HOLY CROSS COLLEGE

SEMESTER 2, 2019

Question/Answer Booklet

11 PHYSICS

Please place your student identification label in this box

SOLUTIONS

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	10	10	50	55	30
Section Two: Extended answer	6	6	90	88	50
Section Three: Comprehension and data analysis	2	2	40	36	20
			Total	179	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% (55 Marks)

This section has **ten (10)** questions. Answer **all** questions. Write your answers in the space provided. Suggested working time for this section is 50 minutes.

Question 1 (5 marks)

The Shinkansen high-speed train in Japan decelerated at 2.00 ms^{-2} for 35.0 s as it approached Kobe station and came to a stop.

(a) What was the velocity of the train before it started braking? (3)

Take forwards as +ve.

$v = 0\ ms^{-1}$

$u = ?$

$a = -2.00\ ms^{-2}$ (1)

$t = 35.0\ s$

$s = ?$

$v = u + at$

$\Rightarrow u = v - at$ (1)

$= 0 - (-2.00)(35.0)$

$= \underline{70.0\ ms^{-1} \text{ forwards}}$ (1)

(b) How far did the train travel while decelerating? (2)

$s = ut + \frac{1}{2}at^2$

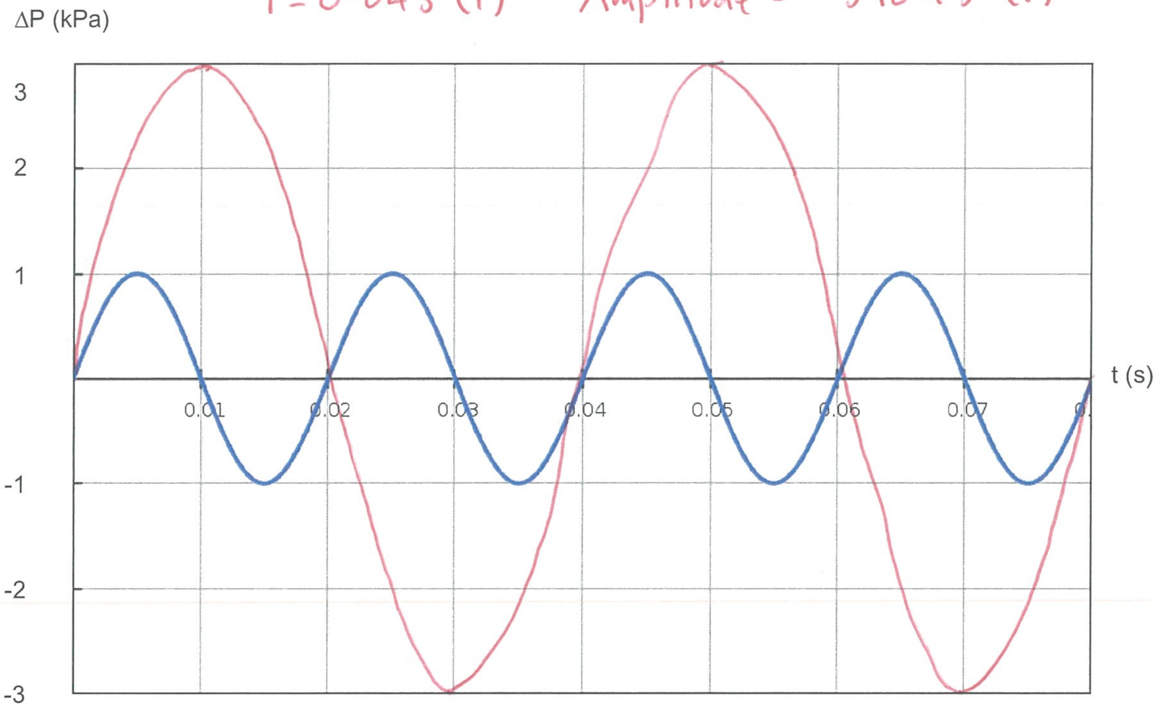
$= (70.0)(35.0) + \frac{1}{2}(-2.00)(35.0)^2$ (1)

$= \underline{1.22 \times 10^3\ m \text{ forwards}}$ (1)

Question 2 **(4 marks)**

A string is vibrating at a frequency and amplitude that produces the pressure difference (ΔP) versus time (t) graph shown in the diagram below. The pressure difference axis has no units – the scale is proportional.

T = 0·04 s (1) Amplitude = −3 to +3 (1)



(a) Calculate the frequency (in Hz) of the sound produced by the string. Show your working. (2)

$$f = \frac{1}{T}$$

$$= \frac{1}{0 \cdot 02} \quad (1)$$

$$= \underline{50 \cdot 0 \text{ Hz}} \quad (1)$$

(b) On the same set of axes, sketch the wave form for a sound produced by the string that has three times the amplitude and half the frequency. (2)

Question 3 **(4 marks)**

An electric stove operates at mains voltage of 240 V. It has separate components that can operate individually or simultaneously. These have the following specifications:

ITEM	NUMBER PRESENT ON STOVE	POWER RATING (W)
Ceramic hob (small area)	1	1250
Ceramic hob (large area)	1	1550
Oven	1	2550

At a particular instant in time, the electric stove has one (1) ceramic hob (small area), one (1) ceramic hob (large area) and the oven operating.

Electric energy costs 28.0 cents per kilowatt hour (kWh).

Calculate the cost of operating the electric stove in this mode of operation for 35.0 minutes.

$$P_{total} = 1250 + 1550 + 2550$$

$$= 5.35 \times 10^3 \text{ W}$$

$$= 5.35 \text{ kW} \quad (1)$$

$$\text{Cost} = P(\text{kW}) \times t(\text{hr}) \times r \quad (1)$$

$$= (5.35)\left(\frac{35.0}{60.0}\right) \times 28.0 \quad (1)$$

$$= \underline{87.4 \text{ cents}} \quad (1)$$

Question 4 **(6 marks)**

A radioactive sample has an initial activity of 2.00 x 10^3 MBq and a half-life of 5.50 minutes.

(a) Calculate the activity of the sample after 14.0 minutes. (3)

$$n = \frac{14 \cdot 0}{5 \cdot 50}$$

$$= 2 \cdot 545 \text{ half-lives} \quad (1)$$

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

$$= \frac{2 \cdot 00 \times 10^3}{2^{2 \cdot 545}} \quad (1)$$

$$= \underline{343 \text{ MBq}} \quad (1)$$

(b) Determine the time taken for the sample's activity to drop to 125 MBq. (3)

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

$$\Rightarrow \quad 125 = \frac{2 \cdot 00 \times 10^3}{2^n} \quad (1)$$

$$\Rightarrow \quad 2^n = 16$$

$$= 2^4$$

$$\therefore \quad n = 4 \text{ half-lives} \quad (1)$$

$$= \underline{22 \cdot 0 \text{ minutes}} \quad (1)$$

Can also be done by inspection,

2000 MBq → 1000 → 500 → 250 → 125

$$\Rightarrow \quad n = 4 \text{ half-lives}$$

$$\therefore \quad t = 4 \times 5 \cdot 50$$

$$= 22 \cdot 0 \text{ minutes}$$

Question 5 **(6 marks)**

(a) The words 'heat' and 'temperature' are often confused. In the space below, distinguish clearly between these two quantities using Physics concepts you have learned. In your answer, include the concept of internal energy.

