3(a)	total kinetic energy associated with random motion of molecules	**B1**
	potential energy (of molecules) is zero	**B1**

3(b)(i)	$pV = NkT$ **and** $U = (3/2)NkT$	**C1**
	$U = (3/2)pV$ $= (3/2) \times 2.0 \times 10^5 \times 0.016$ $= 4800$ J	**A1**

3(b)(ii)	temperature = 800 K	**A1**

3(b)(iii)	volume = 0.032 m^3	**A1**

3(b)(iv)	straight vertical line labelled X between A and (0.016, 4.0)	**B1**
	curve from B with continuously decreasing negative gradient, labelled Y	**B1**
	line labelled Y between (0.016, 4.0) and (0.032, 2.0)	**B1**

Question 3

(a) Some candidates did not mention random motion and/or 'total' when referring to kinetic energy. The fact that the molecular potential energy is zero in an ideal gas was well known. Some candidates did not refer to molecules or particles at all in their answers.

(b) (i) The equation $\frac{3}{2}kT$ was commonly assumed to be the correct equation to use, as the candidate had just derived it in **Question 2**. Many candidates calculated E_K for only one molecule, omitting to calculate and use N.

(ii) Most candidates gave the correct answer.

(iii) Most candidates gave the correct answer. A minority made a power-of-ten error.

(iv) A significant proportion of candidates incorrectly drew a straight line from B to C for line Y. Most candidates placed B and C in the correct positions and drew the correct line for X.

4(a)	change in internal energy = work done + energy transfer by heating	**C1**
	increase in internal energy = work done on system + energy transferred to the system by heating	**A1**

4(b)(i)	$U = (3 / 2)\ pV$	**A1**

4(b)(ii)	$pV = NkT$ and k identified as Boltzmann constant	**B1**
	$U = (3 / 2)\ NkT$	**A1**

4(c)(i)	$W = (+)8XY$	**A1**

4(c)(ii)	$W = -20XY$	**A1**

4(d)	work done during stages BC and DA = 0	**B1**
	change in internal energy (over complete cycle) = 0	**C1**
	thermal energy supplied $= 20XY - 8XY$ $= (+)12XY$	**A1**

Question 4

(a) Many candidates were able to give a partially correct answer, but fully correct statements of the first law were only given by the strongest candidates.

(b) (i) Only the strongest candidates were able to conclude, when comparing Fig. 4.1 and Fig. 4.2, that the internal energy at each of the stages A, B, C and D is given by $U = (3/2)pV$.

(ii) Some candidates deduced the correct equation $U = (3/2)NkT$. Many of these did so from knowledge of the mean kinetic energy of a molecule as $(3/2)kT$ and the definition of internal energy for an ideal gas. Partial credit was available for this approach. For full credit, candidates needed to show how this equation follows from the answer in **(b)(i)**.

(c) (i) Many candidates obtained the correct answer for this question using the knowledge that work done is equal to the product of pressure and change in volume. Some candidates who were using the correct starting equation stopped short of completing the algebra, and others had the wrong sign for the answer.

(ii) The most common mistake in this question was to not realise that the work done on the gas in stage CD must be negative.

(d) Many of the weaker candidates were confused between the concepts of internal energy and transfer of thermal energy, and thought that the net transfer of thermal energy over a complete cycle must be zero. Stronger candidates were generally able to apply the fact that the internal energy returns to its original value and to deduce at least the correct magnitude for the transfer of thermal energy. Again, there were some difficulties over the sign of the answer. For full credit, candidates needed to explain that the work done on the gas during stages BD and DA is zero, but many omitted this part of the explanation.

