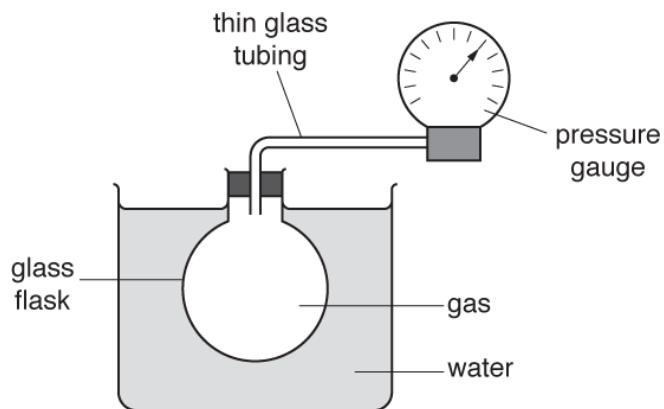


- 1(a).** A group of students are conducting an experiment in the laboratory to determine the value of absolute zero by heating a fixed mass of gas. The volume of the gas is kept constant.  
Fig. 17.1 shows the arrangement used by the students.



**Fig. 17.1**

The gas is heated using a water bath. The temperature  $\theta$  of the water is increased from  $5\text{ }^{\circ}\text{C}$  to  $70\text{ }^{\circ}\text{C}$ . The temperature of the water bath is assumed to be the same as the temperature of the gas. The pressure  $p$  of the gas is measured using a pressure gauge.

The results from the students are shown in a table.

$\theta / ^{\circ}\text{C}$	$p / \text{kPa}$
$5 \pm 1$	$224 \pm 3$
$13 \pm 1$	$231 \pm 3$
$22 \pm 1$	$238 \pm 3$
$35 \pm 1$	$248 \pm 3$
$44 \pm 1$	
$53 \pm 1$	$262 \pm 3$
$62 \pm 1$	$269 \pm 3$
$70 \pm 1$	$276 \pm 3$

Describe and explain how the students may have made accurate measurements of the temperature  $\theta$ .

[2]

**(b)**. Fig. 17.2 shows the pressure gauge. Measurements of  $p$  can be made using the kPa scale or the psi (pounds per square inch) scale. The students used the psi scale to measure pressure and then converted the reading to pressure in kPa.



**Fig. 17.2**

- i. Suggest why it was sensible to use the psi scale to measure  $p$ .

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[1]

- ii. The students made a reading of  $p$  of  $37.0 \pm 0.5$  psi when  $\theta$  was  $44 \pm 1^\circ\text{C}$ .

