HOLY CROSS COLLEGE

SEMESTER 2, 2018

Question/Answer Booklet

SOLUTIONS

11 PHYSICS

Please place your student identification label in this box

Student Name ______________________________

Student's Teacher ______________________________

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

Materials required/recommended for this paper
To be provided by the supervisor
This Question/Answer Booklet
Data Sheet

To be provided by the candidate
Standard items: pens, pencils, eraser, correction fluid, ruler, highlighters

Special items: non-programmable calculators satisfying the conditions set by the School Curriculum and Standards Authority for this course

Important note to candidates
No other items may be taken into the examination room. It is **your** responsibility to ensure that you do not have any unauthorised notes or other items of a non-personal nature in the examination room. If you have any unauthorised material with you, hand it to the supervisor **before** reading any further.

Structure of this paper

Section	Number of questions available	Number of questions to be answered	Suggested working time (minutes)	Marks available	Percentage of exam
Section One: Short answer	13	13	50	54	30
Section Two: Extended answer	7	7	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 examinations at Holy Cross College are detailed in the College Examination Policy. Sitting this examination implies that you agree to abide by these rules.

2. Write your answers in this Question/Answer Booklet.

3. Working or reasoning should be clearly shown when calculating or estimating answers.

4. You must be careful to confine your responses to the specific questions asked and to follow any instructions that are specific to a particular question.

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

6. Answers to questions involving calculations should be ***evaluated and given in decimal form***. It is suggested that you quote all answers to ***three significant figures***, with the exception of questions for which estimates are required. Despite an incorrect final result, credit may be obtained for method and working, providing these are ***clearly and legibly set out***.

7. Questions containing the instruction *"estimate"* may give insufficient numerical data for their solution. Students should provide appropriate figures to enable an approximate solution to be obtained. Give final answers to a maximum of *two significant figures* and include appropriate units where applicable.

8. Note that when an answer is a vector quantity, it must be given with magnitude and direction.

9. In all calculations, units must be consistent throughout your working.

Section One: Short response 30% (54 Marks)

This section has **thirteen (13)** questions. Answer **all** questions. Write your answers in the space provided. Suggested working time for this section is 50 minutes.

Question 1 **(4 marks)**

Fill in the table to show the relative magnitude of various properties of the radioactive particles.

Particle	Alpha	Beta	Gamma
Mass (Zero, Small, Medium, Large)	large	medium	zero
Electric Charge (Zero, Small, Medium, Large)	large	medium	zero
Ionising Ability (Zero, Small, Medium, Large)	large	medium	small
Penetrating Ability (Zero, Small, Medium, Large)	small	medium	large

[$\frac{1}{2}$ mark off for each error]

Question 2 **(4 marks)**

A resistor converts 3.80 x 10^2 J of electrical energy into heat energy over 40.0 s of operation. Find the value of the resistance if 2.18 A flows in the circuit.

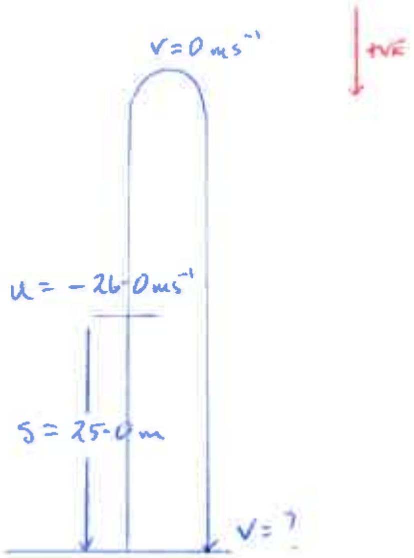
$$P = \frac{E}{t} = I^2 R \quad (2)$$

$$\Rightarrow \frac{3.80 \times 10^2}{40.0} = (2.18)^2 R \quad (1)$$

$$\Rightarrow \underline{R = 2.00\,\Omega} \quad (1)$$

Question 3 **(5 marks)**

A firework is launched straight up from the ground and reaches 26.0 ms^{-1} when 25.0 m above the ground. At this point, ***it stops accelerating*** and continues to rise. It malfunctions and, after failing to explode, falls back down to the ground. Calculate the height the firework achieved above the ground and the velocity with which it hits the ground.



$v = 0\ ms^{-1}$
$u = -26.0\ ms^{-1}$
$a = 9.80\ ms^{-2}$
$t = ?$
$s = ?$

Movement to the top

$$v^2 = u^2 + 2as$$
$$\Rightarrow s = \frac{v^2 - u^2}{2a}$$
$$= \frac{0 - (-26.0)^2}{2(9.80)} \quad (1)$$
$$= -34.5\ m \quad (1)$$

$\therefore$ Height = 59.5 m above the ground (1)

$v = ?$
$u = -26.0\ ms^{-1}$
$a = 9.80\ ms^{-2}$
$t = ?$
$s = 25.0\ m$

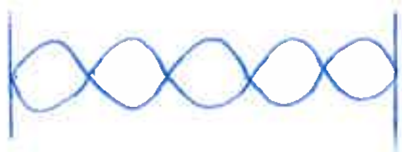
Whole motion

$$v^2 = u^2 + 2as$$
$$= (-26.0)^2 + 2(9.80)(25.0) \quad (1)$$
$$= 1.166 \times 10^3$$
$$\Rightarrow v = 34.2\ ms^{-1}\ \text{down} \quad (1)$$

Height is 59.5 m Velocity is 34.2 ms^{-1} down

Question 4 **(4 marks)**

A 45.0 cm long guitar string is vibrating in its fifth harmonic. Determine the frequency of the string if the air temperature is 25 °C. The speed of the wave is 153 ms^{-1}.



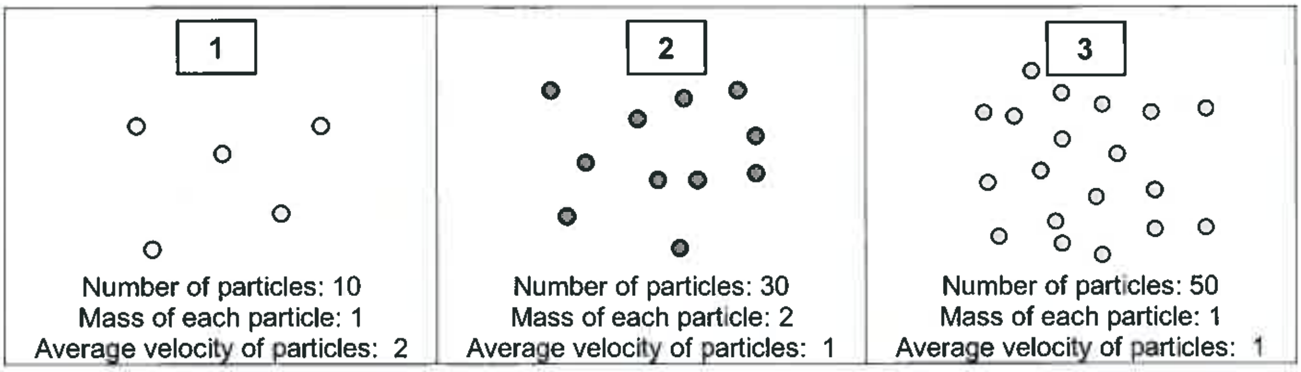
$l = \frac{5\lambda}{2}$

$$l = \frac{5\lambda}{2}$$
$$\Rightarrow \lambda = \frac{2l}{5} \quad (1)$$
$$= \frac{2(0.450)}{5}$$
$$= 0.180\ m \quad (1)$$

$$v = f\lambda$$
$$\Rightarrow f = \frac{v}{\lambda}$$
$$= \frac{153}{0.180} \quad (1)$$
$$= 8.50 \times 10^2\ ms^{-1} \quad (1)$$

Question 5 **(4 marks)**

Consider these three containers, each holding a sample of gas. The number of particles in each container as well as the relative mass and average velocity has also been listed.



(a) Which container of gas (1, 2 or 3) has the highest temperature? Justify your choice.

(2 marks)

- 1
- The particles have the highest average velocity ⇒ highest average E_K.

(b) Which container of gas (1, 2 or 3) has the highest internal energy? Justify your choice.