2(a)	work done on / by system	**B1**
	thermal energy supplied to / removed from system	**B1**

2(b)(i)	no thermal energy transferred to / from system (due to lack of time)	**B1**
	work is done on the gas to compress it / to decrease its volume	**B1**
	internal energy increases so temperature increases	**B1**

2(b)(ii)	(during vaporisation) molecular separation increases	**B1**
	(heating causes) potential energy of molecules to increase	**B1**
	kinetic energy of molecules unchanged so temperature unchanged	**B1**

Question 2

(a) Stronger candidates clearly described the context of a system or gas, and were able to identify that work being done or thermal energy being added or removed would change the internal energy of that system. A significant number of candidates mistakenly appeared to believe that changes of work or changes of thermal energy were required to change the internal energy.

(b) (i) Some candidates did not mention a system or gas, making their descriptions inaccurate. Stronger candidates understood that the change was too quick to allow thermal energy to be involved. Weaker answers confused thermal energy with internal energy or temperature.

(ii) Many answers did not refer to molecular energies directly. Descriptions of bonds being broken were common, but stronger candidates explained that both molecular separation and molecular potential energy increased. The link between molecular kinetic energy and temperature was generally well understood.

3(a)	(gas that obeys) $pV \propto T$ (at all values of p, V and T)	**M1**
	where T is thermodynamic temperature	**A1**

3(b)(i)	$pV = \frac{1}{3} Nm\langle c^2 \rangle$ **and** $Nm / V = \rho$ $(p = \frac{1}{3} \rho \langle c^2 \rangle)$	**C1**
	r.m.s. speed = $\sqrt{\langle c^2 \rangle}$	**C1**
	$1.6 \times 10^5 = \frac{1}{3} \times 1.9 \times \langle c^2 \rangle$ leading to r.m.s. speed = 500 m s^{-1} **or** r.m.s. speed = $\sqrt{(3 \times 1.6 \times 10^5 / 1.9)}$ = 500 m s^{-1}	**A1**

3(b)(ii)	$(pV =) \frac{1}{3} Nm\langle c^2 \rangle = NkT$ (so) $\frac{1}{2} m\langle c^2 \rangle = (3 / 2) kT$	**C1**
	$\frac{1}{2} \times 4.7 \times 10^{-26} \times 503^2 = (3 / 2) \times 1.38 \times 10^{-23} \times T$ T = 290 K	**A1**
	or	
	$pV = NkT$ **and** $Nm / V = \rho$ (so) $T = pm / \rho k$	**(C1)**
	$T = 1.6 \times 10^5 \times 4.7 \times 10^{-26} / (1.9 \times 1.38 \times 10^{-23})$ = 290 K	**(A1)**

3(c)	potential energy (of molecules) is zero	**B1**
	$U = N \times ½\, m\langle c^2 \rangle = 6.0 \times 6.02 \times 10^{23} \times ½ \times 4.7 \times 10^{-26} \times 503^2$ **or** $U = N \times (3 / 2)\, kT = 6.0 \times 6.02 \times 10^{23} \times (3 / 2) \times 1.38 \times 10^{-23} \times 287$ **or** $U = n \times (3 / 2)\, RT = 6.0 \times (3 / 2) \times 8.31 \times 287$	**C1**
	$U = 21000$ J	**A1**

Question 3

(a) This question was generally well answered. Many weaker candidates did not identify the temperature used in the relationship as being thermodynamic temperature.

(b) (i) Stronger candidates ensured that the correct symbol $\langle c^2 \rangle$ was used throughout their answer. Weaker candidates did not use $\langle c^2 \rangle$ for root-mean-square speed or used it incorrectly. Many candidates showed confusion over mass and density, believing the density was the mass of one molecule divided by the volume of the gas.

(ii) The use of the ideal gas equation $pV = NkT$ to form an equation involving molecular kinetic energy illustrated a better understanding in general than the relationships tested in **(i)**. More candidates achieved full credit here than in **(i)**.

(c) The calculation of the internal energy was the part of this question that was most successfully answered, and there were also many candidates who a gave good explanation of the reason for ignoring molecular potential energy in their calculations. Weaker candidates often confused the number of moles with the number of molecules.