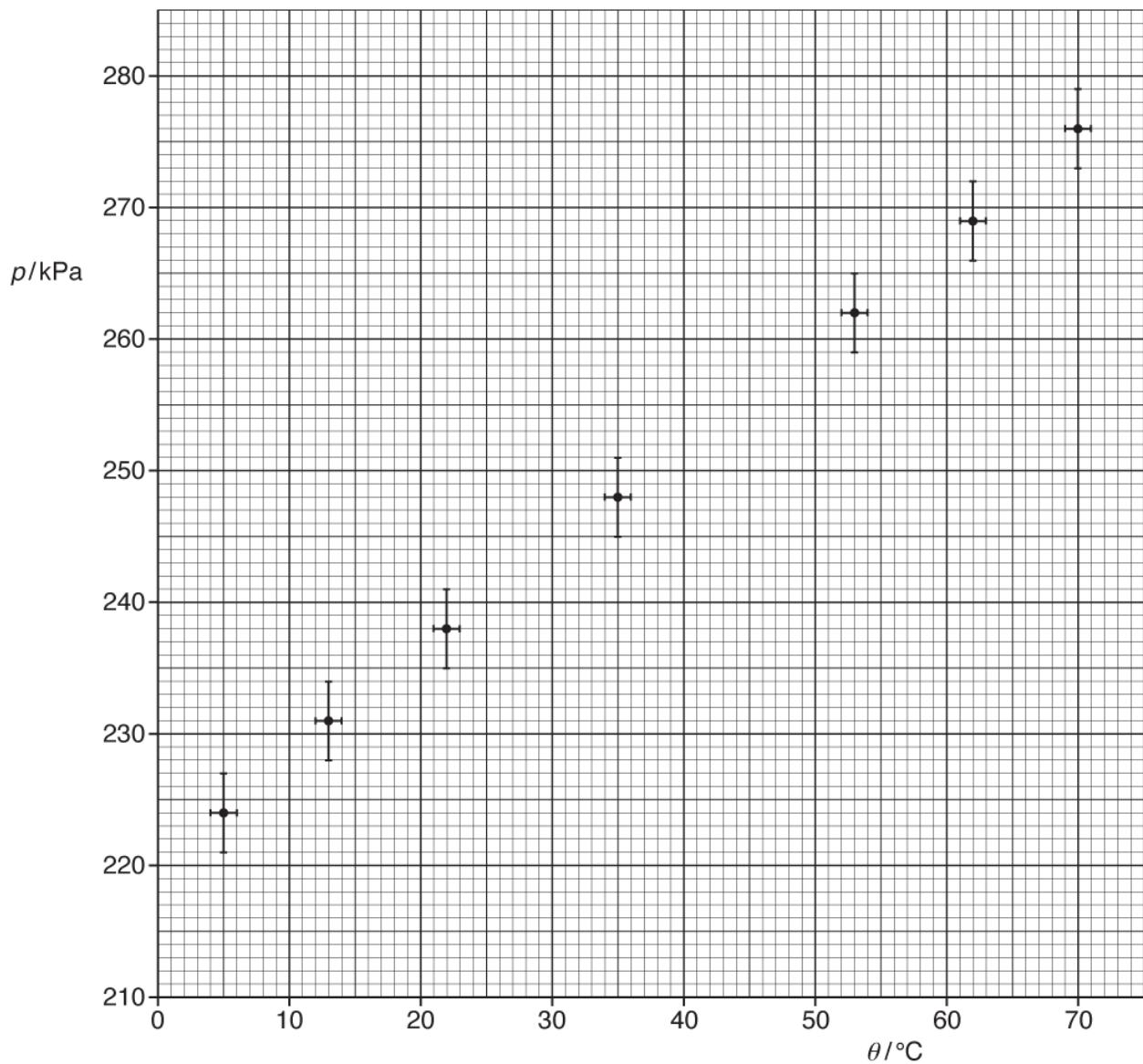
Convert this value of  $p$  from psi to kPa. Complete the table for the missing value of  $p$ . Include the absolute uncertainty in  $p$ .

$$1 \text{ pound of force} = 4.448 \text{ N}$$

$$1 \text{ inch} = 0.0254 \text{ m}$$

[2]

(c). Fig. 17.3 shows the graph of  $p$  against  $\theta$ .



**Fig. 17.3**

- i. Plot the missing data point and the error bars on Fig. 17.3.

[1]



- ii. Explain what is meant by *absolute zero*. Describe how Fig. 17.3 can be used to determine the value of absolute zero.  
Determine the value of absolute zero. You may assume that the gas behaves as an ideal gas.

[6]

**(d).** Describe, without doing any calculations, how you could use Fig. 17.3 to determine the actual uncertainty in the value of absolute zero in **(c)(ii)**.

[2]

**(e).** The experiment is repeated as the water bath quickly cools from 70 °C to 5 °C. Absolute zero was found to be -390°C.

Compare this value with your value from **(c)(ii)** and explain why the values may differ. Describe an experimental approach that could be taken to avoid systematic error in the determination of absolute zero.

[4]

2. A student measures the volume  $V$  of a fixed mass of air for different values of temperature  $T$  and pressure  $p$ . The results are shown in the table.

$T / K$	$V / \text{ml}$	$p / \text{kPa}$	
283	5.5	100	
270	2.2	230	
373	6.0	120	

The student decides that the data are consistent with air obeying the ideal gas equation

$$pV = NkT.$$

Is this conclusion correct, given the precision of the data in the table?