(2 marks)

- 2
- The total E_K (based on mass, speed and number of particles) is greatest.

Question 6 **(4 marks)**

An 85.0 kg rugby player collides with a 76.0 kg rugby player. Both players were moving towards each other at 2.60 ms^{-1}. The players bounce off each other such that the heavy player moves at 2.31 ms^{-1} and the lighter player moves at 2.89 ms^{-1}. Use suitable calculations to explain whether the collision was elastic or not.

$$\Sigma E_K \text{ (initial)} = \frac{1}{2} m_1 u_1^2 + \frac{1}{2} m_2 u_2^2$$
$$= \frac{1}{2}(85.0)(2.60)^2 + \frac{1}{2}(76.0)(2.60)^2 \quad (1)$$
$$= 5.44 \times 10^2 \text{ J} \quad (1)$$

$$\Sigma E_K \text{ (final)} = \frac{1}{2} m_1 v_1^2 + \frac{1}{2} m_2 v_2^2$$
$$= \frac{1}{2}(85.0)(2.31)^2 + \frac{1}{2}(76.0)(2.89)^2$$
$$= 5.44 \times 10^2 \text{ J} \quad (1)$$

∴ collision is elastic (1)

Question 7 **(4 marks)**

Miners in a uranium mine are regularly checked for radiation exposure. Concerns are raised if the miners are exposed to more than 100 mSv a month. The primary mode of decay in the mine is through alpha emission. ***Estimate*** how much radiation energy a 75.0 kg miner can safely absorb in a month. ***(Give your answer to a suitable number of significant figures.)***

Dose equivalent = absorbed dose × quality factor

$\Rightarrow 100 \times 10^{-3} = a.d. \times 20$ (1)

$\Rightarrow a.d. = 5.0 \times 10^{-3}$ Gy (1)

$a.d. = \frac{E}{m}$

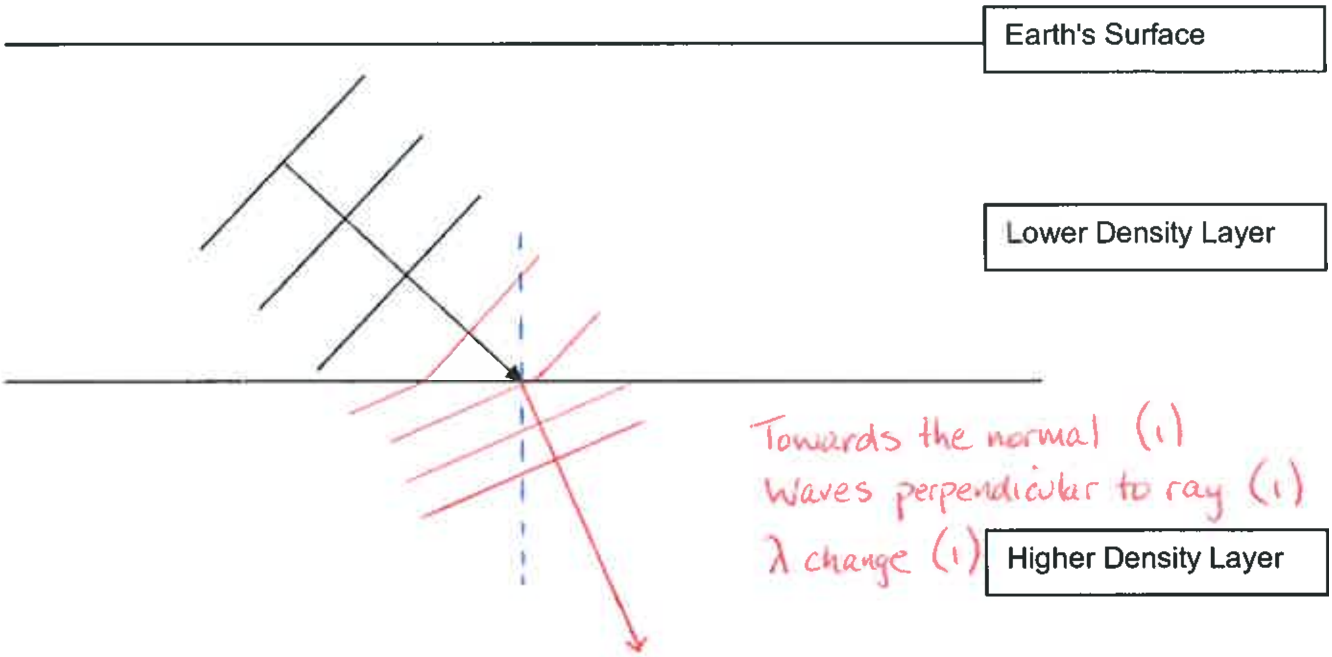
$\Rightarrow E = (5.0 \times 10^{-3})(75.0)$ (1)

$= \underline{0.38 \text{ J}}$ (1)

Answer 0.38 J

Question 8 **(3 marks)**

The P wave produced by an earthquake moves faster in lower density layers of the Earth. Show the behaviour of the P wave moving between layers of the Earth by completing the wave diagram below, ***showing the next two waves***.



Question 9 **(4 marks)**

A 125 kg wind surfer takes advantage of a sudden increase in the wind speed, accelerating from 4.85 ms^{-1} to 7.40 ms^{-1} in 3.30 s. Calculate the force and power of the wind applied to the wind surfer.

$$F = ma$$
$$= \frac{m(v-u)}{t} \quad (1)$$
$$= \frac{(125)(7.40-4.85)}{(3.30)}$$
$$= \underline{96.6\ N\ \text{forwards}} \quad (1)$$

$$P = \frac{\Delta E_k}{t}$$
$$= \frac{\frac{1}{2}mv^2 - \frac{1}{2}mu^2}{t} \quad (1)$$
$$= \frac{\frac{1}{2}(125)[(7.40)^2-(4.85)^2]}{(3.30)}$$
$$= \underline{592\ W} \quad (1)$$

Force is 96.6 N forwards Power is 592 W

Question 10 **(4 marks)**

The half-life of a particular radioactive source is 27.0 minutes. A 10.0 g sample of this source is observed to have an activity of 72.0 Bq. Calculate the time it will take for the activity of this sample to decrease to 12.0 Bq.

$$N = N_0 \frac{1}{2^n}$$
$$\Rightarrow 12.0 = \frac{72.0}{2^n} \quad (1)$$
$$\Rightarrow 2^n = 6.00$$
$$\Rightarrow n \log 2 = \log 6.00 \quad (1)$$
$$\Rightarrow n = 2.58 \quad (1)$$
$$\therefore \text{Time} = (2.58)(27.0)$$
$$= \underline{69.7\ min} \quad (1)$$

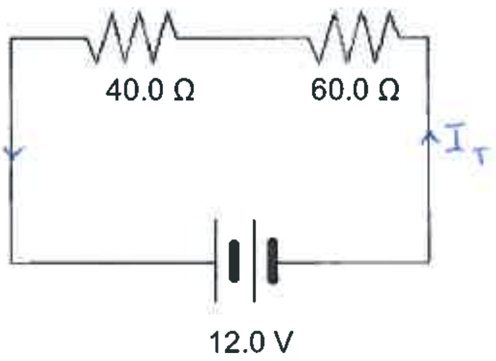
Question 11 **(4 marks)**

The radiator used in a car cooling system is constructed from many narrow passageways which the coolant (liquid for capturing heat from the engine) passes through. A fan is used to force air through the radiator. Describe the reason for having such narrow passageways and why air is forced through the radiator.

- Narrow passageways increase the surface area. (1)
- Increases the rate at which heat is lost. (1)
- Fan pulls air through the radiator. (1)
- Removes hot air so more heat can be removed by the cooler air. (1)

Question 12 **(4 marks)**

Calculate the voltage, current and power of the 60.0 Ω resistor in the circuit below.