3(a)	(thermal) energy per unit mass (to cause temperature change)	**B1**
	(thermal) energy per unit change in temperature	**B1**

3(b)(i)	density = mass / volume	**C1**
	mass $= 2.700 \times 10^{3} \times 3.612 \times 10^{-3}$ $= 9.752$ kg	**A1**

3(b)(ii)	volume $= 3.612 \times 10^{-3} \times (2.700 / 2.620) = 3.722 \times 10^{-3}$ m^3 **or** volume $= 9.752 / (2.620 \times 10^{3}) = 3.722 \times 10^{-3}$ m^3	**A1**

3(b)(iii)	$W = p\Delta V$	**C1**
	$= 1.01 \times 10^{5} \times (3.722 - 3.612) \times 10^{-3}$ $= 11.1$ J	**A1**

3(b)(iv)	volume (of block) increases	**B1**
	work is done against the atmosphere so work done (on block) is negative	**B1**

3(b)(v)	thermal energy = $(4.38 \times 10^6) + 11.1$	**B1**
	specific heat capacity = $(4.38 \times 10^6) / (9.75 \times 500)$	**C1**
	$= 898\ \text{J kg}^{-1}\ \text{°C}^{-1}$	**A1**

3(c)	work done is negligible compared with (change in) internal energy so (answer in **(b)(v)** would be) unchanged	**B1**

Question 3

(a) Many candidates defined a quantity that is an energy (often mixing up units with the definition of the quantity), but candidates that gave a dimensionally correct definition of specific heat capacity were usually able to achieve full credit.

(b) (i) This question was generally well answered, though a significant minority of candidates gave an answer to only two significant figures when the data justified four significant figures.

(ii) There were two possible approaches to answering this question, one that used only the primary data in the question, and the other that used the answer in **(b)(i)**. Candidates choosing the latter route needed to appreciate that the volume to be shown was to four significant figures, and that therefore to correctly 'show' this volume, the mass used also had to be given to at least four significant figures.

(iii) This question was generally well answered. Of candidates that knew the correct starting equation, the main reasons for not achieving full credit were either substituting a volume rather than the change in volume, or giving the answer to fewer significant figures than justified by the data in the question.

(iv) Many candidates had the right idea, but there was much confusion between the block, the gas involved (which is the atmosphere), and the 'system' (which is both the block and the atmosphere).

(v) Achieving full credit in this question required evidence of correct application of the first law of thermodynamics, correct substitution of data, an answer calculated to the correct number of significant figures, and an answer given with correct unit. Many candidates achieved full credit, but many others did not meet one or more of these requirements. It is particularly worth noting that some candidates were confused between degrees Celsius and coulombs as the unit of temperature change.

(c) This question discriminated well amongst stronger candidates. Candidates were required to observe that, since the work done (whether doubled or not) is negligible compared with the increase in internal energy, the three significant figure value for specific heat capacity asked for in **(b)(v)** will be unaffected by the pressure change.

4(a)(i)	sum of potential energy and kinetic energy	**B1**
	(total) energy of random motion of particles	**B1**

4(a)(ii)	potential energy (of molecules) (in an ideal gas) is zero, so the internal energy of the gas is equal to the total kinetic energy (of molecules)	**B1**
	kinetic energy of molecules is proportional to (thermodynamic) temperature (so internal energy is proportional to (thermodynamic) temperature))	**B1**

4(b)	cooling work done = 0	**B1**
	compression increase in internal energy = +2U	**B1**
	cooling change in internal energy = –U	**B1**
	both rows: thermal energy adds to work to give increase in internal energy in terms of U and/or W (if fully correct, thermal energy for compression = $2U - W$ and thermal energy for cooling = $-U$: compression: +W | $2U - W$ | +2U cooling: 0 | –U | –U)	**B1**

Question 4

(a) (i) The definition of internal energy was generally well known, although some of the weaker candidates confused this definition with the first law of thermodynamics and the change in internal energy.

