4. A cylinder fitted with a piston contains 0.1 mol of a monatomic gas at a pressure of $1 \times 10^5$ Pa and a temperature of 300 K. The gas is

   (i) first heated at constant pressure to 400 K, and then
   (ii) compressed isothermally to its initial volume, and finally
   (iii) cooled at constant volume to its initial temperature.

   (a) Find the initial volume of the gas and determine its volume after process (i) is completed. (2 marks)

   $PV = NkT$

   $(1 \times 10^5)V_i = (6.02 \times 10^{22})(1.38 \times 10^{-23})(300)$

   $V_i = 2.5 \times 10^{-3}$ m$^3$

   $(1 \times 10^5)V_f = (6.02 \times 10^{22})(1.38 \times 10^{-23})(400)$

   $V_f = 3.3 \times 10^{-3}$ m$^3$

   (b) Hence sketch the above changes on the following $P - V$ diagram, inserting all the initial and final pressure and volume values for each of the processes (i), (ii) and (iii). (4 marks)

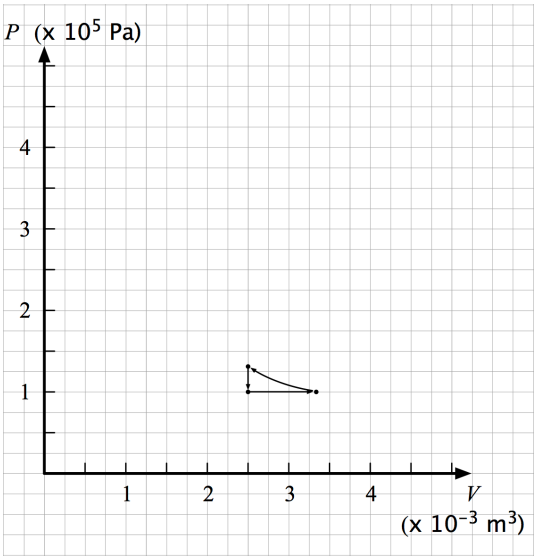
   First, find the final pressure for process (ii):

   We know the temperature is $T = 400$ K. We know the volume is $V = 2.5 \times 10^{-3}$ m$^3$.

   $PV = NkT$

   $P_f(2.5 \times 10^{-3}) = (6.02 \times 10^{22})(1.38 \times 10^{-23})(400)$

   $P_f = 1.3 \times 10^5$ Pa



(c) What is the change in internal energy of the gas in process (i)? (3 marks)

$E_f = \frac{3}{2}NkT$
$E_f = \frac{3}{2}(6.02 \times 10^{22})(1.38 \times 10^{-23}(400)$
$E_f = 498$ J
$E_i = \frac{3}{2}NkT$
$E_i = \frac{3}{2}(6.02 \times 10^{22})(1.38 \times 10^{-23}(300)$
$E_i = 374$ J
$\Delta E = 124$ J

(d) Hence determine the heat input to the cylinder in process (i). (3 marks)

$\Delta E = Q - W$
We need to find $W$ in order to find $Q$.
$W =$ "area" under process (i) plot.
Area $= W = P\Delta V$
$W = (1 \times 10^5)(3.3 \times 10^{-3} - 2.5 \times 10^{-3})$
$W = +80$ J (Expansions are positive work.)
$124$ J $= Q - 80$ J
$Q = 204$ J

(e) What does the area bounded by the curves sketched in part (b) represent? (1 mark)
The area represents the total amount of work done by this engine in one cycle. Note that this will be a negative amount of work. The compression work (process (ii) ) is greater than the expansion work (process (i) ).