$V_T = I_T R_T$

$\Rightarrow I_T = \frac{12.0}{100.0}$ (1)

$= \underline{0.120 \text{ A}}$ (1)

$V_{60\Omega} = I_T R$

$= (0.120)(60.0)$

$= \underline{7.20 \text{ V}}$ (1)

$P_{60\Omega} = V_{60\Omega} I_T$

$= (7.20)(0.120)$

$= \underline{0.864 \text{ W}}$ (1)

Voltage is 7.20 V Current is 0.120 A Power is 0.864 W

Question 13 **(6 marks)**

A toddler places a metal toy train into a toaster, which provides an electrical contact between the interior electrical components and the exterior metal case of the toaster. The train has a very high resistance such that when the toaster is turned on, a ***small current*** flows through the train into exterior case and then into the person who was holding the toaster.

(a) Name ***two*** safety devices that would help prevent this particular electrocution and describe why each device would be useful. (4 marks)

- RCD
- Will detect a change in the current flow and shut off the electricity.
- Earth wire
- Will conduct current to the Earth.

(b) Name ***one*** safety device that would ***not*** be useful for this particular electrocution and describe why. (2 marks)

- Fuse or circuit breaker.
- Both will only work when the current flow is too large. Both will not work with a small current.

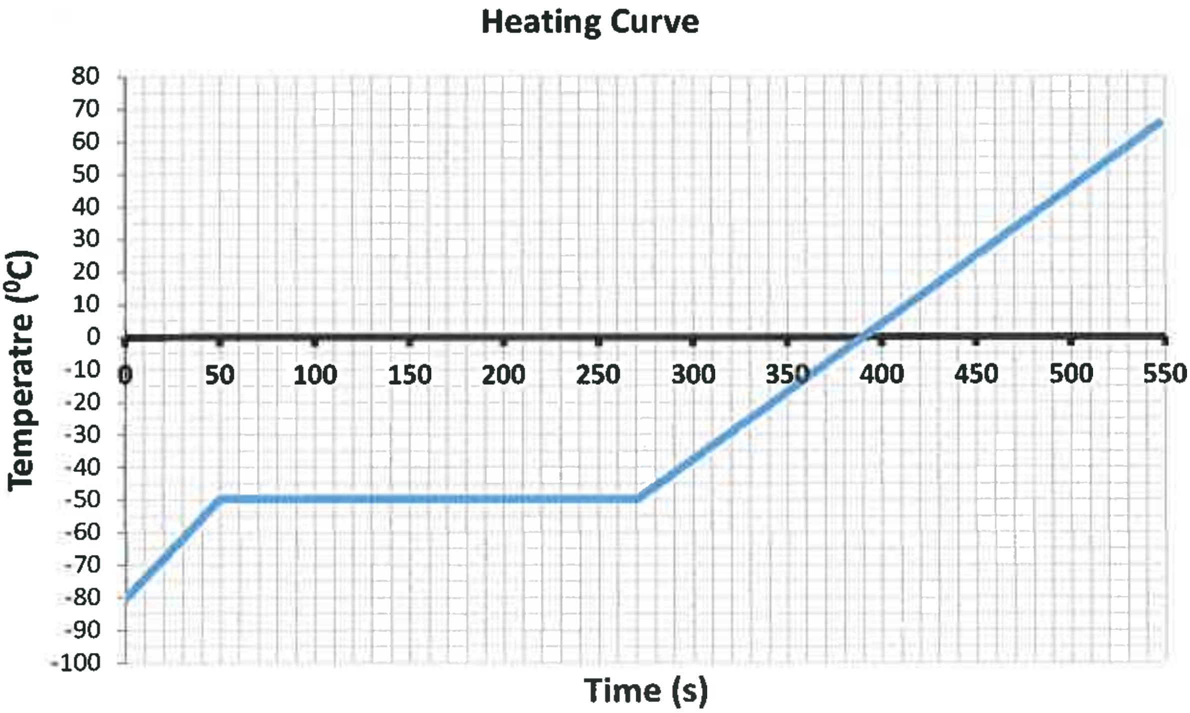
End of Section One

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

This section has **seven (7)** questions. You must answer **all** questions. Write your answers in the space provided. Suggested working time for this section is 90 minutes.

Question 14 **(12 marks)**

A 0.60 kg substance, beginning in its liquid phase, was heated using a 0.30 kW source. The substance produced the following heating curve.



(a) State the boiling point of the substance. (1 mark)

• −50°C (1)

(b) State the range(s) of time that the kinetic energy of the substance was increasing. (2 marks)

• Between 0 and 50 s (1)

• Between 270 and 550 s (1)

(c) State a time where the substance would be a mixture of both liquid and gas phases. (1 mark)

• Between 50 s and 270 s (but not at either of these extremes) (1)

(d) Calculate the latent heat of vaporisation from the data available on the graph. (3 marks)

$P = \frac{Q}{t}$

$\Rightarrow Q = Pt$

$= (300)(270-50)$ (1)

$= 6.60 \times 10^4$ J (1)

$Q = mL_f$

$\Rightarrow L_f = \frac{Q}{m}$

$= \frac{6.60 \times 10^4}{0.600}$

$= 1.10 \times 10^5$ J kg^{-1} (1)

Answer 1.10×10^5 J kg^{-1}

(e) Calculate the specific heat capacity of the gas phase of the substance from the data available on the graph. (3 marks)

Consider the time from 270 s → 390 s.

$P = \frac{Q}{t}$

$\Rightarrow Q = Pt$

$= (300)(390-270)$

$= 3.60 \times 10^4$ J (1)

$Q = mc\Delta T$

$\Rightarrow c = \frac{Q}{m\Delta T}$

$= \frac{3.60 \times 10^4}{(0.600)(0-(-50))}$ (1)

$= 1.20 \times 10^3$ J kg^{-1} K^{-1} (1)

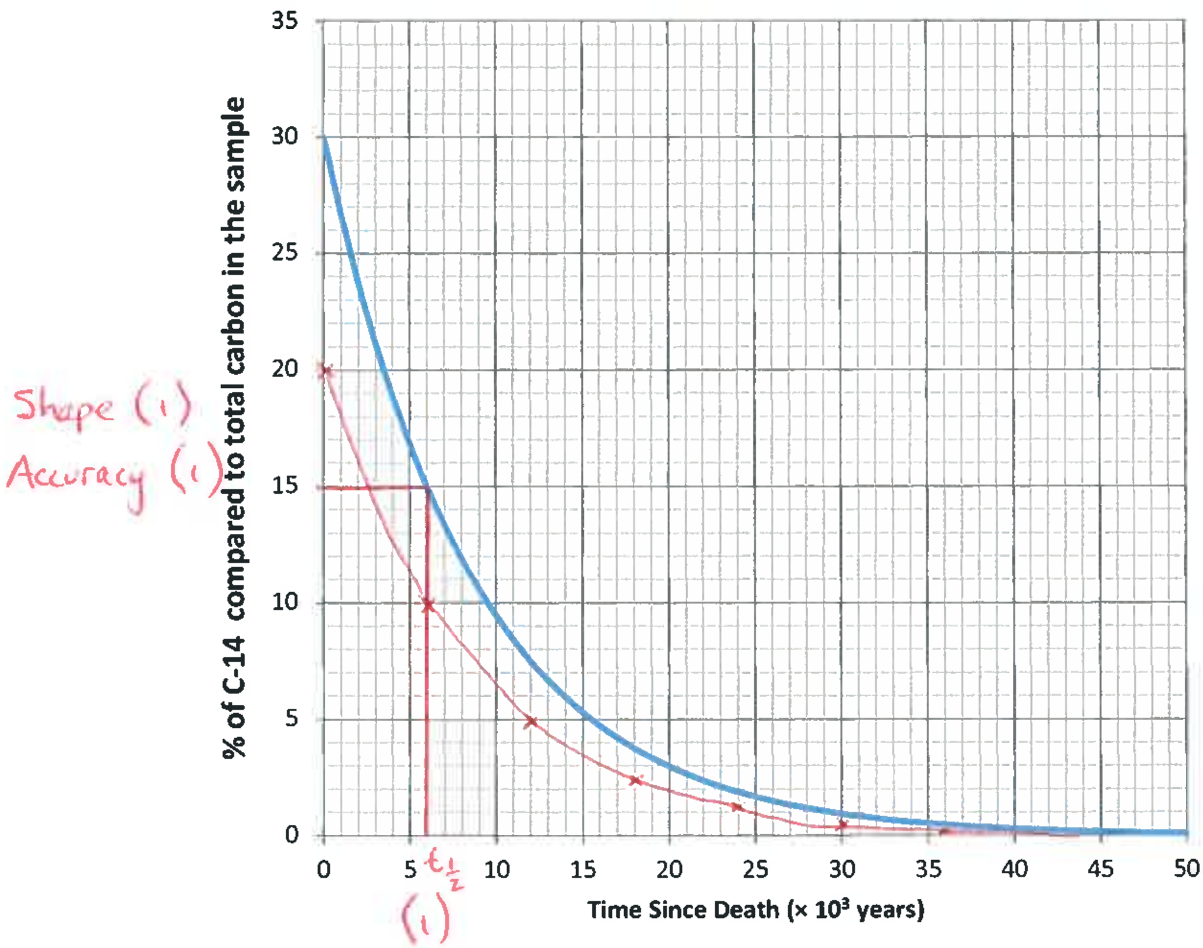
Answer 1.20×10^3 J kg^{-1} K^{-1}

(f) Is the specific heat capacity of the liquid phase of this substance higher or lower than when in its gas phase? No calculation is required but you must refer to elements of the graph to justify your choice. (2 marks)