Justify your answer with calculations.

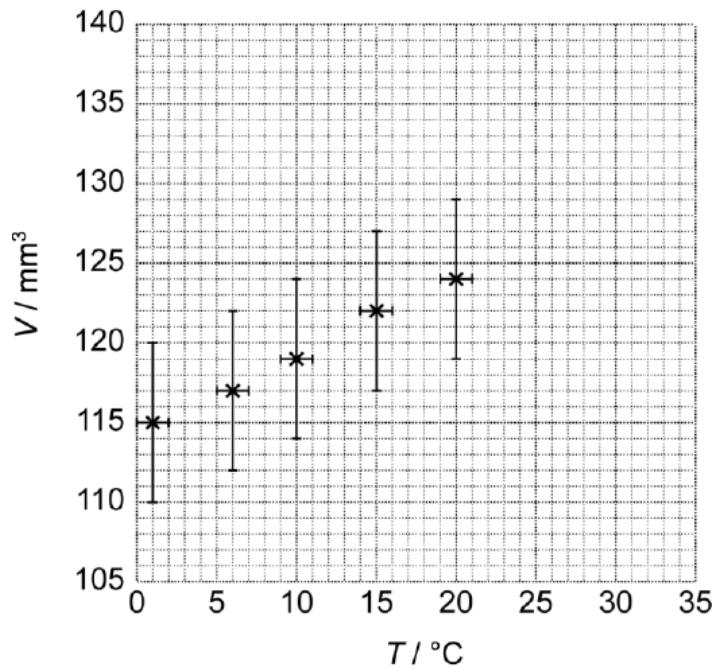
[3]

**3(a).** This question is about an experiment investigating the relationship between volume of a gas,  $V$ , and temperature,  $T$ , at constant pressure. Fig 4.1 shows measurements taken by a student.

$T / ^\circ\text{C}$ $\pm 1 ^\circ\text{C}$	$V / \text{mm}^3$ $\pm 5 \text{ mm}^3$
1	115
6	117
10	119
15	122
20	124
25	127
30	130

**Fig. 4.1**

Fig. 4.2 shows the graph for five of the data points.



**Fig. 4.2**

- Add the **two** remaining data points to the graph. Include uncertainty bars for the points and an appropriate line of best fit.

[4]

- Calculate the percentage uncertainty for the values of  $V$  and  $T$  at point (30, 130).

Percentage uncertainty in  $V = \dots \%$

Percentage uncertainty in  $T = \dots \%$

[2]

- iii. The sample contains  $4.5 \mu\text{mol}$  of particles. Use data from the graph to calculate the pressure of the gas,  $P$ .

$$P = \dots \text{Pa}$$

[4]

- (b). Fig. 4.3 shows the same data set plotted on different axes. The uncertainties in  $T$  and  $V$  are too small to be shown on this graph.