(ii) Most candidates correctly stated that the potential energy of molecules in an ideal gas is zero. Some went on to state that internal energy was therefore proportional to the total kinetic energy of the molecules rather than equal to it. Most candidates also correctly stated that the kinetic energy of the molecules is proportional to the thermodynamic temperature.

(b) Only the strongest candidates obtained full credit for this question, but many candidates earned partial credit for the work done and the increase in internal energy during cooling. Weaker candidates sometimes gave responses which were dimensionally incorrect, e.g. including temperature T as a quantity of energy.

3(a)(i)	(P and Q are at the) same temperature	**B1**
	no <u>net</u> transfer of thermal energy (between P and Q)	**B1**

3(a)(ii)	$Q = mc\Delta T$	**C1**
	$24 \times 10^3 = (0.54 \times 390 \times \Delta T) + (0.37 \times 910 \times \Delta T)$	**C1**
	$\Delta T = 44\,\text{K}$	**A1**

3(b)(i)	work done $= p\Delta V$	**C1**
	$= (1.6 \times 10^5) \times (0.18 - 0.32)$	**C1**
	$= -2.2 \times 10^4\,\text{J}$	**A1**

3(b)(ii)	$pV = NkT$	**C1**
	$N = (1.6 \times 10^5 \times 0.18) / (1.38 \times 10^{-23} \times 273)$ $= 7.6 \times 10^{24}$	**A1**

3(b)(iii)	$\frac{1}{2}m\langle c^2\rangle = (3/2)kT$	**C1**
	r.m.s. speed $= \sqrt{[(3 \times 1.38 \times 10^{-23} \times (210 + 273) / (4.7 \times 10^{-26})]}$ $= 650\,\text{ms}^{-1}$	**A1**

Question 3

(a) (i) Generally well answered by the stronger candidates. However, several misconceptions are worth highlighting. Firstly, many candidates appeared to think that ‘constant temperature’ and ‘equal temperatures’ mean the same thing. Secondly, many candidates confused internal energy and thermal energy and gave answers that were contradictory.

(ii) Most candidates knew the general equation for specific heat capacity and were therefore able to achieve the first ‘working’ mark. However, only the strongest candidates correctly analysed the energy transfers involved to arrive at the correct answer.

(b) (i) Many candidates correctly used the equation for work done on a gas when changing volume at constant temperature. However, only the strongest candidates realised that, because the gas is expanding, the work done on the gas must be negative.

(ii) Generally well-answered. However, one misconception that was common in a minority of candidates, warrants mention. Having correctly stated the starting equation $pV = NkT$, some candidates substituted the change in volume from part **(b)(i)** as the value of V.

(iii) Generally well-answered by the stronger candidates. The common confusion among weaker candidates was the difference between r.m.s. speed and mean-square speed. Many candidates stopped at the mean-square speed and gave this as their answer to the r.m.s. speed.

3(a)	sum of potential energy and kinetic energy	**B1**
	(total) energy of random motion of particles	**B1**

3(b)(i)	no change in separation so no change in (molecular) potential energy	**B1**
	temperature increases so kinetic energy (of molecules) increases	**B1**
	kinetic energy increases and potential energy unchanged, so internal energy increases	**B1**

3(b)(ii)	temperature constant so no change in (molecular) kinetic energy	**B1**
	separation increases so potential energy (of molecules) increases	**B1**
	potential energy increases and kinetic energy unchanged, so internal energy increases	**B1**

Question 3

(a) The definition of internal energy was generally well known, although many of the weaker candidates confused the definition of internal energy with the first law of thermodynamics as a means of describing how the internal energy of an object may be changed.

(b) In both parts of this question, candidates were expected to explain how the change in temperature affected molecular kinetic energy and how the change in molecular separation affected molecular potential energy. Having deduced the changes (or lack of changes) in those two energies, they were then expected to relate the overall change in internal energy to them.