- lower (1)
- Gradient of the liquid phase is steeper
  ⇒ Temperature rises quicker in liquid phase. (1)

Question 15 **(14 marks)**

Radio carbon dating is a useful technique for establishing the date of death of organic matter. Two pieces of information are required; the half-life of carbon-14 and the ratio of carbon-14 to non-radioactive forms of carbon the organic matter contained while it was alive. The fraction of carbon-14 compared to total carbon for a sample as a function of time is shown below.



(a) What percentage of carbon in this organic matter was ***not*** radioactive while the organism was alive? (2 marks)

- 30% radioactive (1)
- ⇒ 70% non-radioactive (1)

(b) What is the half-life of carbon-14 as indicated by the graph? Show evidence of how you determined your answer on the graph to help support your answer. (2 marks)

- 6000 yrs (1)

Line on graph (1)

(c) The graph scale reveals the percentage of carbon-14 becomes negligible at 40 x 10^3 years since time of death. Determine, by use of a calculation, what the likely percentage of carbon-14 is after 40 x 10^3 years has passed. (3 marks)

$n = \frac{40 \times 10^3}{6000}$

$= 6.67$ (1)

$N = N_0 \frac{1}{2^n}$

$= (30.0)\left(\frac{1}{2^{6.67}}\right)$ (1)

$= \underline{0.295\ \%}$ (1)

Answer $0.295\ \%$

(d) Explain why your calculation in the previous answer will only be the "likely" percentage, no matter how accurate the half-life used in the calculation is. (2 marks)

- Half-life is the average of how long it takes for half of a sample to decay. (1)
- There is a chance that a decay will deviate from this average; hence it is only the "likely" percentage. (1)

(e) Each radioisotope has a different half-life. This is due to differences in the stability of forces acting within the nuclei. Explain why some nuclei are more unstable than others. (3 marks)

- The protons in a nucleus repel each other due to electrostatic repulsion. (1)
- The nucleons attract each other through the strong nuclear force. (1)
- The ratio of protons : neutrons and their total number affect the size of these forces and the stability of the nuclei. (1)

(f) On the graph, sketch the curve showing the percentage of carbon-14 for a sample that had 20% carbon-14 prior to its death. (2 marks)

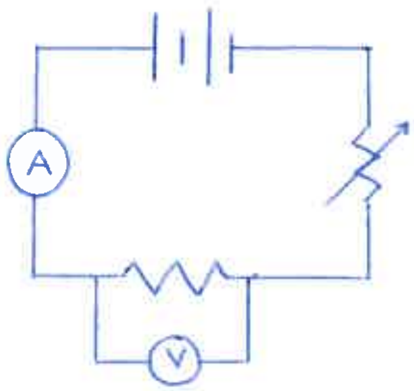
See the graph. Shape (1)

Accuracy (1)

Question 16 **(15 marks)**

Students were asked to find and then analyse the voltage-current profile of a circuit element. The students were required to measure current through the element for a variety potential differences. The equipment available to them was the circuit element, a 24.0 V battery, variable resistor (rheostat), voltmeter, ammeter and a collection of wires.

(a) Draw a circuit diagram of the circuit the students could use to vary the potential difference applied to the circuit element and to measure this potential difference and the current through the element. (4 marks)



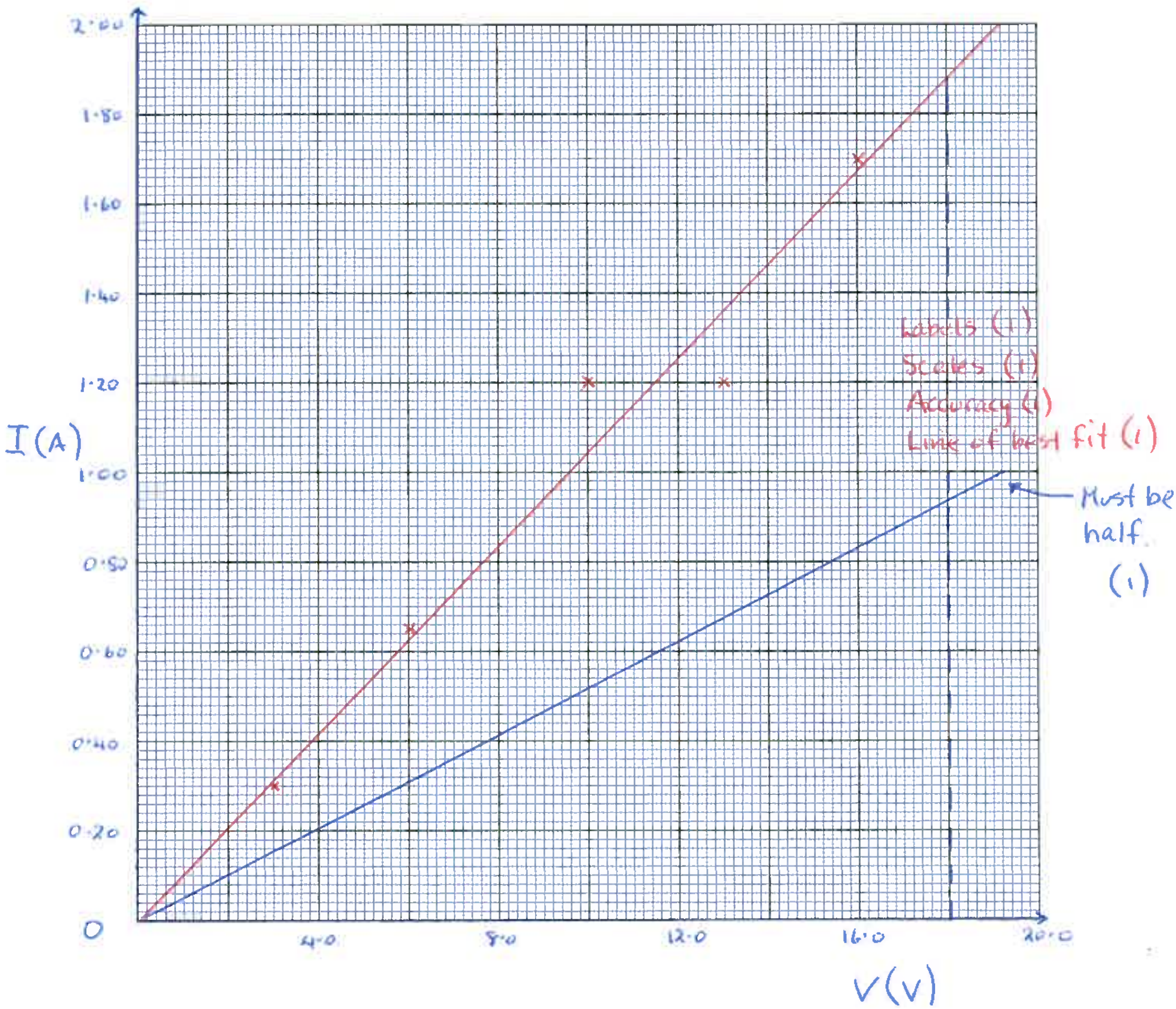
Circuit symbols (2)
Ammeter in series (1)
Voltmeter in parallel (1)

