CHAPTER

3

The First Law of Thermodynamics:

Closed Systems

Closed system

Energy can cross the boundary of a closed system in two forms: Heat and work

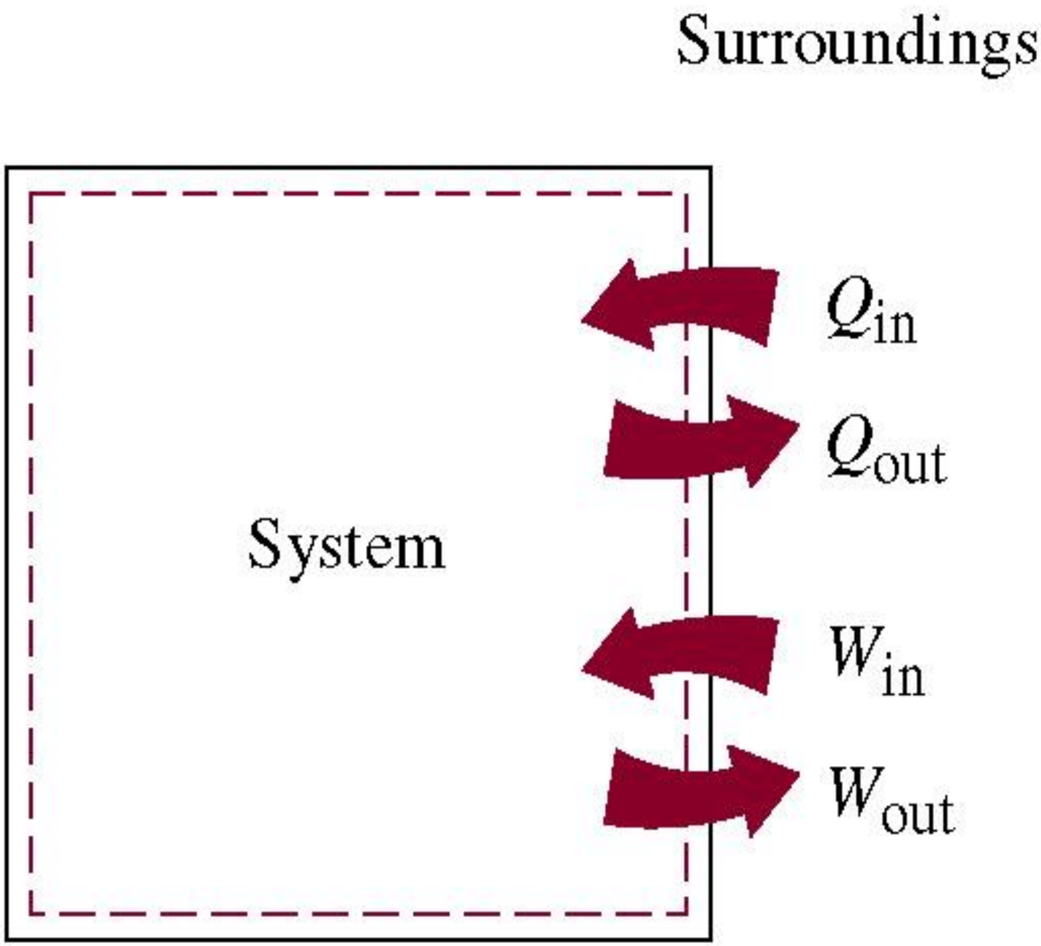


FIGURE 3-1
Specifying the directions of heat and work.

ENERGY TRANSFER BY HEAT

Heat: The form of energy that is transferred between two systems (or a system and its surroundings) by virtue of a temperature difference.

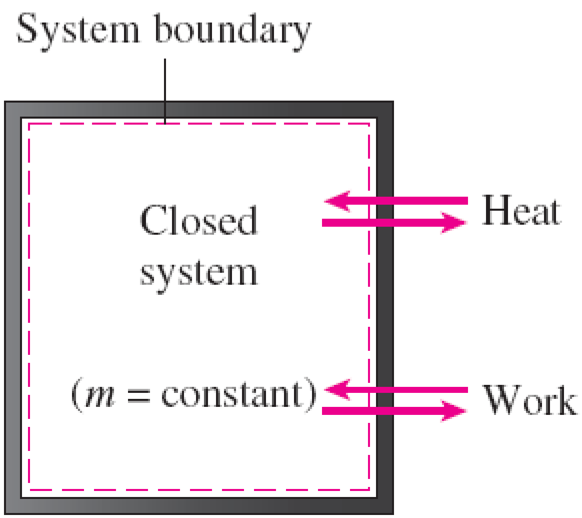


FIGURE 2–13
Energy can cross the boundaries of a closed system in the form of heat and work.

