2.3 **a.** One kilogram of steam contained in a horizontal frictionless piston and cylinder is heated at constant pressure of 1.013 bar from 125°C to such a temperature that its volume doubles. Calculate the amount of heat that must be added to accomplish this change, the final temperature of the steam, the work the steam does against its surroundings, and the internal energy and enthalpy changes of the steam for this process.

b. Repeat the calculation of part a if the heating occurs at constant volume to a pressure that is twice the initial pressure.

c. Repeat the calculation of part a assuming that steam is an ideal gas with a constant pressure heat capacity of 34.4 J/mol K.

d. Repeat the calculation of part b assuming steam is an ideal gas as in part c.

2.1 (a) By an energy balance, the bicycle stops when final potential energy equals initial kinetic energy. Therefore

$$\frac{1}{2}mv_i^2 = mgh_f \quad \text{or} \quad h_f = \frac{v_i^2}{2g} = \frac{\left(20\frac{\text{km}}{\text{hr}} \times 1000\frac{\text{m}}{\text{km}} \times \frac{1\ \text{hr}}{3600\ \text{sec}}\right)^2}{2 \times 9.807\frac{\text{m}}{\text{sec}^2}}$$

or h=1.57 m.

(b) The energy balance now is

$$\frac{1}{2}mv_f^2 = \frac{1}{2}mv_i^2 + mgh_i \quad \text{or} \quad v_f^2 = v_i^2 + 2gh_i$$

$$v_f^2 = \left(20\ \frac{\text{km}}{\text{hr}}\right)^2 + 2 \times 9.807\frac{\text{m}}{\text{sec}^2} \times 70\ \text{m} \times \left(\frac{\text{km}}{1000\ \text{m}} \times \frac{3600\,\text{sec}}{\text{hr}}\right)^2$$

v_f = 134.88 km/hr. Anyone who has bicycled realizes that this number is much too high, which demonstrates the importance of air and wind resistance.

2.2 The velocity change due to the 55 m fall is

$$\left(\Delta v^2\right) = 2 \times 9.807\frac{\text{m}}{\text{sec}^2} \times 55\ \text{m} \times \left(\frac{\text{km}}{1000\ \text{m}} \times \frac{3600\,\text{sec}}{\text{hr}}\right)^2$$

v_f = 118.24 km/hr. Now this velocity component is in the vertical direction. The initial velocity of 8 km/hr was obviously in the horizontal direction. So the final velocity is

$$v = \sqrt{v_x^2 + v_y^2} = 11851\frac{\text{km}}{\text{hr}}$$

2.3 (a) System: contents of the piston and cylinder
(closed isobaric = constant pressure)

M.B.: $M_2 - M_1 = \Delta M = 0 \Rightarrow M_2 = M_1 = M$

$$\text{E.B.:} \quad M_2\hat{U}_2 - M_1\hat{U}_1 = \Delta M(\hat{H})^0 + Q + W_s^0 - \int P dV$$

$$M(\hat{U}_2 - \hat{U}_1) = Q - \int P dV = Q - P\int dV = Q - P(V_2 - V_1)$$

$$M(\hat{U}_2 - \hat{U}_1) = Q - PM(\hat{V}_2 - \hat{V}_1)$$

$$Q = M(\hat{U}_2 - \hat{U}_1) + M(P\hat{V}_2 - P\hat{V}_1) = M[(\hat{U}_2 + P\hat{V}_2) - (\hat{U}_1 + P\hat{V}_1)]$$

$$= M(\hat{H}_2 - \hat{H}_1)$$

$P = 1.013 \text{ bar} \approx 0.1 \text{ MPa}$

	$\hat{V}$	$\hat{U}$	$\hat{H}$	
$T = 100$	1.6958	2506.7	2676.2	
$T = 150$	1.9364	2582.8	2776.4	
Linear interpolation				
$T = 125°C$	1.8161	2544.8	2726.3	Initial state

Final state $P = 0.1 \text{ MPa}, \hat{V}_2 = 3.6322 \text{ m}^3/\text{kg}$

	$\hat{V}$	$\hat{H}$
$T = 500°C$	3.565	3488.1
$T = 600°C$	4.028	3704.7

Linear interpolation

$$\frac{3.6322 - 3.565}{4.028 - 3.565} = \frac{T_2 - 500}{600 - 500} \qquad T_2 = 514.5°C$$

$$\frac{514.5 - 500}{600 - 500} = \frac{\hat{H}_2 - 3488.1}{3704.7 - 3488.1} \qquad \hat{H}_2 = 3519.5$$

$$Q = 1 \text{ kg}(3519.5 - 2726.3) \text{ kJ/kg} = 793.2 \text{ kJ}$$

$$W = -\int PdV = -1 \text{ bar} \times (V_2 - V_1) = -1 \text{ bar} \times (3.6322 - 1.8161) \text{ m}^3/\text{kg}$$