These extended writing questions proved to be a good test of understanding of physics and the ability to articulate physics. Many of the stronger candidates were awarded full or almost full credit. For all candidates, a significant problem was not reading the question carefully enough, and therefore not answering it. Many candidates ignored the instruction to discuss the molecular kinetic and potential energies, and instead gave arguments based on the first law of thermodynamics.

Many weaker candidates confused the notion of no change in energy with the energy being zero. Candidates that stated that the kinetic or potential energy of the molecules was zero were very restricted in the credit that could be received.

2(a)	total kinetic energy associated with random motion of molecules	**M1**
	plus total potential energy (of molecules) but potential energy is zero	**A1**

2(b)(i)	$W = p\Delta V$	**C1**
	$= 1.01 \times 10^5 \times 5.20 \times 10^{-5}$ $= (+)5.25$ J	**A1**

2(b)(ii)	$V \propto T$ *or* V / T = constant	**C1**
	$1.24 / (273 + 20) = (1.24 + 0.520) / T$ $T = 416$ K	**A1**

2(b)(iii)	$c = Q / m\Delta T$	**C1**
	$= 960 / (0.016 \times (416 - 293))$ $= 490$ J kg^{-1} K^{-1}	**A1**

2(c)	no change in volume so no work is done (by the gas)	**B1**
	(same temperature change so) same change in internal energy	**B1**
	less thermal energy needs to be supplied so c is less	**B1**

NOT FOUND:
9702_m24_qp_42 EXAMINER REPORT (Qu 2)

3(a)	sum of potential energy and kinetic energy (of particles)	**B1**
	(total) energy of random motion of particles	**B1**

3(b)(i)	no thermal energy transferred	**B1**
	work is done on the spring (increasing the potential energy of particles)	**M1**
	so internal energy increases	**A1**

3(b)(ii)	thermal energy transferred to water	**B1**
	work is done by water (expanding against atmosphere as it vaporises)	**B1**
	more thermal energy transferred than work done so internal energy increases	**B1**

Question 3

(a) There was much confusion between the definition of internal energy and the first law of thermodynamics (which deals with ways in which internal energy can be changed).

(b) In both parts of this question, there was a widespread misunderstanding of the terms involved in the first law of thermodynamics. Many candidates seemed to think that all three of internal energy, thermal energy and work are quantities that are possessed by the system. Awareness was rare that it is internal energy that is possessed by the system, and that the transfer of thermal energy and the doing of work are simply ways in which internal energy may be changed. It was common for candidates to write about work and thermal energy increasing or decreasing, or remaining constant, and it was clear that these candidates had a poor understanding of the law.

It is also important to stress to candidates that explanation questions like this require accurate use of technical terminology, and that credit is not awarded for use of undefined symbols. Responses should be rooted in the context of the question, in this case a spring and a puddle of water, rather than some undefined ‘gas’ or ‘system’.

In **(b)(i)**, it was common for weaker candidates to think of the spring as a gas, and to conclude that if it expands it must be doing work against the atmosphere. Candidates that realised that work has to be done on a spring to stretch it were usually then able to conclude that the internal energy increases.

In **(b)(ii)**, the candidates that understood the physics of evaporation were usually able to state that the water does work against the atmosphere (or that the work done on the water is negative) as it evaporates and that thermal energy is supplied to the water by the Sun. For the award of credit, the directions of energy transfer needed to be clear. Full credit required reasoning how these two transfers interact to result in an increase in internal energy, and proved to be challenging but nevertheless accessible to the strongest candidates.