(3)

INTERNAL ENERGY: $E_T = E_P + E_K$ of the particles in an object. (1)

HEAT: flow of internal energy from a hotter to cooler object until thermal equilibrium is reached. (1)

TEMPERATURE: a measure of the average E_K of the particles in an object. (1)

(b) "It is impossible to add thermal energy to a substance without causing a temperature increase." Do you agree or disagree with this statement? Briefly explain your choice.

(3)

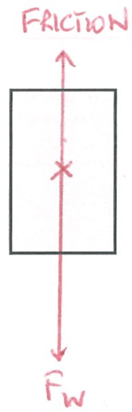
- Disagree. (1)
- Consider a phase change. (1)
- Added heat changes the phase without a temperature increase. (1)

Question 6 **(6 marks)**

If they fall for long enough, objects that fall to the Earth will reach a speed called 'terminal velocity'. Terminal velocity is a constant speed that is reached when the nett force acting on the object is reduced to zero.

(a) On the falling object below, draw two labelled vectors to represent the vertical forces that are acting on it BEFORE 'terminal velocity' is reached.

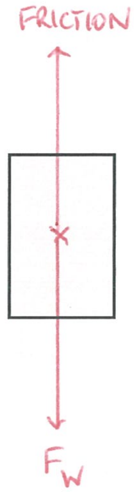
(2)



Correct labels (1)
Upward force smaller (1)

(b) Now draw the same two vectors ONCE 'terminal velocity' is reached.

(2)



(c) Briefly explain your answer to part (b). Include Newton's Laws in your explanation.

(2)

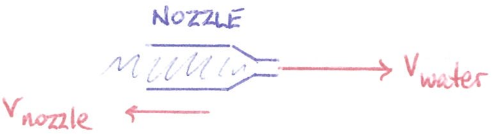
- As the object accelerates down (action), air resistance exerts an opposing upward force (reaction) according to the Third law. (1)
- $\Sigma F = 0$ when terminal velocity is reached so acceleration equals zero according to the Second law. (1)

Question 7 **(7 marks)**

When holding a fire hose ejecting water from its nozzle, fire-fighters need to brace themselves to ensure that they are not pushed backwards - especially when the water is ejected at a very high speed.

(a) Using the Law of Conservation of Momentum, explain why fire-fighters must brace themselves in the way described above.

(3)



- Initially, the water and nozzle are stationary, so $\Sigma p_i = 0$. (1)
- As the mass of water moves out of the nozzle, the nozzle moves backwards to conserve momentum. (1)
- The fire-fighters must exert a forward force to overcome the momentum of the nozzle moving backwards. (1)

(b) 20.0 kg of water is ejected from the nozzle of the hose (mass = 10.0 kg) in a horizontal direction for 1.50 s. This volume of water leaves the nozzle with a velocity of 30.0 ms^{-1}. Calculate the force (magnitude and direction) experienced by a fire-fighter holding this hose.

(4)

Take movement of water as +ve.

$$\Sigma p_i = \Sigma p_f$$

$$\Rightarrow m_1 u_1 + m_2 u_2 = m_1 v_1 + m_2 v_2$$

$$\Rightarrow 0 + 0 = (20.0)(30.0) + (10.0)v_2 \quad (1)$$

$$\Rightarrow v_2 = -60.0 \text{ ms}^{-1} \text{ backwards} \quad (1)$$

$$I = Ft = m\Delta v = \Delta p$$

$$\Rightarrow F = \frac{m\Delta v}{t}$$

$$= \frac{(10.0)(0-(-60.0))}{1.50} \quad (1)$$

$$= \underline{4.00 \times 10^2 \text{ N forwards}} \quad (1)$$

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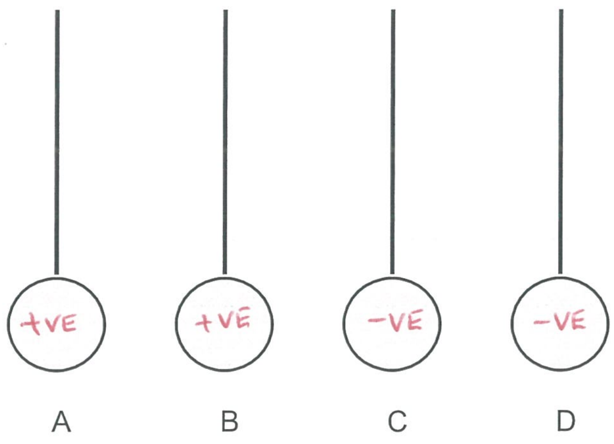
Question 8 **(5 marks)**

To test the properties of charged objects, some students obtain four very small glass spheres (A, B, C and D) and hang them from some cotton thread (which is neutrally charged). See below.



To begin the experiment, one student rubs sphere A with silk. At the end of this process, the students know that the silk ends up with excess electrons on it.

(a) Given this information, what charge must sphere A possess? Explain briefly. (2)

- Positive (1)
- Electrons have been rubbed off the glass and onto the silk. (1)

The other glass spheres are the given an electric charge by being rubbed with different materials (including silk). In this way, some of the spheres will be positively charged; some will be negatively charged.

After this rubbing process, the students note the following:

Sphere B is **repelled** by sphere A.
Sphere C is **attracted** to sphere B.
Sphere D is **repelled** by sphere C.

(b) Which sphere – B, C or D – was also rubbed with silk? Explain. (3)

- B (1)
- Repelled by A ⇒ must be +VE charge. (1)
- C is attracted to B (∴ is −VE) and D is repelled by C (∴ is −VE). (1)

SEE NEXT PAGE

Question 9 **(7 marks)**

An ice cube at 0.0 ^{0}C was placed into a glass with 150 g of water at 45.0^{0}C. In one minute, the ice cube had melted. The final mass of water in the glass was 174 g and the final temperature of the water was 28.0 °C. Assume the heat lost from the glass is negligible.

(a) Using the data provided, calculate the latent heat of fusion of water. (4)

$$Q_{lost} = Q_{gained}$$

$$\Rightarrow m_w c_w \Delta T = m_i L_f + m_i c_w \Delta T \quad (1)$$

$$\Rightarrow (0.150)(4.18\times10^3)(45.0-28.0) = (0.0240)L_f + (0.0240)(4.18\times10^3)(28.0-0.0) \quad (2)$$

$$\Rightarrow \underline{L_f = 3.27\times10^5 \text{ J kg}^{-1}} \quad (1)$$

(b) As more ice was added to the glass, a layer of water formed on the wall of the glass. Name this phenomenon and briefly explain how it happens. (3)

- Condensation (1)
- H_2O vapour in the air is at a higher temperature than the ice water and glass. (1)
- Heat is removed from the water vapour until it is able to change phase to a liquid on the glass. (1)

Question 10 **(5 marks)**

A speaker is emitting a sound whose intensity is measured as 1.00×10^{-6} Wm^{-2} at a distance of 1.50 m from the source.

(a) Calculate this sound's predicted intensity at a distance of 4.50 m.