(b) Use the record of the student's results in the following table to produce a voltage-current graph. Place the voltage along the horizontal axis. A grid is available on the next page. If you require, a spare grid is found at the back of the exam paper. (4 marks)

Voltage (V)	3.00	6.00	10.0	13.0	16.0
Current (A)	0.30	0.65	1.20	1.20	1.70

(c) Is this circuit element ohmic or non-ohmic? Justify your choice by referring to the graph. (2 marks)

- Ohmic (1)
- $V \propto I$ - linear graph (1)



(d) Calculate the gradient of the line of best fit. (2 marks)

$$\text{gradient} = \frac{1{\cdot}88 - 0{\cdot}0}{18{\cdot}0 - 0{\cdot}0} \quad (1)$$

$$= \underline{0{\cdot}104\ AV^{-1}} \quad (1)$$

[Must use gradient, not 1 datapoi

Answer $0{\cdot}104\ AV^{-1}$

(e) Using the gradient, determine the resistance of the circuit element. (2 marks)

$$\text{gradient} = \frac{I}{V} = 0{\cdot}104\ AV^{-1}$$

$$V = IR$$

$$\Rightarrow R = \frac{V}{I}$$

$$= \frac{1}{0{\cdot}104}$$

$$= 9{\cdot}61\ \Omega \quad (\pm 0{\cdot}40\ \Omega)$$

Answer $9{\cdot}61\ \Omega\ (\pm 0{\cdot}40\ \Omega)$

(f) On to your graph, sketch the voltage-current curve for another circuit element that has ***twice*** the resistance of the element investigated by the students. (1 mark)

- Twice R ⇒ half I for the same voltage.
- gradient must be half. (See graph)

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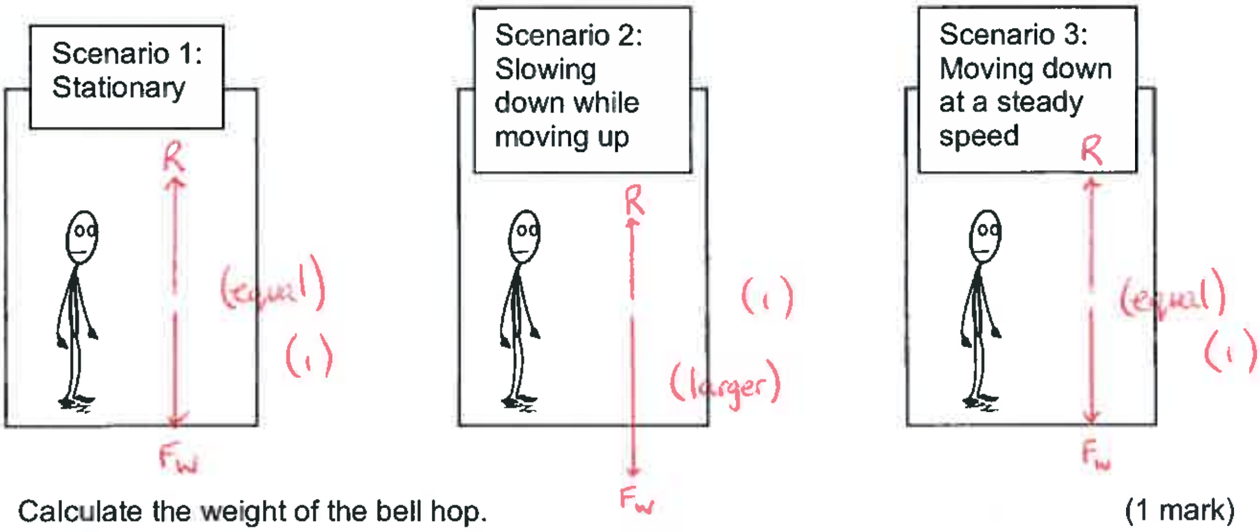
Question 17 **(15 marks)**

In the 1950s, it was common practice for elevators to be operated by a bell hop; a person who would manipulate hand controls to determine both the speed and direction of the elevator. A 60.0 kg bell hop is bored and decides to play around with the elevator controls.

(a) Draw a free body diagram showing a labelled ***weight force*** and ***normal force*** that would be acting on the bell hop ***for each scenario*** the elevator is found in below. For clarity, draw the forces in the white space next to each bell hop, not over the bell hop. (3 marks)

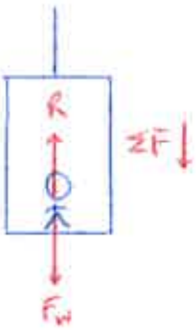


(b) Calculate the weight of the bell hop. (1 mark)

$$F_w = mg$$
$$= (60.0)(9.80)$$
$$= \underline{588\ N} \quad (1)$$

Answer $588\ N$

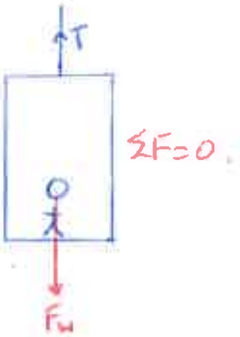
(c) Calculate the magnitude of the normal force acting on the bell hop in scenario 2 if the acceleration of the elevator is 3.20 ms^{-2}. (3 marks)



$$\Sigma F = F_w - R$$
$$\Rightarrow R = F_w - \Sigma F$$
$$= mg - ma$$
$$= (60.0)(9.80 - 3.20)$$
$$= \underline{396\ N}$$

Answer $396\ N$

(d) The elevator itself has a 180 kg mass. Calculate the tension in the cable supporting the elevator with the bell hop inside if the elevator was stationary. (2 marks)



$\Sigma F = 0$

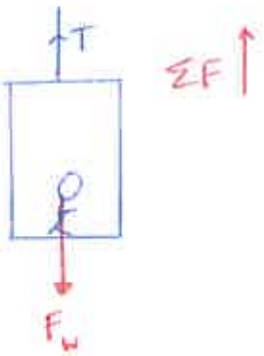
$\Rightarrow \quad T = F_w = mg$

$= (180 + 60.0)(9.80)$ (1)

$= \underline{2.35 \times 10^3 \text{ N up}}$ (1)

Answer $\underline{2.35 \times 10^3 \text{ N up}}$

(e) Explain whether the tension in the cable would ***increase, decrease or remain the same*** as the elevator begins to move up, compared to when it was stationary. State and refer to one of Newton's laws of motion in your answer. (3 marks)



- ΣF is up as it accelerates up. (1)

$\Sigma F = T - F_w$

$\Rightarrow \quad T = \Sigma F + F_w \quad (> F_w)$ (1)

$\therefore$ <u>T is greater</u> (1)

(f) Describe why the bell hop would feel weightless if the cable supporting the elevator breaks. (3 marks)

- The bell hop and elevator accelerate downwards equally. (1)
- $R = 0$ - no reaction force exists. (1)
- Feels no reaction force, so feels weightless. (1)

Question 18 **(13 marks)**

An organ is a musical instrument that operates on the resonance of both open and closed pipes of varying length. A keyboard of white and black keys, similar in appearance to those on a piano, are used to activate wind that passes through the pipes, causing them to vibrate at their natural frequencies.

A full-size organ spans 5 octaves from the lowest note to the highest note across the keyboard. In music, an octave is the separation between two notes if one note has either double or half the frequency of the other. ***(i.e. 5 octaves means that the frequency doubles 5 times.)***

(a) Explain why pipes of varying length and type (open/closed) are required to produce different notes. (3 marks)

- Each note is a particular frequency. (1)
- Each pipe length (either open or closed) has a unique fundamental frequency. (1)
- Hence each note will need a particular length of pipe. (1)

(b) A full-sized organ can produce notes as low as 8.00 Hz.

(i) Calculate the shortest length of pipe able to produce this note. (3 marks)
(HINT: Consider whether an open is closed pipe is required.)