2(a)	(thermal) energy per unit mass (to change temperature)	**B1**
	(thermal) energy per unit change in temperature	**B1**

2(b)(i)	work done $= p\Delta V$ $= (2.0 \times 10^5) \times (0.063 - 0.038) = 5000\ \text{J}$	**A1**

2(b)(ii)	gas is expanding (against external pressure)	**B1**
	gas does work / work is done by gas, so (work done on gas is) negative	**B1**

2(b)(iii)	$\Delta U = q + W$	**C1**
	$7600 = q + (-5000)$ $q = 12\,600\ \text{J}$	**A1**

2(b)(iv)	specific heat capacity $= q / m\Delta T$ $= 12600 / (0.35 \times 56)$	**C1**
	$= 640\ \text{J kg}^{-1}\ \text{K}^{-1}$	**A1**

2(c)	same gain in internal energy so same temperature rise	**B1**
	no change in volume so no work done **or** no work done so less thermal energy needed (for same change in internal energy)	**B1**
	less thermal energy needed (for same temperature change) so lower specific heat capacity	**B1**

NOT FOUND:
9702_w23_qp_41 EXAMINER REPORT (Qu 2)

3(a)	change in internal energy = work done + energy transfer by heating	**C1**
	increase in internal energy = work done on system + energy transferred to the system by heating	**A1**

3(b)(i)	AB change in internal energy:	decrease	**B1**
	AB work done on gas:	positive	**B1**
	BC change in internal energy:	increase	**B1**
	BC work done on gas:	zero	**B1**

3(b)(ii)	more work done by gas in CD than is done on gas in AB **or** (no work done on gas in BC and DA so) (overall) gas does work	**B1**
	(overall) change in internal energy is zero	**B1**
	(must be an overall) input of thermal energy	**B1**

Question 3

(a) Most candidates knew that the first law of thermodynamics involves a relationship between change in internal energy, the transfer of thermal energy and the work done. Only a minority of candidates could give a fully correct statement of the law, with the directions of transfer clearly and consistently stated for all three quantities. A common confusion was between the energy possessed by the system and the transfers that are the means by which this quantity can be changed. Candidates should appreciate that thermal energy and work are not energies that are possessed by the system (and so they cannot 'change') but are means of energy transfer that result in changes to the internal energy of the system.

(b) (i) There were several misconceptions, including in some cases a lack of appreciation that the internal energy of the gas is proportional to the product pV and that its direction of change can be determined directly from the pV graph.

(ii) Candidates found this question difficult. It required candidates to apply the first law of thermodynamics to the complete cycle and to discuss the overall energy changes involved. Some candidates gained credit for observing that the overall change in internal energy over a full cycle is zero, but those that also went on to consider the transfer of thermal energy and the doing of work over the full cycle often incorrectly stated that these terms were zero as well. Only the strongest candidates appreciated that the work done by the gas in stage CD is greater than the work done on the gas in stage AB and that, over a complete cycle, the gas therefore does work that must come from a net input of thermal energy.

3(a)	no net thermal energy is transferred (between them)	**B1**

3(b)(i)	variation (of density with temperature) is linear **or** each temperature has a unique value of density	**B1**

3(b)(ii)	• variation (of density with temperature) is not linear • region where the density does not vary with temperature • different temperatures have the same density *Any two points, 1 mark each*	**B2**

3(c)(i)	boiling point = 80 °C	**A1**

3(c)(ii)	$Q = Pt$ **and** $t = 21$ s (thermal energy supplied = $810 \times 21 = 17000$ J)	**C1**
	$c = Q / m\Delta\theta$	**C1**
	thermal energy absorbed by beaker = $42 \times 0.84 \times (80 - 25)$ (= 1940 J)	**C1**
	s.h.c. of liquid = $[(810 \times 21) - (42 \times 0.84 \times (80 - 25))] / [120 \times (80 - 25)]$ = 2.3 J g^{-1} K^{-1}	**A1**

3(d)	sketch: straight diagonal line from 25 °C to 100 °C **and** then horizontal at 100 °C	**B1**
	straight diagonal line starting at 25 °C with gradient approximately half that of the original line	**B1**

Question 3

(a) Candidates found it difficult to demonstrate a good understanding of thermal equilibrium. The idea that thermal energy would still transfer between the two objects, but that the resultant or net transfer was zero, was often not known. This was seen through the omission of the word ‘net’. In addition, some candidates did not clarify that the relevant energy was thermal energy.