(3)

$$\frac{I_2}{I_1} = \frac{r_1^2}{r_2^2} \quad (1)$$

$$\Rightarrow I_2 = \frac{(1.00 \times 10^{-6})(1.50)^2}{(4.50)^2} \quad (1)$$

$$= \underline{1.11 \times 10^{-7} \text{ Wm}^{-2}} \quad (1)$$

(b) The figure you calculated in part (a) would not be the value measured in reality. Comment on your calculated value for intensity at a distance of 4.50 m. How would it be different in reality? Explain.

(2)

- Value would be lower. (1)
- Air is inelastic and some energy is lost as sound energy travels through it. (1)

[Could also talk about air constantly moving so energy is lost.]

End of Section One

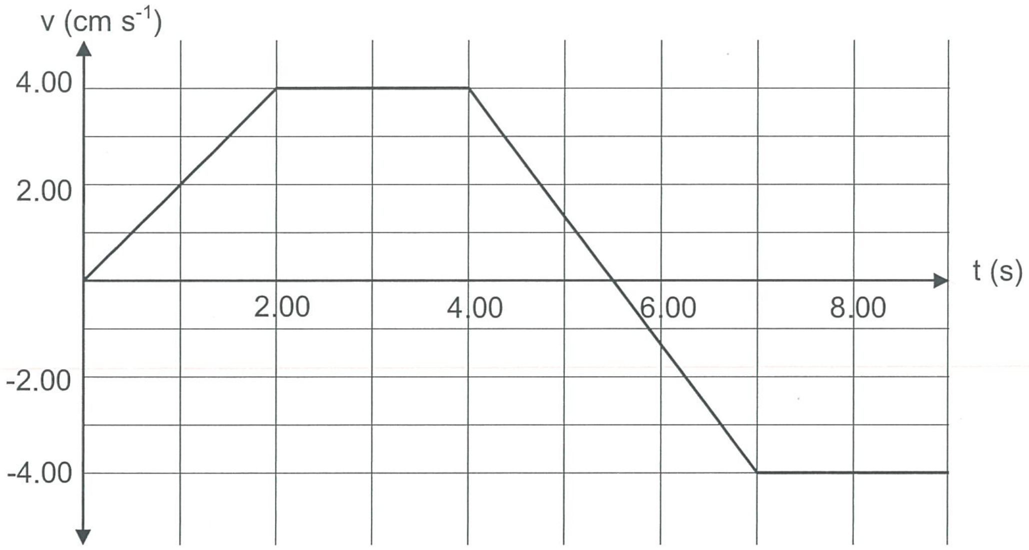
Additional working space

Section Two: Problem-solving 50% (88 Marks)

This section has **six (6)** questions. You must answer **all** questions. Write your answers in the space provided. Suggested working time for this section is 90 minutes.

Question 11 (16 marks)

The graph below shows the motion of an ant during a 9.00 s period. As can be seen, the ant's velocity has been measured in centimetres per second (cms^{-1}) over this time. The ant is initially travelling in an easterly direction.



(a) State the time period during which the ant is moving in a westerly direction. (2)

5·50 s → 9·00 s
(1) (1)

(b) State the times when the ant is stationary. (2)

t = 0·0 s, 5·50 s
(1) (1)

(c) State the time periods when the ant's acceleration is equal to zero. (2)

2·00 s → 4·00 s (1)
7·00 s → 9·00 s (1)

(d) Calculate the ant's acceleration (***in ms***$^{-2}$) at:

(i) t = 1.00 s (2)

$$a = \frac{(4.00 - 0.00) \times 10^{-2}}{2.00} \quad (1)$$

$$= \underline{2.00 \times 10^{-2}\ \text{ms}^{-2}\ \text{East}} \quad (1)$$

(ii) t = 5.50 s (2)

$$a = \frac{(0.00 - 4.00) \times 10^{-2}}{(5.50 - 4.00)} \quad (1)$$

$$= \underline{-2.67 \times 10^{-2}\ \text{ms}^{-2}\ \text{West}} \quad (1)$$

(e) Calculate the ant's change in displacement (***in cm***) between:

(i) t = 0 s – 5.50 s. (3)

s = area under the graph

$$= \tfrac{1}{2}(2.00)(4.00) + (2.00)(4.00) + \tfrac{1}{2}(1.50)(4.00) \quad (2)$$

$$= \underline{15.0\ \text{cm East}} \quad (1)$$

(ii) t = 0 s – 9.00s. (3)

s = area under the graph

$$= 15.0 + \tfrac{1}{2}(1.50)(-4.00) + (2.00)(-4.00) \quad (2)$$

$$= \underline{4.00\ \text{cm East}} \quad (1)$$

Question 12 **(14 marks)**

Uranium-238 (U-238) is a radioisotope and an α-emitter. The data below will be of use to you in this question. You will also need to refer to the Periodic Table in the Formulae and Constants Sheet.

[Note – when performing calculations in this question, do ***NOT*** round to three (3) significant figures]

Particle	Atomic Mass (u)
U-238	238.05079
Th-234	234.04360
He-4	4.00260
Proton	1.00727
Neutron	1.00867
Electron	0.00055

(a) Use the above data to perform a calculation showing that the ***mass defect*** for a U-238 nucleus is ***about 1.90 u***.

(3)

92 p = 92 × 1·00727u = 92·66884u
146n = 146 × 1·00867u = 147·26582u
92e = 92 × 0·00055u = 0·05060u
239·98526 u
(2)

Mass defect = 239·98526 u − 238·05079 u

= 1·93447 u (1)

(b) Hence, calculate the ***binding energy*** for a U-238 nucleus.

(2)

Binding energy = (1·93447)(931) (1)

= 1800·99157 MeV (1)

(c) Using your answer to part (b), calculate the ***binding energy per nucleon*** for a U-238 nucleus ***in MeV***. [If you were unable to calculate an answer for part b), use a value of 1750 MeV]

(2)

$$\text{Binding energy / nucleon} = \frac{1800.99157}{238} \quad (1)$$

$$= \underline{7.57 \text{ MeV}} \quad (1)$$

(d) Ni-62 has one of the highest binding energy per nucleon of any known isotope - with a value of 8.7945 MeV. Compare this value with the corresponding value for U-238 calculated in part (c). Use this comparison to compare the stability of a Ni-62 nucleus versus a U-238 nucleus and to explain their contrasting properties in this regard.

(2)

- U-238 has a lower binding energy so it is more unstable than Ni-62. (1)
- Hence U-238 is radioactive while Ni-62 is not. (1)

(e) As stated earlier, U-238 is an alpha emitter.

(i) Complete the nuclear equation below for this transmutation. Show the chemical symbol, atomic number and mass number for the missing product.

(1)

$$U_{92}^{238} \rightarrow {}^{234}_{90}\text{Th} + He_2^4$$

(ii) Use the data in the table provided earlier to calculate the energy released (in Joules) during the alpha decay in part (e) (i).