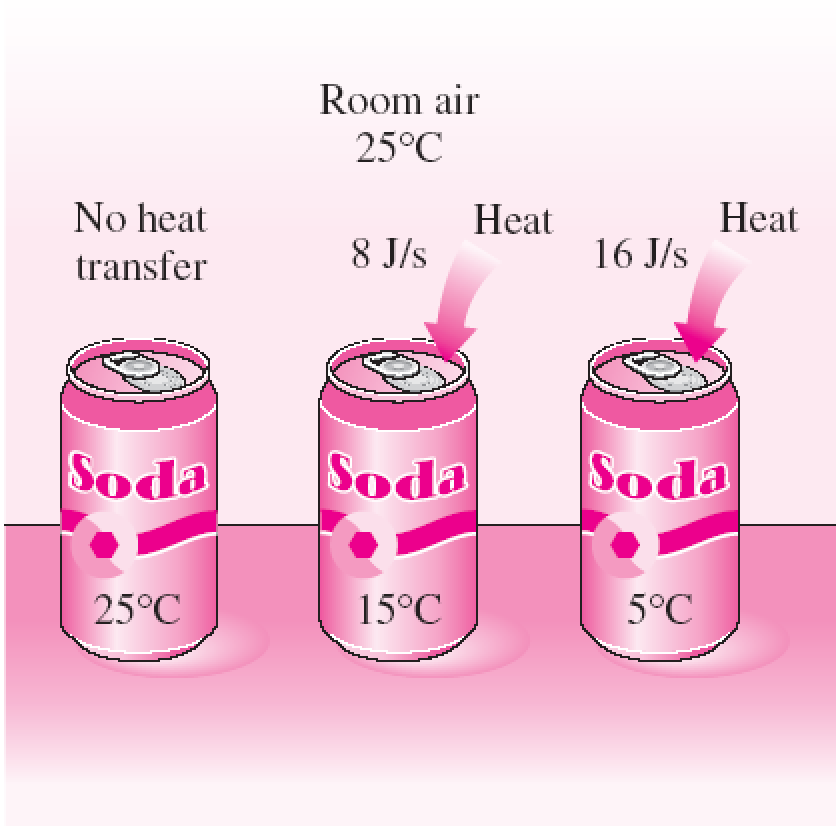


FIGURE 2–14
Temperature difference is the driving force for heat transfer. The larger the temperature difference, the higher is the rate of heat transfer.

$$q = \frac{Q}{m} \qquad (\text{kJ/kg})$$

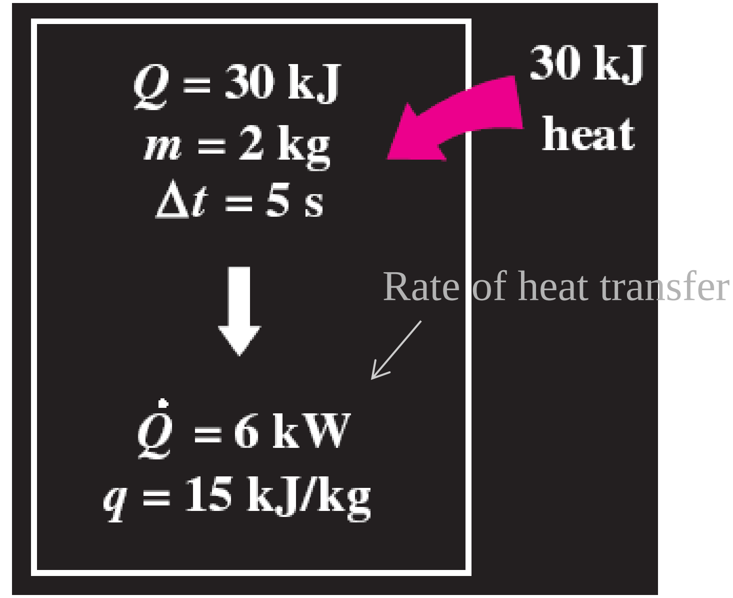
Heat transfer per unit mass

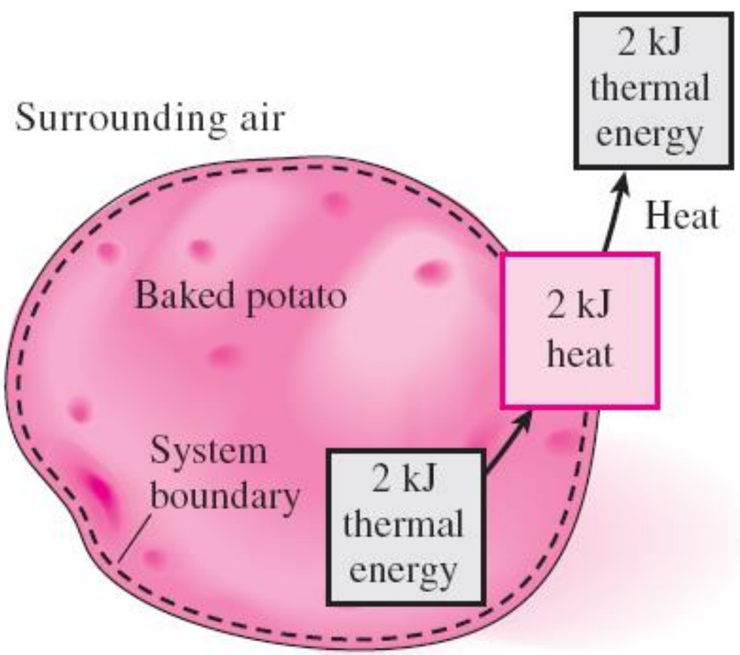
$$Q = \dot{Q}\,\Delta t \qquad (\text{kJ})$$