(b) Candidates needed to refer to the information provided in the graphs. It was common for candidates to refer to the linearity of the relationship, or lack of linearity. Some candidates, however, stated that the relationship between density and temperature for mercury was proportional, which is incorrect. A small number of candidates correctly referred to state changes, but the evaporation of water was not appropriate here.

(c) (i) The majority of candidates correctly stated the boiling temperature of the liquid.

(ii) This calculation proved to be challenging. Many candidates ignored the energy required to raise the temperature of the beaker. A large number of candidates who included the beaker began with the incorrect statement that the energy gained by the beaker was equal to the energy gained by the water. Some candidates calculated the change in temperature correctly as 55 °C but then converted this change into kelvin as if it were a Celsius temperature. This is incorrect physics.

(d) The general shape of the line was correct for most candidates here. Some details were often incorrect, including the approximate gradient of the first part of the line and starting the line from the same temperature.

4(a)	• particles are in (continuous) random motion • particles have negligible volume (compared with the gas) • negligible forces between particles (except during collisions) • (all) collisions (perfectly) elastic • time of collision negligible (in comparison with time between collisions) *Any two points, 1 mark each*	**B2**

4(b)(i)	(general starting equation) $pV = nRT$	**C1**
	$T = (2pV / nR)$ where R is the (molar) gas constant	**A1**

4(b)(ii)	sketch: straight vertical line XY from $(V, 2p)$ to (V, p)	**B1**
	straight horizontal line YZ from (V, p) to $(2V, p)$	**B1**
	curve with gradient increasing from Z to X from $(2V, p)$ to $(V, 2p)$	**B1**

<table>
<tr><td rowspan="5">4(b)(iii)</td><td>XY work done on gas correct (= 0)</td><td>B1</td></tr>
<tr><td>ZX increase in internal energy correct (= 0)</td><td>B1</td></tr>
<tr><td>YZ work done on gas correct (= $-pV$)</td><td>B1</td></tr>
<tr><td>XY increase in internal energy such that the increase in internal energy column adds up to zero</td><td>B1</td></tr>
<tr><td>all three thermal energies transferred such that $\Delta U = q + w$ in each row

(completely correct answer:

<table><tr><th>change</th><th>ΔU</th><th>Q</th><th>w</th></tr><tr><td>X to Y
Y to Z
Z to X</td><td>$-U$
[$+U$]
0</td><td>$-U$
$U + pV$
$-W$</td><td>0
$-pV$
[$+W$]</td></tr></table>
)</td><td>B1</td></tr>
</table>

Question 4

(a) The basic assumptions of the kinetic theory of gases are generally well known. Candidates sometimes referred to the volume of the gas rather than the volume of the particles. Others incorrectly referred to the volume of a single particle.

(b) (i) Most candidates started with the correct equation here. Some candidates then did not go on to use the conditions given in the question which included a pressure of $2p$ when the volume was V. Some candidates did not rearrange the starting equation to make T the subject when they had been asked to determine an expression for T.

(ii) There were many correct responses here, although the line drawn to join Z to X was often a straight line rather than a curve. Some candidates drew more than two dots and some did not add the lines. The lines were needed to show the variation of the pressure with the volume as required by the question.

(iii) Only the strongest candidates correctly completed this table in full. Many candidates found it difficult to correctly apply the first law of thermodynamics for the three changes. They often did not know where to begin on the table, which was by filling in the information for changes already given to them. The information for the remaining changes was deduced from these. Finally, some candidates used letters that were not appropriate, for example a Q to denote thermal energy and a single letter p, which was not an energy.