(4)

Mass (reactants) = 238.05079 u

Mass (products) = 234.04360 u + 4.00260 u

= 238.04620 u (1)

Mass defect = 238.05079 u − 238.04620 u

= 0.00459 u (1)

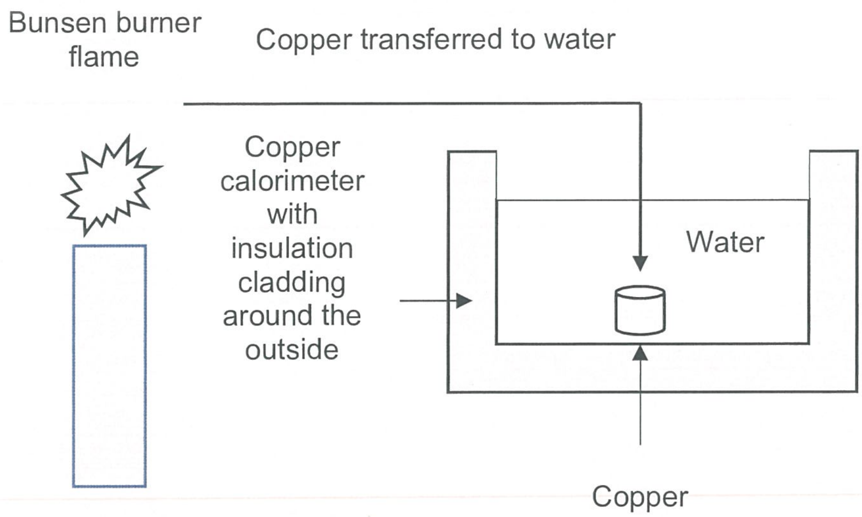
= 4.27329 MeV (1)

= $\underline{6.84 \times 10^{-13} \text{ J}}$ (1)

Question 13 **(12 marks)**

A student performs an experiment to calculate the temperature of a Bunsen burner flame.

A piece of copper with mass 250 g is held in the Bunsen flame for a few minutes. The copper metal is then transferred as quickly as possible to a copper calorimeter of mass 40.0 g containing 0.285 kg of water. The calorimeter and the water are initially at a temperature of 15.0°C.



After the piece of copper is placed in the water, the water is stirred until a thermal equilibrium temperature of 80.0°C is achieved.

(a) Explain why the metal is transferred from the flame to the water as quickly as possible. (2)

- The metal is initially at the temperature of the flame. (1)
- If it loses heat to the air during transfer, it won't be a good representation of the temperature of the flame. (1)

Assume that heat losses to the surroundings of the water and calorimeter are negligible. The specific heat capacity of copper is 390 $Jkg^{-1}°C^{-1}$.

(b) Calculate the quantity of thermal energy absorbed by the water and the copper calorimeter. (3)

$$Q = m_w c_w \Delta T + m_{Cu} c_{Cu} \Delta T \quad (1)$$

$$= (0.285)(4.18 \times 10^3)(80.0 - 15.0) + (0.0400)(390)(80.0 - 15.0) \quad (1)$$

$$= \underline{7.84 \times 10^4 \text{ J}} \quad (1)$$

(c) Using your answer from part (b), calculate the temperature of the Bunsen burner flame. Show all working. (4)

$$Q_{lost} = Q_{gained}$$

$$\Rightarrow m_{Cu} c_{Cu} \Delta T = m_w c_w \Delta T \quad (1)$$

$$\Rightarrow (0.250)(390) \Delta T = 7.84 \times 10^4 \quad (1)$$

$$\Rightarrow \Delta T = 804 °C \quad (1)$$

$$T_{Bunsen} = \Delta T + T_f$$

$$= 804 + 80$$

$$= \underline{884 °C} \quad (1)$$

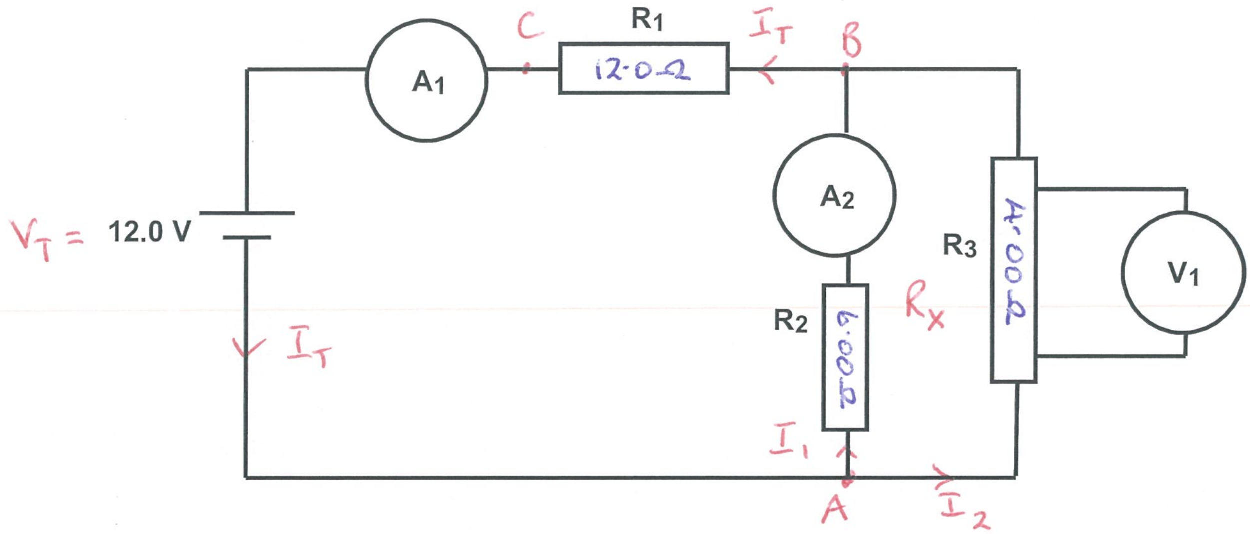
(d) In reality, heat will be lost to the surroundings of the copper calorimeter and water. In light of this, comment on the Bunsen burner flame temperature calculated in part (c) and explain your reasoning. (3)

- The heat contained by the copper would have been greater than 7.84×10^4 J.
- The heat lost to the surroundings means that ΔT for the water and calorimeter is greater.
- Both of these mean that ΔT for the piece of copper would be greater, so the temperature of the Bunsen flame is greater.

Question 14 **(11 marks)**

Three resistors are connected in the circuit as shown in the circuit diagram below.
The voltage supplied to the circuit by the battery is 12.0 V. The table below shows the values of the three resistors shown.

R_1	12.0 Ω
R_2	6.00 Ω
R_3	4.00 Ω



(a) Calculate the total resistance (R_T) of the circuit. Assume the resistance of the potential difference supplied and the wires is negligible. (3)

$$\frac{1}{R_x} = \frac{1}{6.00} + \frac{1}{4.00}$$

$$= 0.4167\ \Omega^{-1} \quad (1)$$

$$\Rightarrow R_x = 2.40\ \Omega \quad (1)$$

$$R_T = 2.40 + 12.0$$

$$= 14.4\ \Omega \quad (1)$$

(b) Calculate the reading on the ammeter, A_1. Show working. (2)

$$V_T = I_T R_T$$

$$\Rightarrow I_T = \frac{V_T}{R_T}$$

$$= \frac{12.0}{14.4} \quad (1)$$

$$= \underline{0.833\ A} \quad (1)$$

(c) Calculate the reading on the voltmeter, V_1. Show working. (3)

$$V_{AB} = I_T R_x \quad (1)$$

$$= (0.833)(2.40) \quad (1)$$

$$= \underline{2.00\ V} \quad (1)$$

(d) Hence, calculate the reading on the ammeter, A_2. Show working. (3)

$$V_{AB} = I_1 R_2$$

$$\Rightarrow I_1 = \frac{V_{AB}}{R_2} \quad (1)$$

$$= \frac{2.00}{6.00} \quad (1)$$

$$= \underline{0.333\ A} \quad (1)$$

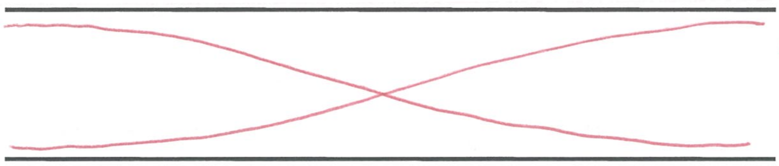
Question 15 **(17 marks)**

An organ pipe X, with both ends open, sounds its fundamental frequency of 330 Hz. The pipe is filled with dry air at 25 °C.