Amount of heat transfer when heat transfer rate is constant

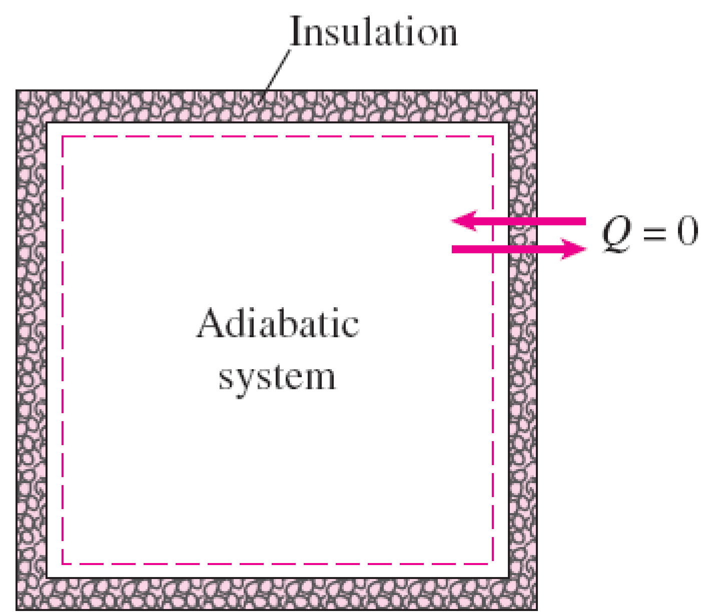
$$Q = \int_{t_1}^{t_2} \dot{Q}\,dt \qquad (\text{kJ})$$

Amount of heat transfer when heat transfer rate changes with time





Energy is recognized as heat transfer only as it crosses the system boundary.

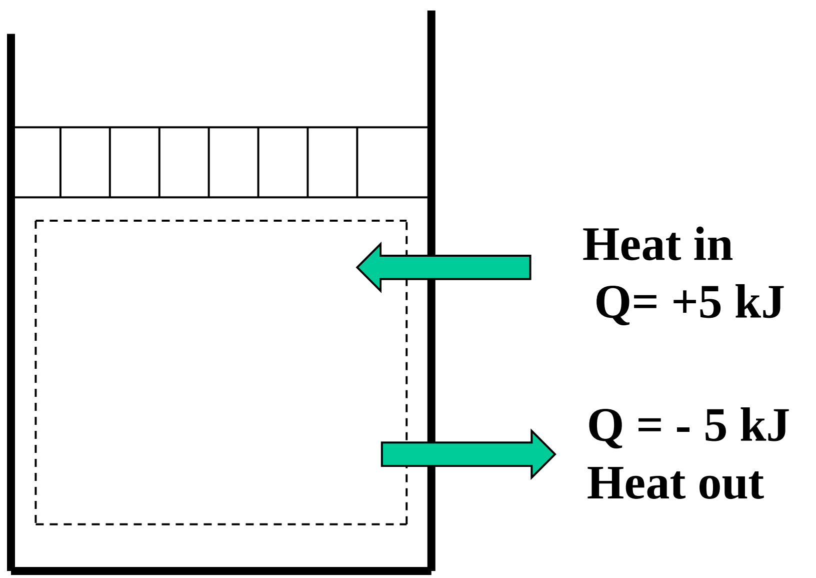


During an adiabatic process, a system exchanges no heat with its surroundings.

Sign Convention for Heat

(+) ve if to the system

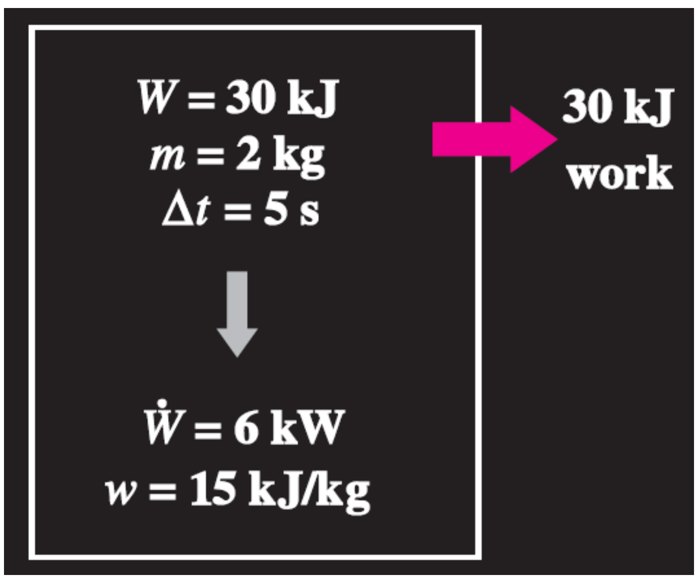
(-) ve if from the system



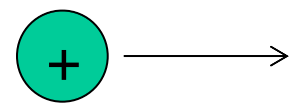
ENERGY TRANSFER BY WORK

- **Work**: The energy transfer associated with a force acting through a distance.
- Or an energy interaction which is not caused by a temperature difference between a system and its surroundings
  - **A rising piston, a rotating shaft**, and **an electric wire crossing the system boundaries** are all associated with work interactions

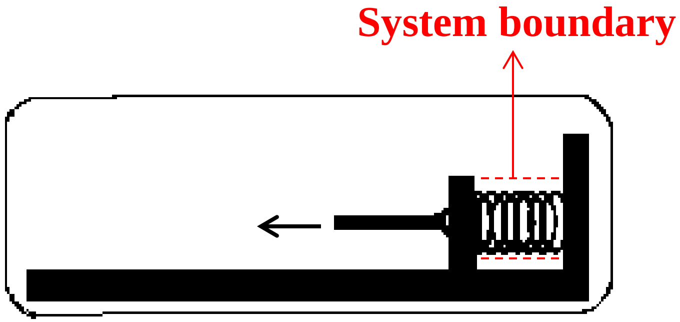
$$w = \frac{W}{m} \quad (\text{kJ/kg})$$ Work done per unit mass



