

48. Two formulas (other than the first law of thermodynamics) will be of use to us. It is straightforward to show, from Eq. 20-11, that for any process that is depicted as a *straight line* on the pV diagram – the work is

$$W_{\text{straight}} = \left(\frac{p_i + p_f}{2} \right) \Delta V$$

which includes, as special cases, $W = p\Delta V$ for constant-pressure processes and $W = 0$ for constant-volume processes. Further, Eq. 20-44 with Eq. 20-51 gives

$$E_{\text{int}} = n \left(\frac{f}{2} \right) RT = \left(\frac{f}{2} \right) pV$$

where we have used the ideal gas law in the last step. We emphasize that, in order to obtain work and energy in Joules, pressure should be in Pascals (N/m^2) and volume should be in cubic meters. The degrees of freedom for a diatomic gas is $f = 5$.

- (a) The internal energy change is

$$\begin{aligned} E_{\text{int } c} - E_{\text{int } a} &= \frac{5}{2} (p_c V_c - p_a V_a) \\ &= \frac{5}{2} ((2000 \text{ Pa}) (4.0 \text{ m}^3) - (5000 \text{ Pa}) (2.0 \text{ m}^3)) \\ &= -5000 \text{ J} . \end{aligned}$$

- (b) The work done during the process represented by the diagonal path is

$$W_{\text{diag}} = \left(\frac{p_a + p_c}{2} \right) (V_c - V_a) = (3500 \text{ Pa}) (2.0 \text{ m}^3)$$

which yields $W_{\text{diag}} = 7000 \text{ J}$. Consequently, the first law of thermodynamics gives

$$Q_{\text{diag}} = \Delta E_{\text{int}} + W_{\text{diag}} = -5000 + 7000 = 2000 \text{ J} .$$

- (c) The fact that ΔE_{int} only depends on the initial and final states, and not on the details of the “path” between them, means we can write

$$\Delta E_{\text{int}} = E_{\text{int } c} - E_{\text{int } a} = -5000 \text{ J}$$

for the indirect path, too. In this case, the work done consists of that done during the constant pressure part (the horizontal line in the graph) plus that done during the constant volume part (the vertical line):

$$W_{\text{indirect}} = (5000 \text{ Pa}) (2.0 \text{ m}^3) + 0 = 10000 \text{ J} .$$

Now, the first law of thermodynamics leads to

$$Q_{\text{indirect}} = \Delta E_{\text{int}} + W_{\text{indirect}} = -5000 + 10000 = 5000 \text{ J} .$$