(a) On the diagram below, draw a wave envelope representing the particle displacement in the pipe when it is sounding at its fundamental frequency?

(2)

Antinode (1)



$l = \frac{\lambda}{2}$ (1)

(b) Calculate the length of this organ pipe.

(4)

$v = f\lambda$

$\Rightarrow \lambda = \frac{v}{f}$

$= \frac{346}{330}$ (1)

$= 1.05\ m$ (1)

$l = \frac{\lambda}{2}$ (1)

$= \frac{1.05}{2}$

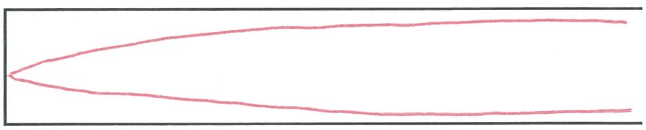
$= \underline{0.525\ m}$ (1)

A second pipe Y is closed at one end. Dry air at 25 °C is in the pipe.

(c) On the diagrams below, draw wave envelopes for the first two harmonics produced by this pipe. Number each of the harmonics in the space provided.

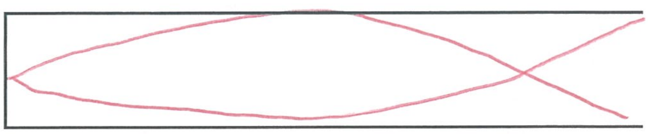
(3)

1ST HARMONIC



(1)

3RD HARMONIC



(1)

Label (1)

The third harmonic (first overtone) of the closed end pipe Y has the same frequency as the second harmonic (first overtone) of the open-ended pipe X.

(d) (i) Calculate the frequency of the second harmonic of pipe X. (3)

$$f_2 \text{ (open)} = 2 \times f_1 \quad (1)$$
$$= 2 \times 330 \quad (1)$$
$$= \underline{660 \text{ Hz}} \quad (1)$$

(ii) Hence, calculate the wavelength of this sound. (2)

$$v = f\lambda$$
$$\Rightarrow \lambda = \frac{v}{f}$$
$$= \frac{346}{660} \quad (1)$$
$$= \underline{0.524 \text{ m}} \quad (1)$$

(iii) Hence, calculate the length of the pipe Y. (3)

3RD HARMONIC: $l = \frac{3\lambda}{4}$ (1)

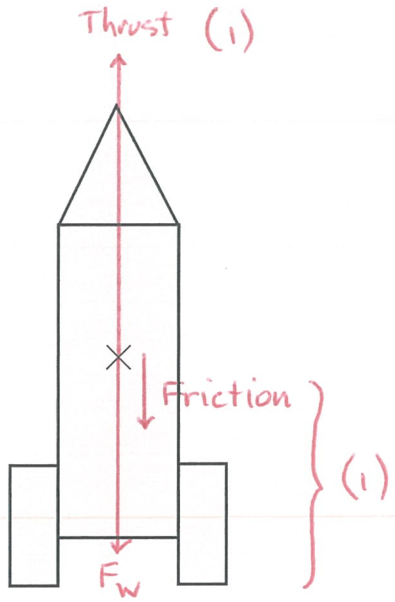
$$= \frac{3(0.524)}{4} \quad (1)$$
$$= \underline{0.393 \text{ m}} \quad (1)$$

Question 16 **(18 marks)**

A toy rocket with a mass of 0.550 kg is fired straight upward. The chemical engine provides 9.50 N of thrust for 1.70 s with negligible loss of mass. The engine works for 1.70 s.

(a) Draw labelled vectors from point X on the rocket to show all the forces acting on the rocket in the first 1.70 s of flight. Include any frictional forces. The length of each arrow should represent the approximate magnitude of the force that is acting.

(4)



Labels (1)

Thrust > ΣF down (1)

(b) Calculate the acceleration of the rocket just before its engine stops working. Consider only the thrust of the engine and gravity. Show ***all*** working.

(4)

↑ +VE

$$\Sigma F = F_{rocket} - F_W \quad (1)$$

$$\Rightarrow ma = F_{rocket} - mg \quad (1)$$

$$\Rightarrow (0.550)a = 9.50 - (0.550)(9.80) \quad (1)$$

$$\Rightarrow \underline{a = 7.47 \text{ ms}^{-2} \text{ up}} \quad (1)$$

(c) Calculate the height reached by the rocket at the moment when the engine stops working. If you were unable to calculate an answer to part (b), use an acceleration value of 8.00 ms^{-2}. (3)

$v = ?$
$u = 0\ ms^{-1}$
$a = 7.47\ ms^{-2}$
$t = 1.70\ s$
$s = ?$

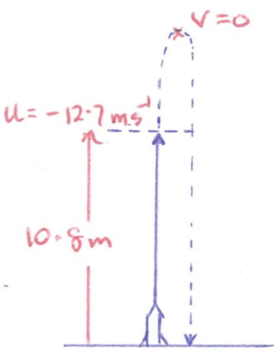
↑ +VE

$s = ut + \frac{1}{2}at^2$ (1)
$= 0 + \frac{1}{2}(7.47)(1.70)^2$ (1)
$= \underline{10.8\ m\ up}$ (1)

(d) Calculate the velocity of the rocket, 1.70 s after the engine starts. If you could not calculate an answer to Part (b), use an acceleration of 8.00 ms^{-2} upward. Show ***all*** working. (2)

$v = u + at$
$= 0 + (7.47)(1.70)$ (1)
$= \underline{12.7\ ms^{-1}\ up}$ (1)

(e) Calculate the maximum height reached by the rocket. Show ***all*** working. (5)



↓ +VE

Rocket now moves under the effect of gravity.

$v = 0\ ms^{-1}$
$u = -12.7\ ms^{-1}$ (1)
$a = 9.80\ ms^{-2}$
$t = ?$
$s = ?$

$v^2 = u^2 + 2as$
$\Rightarrow s = \frac{v^2 - u^2}{2a}$ (1)
$= \frac{0 - (-12.7)^2}{2(9.80)}$ (1)
$= -8.23\ m$ (1)

$\therefore$ height $= 10.8 + 8.23$
$= \underline{19.0\ m\ above\ the\ ground}$ (1)

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 17 **(18 marks)**

Chernobyl Nuclear Accident

The catastrophic nuclear accident known as the 'Chernobyl Disaster' occurred over 25 and 26 April 1986 at the Chernobyl nuclear power plant in Northern Ukraine. The accident occurred during a late-night safety test that was simulating a power failure resulting in a station blackout.