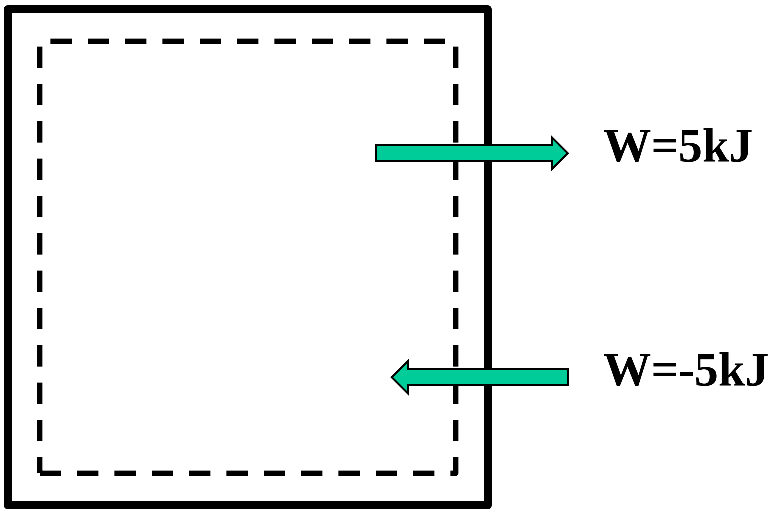
Power is the work done per unit time (kW)



Moving a positive charge from one place to another requires work



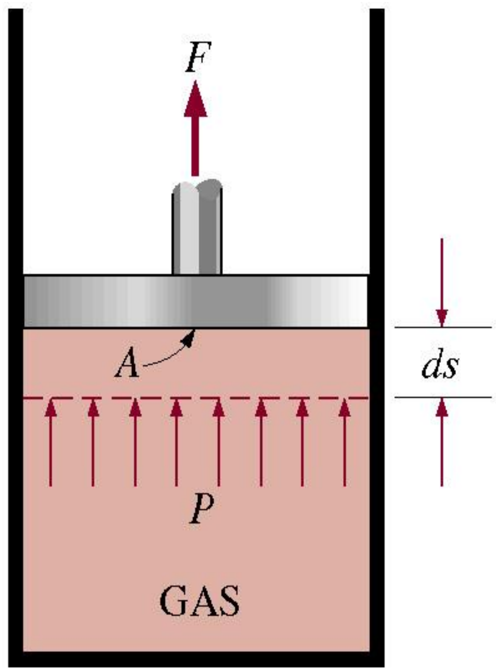
A spring is doing work on the surroundings



Sign Convention of Work

(+)ve if work done by a system

(-)ve if work done on a system



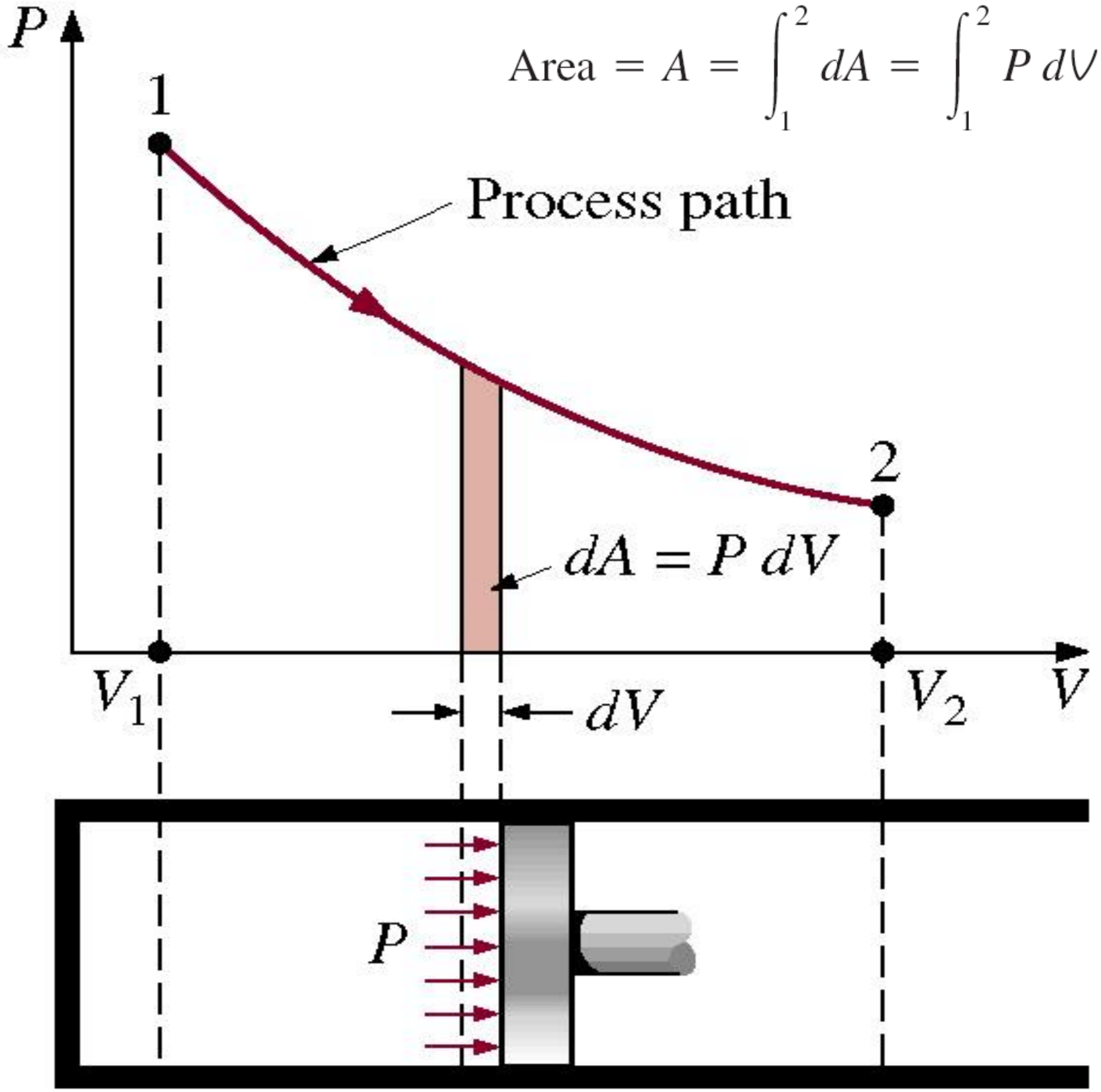
Moving boundary work (*P dV* work):
The expansion and compression work in a piston-cylinder device.

