{91}_{36}Kr}_{1} + \underbrace{3\,{}^{1}_{0}n}_{1}$$

(b) One kilogram of uranium-235 contains approximately 2.5 x 10^{24} nuclei. Use information provided in paragraph 2 to estimate the energy released by a kilogram of uranium-235 undergoing fission. Express your answer in joules. [4 marks]

Energy released per fission = 200 MeV 1

Energy released by one kg of U-235 is

$E = 2.5 \times 10^{24} \times 200\ \text{MeV} = 5 \times 10^{26}\ \text{MeV}$ 1

$= 5 \times 10^{32}\ \text{eV} = 5 \times 10^{32} \times (1.6 \times 10^{-19}\ \text{J})$ 1

$= 8 \times 10^{13}\ \text{J}$ 1

(c) Briefly explain what is meant by each of the following terms. [4 marks]

enrichment

increasing the concentration of the fissile 1 isotope U-235 in a sample of uranium to at least 3%, sufficient to sustain a steady 1 fission reaction in the reactor core

critical state

where on average one neutron from each 1 fission causes another fission to occur, enabling the overall reaction to proceed at a constant 1 rate

(d) In a typical nuclear power plant the fuel rods are submerged in water. Describe two functions the water may serve in the operation of the reactor. [4 marks]

1

• the water may serve as a coolant, transferring heat from the reactor core so as to drive the steam turbines and generators 1

1

• the water may act as a moderator, slowing down emitted neutrons to increase their probability of being captured by a nucleus 1

(e) State the purpose of the

control rods [1 mark]

to control the rate of the fission reaction in the reactor core

secondary containment structures [1 mark]

to prevent the leakage of any radioactive materials

(f) Plutonium-239 can be produced from uranium-238 in a nuclear reactor, after the absorption of a neutron by the uranium-238, in a three step process. Show the two intermediate nuclides that are involved in this process. [2 marks]

U-238 → U-239 → Np-239 → Pu-239

1 1