A complete station blackout would cause the plant's safety systems to cease functioning. On the night of 25 April, as part of the complicated test, technicians deliberately removed nearly all of the control rods from the reactor core. This, along with several other actions, created a power surge in the reactor and excessive quantities of steam were produced from the coolant in the reactor core. In short, the reactor was in an extremely unstable position – and any changes that pushed it into 'super-criticality' would mean that it would be unable to recover a stable configuration automatically. That would require manual intervention from the technicians in the control room of the plant.

Unfortunately, pushing the reactor into 'super-criticality' was part of the planned test. As the test proceeded, more coolant water in the reactor 'flashed' into steam due to the extremely high temperatures. The extreme pressure of the steam in the reactor vessel blew the containment structure apart – including the roof of the containment building, exposing the radioactive interior to the outside atmosphere.

The explosion ejected large amounts of radioactive nuclear fuel into the atmosphere. Fission fuel (Uranium-235 was the main fissile fuel used at Chernobyl) and far more dangerous fission products such as Caesium-137, Iodine-131, Strontium-90 and other radionuclides were dispersed into the atmosphere. One positive consequence of the explosion was that the nuclear fission reaction occurring in the reactor core was effectively terminated by the dispersal of fissile material. However, a disastrous situation was unfolding.

Radiation levels in the plant immediately after the accident were enormous. A dose equivalent to about 5 Sieverts (5 Sv) is usually lethal to a human being. The table below shows the radiation levels at some specific locations at the plant.

Location	Sieverts per Hour
Vicinity of the reactor core	300
Debris heap at the circulation pumps	100
Fuel fragments on roof of containment building	175
Control Room	0.04

https://en.wikipedia.org/wiki/Chernobyl_disaster

Many workers, fire fighters and first responders to the accident were exposed to radiation levels much higher than that and many died within a short time after the accident. Firefighters were sent to the roof of the containment building for short periods of time to try and limit their exposure. However, many of the fire fighters died from radiation sickness not long after their heroic work was completed.

The high radiation levels and large dispersal of radioactive materials in the surrounding area necessitated a mass evacuation from the surrounding urban areas. Residents in the nearby town of Pripyat were not evacuated until 11:00 am on 26 April and many exhibited signs of radiation sickness; i.e. vomiting, headaches, metallic taste in the mouth, pins and needles on exposed skin. Many of these residents have developed health problems connected to their exposure after the accident.

Immediately after the evacuation, an exclusion zone (i.e. a place where humans are not allowed to enter) was set up around the Chernobyl power plant with a radius of about 30 kilometres. Its borders were then extended so that this exclusion zone now covers a larger area of about 2600 square kilometres. It is one of the most radioactively contaminated areas in the world; because of this, it is of significant interest to scientists – especially those studying the effect of high levels of radiation exposure in the environment.

As the radiation levels in the outer parts of this zone decrease, talks have begun in February 2019 to redraw the boundaries and reduce the size of the exclusion area.

(a) The planned safety test at Chernobyl on 25 April 1986 required the deliberate removal of the reactors control rods. Describe the effect that this removal would have had in the reactor core. As part of your answer, describe the role that the control rods have in a nuclear reactor. (4)

- Control rods control the rate of the fission reaction. (1)
- They absorb neutrons. (1)
- Removal means the rate of fission increases significantly. (1)
- Huge amounts of heat energy would be released in the core. (1)

Uranium-235 was the main fission fuel used in the Chernobyl reactor. Uranium-235 is an alpha emitter with a half-life of 4.5 billion years. Its nuclei have a mass of 235.0439299 u. The periodic table on the Formulae and Constants Sheet will be needed for parts (b) and (c).

One possible fission reaction involving uranium-235 is described in words below:

A slow-moving neutron collides and is captured by a uranium-235 nucleus; the nucleus splits and forms the fission products rubidium-90, caesium-143, some neutrons and a large amount of thermal energy.

(b) Write a balanced nuclear equation depicting the fission reaction described above. Determine the number of neutrons produced in this reaction and state this clearly in the equation. (3)

$$\underbrace{{}^{1}_{0}n + {}^{235}_{92}U}_{(1)} \longrightarrow \underbrace{{}^{90}_{37}Rb + {}^{143}_{55}Cs}_{(1)} + \underbrace{3\,{}^{1}_{0}n}_{(1)}$$

Another possible fission reaction is described in the nuclear equation below:

$$^{235}_{92}\mathbf{U} + {}^{1}_{0}\mathbf{n} \longrightarrow {}^{90}_{38}\mathbf{Sr} + {}^{143}_{54}\mathbf{Xe} + 3\,{}^{1}_{0}\mathbf{n} + \mathbf{energy}$$

The relevant atomic masses for the reactants and products in this reaction are shown in the table below:

U-235	**235.0439299 u**
Neutron ($^{1}_{0}$n)	**1.00867 u**
Sr-90	**89.907738 u**
Xe-143	**142.935370 u**

(c) Calculate the quantity of energy released (in MeV) during this fission reaction. Show all working. [Do ***NOT*** round to three (3) significant figures in this calculation] (3)

Mass(reactants) = 235·0439299 u + 1·00867 u
= 236·0525999 u (1)

Mass (products) = 89·907738 u + 142·935370 u + 3(1·00867 u)
= 235·869118 u (1)

Mass defect = 236·0525999 u − 235·869118 u
= 0·1834819 u
= <u>170·8216489 MeV</u> (1)

(d) Hence, calculate the energy released (in Joules) if 1.00 kg of U-235 nuclei completely undergo fission as per the reaction in part (c).

(4)

$$\# \text{ particles} = \frac{1.00}{(235.0439299)(1.66 \times 10^{-27})} \quad (1)$$

$$= 2.563 \times 10^{24} \quad (1)$$

$$\text{Energy released} = (2.563 \times 10^{24})(170.8216489)$$

$$= 4.38 \times 10^{26} \text{ MeV} \quad (1)$$

$$= \underline{7.00 \times 10^{13} \text{ J}} \quad (1)$$

(e) Firefighters were sent on to the damaged roof of the containment plant to remove radioactive debris that had been deposited there due to the explosion. Using information from the article, calculate the ***MAXIMUM*** time that the firefighters could remain on the roof of the containment building to ensure they received ***LESS*** than a lethal dose of radiation.

(2)

$$\text{Max. time} = \frac{5}{175} \quad (1)$$

$$= \underline{2.86 \times 10^{-2}} \text{ hr} \quad (1.71 \text{ mins}, 103 \text{ s}) \quad (1)$$

The table below shows some of the properties of the radioisotopes that were ejected from the fuel rods during the explosion.

Radioisotope	Radiation emitted	Half Life
Uranium-235	α-emitter	4.5 billion years
Caesium-137	β-emitter	30.2 years
Iodine-131	β-emitter	8 days
Strontium-90	β-emitter	28.8 years

(f) In the article, the following statement is made:

"Fission fuel (uranium-235 was the main fissile fuel used at Chernobyl) and far more dangerous fission products such as caesium-137, Iodine-131, strontium-90 and other radionuclides were dispersed into the atmosphere."

Using the data above, explain why the three fission products mentioned are 'far more dangerous' than uranium-235.