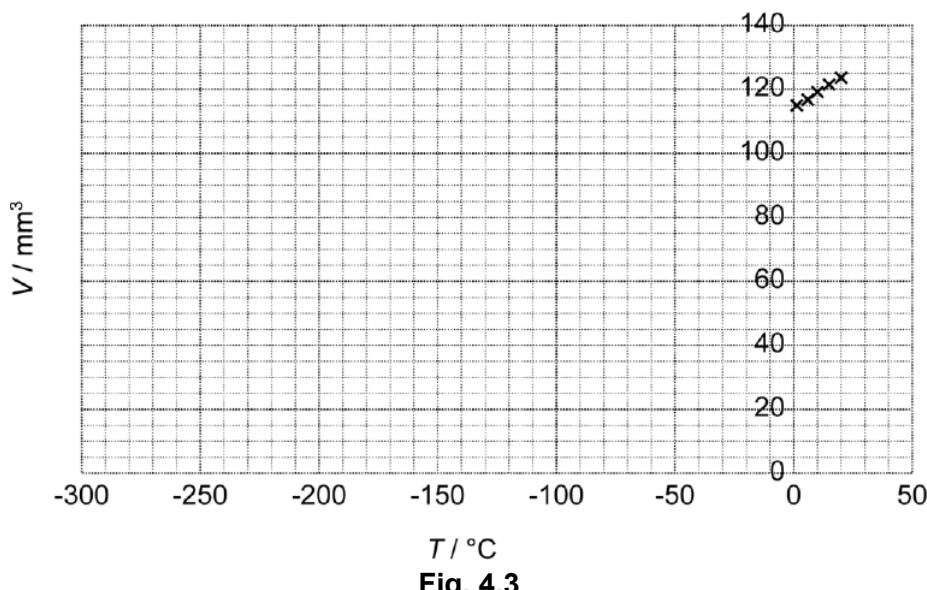


Fig. 4.3

- i. Add a line of best fit to the data points and extrapolate the line so that it intercepts the x-axis.

State the value of the x-intercept from the graph.

$$\text{x-intercept} = \dots [1]$$

- ii. Describe and explain how the motion of the particles in an ideal gas changes as the gas approaches and reaches the temperature given in b(i). Compare and explain any differences in the behaviour of a real gas such as nitrogen as it reaches the temperature given in b(i).

[4]

- iii. The accepted value of the x-intercept is  $-273\text{ }^{\circ}\text{C}$ . Use your answer from **b(i)** to determine the percentage difference between the experimental and accepted value.

.....% [1]

- iv. The uncertainty in the x-intercept is found to be 7%. Use this and your answer to **b(iii)** to discuss the accuracy of the investigation.

[2]

- v. State and explain whether the gas in the investigation can be treated as an ideal gas in the temperature range used.

[1]

- vi. The molar mass of  $\text{N}_2$  is  $28\text{ g mol}^{-1}$ .

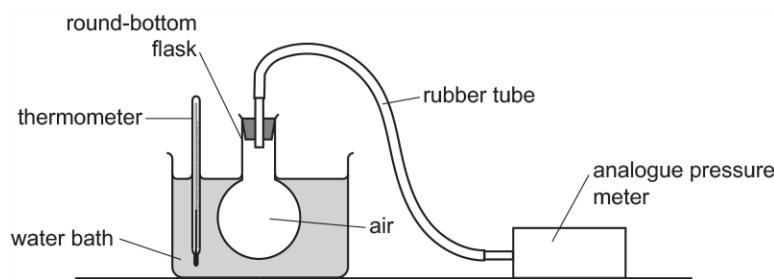
Treating nitrogen as an ideal gas, calculate the ratio of the r.m.s speed of the gas molecules between  $T = 20\text{ }^{\circ}\text{C}$  and  $T = -196\text{ }^{\circ}\text{C}$ .

number of particles in one mole =  $6.0 \times 10^{23}\text{ mol}^{-1}$

[4]

**4(a).** A student performs an experiment to investigate if the pressure of a constant volume of air is directly proportional to its absolute (kelvin) temperature.

Fig. 4.1 shows the apparatus used.