2(a)	gas for which $pV \propto T$	**M1**
	where T is thermodynamic temperature	**A1**

2(b)(i)	evidence of two temperature conversions between °C and K	**B1**
	two calculations shown, one for each state e.g. $\frac{1.10\times10^{5}\times540\times10^{-6}}{(273+27)} = 0.198$ **and** $\frac{6.70\times10^{6}\times30\times10^{-6}}{(273+742)} = 0.198$	**A1**

2(b)(ii)	work is done on the gas	**M1**
	internal energy increases (so temperature increases)	**A1**

2(b)(iii)	$pV = NkT$ e.g. $N = \frac{1.10\times10^{5}\times540\times10^{-6}}{1.38\times10^{-23}\times300}$ $= 1.435\times10^{22}$ $\Delta E_k = (3/2)\, k\Delta TN$	**C1**
	$= (3/2)\times1.38\times10^{23}\times(742-27)\times\frac{1.10\times10^{5}\times540\times10^{-6}}{1.38\times10^{-23}\times300}$	**C1**
	$= 212\,\text{J}$	**A1**

2(c)	$E = mc\Delta\theta$ **and** $E = mL$	**C1**
	$\Delta\theta$ = (27 + 196) or 223	**C1**
	E = 0.0240 × 1.04 × (27 + 196) + 0.0240 × 199 = 10.3 kJ	**A1**

Question 2

(a) There was much confusion here between the definition of an ideal gas and the assumptions of the kinetic theory. The stronger candidates defined the symbols, including 'thermodynamic temperature' for *T*.

(b) (i) Most candidates were able to use the provided data to show that the helium gas was behaving as an ideal gas. A few candidates omitted the conversion from temperature in degrees Celsius to kelvin.

(ii) Many candidates gave answers that confused internal and thermal energy, and whether the gas is doing work or having work done on it. Many candidates regarded the internal energy and the change in internal energy as the same thing. For example, comments such as 'ΔU increases' were common, where the correct comment would have been either 'U increases' or 'ΔU is positive'.

(iii) Most candidates calculated the change in kinetic energy for a single molecule, rather than the change in the total kinetic energy of the molecules of the gas. A few who completed the correct calculation did not write the final answer to the expected 3 significant figures because the data was given to 3 significant figures. A few candidates incorrectly added 273 to the temperature change.

(c) Most candidates were able to set up this calculation. However, many candidates then made an error with significant figures or subtracting the two energies calculated, rather than adding them. Candidates were confused by the final negative temperature and the removal of thermal energy.

2(a)	(thermal) energy per unit mass (to cause temperature change)	**B1**
	(thermal) energy per unit change in temperature	**B1**

2(b)(i)	work done correct (0)	**B1**
	increase in internal energy correct (+E)	**B1**

2(b)(ii)	work done correct (−W) **and** increase in internal energy same as **(b)(i)**	**B1**
	thermal energy correct so that it adds to work done to give increase in internal energy	**B1**

2(c)	more thermal energy needed so specific heat capacity is greater	**B1**

Question 2

(a) Many candidates found it difficult to give definitions that were dimensionally correct, often giving definitions of a quantity that was an energy rather than an energy per unit mass per unit temperature change. Confusion between quantities and units was another common problem for candidates in answering this question.

(b) Many candidates attempted to give answers that were in terms of different letters from the ones defined in the question. In **(i)**, candidates were expected to realise that the work done is zero when there is no net change in volume, and then to apply the first law correctly. In **(ii)**, they were expected to realise that the work done on the system is negative *W*, and then again to apply the first law correctly to an increase in internal energy that was the same as that in **(i)**.

(c) It was expected that candidates would explain that the second temperature increase required a larger amount of thermal energy to produce the same temperature rise, hence leading to a greater specific heat capacity. There was much confusion between thermal energy and internal energy, and the question was not answered well other than by the strongest candidates.