$$\delta W_b = F\,ds = PA\,ds = P\,dV$$

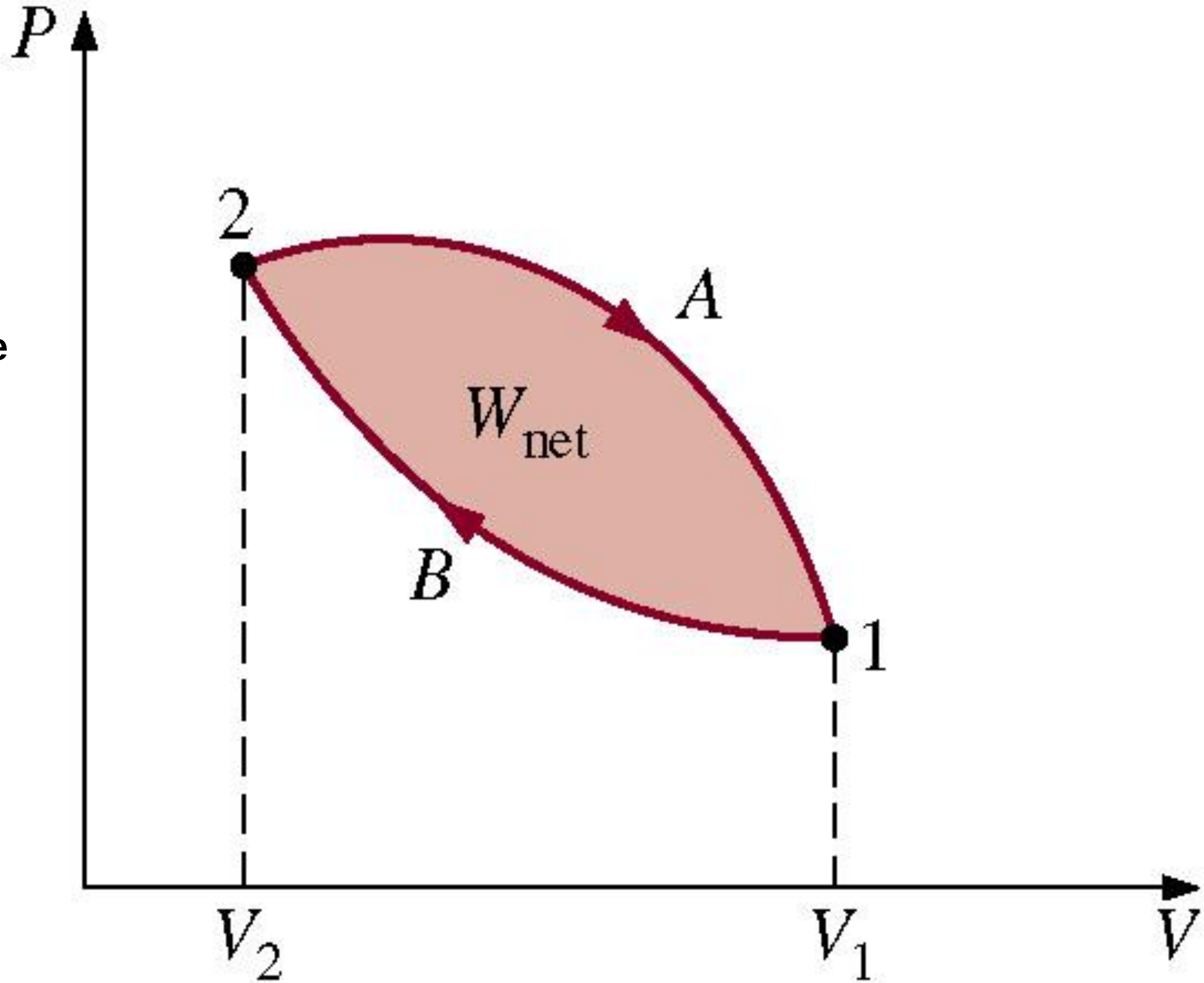
$$W_b = \int_1^2 P\,dV \qquad \text{(kJ)}$$

FIGURE 3-2
A gas does a differential amount of work dW_b as it forces the piston to move by a differential amount *d*s.

The area under the process curve on a *P-V* diagram represents the boundary work.



The net work done during a cycle is the difference between the work done by the system and the work done on the system.