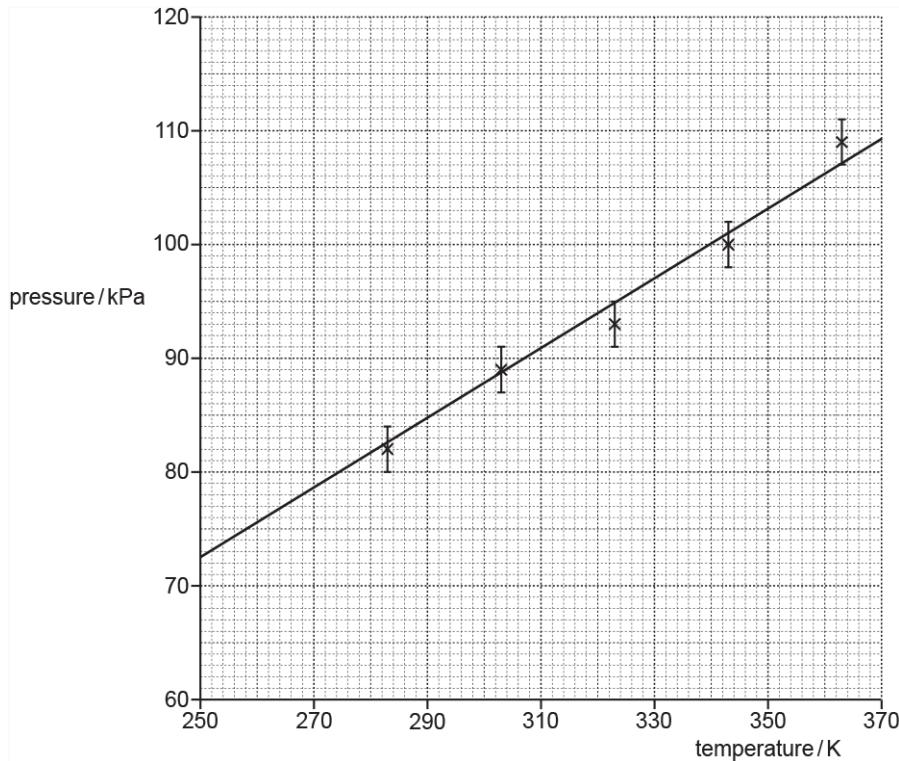
**Fig. 4.1**

- i. Fifteen apparently identical thermometers are available.

Describe how the student can determine the uncertainty in the reading of the temperature by using all the available thermometers.

[2]

- ii. Fig. 4.2 shows the graph of the data collected, including the uncertainty in the pressure readings.



**Fig. 4.2**

- 1 The best-fit straight line is shown.

On Fig. 4.2, add a worst-fit straight line that gives the **maximum gradient**.

[1]

- 2 The gradient of the best-fit straight line suggests that the pressure of the gas will fall to zero at a temperature of about 10 K.

Determine the gradient of your worst-fit straight line.

Use your gradient value to calculate the temperature at which the pressure falls to zero, assuming the change in pressure per unit kelvin is constant.

Show all your working.

temperature at which pressure falls to zero = ..... K [5]

**(b)**. The student notices that the top of the round-bottom flask is above the level of the liquid in the water bath and suggests that this will produce a systematic error in the data which could account for the incorrect value for the temperature at which the gas pressure falls to zero.

The temperature of the laboratory at the time of the experiment was 25 °C.

Explain what is meant by a *systematic error*. Explain how the low level of liquid in the water bath could lead to a systematic error and assess if the error is likely to be significant.

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[4]