$$= -1 \text{ bar} \times 100{,}000 \frac{\text{Pa}}{\text{bar}} \times \frac{1 \text{ kg}}{\text{m} \cdot \text{s}^2 \cdot \text{Pa}} \times \frac{1 \text{ J}}{\text{m}^2 \cdot \text{s}^2 \cdot \text{kg}} \times 1.8161 \text{ m}^3/\text{kg}$$

$$= -181.6 \text{ kJ/kg}$$

(b) System is closed and constant volume

M.B.: $M_2 = M_1 = M$

E.B.: $M_2\hat{U}_2 - M_1\hat{U}_1 = \Delta M(\hat{H})^0 + Q + W_s^0 - \int PdV^0$

$$Q = M(\hat{U}_2 - \hat{U}_1)$$

Here final state is $P = 2 \times 1.013 \text{ bar} \sim 0.2 \text{ MPa}$; $\hat{V}_2 = \hat{V}_1 = 1.8161 \text{ m}^3/\text{kg}$ (since piston-cylinder volume is fixed)

$P = 0.2 \text{ MPa}$; $\hat{V}_2 = 1.8161$

T(°C)	$\hat{V}$	$\hat{U}$
500	1.7814	3130.8
600	2.013	3301.4

$$\frac{1.8161 - 1.7814}{2.013 - 1.7814} = \frac{T - 500}{600 - 500} = \frac{0.0347}{0.2316} = 0.1498 \sim 0.15$$

$$T = 515°C$$

$$\frac{\hat{U}_2 - 3130.8}{3301.4 - 3130.8} = 0.1498 \qquad \hat{U}_2 = 3156.4 \text{ kJ/kg}$$

$$Q = 1 \text{ kg} \times (3156.4 - 2544.8) \text{ kJ/kg} = 611.6 \text{ kJ}$$

(c) Steam as an ideal gas—constant pressure

$$N = \frac{PV}{RT} \Rightarrow \frac{P_1\underline{V}_1}{RT_1} = \frac{P_2\underline{V}_2}{RT_2} \text{ but } \underline{V}_2 = 2\underline{V}_1;\ P_1 = P_2$$

$$\frac{P_1\underline{V}_1}{T_1} = \frac{P_1 2\underline{V}_1}{T_2} \Rightarrow T_2 = 2\times T_1$$
$$T_1 = 273.15 + 125 = 398.15 \text{ K}$$
$$T_2 = 2\times T_1 = 796.3 \text{ K} = 523.15°\text{C}$$

$$Q = N\Delta\underline{H} = \frac{1000 \text{ g/kg}}{18 \text{ g/mol}} \times 34.4 \text{ J/mol K} \times (796.3 - 398.15) \text{ K} \times \frac{1 \text{ kJ}}{1000 \text{ J}}$$
$$= 760.9 \text{ kJ}$$
$$W = -\int PdV = -P\Delta V = -P\left(\frac{NRT_2}{P} - \frac{NRT_1}{P_1}\right) = -NR(T_2 - T_1)$$
$$= -\frac{1000}{18} \times 8.314 \times 398.15 = -183.9 \text{ kJ}$$

(d) **Ideal gas - constant volume**

$$\frac{P_1\underline{V}_1}{RT_1} = \frac{P_2\underline{V}_2}{RT_2} \text{ here } \underline{V}_1 = \underline{V}_2;\ P_2 = 2P_1$$

So again $\frac{P_1V_1}{T_1} = \frac{2P_1 \cdot V_1}{T_2}$; $T_2 = 2T_1 = 796.3$ K.

$$Q = N\Delta\underline{U} = \frac{1000 \text{ g/kg}}{18 \text{ g/mol}} \times (34.4 - 8.314) \times (796.3 - 398.15) \times \frac{1}{1000}$$
$$C_V = C_P - R;\ Q = 577.0 \text{ kJ}$$

2.4

$$M_w\hat{U}_{w,f} - M_w\hat{U}_{w,i} = W_s = M_{weight} \times g \times 1 \text{ m}$$
$$M_w = M_{weight} = 1 \text{ kg}$$
$$1 \text{ kg} \times C_P(T_f - T_i) = 1 \text{ kg} \times 9.807 \text{ m/s}^2 \times 1 \text{ m} \times \frac{1 \text{ J}}{\text{m}^2\text{kg/s}^2} = 9.807 \text{ J}$$
$$1 \text{ kg} \times 4.184 \text{ J/g K} \times \frac{1000 \text{ g}}{\text{kg}} \times \Delta T = 9.807$$
$$\Delta T = \frac{9.807}{4.184\times 1000} \text{ K} = 2.344\times 10^{-3} \text{ K}$$

2.5 From Illustration 2.3-3 we have that $\underline{H}(T_1, P_1) = \underline{H}(T_2, P_2)$ for a Joule-Thomson expansion. On the Mollier diagram for steam, Fig. 2.4-1a, the upstream and downstream conditions are connected by a horizontal line. Thus, graphically, we find that $T \sim 383$ K. (Alternatively, one could also use the Steam Tables of Appendix III.)