Question 5

10 points total **Distribution of points**

(a)

(i) 1 point

For the correct use of the ideal gas law to find the temperature of the gas in state 1 — 1 point

$P_1V_1 = nRT_1$

$T_1 = P_1V_1/nR$

(ii) 2 points

For the correct application of the ideal gas law at states 3 and 1 — 1 point

$\frac{PV}{T} = nR = \text{ const}$, so $\frac{P_3V_3}{T_3} = \frac{P_1V_1}{T_1}$

For correct substitutions of $T_3 = T_1$ and $V_3 = \frac{V_1}{2}$ to arrive at the correct answer — 1 point

$P_3\frac{V_1}{2} = P_1V_1$

$P_3 = 2P_1$

(iii) 2 points

$W = -P\Delta V$

For recognition that for process $2 \to 3$, $\Delta V = 0$, so $W_{2\to3} = 0$ — 1 point

For the correct expression for the work done on the gas during process $1 \to 2$ — 1 point

$W_{1\to2} = -P_1\left(\frac{V_1}{2} - V_1\right) = \frac{P_1V_1}{2}$

$W_{tot} = W_{1\to2} + W_{2\to3} = \frac{P_1V_1}{2} + 0$

$W_{tot} = \frac{P_1V_1}{2}$

(b) 3 points

For indicating that heat is added to the gas — 1 point

For a correct justification — 2 points

For example: From the first law of thermodynamics, $\Delta U = Q + W$, it follows that $Q = \Delta U - W$. During process $2 \to 3$ the volume is constant, so $W = -p\Delta V = 0$. The temperature increases and the internal energy is proportional to temperature, so ΔU is positive. Therefore Q is positive. Heat must be added to increase the internal energy.

Note: 1 point partial credit may be given for a partially correct answer.

Question 5 (continued)

Distribution of points

(c) 2 points

For indicating that heat is added to the gas 1 point
For a correct justification 1 point
For example: From the first law of thermodynamics it follows that $Q = \Delta U - W$.
Process $3 \rightarrow 1$ is isothermal and since the internal energy is proportional to temperature, $\Delta U = 0$. Therefore $Q = -W = -(-p\Delta V) = p\Delta V$. Since V increases, ΔV is positive. Therefore Q is positive. Heat must be added to maintain the internal energy.