**END OF QUESTION PAPER**

# Mark scheme

Question			Answer/Indicative content	Marks	Guidance
1	a		Use a thermometer (with $\pm 1 \text{ }^{\circ}\text{C}$ )  Stir water bath / avoid parallax (for glass thermometer)	B1 B1	<b>Allow</b> 'temperature sensor / gauge'  <b>Allow</b> 'avoid touching sides of water bath with thermometer' <b>Allow</b> 'take temperature in several places / times and average' <b>Allow</b> idea of 'leave thermometer for long time (to reach thermal equilibrium)' <b>Not</b> idea of 'use thermometer with finer resolution'
	b	i	Smaller (spacing between) divisions / increments (AW)	B1	<b>Ignore</b> any reference to accuracy or precision <b>Allow</b> 'less uncertainty' <b>Allow</b> better or smaller or greater or higher resolution
		ii	$p = 37.0 \times 4.448 / (1000 \times 0.0254^2)$ 255 (kPa) uncertainty = 3 (kPa)	B1 B1	<b>Allow</b> clearly identified correct answer in table or in working area.  Must be 3sf Must be 1sf  <b>Allow</b> $255.1 \pm 3.4$ scores mark 1
	c	i	Point plotted at (44, 255)	B1	ECF from (b)(ii) Plot to with $\pm$ half a small square <b>Ignore</b> checking error bars
		ii	<b>Level 3 (5–6 marks)</b> Clear explanation, description <b>and</b> determination  <i>There is a well-developed line of reasoning which is clear and logically structured.</i> <i>The information presented is relevant and substantiated.</i>  <b>Level 2 (3–4 marks)</b> Some explanation, description <b>and</b> determination Or Some explanation and clear determination  <i>There is a line of reasoning presented with some structure. The information presented is in the most part relevant and supported by some evidence.</i>	B1 × 6	<b>Indicative scientific points may include:</b>  <b>Explanation and Description</b> <ul style="list-style-type: none"> <li>Absolute zero is the minimum possible temperature / at absolute zero KE is zero</li> <li>At absolute zero <math>p</math> is zero</li> <li>At absolute zero, the internal energy is minimum (allow 0)</li> <li>Absolute zero should be (about) <math>-273 \text{ }^{\circ}\text{C}</math></li> <li>Reference to <math>pV = nRT</math> or <math>pV = NkT</math> or <math>p \propto T</math></li> <li>A graph of <math>p</math> against <math>\theta</math> is a straight line / straight line drawn on graph</li> <li>Intercept of straight line with <math>x</math>-axis or <math>\theta</math>-axis is absolute zero calculated by using <math>y = mx + c</math></li> </ul>

		<p><b>Level 1 (1–2 marks)</b> Limited explanation or description or determination</p> <p><i>The information is basic and communicated in an unstructured way.</i></p> <p><i>The information is supported by limited evidence and the relationship to the evidence may not be clear.</i></p> <p><b>0 marks</b> No response or no response worthy of credit.</p>		<p><b>Determination</b></p> <ul style="list-style-type: none"> <li>Gradient in the range 0.7 to 0.9 (<math>\text{kPa K}^{-1}</math>)</li> <li><math>y = mx + c</math> used to determine the intercept <math>c</math> or absolute zero</li> <li>Absolute zero in the range <math>-320 \text{ }^{\circ}\text{C}</math> to <math>-240 \text{ }^{\circ}\text{C}</math></li> </ul>																
	d	<p>Draw the worst fit line (through all the error bars) (AW).</p> <p>Determine the new value for absolute zero and find the difference between the value in (c)(ii) and this new intercept. (AW)</p>	B1  B1																	
	e	<p>Cooling gas value of absolute zero is lower than (c)(ii)</p> <p>(Whilst cooling, the) temperature of gas lags behind the temperature of water (AW, ORA)</p> <p>Graph is shifted to the left</p> <p>Stir water / <u>wait</u> for temperatures to be the same / attempt at measuring temperature of gas directly (AW)</p>	B1  B1  B1	<p><b>Allow:</b> gradient is too shallow</p> <p><b>Allow:</b> <math>p</math> measured is higher than expected for incorrect measurement of <math>T</math> (so affects the graph) (AW, ORA)</p> <p><b>Not:</b> insulation of water bath</p> <p><b>Not:</b> heat losses</p>																
		<b>Total</b>		18																
2		<table border="1"> <thead> <tr> <th><math>T / \text{K}</math></th><th><math>V / \text{ml}</math></th><th><math>p / \text{kPa}</math></th><th><math>pV/T</math></th></tr> </thead> <tbody> <tr> <td>283</td><td>5.5</td><td>100</td><td>1.94</td></tr> <tr> <td>270</td><td>2.2</td><td>230</td><td>1.87</td></tr> <tr> <td>373</td><td>6.0</td><td>120</td><td>1.93</td></tr> </tbody> </table>	$T / \text{K}$	$V / \text{ml}$	$p / \text{kPa}$	$pV/T$	283	5.5	100	1.94	270	2.2	230	1.87	373	6.0	120	1.93	3	<p>evidence of calculating <math>pV/T</math> or an appropriate equivalent ... e.g., <math>pV/kT</math>, <math>T/pV</math>, <math>kT/pV</math> for [1]</p> <p>correct evaluation to at least 2 s.f. for all three rows [1]</p> <p>correct conclusion with reason: yes, because all same value to 2 s.f. set by <math>V</math> for [1]</p> <p>Note: If the student uses <math>pV/kT</math> with <math>k = 1.4 \times 10^{-23}</math>, the values are not the same to 2SF (1.4, 1.3, 1.4) but accept a sensible conclusion based on the SF set by <math>V</math>. The focus here, is on SF so IGNORE any reference to decimal places.</p>
$T / \text{K}$	$V / \text{ml}$	$p / \text{kPa}$	$pV/T$																	
283	5.5	100	1.94																	
270	2.2	230	1.87																	
373	6.0	120	1.93																	