First Law of Thermodynamics or the Conservation of energy Principle:

$$\left\{\begin{array}{l}\text{Net energy transfer}\\ \text{to (or from) the system}\\ \text{As heat and work}\end{array}\right\} = \left\{\begin{array}{l}\text{Net increase (or decrease)}\\ \text{İn the total energy}\\ \text{of the system}\end{array}\right\}$$

$$\boldsymbol{Q - W \quad = \quad \Delta E}$$

$$Q_{\text{net,in}} - W_{\text{net,out}} = \Delta E_{\text{system}} \quad \text{or} \quad Q - W = \Delta E$$

(Remember from chapter 1: $\Delta E = \Delta U + \Delta KE + \Delta PE$)

$$Q - W = \Delta U + \Delta KE + \Delta PE \quad \text{(kJ)}$$

where $\Delta U = m(u_2 - u_1)$

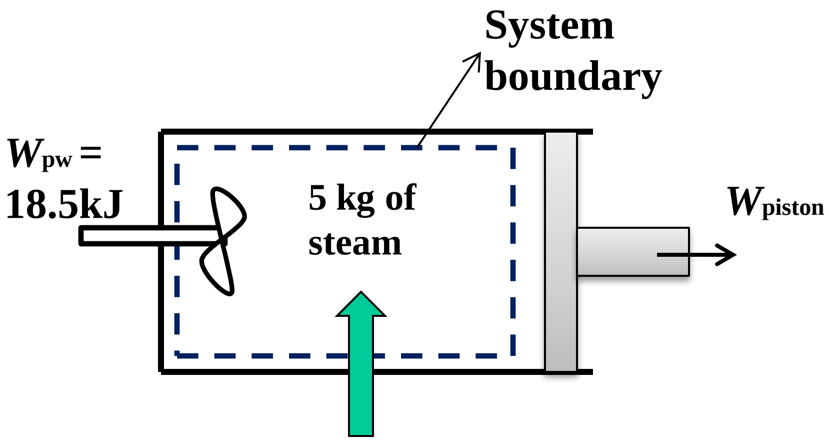
$\Delta KE = 1/2\, m(V_2^2 - V_1^2)$

$\Delta PE = mg(z_2 - z_1)$

Most closed systems encountered in practice are stationary i.e. $\Delta PE = 0$ $\Delta KE = 0$

$$\boxed{Q - W = \Delta U}$$

Example:



$$Q - W = \Delta U + \cancel{\Delta KE}^{\,0} + \cancel{\Delta PE}^{\,0}$$

$\longrightarrow$ **$\Delta U = m(u_2 - u_1)$**

$\longrightarrow$ **$W = W_{pw} + W_{piston}$**

Q -(Wpw +Wpiston)= m(u₂ - u₁)

$$u_1 = 2709.9 \text{ kJ/kg}$$

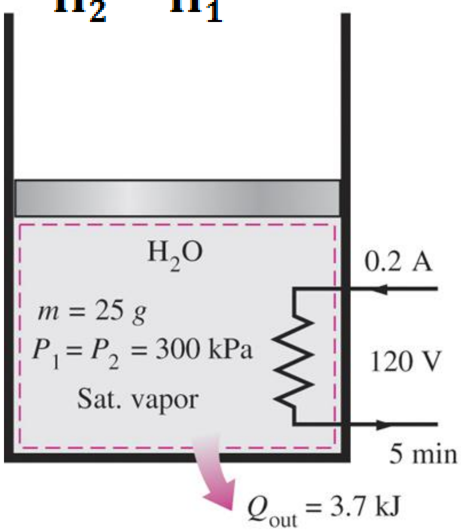
$$u_2 = 2659.6 \text{ kJ/kg}$$

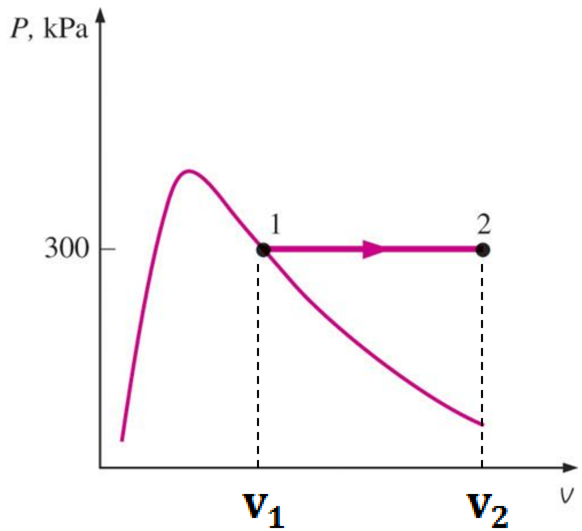
(+80kJ) –((-18.5kJ)+ Wpiston=(5kg)(2659.6 -2709.9)kJ/kg

$\longrightarrow$ **Wpiston =350kJ**

Example: **constant-pressure process, initially saturated water vapor.** T_2 **=?**