Shortest length is for closed pipe: $l = \frac{\lambda}{4}$ (1)

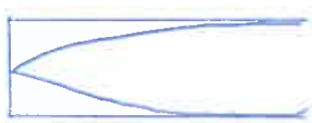
$v = f\lambda$

$\Rightarrow \lambda = \frac{v}{f} = \frac{346}{8.00} = 43.25\text{m}$ (1)

$l = \frac{\lambda}{4} = \frac{43.25}{4} = 10.8\text{ m}$ (1)

Answer 10.8 m

(ii) Draw the standing wave pattern inside this pipe when producing this note. (1 mark)



(1)

(iii) Calculate the highest frequency this full-sized organ will produce when activating a key on the other end of the keyboard. (1 mark)

5 octaves $\Rightarrow$ frequency increases 2^5

$\therefore$ Highest $f = (8.00)(2^5)$

$= 256$ Hz. (1)

Answer 256 Hz

(c) Show that the wavelength of ***any*** harmonic of an open pipe can also be produced by a closed pipe of equal length resonating at twice the harmonic of the open pipe. (3 marks)

CLOSED

$\lambda_c = \frac{4l}{(2n-1)}$

OPEN

$\lambda_o = \frac{2l}{n}$

Let n' = the closed harmonic.

$\lambda_c = \lambda_o$ (1)

$\Rightarrow \frac{\cancel{4}^{2} l}{n'} = \frac{\cancel{2} l}{n}$ (1)

$\Rightarrow \underline{n' = 2n}$ (1)

(d) On hot days, the organ can sound slightly out of tune. Suggest a reason for this. (2 marks)

- On hotter days, speed of sound increases. (1)
- As $f \propto v$, f increases. (1)

Question 19 **(11 marks)**

The nuclear fission of uranium-235 within nuclear fuel rods has a range of possible products. While the average mass of a fission fragment is 118, it is unlikely to find fragments of this mass since the uranium nucleus usually splits unevenly. The most common fission result is barium-137 and krypton-95 in addition to some neutrons. The mass of reactants and products of this common reaction are found in the table below.

Particle	Mass (u)
Uranium-235	235.043930
Barium-137	136.905827
Krypton-95	94.939844
Neutron	1.000866

(a) Write the nuclear reaction showing the most commonly occurring fission of uranium-235. ***(Ignore the neutron that causes the fission of the U-235 atom.)*** (3 marks)

$$^{235}_{92}U \rightarrow {}^{137}_{56}Ba + {}^{95}_{36}Kr + 3\,^{1}_{0}n$$ [1 mark each product]

(b) Calculate the mass defect of this fission reaction. (3 marks)

Mass (reactants) = 235·043930 u

Mass (products) = 136·905827 u + 94·939844 u + 3(1·000866 u)

= 234·848269 u (1)

Mass defect = 235·043930 u − 234·848269 u (1)

= 0·195661 u (1)

Answer 0·195661 u

(c) Calculate the energy released by a single fission event ***in joules***. (3 marks)

$E = (0.195661)(931)$ (1)

$= 182$ MeV (1)

$= 2.91 \times 10^{-11}$ J (1)

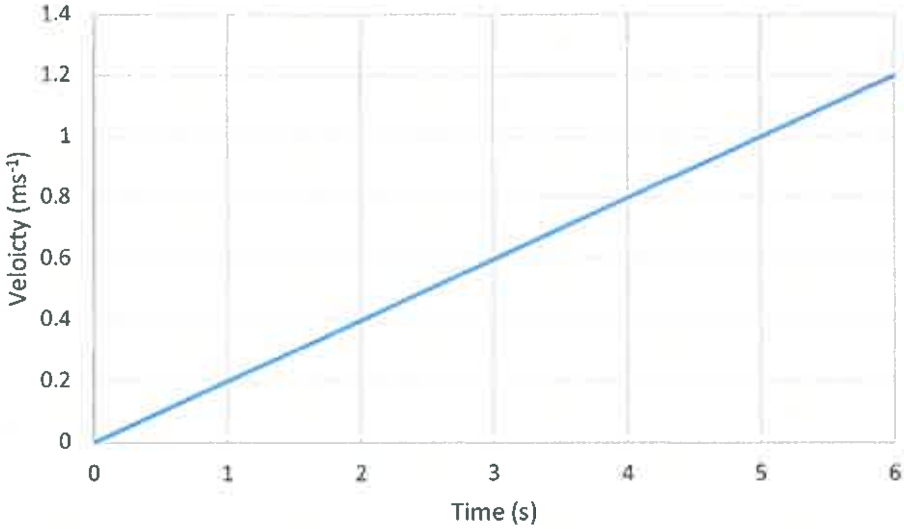
Answer 2.91×10^{-11} J

(d) In what form does this released energy exist? (2 marks)

- Heat (1)
- E_k of the product particles (1)

Question 20 **(10 marks)**

A 0.850 kg remote-controlled car is powered by a 2.00 W electric motor. Its operator, standing next to the car, pushes the control stick forward to its maximum position, causing the car to accelerate along the flat path away from the operator. The car's velocity for the first 6.00 s of its journey is shown below.



(a) Calculate the acceleration of the car by ***analysing the graph***. (2 marks)

gradient = a

$= \frac{1.2 - 0.0}{6.0 - 0.0}$ (1)

$= \underline{0.20\ ms^{-2}}$ (1)

[Using equation of motion (1)]

Answer $0.20\ ms^{-2}$

(b) Calculate the distance covered by the car in the 6.00 s by ***analysing the graph***. (2 marks)

s = area under graph

$= \frac{1}{2}(6.0)(1.2)$ (1)

$= \underline{3.6\ m}$ (1)

Answer 3.6 m

(c) Calculate the efficiency of the car's motor. (3 marks)
(HINT: Consider the energy output of the motor and the E_k of the car.)

$P = \frac{E}{t}$

$\Rightarrow E = Pt$
$= (2.00)(6.0)$
$= 12\text{ J}$ (1)

$\Delta E_k = \frac{1}{2}mv^2 - \frac{1}{2}mu^2$
$= \frac{1}{2}(0.850)(1.2)^2 - 0$
$= 0.612\text{ J}$ (1)

$\%\text{ eff} = \frac{0.612}{12} \times \frac{100}{1}$
$= \underline{5.1\%}$ (1)

Answer 5.1%

(d) At the 6.00 s mark, the operator released the control stick and the car slowed down, coming to a complete stop 4.40 m from the operator. Calculate the average frictional force acting on the car during its deceleration. (3 marks)

At $t = 6.00\text{ s}$: $s = 3.60\text{ m}$.

$\therefore s\,(\text{slowing}) = 4.40 - 3.60$
$= 0.80\text{ m}$ (1)

$W = \Delta E_K = Fs$
$\Rightarrow F = \frac{\Delta E_K}{s}$ (1)
$= \frac{0.612}{0.80}$
$= \underline{0.76\text{ N backwards}}$ (1)

Answer 0.76 N backwards

End of Section 2

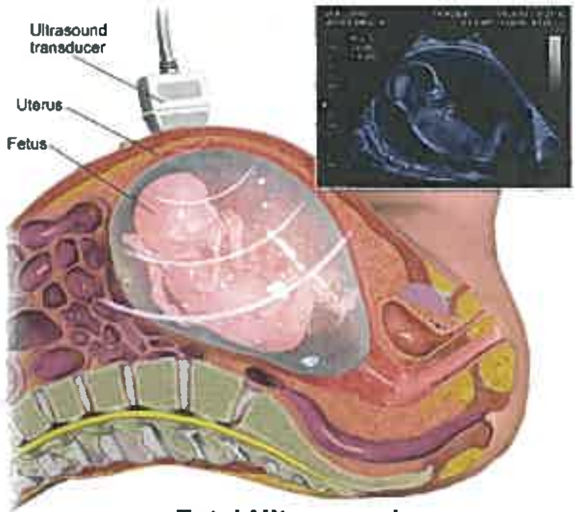
Section Three: Comprehension 20% (36 Marks)

This section contains **two (2)** questions. You must answer both questions. Write your answers in the spaces provided. Suggested working time for this section is 40 minutes.