		Total	3	
3	a	i	<p>Points plotted correctly ✓  uncertainty bars for temperature plotted correctly ✓  uncertainty bars for volume plotted correctly ✓  Straight line of best fit plotted going through all of the error bars ✓</p>	4    ± ½ square ± ½ square ± ½ square
		ii	$1/30 = 0.033 \text{ or } 3.3\% \checkmark$ $5/130 = 0.038 \text{ or } 3.8\% \checkmark$	2  Accept as a decimal Accept as a decimal. Accept to 1 sf.
		iii	<p>Calculation of the gradient = <math>4.29 \times 10^{-10} \checkmark</math></p> <p>Gradient shown to be equivalent to  <math>\frac{Nk}{P}</math> or <math>\frac{nR}{P} \checkmark</math></p> <p>Correct values substituted in;</p> $\frac{4.5 \times 10^{-6} \times 6.022 \times 10^{23} \times 1.38 \times 10^{-23}}{P} = 4.29 \times 10^{-10}$ Or $\frac{4.5 \times 10^{-6} \times 8.31}{P} = 4.29 \times 10^{-10} \checkmark$ <p>Evaluation, P = 87.2 kPa ✓</p>	4    Must be clearly shown that graph was used rather than the data. Gradient within the range $4.0 \times 10^{-10} - 5.1 \times 10^{-10}$ Penalise small triangles    Gives answer within range 73.3 – 93.5 kPa
	b	i	Suitable line of best fit drawn with x-intercept in the range –260 to –280. ✓	1  Only straight LOBF given credit.
		ii	<p>Particles slow down to zero speed✓ as the average energy of particles reduces ✓</p> <p>Gas will liquefy / solidify✓ As inter-molecular bonds will form✓</p>	4    Zero velocity will not be achieved/particles will continue to vibrate Absolute zero cannot be reached
		iii	$\frac{b(i) - 273}{-273} (\times 100\%) \checkmark$	1    Must be the candidate's value from b(i) Accept a decimal accepted value must be the denominator
		iv	Meaningful comparison of percentage uncertainty and percentage difference. ✓ Correct conclusion. ✓	2    Expect % uncert > % diff accurate
		v	If accurate from b(iv) yes (no mark) As T is <b>directly</b> proportional to V ✓	1    If inaccurate from b(iv) no (no mark) As T is <b>not directly</b> proportional to V
		vi	<p>Calculation of molecular mass =</p> $\frac{28}{6.0 \times 10^{23}} = 4.7 \times 10^{-23} \text{ g} \checkmark$ <p>Equation of <math>pV = nRT</math> and <math>pV = \frac{1}{2}Nm\bar{c}^2</math>  re-arranged to <math>\sqrt{\bar{c}^2} = \frac{3kT}{m} \checkmark</math></p>	4    Accept use of $KE = 1/2 m\bar{c}^2$ and $KE = 3/2 kT$