$H_2 - H_1$





$$E_{in} - E_{out} = \Delta E_{system}$$

Net energy transfer by heat, work, and mass — Change in internal, kinetic, potential, etc., energies

$$Q - W = \Delta U + \Delta \cancel{KE}^{\,0} + \Delta \cancel{PE}^{\,0}$$

$$Q - W_{other} - W_b = U_2 - U_1$$

$$Q - W_{other} - P_0(V_2 - V_1) = U_2 - U_1$$

$$Q - W_{other} = (U_2 + P_2V_2) - (U_1 + P_1V_1)$$

$$H = U + PV$$

$$Q - W_{other} = H_2 - H_1$$

$$w_b = P(v_2 - v_1)$$

$$W_b = P(V_2 - V_1)$$

$$Q - W_{el} = m(h_2 - h_1) =$$

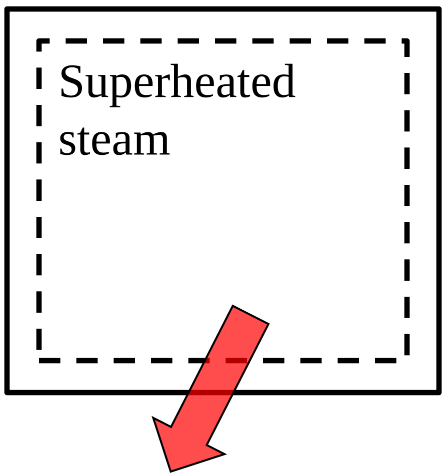
$$-3.7\text{ kJ} - (-7.2\text{kJ}) = 0.025\text{ kg}\,(h_2 - 2725.3\text{ kJ/kg})$$

$$h_2 = 2865.3\text{ kJ/kg}$$

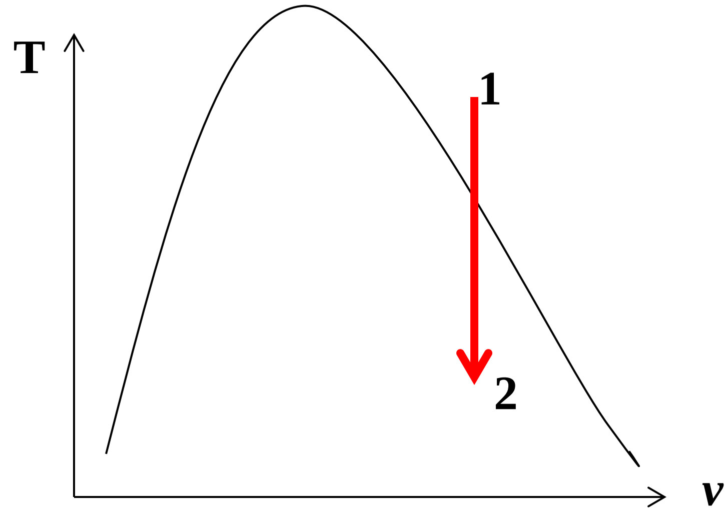
$$\left.\begin{array}{l} P_2 = 300\text{ kPa} \\ h_2 = 2865.3 \end{array}\right\} \quad T_2 = 200^{o}\text{C} \quad \text{Table A-6}$$

Note: for constant pressure case: $Q - W_{other} = \Delta H$ **and** $W = W_{boundary} + W_{other}$

Example: constant volume



Q

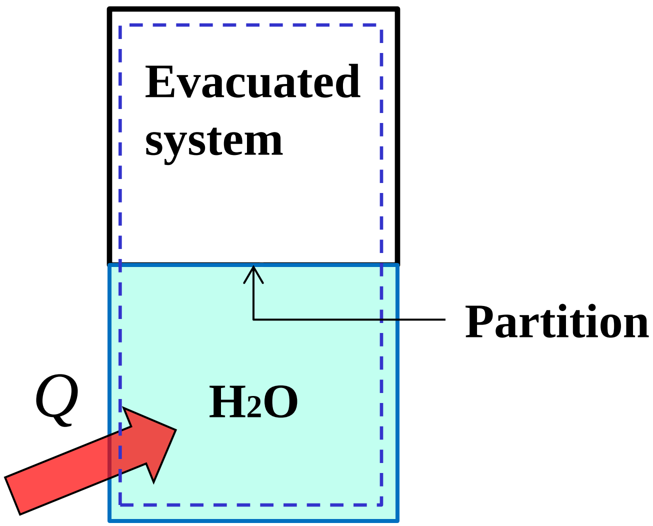


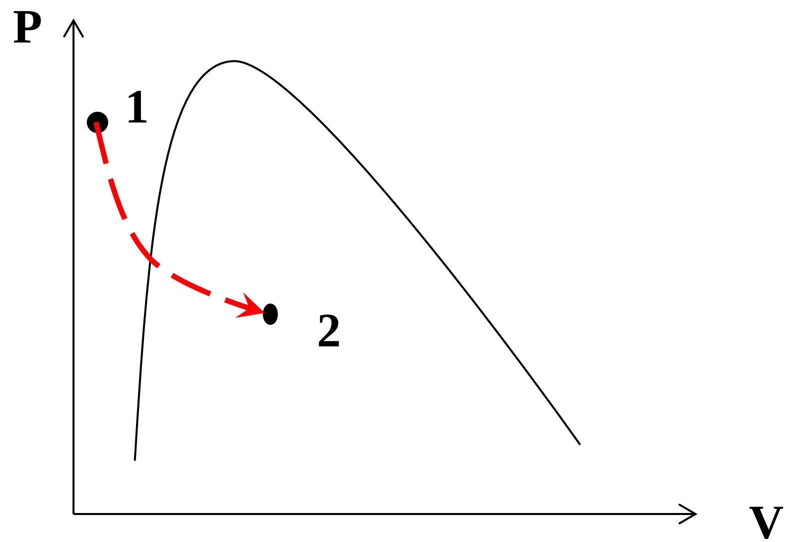
$$Q - \cancelto{0}{W} = \Delta U + \Delta \cancelto{0}{KE} + \Delta \cancelto{0}{PE}$$

$$Q = m(u_2 - u_1)$$

Note: for constant volume case: $Q - W_{other} = \Delta U + \Delta KE + \Delta PE$