(2)

- U-235 is an α-emitter so its radiation won't penetrate the skin (1)
- U-235 has a huge half-life so it is less radioactive. (1)

Additional working space

Question 18 **(18 marks)**

The speed of sound in dry air is dependent on several factors. The most significant, however, is the temperature of the air itself.

In fact, if all other factors are kept constant (e.g. altitude, barometric pressure, density of the air, etc.), there is a direct relationship between the speed of sound in dry air (v_{air}, measured in ms^{-1}) and the temperature of the dry air (T_c, measured in degrees Celsius). A general equation for this relationship is shown below:

$$v_{air} = a\,T_c + k$$

Where: v_{air} = the speed of sound in dry air (ms^{-1});

a = constant value;

T_c = the temperature of the dry air (°C); and

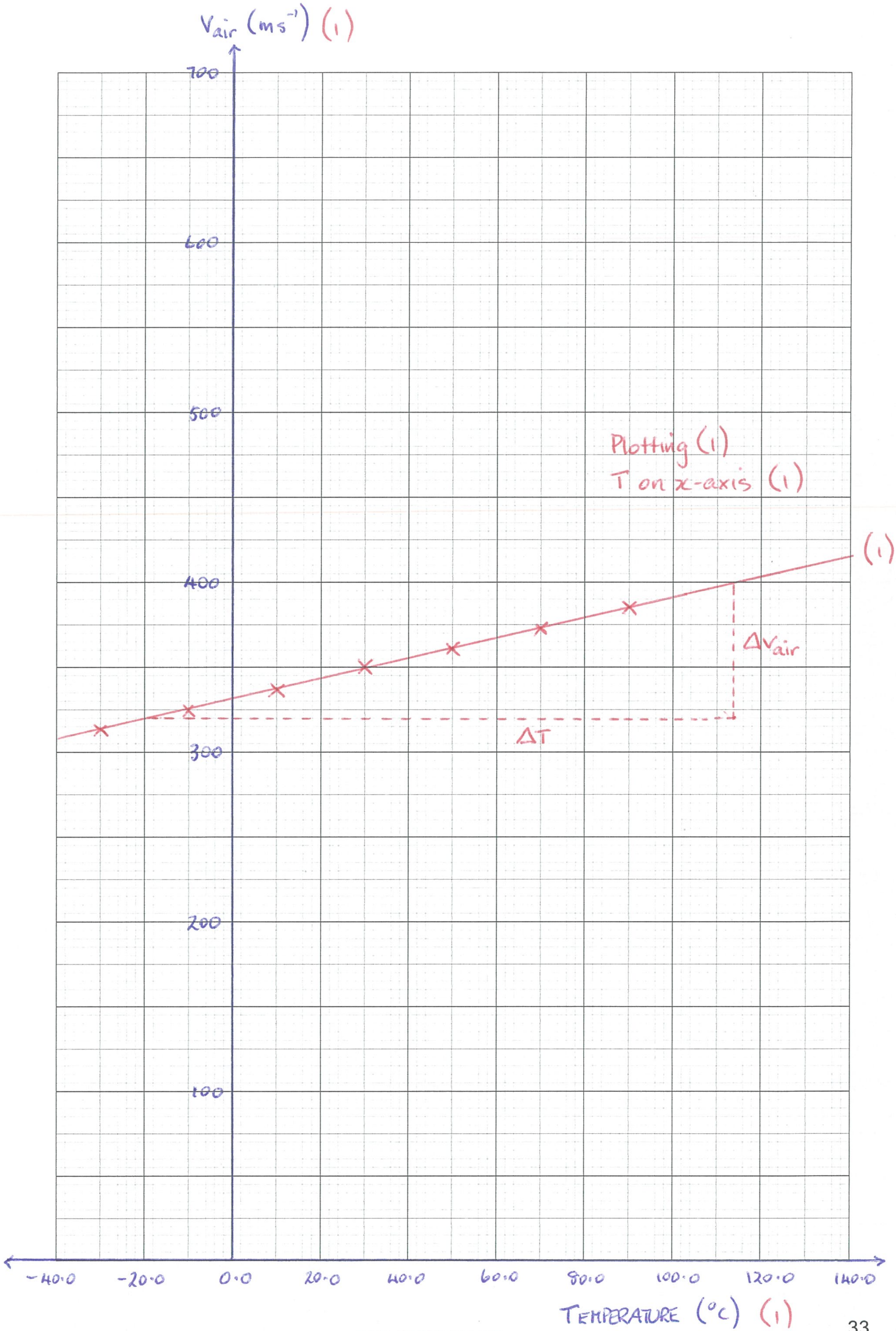
k = the speed of sound in dry air when T_c = 0 °C.

An audio technician performed an experiment and collected the following data (measurements of the speed of sound in dry air (v_{air}) for various dry air temperatures (T_c)):

T_c (°C)	V_{air} (ms^{-1})
-30.0	313
-10.0	325
10.0	337
30.0	350
50.0	361
70.0	373
90.0	385

(a) Using the grid on the next page, draw a graph plotting the speed of sound in dry air (v_{air}) against corresponding dry air temperatures (T_c) and then draw a line of best fit for the data. Place 'T_c' on the horizontal axis.

(5)



V_{air} (ms^{-1}) (1)
700
600
500
400
300
200
100
Plotting (1)
T on x-axis (1)
(1)
ΔV_{air}
ΔT
-40.0
-20.0
0.0
20.0
40.0
60.0
80.0
100.0
120.0
140.0
TEMPERATURE (°C) (1)

(b) Calculate the slope of your line of best fit. Show clearly how you did this. State the units for this slope.

(3)

$$\text{gradient} = \frac{(400-320)}{(117.0-(-20.0))} \quad (1)$$

$$= \underline{0.584\ ms^{-1}\,{}^{\circ}C^{-1}} \quad (\pm 0.03)$$

(1) (1)

(c) Write the speed of sound in dry air when T_c = 0 °C in the space below.

(1)

$332\ ms^{-1}$ (1)

(d) Hence, write down the equation for the speed of sound in dry air by substituting in appropriate values for 'a' and 'k'.

(2)

$$V_{air} = 0.584\, T_c + 332$$

(1) (1)

(e) Using the equation you derived in part (d), find the ratio between the wavelengths of a 256 Hz sound when the temperature of the dry air is 20.0 °C and 100.0 °C. Show working.

[If you were unable to produce the equation in part (d), use the following equation for this question: $\mathbf{v_{air} = 0.70\ T_c + 320}$.]