Question 21 **(18 marks)**

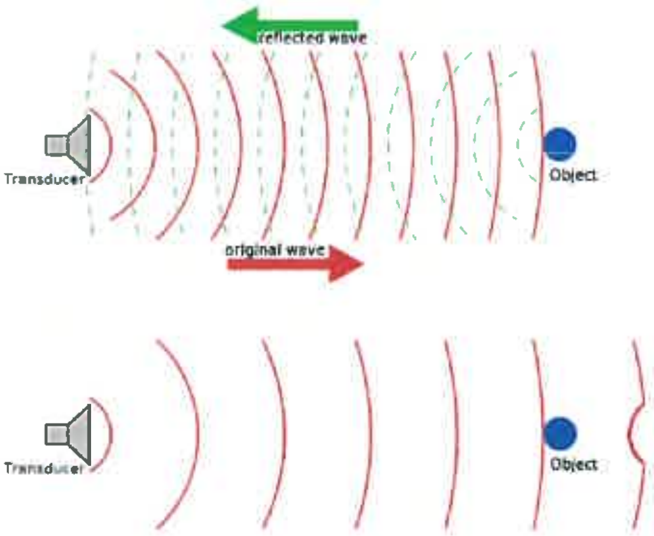
The Medical Use of Ultrasound

The term ultrasound refers to sound vibrations with a frequency higher than is perceptible by humans; in the range of 20.0 kHz or more. As with all sound, ultrasound waves will undergo reflection and refraction at boundaries between mediums as well as undergoing interference. Ultrasound's wave behaviours allow for it to be used as a non-invasive, safe imaging technique for medical diagnosis; The most common being to monitor foetal development.



Fetal Ultrasound

An ultrasound wave is produced within a device called a transducer which houses a piezoelectric material that vibrates in response to an electric current. The wave is directed into the body where it reflects or refracts at the boundary between different tissue layers (e.g. between fat and muscle or blood and arterial walls). Reflected waves are detected by the piezoelectric material in the transducer, converted into a current and interpreted by software to form an image.



When using a wave to form an image it is important that the wavelength is similar or smaller than the size of the features that need to be distinguished. If the wavelength is larger than the feature, the wave tends to bend around the feature instead of being reflected (see image on left). Monitoring foetal development requires observation of features as small as one millimetre wide. This is why the 'ultra' part of ultrasound is required – it has a small enough wavelength to reveal the necessary details.

Can we keep increasing the frequency to obtain clearer images? Unfortunately, the energy of the wave is absorbed easily by body tissues at higher frequencies. This limits how deep a high frequency wave can penetrate into the body before it must reflect, otherwise it will be absorbed before returning to the transducer. Thus, higher frequencies have low penetration but clearer images while low frequencies have higher penetration but lower clarity. The right frequency to use will be one that maximises clarity while still being able to reach deep enough into the part of the body needing to be imaged.

As stated earlier, the ultrasound will reflect and refract at the boundary between tissue layers. How much of the wave reflects and how much refracts depends on the difference between the acoustic impedance of each layer. The acoustic impedance (Z) is the resistance the ultrasound wave encounters moving through tissue. As the difference in acoustic impedance between the layers increases, the fraction of the wave that reflects also increases. The fraction of the amount reflected can be calculated using:

$$reflection\ fraction = \left(\frac{Z_2 - Z_1}{Z_1 + Z_2}\right)^2$$

Where Z_1 and Z_2 are the acoustic impedance of tissue layer 1 and tissue layer 2 respectively.

A similar observation can be made with audible sounds. An echo heard from a canyon wall occurs because the difference in acoustic impedance between the air and the dense rock is large, causing the sound to be reflected back. However, sound waves moving through different density layers of air mostly refracts because the layers have similar impedances.

Questions:

(a) What is the maximum wavelength of an ultrasound passing through air at 25.0 °C? Give your answer to a suitable number of significant figures. (3 marks)

$v = f\lambda$

$\Rightarrow \lambda = \frac{346}{20.0 \times 10^3}$ (1)

$= 1.73 \times 10^{-2}$ m (1) [3 sig. fig. (1)]

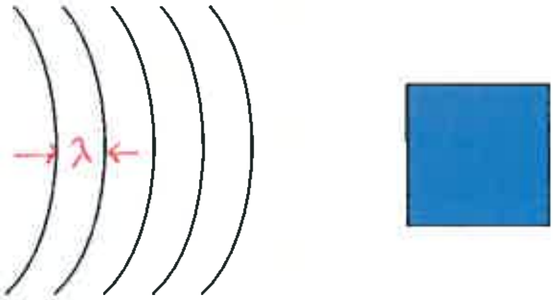
Answer 1.73×10^{-2} m

(b) Describe the role of a transducer in a medical ultrasound. (2 marks)

- Produces and transmits the ultrasound wave. (1)
- Detects the reflected ultrasound wave. (1)

(c) In the diagram below, is it possible for the incident wave to reflect off the object that is in the path of the wave? Justify your answer by referring to information available in the diagram and article. (2 marks)

- Yes (1)
- λ for the wave is much less than the width of the object. (1)



(d) Typically, a 2.50 MHz wave is used for a medical ultrasound of a foetus.

(i) What is the size of the smallest feature required to be distinguished when monitoring a foetus? (1 mark)

- 1 mm

(ii) Via a suitable calculation, ***estimate*** the speed of sound inside the womb where the foetus is located. (3 marks)

Assume $\lambda = 1.0 \times 10^{-3}$ m (1)

$v = f\lambda$

$= (2.50 \times 10^{6})(1.0 \times 10^{-3})$ (1)

$= \underline{2.5 \times 10^{3} \text{ ms}^{-1}}$ (2 sig. fig) (1)

Answer $2.5 \times 10^{3} \text{ ms}^{-1}$

(e) Describe why increasing the frequency of the ultrasound waves is not always the best option to produce useful medical images. (2 marks)

- Reduces the penetrative power of the wave. (1)
- May not be able to image deep enough into the body. (1)

(f) The table below shows the acoustic impedance of mediums relevant to ultrasound medical imaging.

Medium	Impedance (× 10^6 kg m^{-2} s^{-1})
Air	0.0004
Skin	1.99
Fat	1.38
Kidney	1.65

(i) Calculate the fraction of an ultrasound wave that is reflected at the boundary of fat and kidney tissue. (3 marks)

$$\text{reflection fraction} = \left(\frac{Z_2 - Z_1}{Z_1 + Z_2}\right)^2 \quad (1)$$

$$= \left(\frac{1.65\times10^6 - 1.38\times10^6}{1.38\times10^6 + 1.65\times10^6}\right)^2 \quad (1)$$

$$= \underline{7.94\times10^{-3}} \quad (1)$$

Answer 7.94×10^{-3}

(ii) A special gel is placed on the transducer so that when it is placed on the skin of the patient there is no air between the transducer and the skin. Suggest a reason why this is important. (2 marks)

- Difference in impedance between air and skin is large. (1)
- The gel reduces this greatly so the wave enters the body with little reflection. (1)

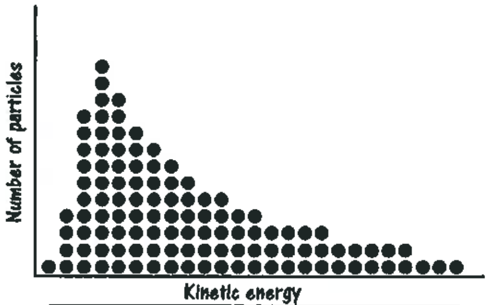
Question 22 **(18 marks)**

Colder than Absolute Zero

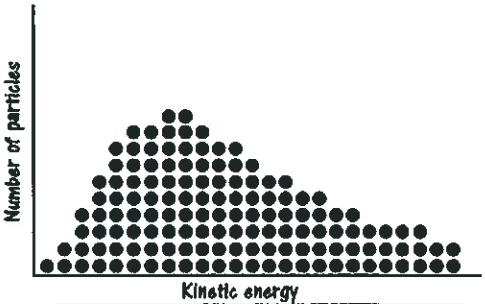
While studying Physics Unit 1, you were likely exposed to the concept of absolute zero; the lowest possible temperature, occurring when particles have zero kinetic energy. However, experiments conducted within the last 5 years have produced negative temperatures. That is, temperatures below absolute zero. In a bizarre twist, it's also possible to view a substance at a negative temperature as also being hotter than infinity.

