PROBLEM 3.115

KNOWN: Data are provided for nitrogen contained within a piston-cylinder assembly and undergoing a process.

FIND: For the process, evaluate Q.

SCHEMATIC & GIVEN DATA:

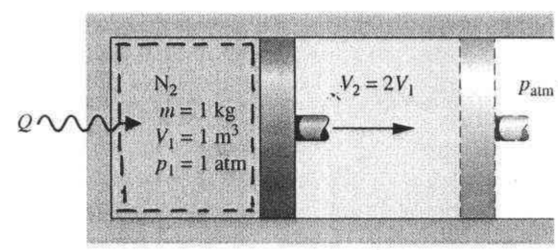

Fig. P3.115

ENGR. MODEL:

1. The nitrogen is the system.
2. The heating occurs slowly, so there is no acceleration of the piston.
3. Friction between the piston and cylinder can be ignored.
4. For the process $\Delta KE = \Delta PE = 0$.
5. The specific heat ratio is constant, and the ideal gas model applies.

ANALYSIS: Since $p_R = p/p_c = 1/37.2 = 0.03$, the ideal gas model is applicable (Sec. 3.11). Also, with Assumptions 2 and 3, the process occurs at a constant pressure of 1 atm. Applying an energy balance, $\Delta U + \cancel{\Delta KE} + \cancel{\Delta PE} = Q - W$. So $Q = \Delta U + W$. In this case, W can be found from Eq. 2.17: $W = \int_1^2 p\,dV = p\Delta V$. Collecting results

$$Q = m(u_2 - u_1) + p(V_2 - V_1)$$

With Eq. 3.50, $(u_2 - u_1) = c_v(T_2 - T_1)$. Thus

$$Q = m c_v (T_2 - T_1) + p(V_2 - V_1) \qquad (1)$$

Since $p_1 V_1 = mRT_1$ and $p_2 V_2 = mRT_2$, $T_2 = \left(\frac{p_2 V_2 / mR}{p_1 V_1 / mR}\right) T_1 = \frac{V_2}{V_1} T_1$. Thus

$T_2 = 2T_1$, where

$$T_1 = \frac{p_1 V_1}{mR} = \frac{(1.01325 \times 10^5 \, N/m^2)(1 m^3)}{(1 kg)\left(\frac{8314}{28.01} \frac{N \cdot m}{kg \cdot K}\right)} = 341.4 K$$

So, $T_2 = 2(341.4 K) = 682.8 K$.

The specific heat c_v can be found from Eq. 3.47b,

$$c_v = \frac{R}{k-1} = \left(\frac{8.314}{28.01} \frac{kJ}{kg \cdot K}\right)\left(\frac{1}{1.4-1}\right) = 0.742 \frac{kJ}{kg \cdot K}$$

Substituting data into Eq. (1) gives

$$Q = (1 kg)\left(0.742 \frac{kJ}{kg \cdot K}\right)(682.8 - 341.4) K + \left(1.01325 \times 10^5 \frac{N}{m^2}\right)(2m^3 - 1m^3)\left|\frac{1 kJ}{10^3 N \cdot m}\right|$$

$$= 354.6 kJ$$