(3)

$$T = 20.0^{\circ}C: \quad V_{air} = (0.584)(20.0) + 332$$
$$= 344\ ms^{-1}$$

$$T = 100.0^{\circ}C: \quad V_{air} = (0.584)(100.0) + 332$$
$$= 390\ ms^{-1}$$

(1)

$$v = f\lambda$$

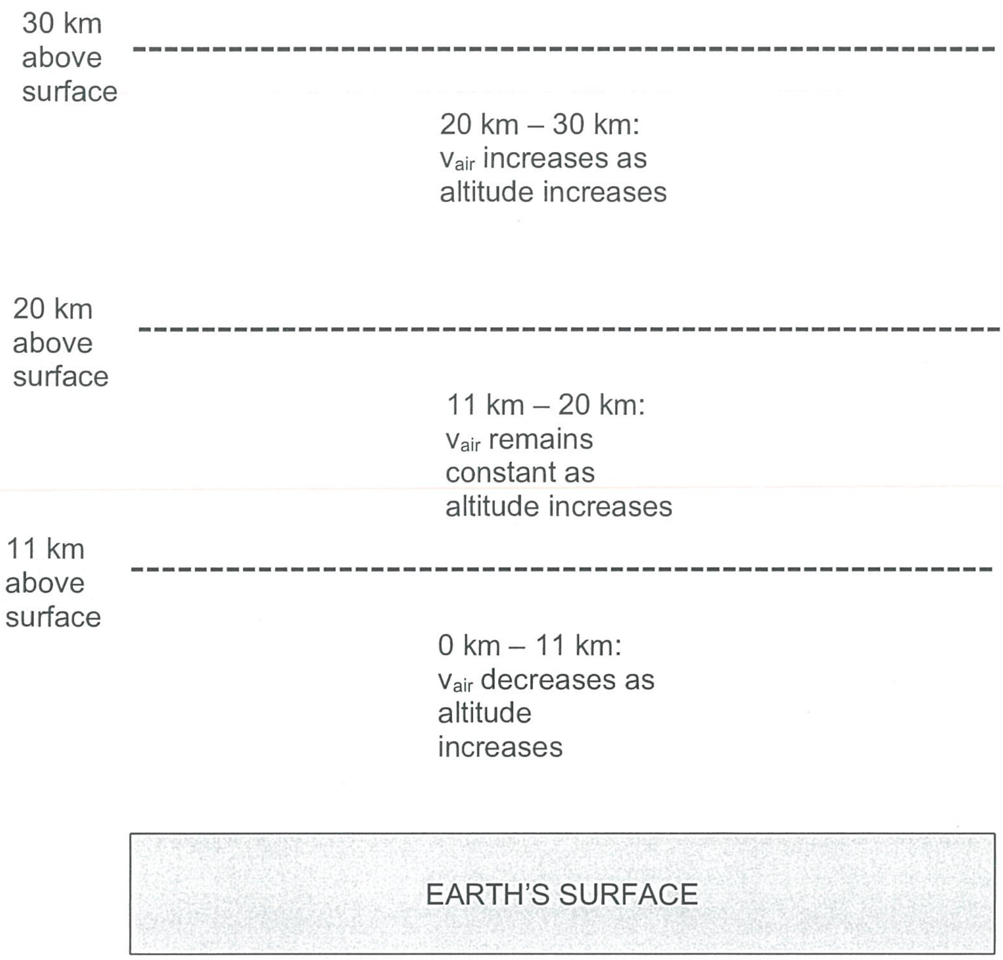
$$\Rightarrow f = \frac{v}{\lambda}$$

$$\therefore f = \frac{V_{20}}{\lambda_{20}} = \frac{V_{100}}{\lambda_{100}} \quad (1)$$

$$\Rightarrow \frac{\lambda_{20}}{\lambda_{100}} = \frac{V_{20}}{V_{100}} = \frac{344}{390} = 0.882 \quad (1)$$

$$\left[\frac{\lambda_{100}}{\lambda_{20}} = 1.13\right]$$

Another factor that can affect the speed of sound in dry air is altitude above the earth's surface. The main reason for this is that the temperature of the air changes as the altitude changes. The diagram below shows how the temperature of the dry air in the earth's atmosphere changes as altitude above its surface increases.

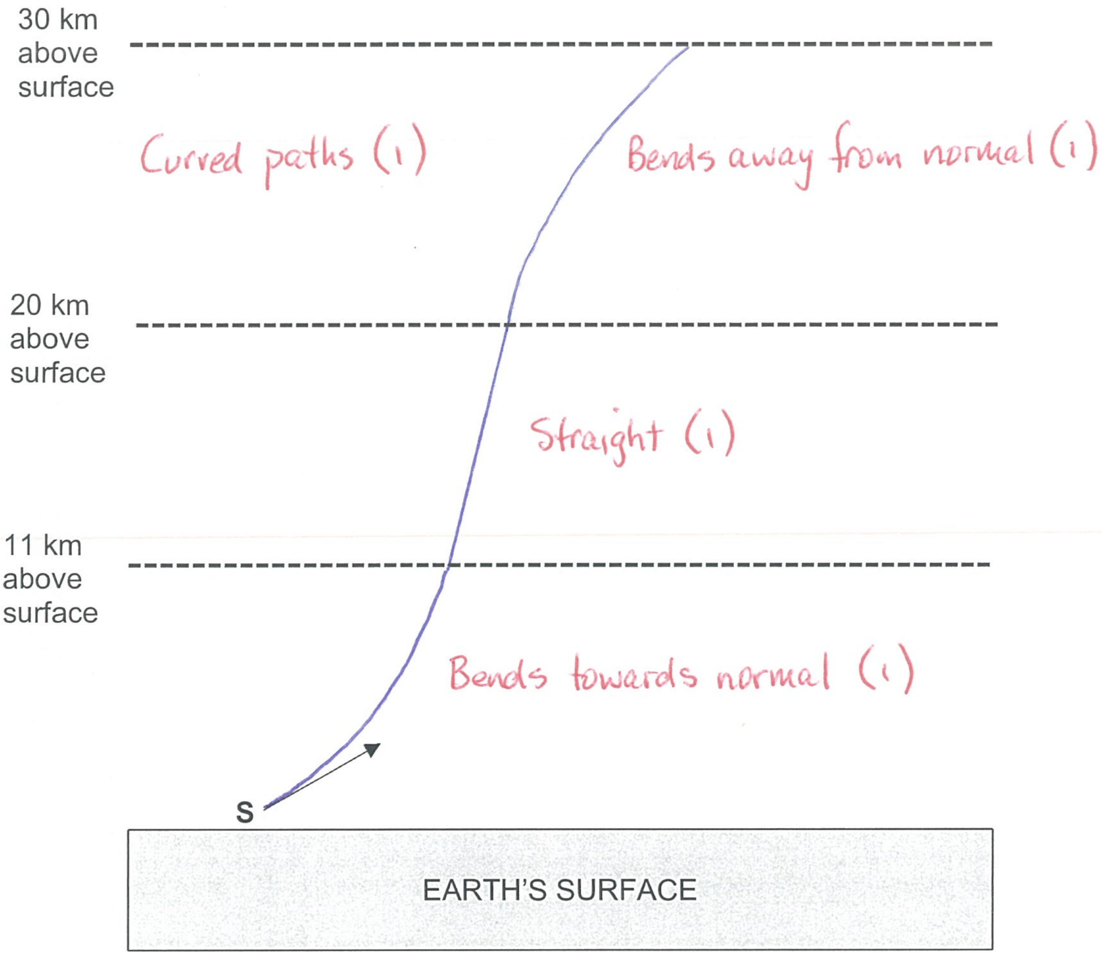


Due to these changes in speed, sound refracts as it travels upwards and away from the earth.

Question 18 continued on the next page

(f) On the diagram below which shows the altitudes at various points above the earth, draw the path of the initial sound shown (starting on the earth's surface at 'S') as it travels within and between the altitude boundaries shown.

(4)



End of examination

Additional working space

Spare grid for graph

Additional working space