			Calculation of $\sqrt{c^2}$ for both temperatures: For T = 293 K, $\sqrt{c^2} = 508 \text{ ms}^{-1}$ ✓ For T = 77 K, $\sqrt{c^2} = 260 \text{ ms}^{-1}$ ✓ Ratio 1.95 : 1 ✓		Accept 1.95
			<b>Total</b>	<b>23</b>	
4	a	i	<p>Two from:</p> <ul style="list-style-type: none"> <li>• Record the temperature will all the thermometers (in the water bath)</li> <li>• Uncertainty = <math>\pm</math> range <math>\div 2</math> or <math>\pm</math> spread.</li> <li>• Ignore/identify anomalous values or outliers as values greater than <math>x2</math> spread from mean</li> </ul>	1 x 2	<p>IGNORE find mean, percentage uncertainty.</p> <p>ALLOW uncertainty = max value – mean, OR uncertainty = mean – min value.</p> <p>ALLOW outliers identified as being clearly different from the other readings.</p> <p>NOT just ignore outliers.</p>
		ii	Worst fit line has steeper gradient and passes through all the uncertainty bars.	1	<p>In particular, watch for the top of the fourth error bar and the bottom of the first within half a small square in vertical direction. Put a tick/cross near the 4<sup>th</sup> error bar.</p> <p>Line from (250, 68) to (370, 112) to nearest half a small square</p>
		iii	<p>Gradient calculated (<math>\frac{dy}{dx}</math> or) <math>\frac{dP}{dT}</math> ✓  <math>dT \geq 60 \text{ K}</math> ✓  Coordinates of two points on the line read off to the nearest half square ✓</p> <p>EITHER:  Find intercept by substituting coordinates of point on line into <math>p = mT + c</math>, using their value of gradient as <math>m</math>.✓  Substitute P = 0 to find T. ✓</p> <p>OR:  Calculation of the temperature drop required to reach zero pressure from a stated temperature by dividing a value of pressure on the line by the gradient.  Temperature at 0 Pa calculated;</p>	1 1 1 1 1 (1) (1)	<p>All coordinates to be read off to the nearest half a small square.</p> <p>e.g. (250,68) and gradient value = 0.37  <math>68 = 0.37 \times 250 + c</math>; to give <math>c = -24.5</math> ✓  Substitute P = 0; <math>0 = 0.37T - 24.5</math>; <math>T = 66\text{K}</math>  No ecf for wrong value of c (unless transcription or arithmetic error). Watch for false origin read-off.</p> <p>e.g taking (250,68) as a point on their worst fit line.  <math>68 \div \text{gradient} = 185</math> ✓  <math>250 - 185 = 65\text{K}</math> ✓</p> <p>IGNORE any calculation of gradient and/intercept of the printed line of best fit.</p> <p>ALLOW ecf of incorrect gradient calculated for intercept calculation.</p> <p>ALLOW ecf for incorrect read-offs used in subsequent calculations. [ie only penalise incorrect read-off once]</p> <p>If both read-offs are wrong for the gradient calculation and either of them are used again</p>

				in subsequent calculations then the fourth mark will be lost.
b		<p>Any four points from:</p> <div style="border: 1px solid black; padding: 5px;"> <p>Systematic error means that measurements</p> <ul style="list-style-type: none"> <li>• differ from true value by a consistent amount each time a measurement is taken.)</li> <li>• Systematic error is not reduced by taking multiple readings of each measurement.</li> </ul> <p>Actual temperature of the gas will be lower</p> <ul style="list-style-type: none"> <li>• than measured temperature (for most data points)</li> <li>• For the first data point (at 283K) the actual temperature will be higher than measured.</li> </ul> <p>The effect will be more significant when the</p> <ul style="list-style-type: none"> <li>• temperature difference between the water bath and the air is higher.</li> </ul> <p>A small change in the line will have a</p> <ul style="list-style-type: none"> <li>• significant effect on the temperature when <math>P = 0</math> (x-intercept).</li> </ul> <p>Convection currents within the gas inside the</p> <ul style="list-style-type: none"> <li>• flask will help to maintain uniform temperature.</li> </ul> <p>The significance of the effect depends on the</p> <ul style="list-style-type: none"> <li>• proportion of the flask/volume/air which is above the water level.</li> <li>• Glass/bung provide insulation which will reduce significance.</li> </ul> </div>	1 x 4	
		<b>Total</b>	<b>12</b>	