For a substance at any positive temperature, the particles of the substance have a range of kinetic energies. The higher the temperature, the higher the average kinetic energy. However, regardless of how high the temperature is, it is more likely to find a particle at lower kinetic energies than higher kinetic energies. The number of particles across the range of all kinetic energy values is described by the Maxwell-Boltzmann distribution (see below).

Maxwell-Boltzmann particle distributions:



Low positive temperature



High positive temperature

Approaching 0 K, the particles all bunch up on the left side of the horizontal axis as no particles have any kinetic energy. As the temperature increases more and more, particles move towards higher kinetic energies but there are always some particles with very little, or no kinetic energy. Even at a theoretical infinite temperature the particles would ***not*** all bunch up on the right side of the horizontal axis. There will always be particles with zero, or low, kinetic energy; this is how a chaotic system of particles naturally organises itself.

For negative temperatures to be achieved, the particles must exist in an unnatural state. If you take a collection of particles and make sure they all have around the same (non-zero) kinetic energy, then you have achieved a negative temperature. What makes this a negative temperature you ask? After all, the particles still have a positive average kinetic energy and temperature is simply average kinetic energy, right? Well that depends on who you ask. There are several definitions of temperature, including:

1. the measurement of warmth or coolness (non-scientist)
2. the average kinetic energy of the particles (large objects)
3. the amount of entropy compared to the energy of the particles (small clusters of particles)

It's that last definition that has allowed for negative temperatures to be achieved. Entropy is the amount of randomness within a system. High positive temperatures have high entropy because of the large spread (randomness) of the particle kinetic energies. Negative temperatures have low entropy because the particle kinetic energies are not spread out (low randomness). Scientists have trapped collections of potassium atoms using lasers and magnetics such that they all have the same kinetic energy and cannot collide with each other. This is how the negative temperature was achieved.

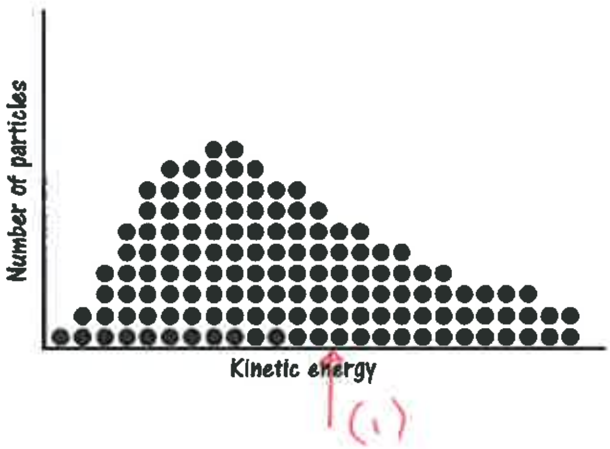
It's worthwhile noting that negative temperatures are actually warmer than positive temperatures. If a collection of particles at a negative temperature was brought into contact with a collection of particles at (any) positive temperature then heat would flow from the negative temperature region to the positive temperature region. As heat flows from hot to cold, negative temperatures are warmer. So negative temperatures are hotter than infinity!

Questions:

(a) The lowest temperatures in Western Australian occur at night in the desert and are as low as - 4.50 ^{0}C. Explain why this article is so impressed with the concept of negative temperatures when even a warm country like Australia experiences them. (3 marks)

- -4.50 °C is on the Celsius scale, which allows for negative temperatures below 0 °C. (1)
- The article refers to the Kelvin scale. (1)
- Temperatures below 0 K have been achieved in the laboratory. (1)

(b) For the Maxwell-Boltzmann distribution below, place an arrow on the horizontal axis indicating the approximate value of the average kinetic energy of all the particles. Label this arrow clearly. (1 mark)



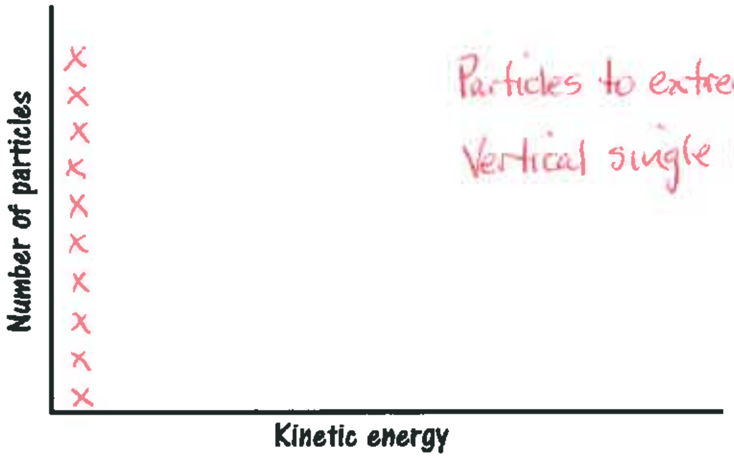
(c) Explain why negative temperatures do not occur naturally. (2 marks)

- It requires all particles to have the same E_K. (1)
- In nature, particles have a range of E_K values due to entropy. (1)

Question 22 (continued)

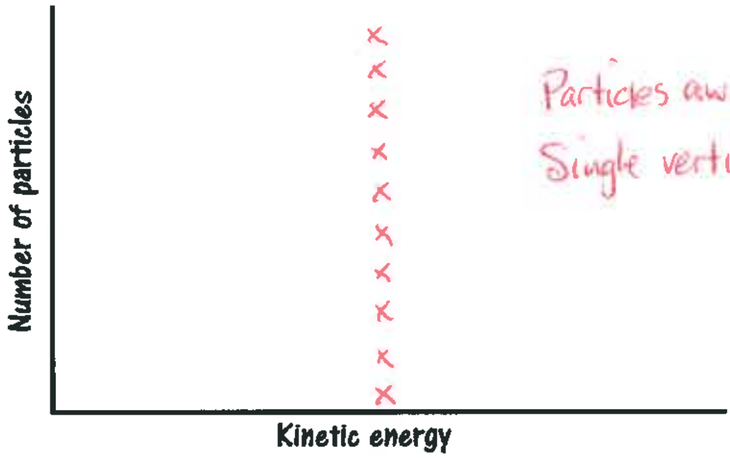
(d) On the set of axes provided, draw the distribution of particle kinetic energies expected for the following conditions:

(i) Absolute zero (2 marks)



Particles to extreme left. (1)
Vertical single line. (1)

(ii) Negative temperature (2 marks)



Particles away from left axis. (1)
Single vertical line. (1)

(e) Describe one similarity and one difference between a substance at a positive temperature and a substance at a negative temperature. (3 marks)

SIMILARITY: particles have non-zero E_K (1)

DIFFERENCE: particles in positive temperature have a range of E_K. (1)
Negative temperatures have only a single E_K. (1)

(f) What equipment was used to create negative temperatures in the lab? (1 mark)

• lasers and magnets.

(g) Why do you suppose it was important that the potassium atoms were stuck in place and not able to collide with each other? (2 marks)

• Colliding particles transfer E_k, causing a range. (1)
• Negative temperature systems have particles with one E_k. (1)

(h) Explain why negative temperatures are hotter than positive temperatures. (2 marks)

• Energy will flow from a negative temperature region to a positive temperature region. (1)
• As heat always flows from hot to cold, the negative temperature region is hotter. (1)

End of Questions

Additional working space

Spare grid for graph

End of examination

Acknowledgements

Question 20
Foetal Ultrasound
https://commons.wikimedia.org/wiki/File:Fetal_Ultrasound.png
By BruceBlaus (Own work) [CC BY-SA 4.0 (http://creativecommons.org/licenses/by-sa/4.0)], via Wikimedia Commons

Wave Reflection
Adapted from https://commons.wikimedia.org/wiki/File%3ASonar_Principle_EN.svg
By Georg Wiora (Dr. Schorsch) (Self drawn with Inkscape) [GFDL (http://www.gnu.org/copyleft/fdl.html), CC-BY-SA-3.0 (http://creativecommons.org/licenses/by-sa/3.0/) or CC BY-SA 2.5 (http://creativecommons.org/licenses/by-sa/2.5)], via Wikimedia Commons