Example: changing volume and pressure





$$Q - \overset{0}{\cancel{W}} = \Delta U + \Delta \overset{0}{\cancel{KE}} + \Delta \overset{0}{\cancel{PE}}$$

$$Q = m(u_2 - u_1)$$

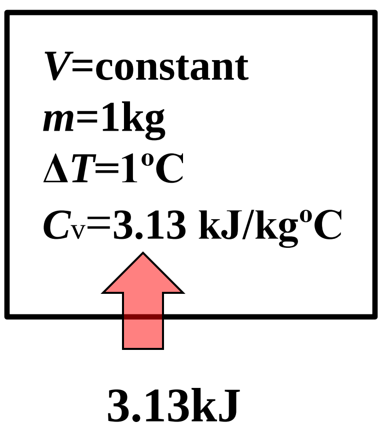
note: $u_1 \approx u_{f@Tsat}$

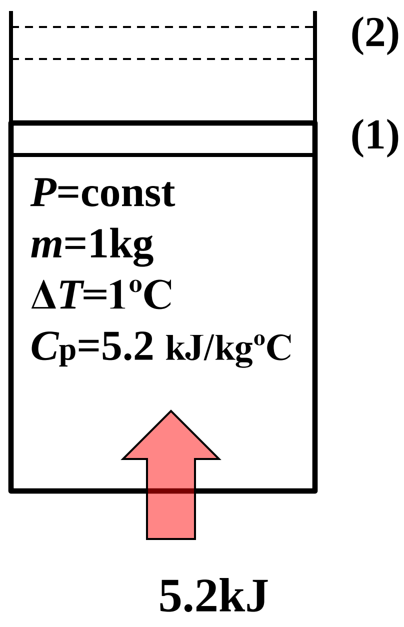
$u_2 = u_f + x_2 u_{fg}$

Specific Heats

- → The energy required to raise the temperature of a unit of a substance by one degree.
- → C_v : specific heat at constant volume
- → C_p : specific heat at constant pressure

Helium gas:





$C_p > C_v$

Because at constant pressure, the energy required for expansion work must also be supplied to system.

First law for constant volume:

$$(w_b = 0) \rightarrow \underbrace{\delta q - \delta w_{other}}_{C_v dT} = du$$

$$\boxed{\rightarrow du = C_v dT \text{ or } C_v = \left(\frac{\partial u}{\partial T}\right)_v}$$

First law for constant pressure:

$$(w_b \neq 0) \rightarrow \underbrace{\delta q - \delta w_{other}}_{C_p dT} = dh$$

$$\boxed{\rightarrow dh = C_p dT \text{ or } C_p = \left(\frac{\partial h}{\partial T}\right)_h}$$

Ideal Gases:

$$Pv = RT$$

Joule demonstrated that for ideal gases $\rightarrow$ $u=u(T)$ $\rightarrow$ $C_v=C_v(T)$

$$\left.\begin{aligned} h &= u + Pv \\ Pv &= RT \end{aligned}\right\} \quad h = u + RT$$

Since R is constant and $u=u(T)$ $\rightarrow$ $h=h(T)$ $\rightarrow$ $C_p=C_p(T)$

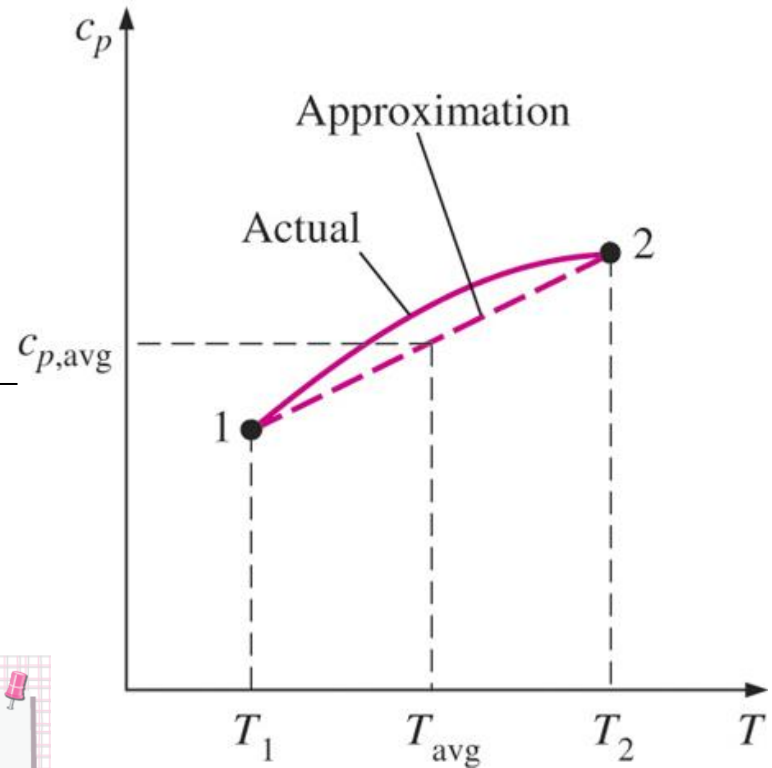
$$du = C_v dT \qquad \text{and} \qquad dh = C_p dT$$

Three ways of calculating Δu *and* Δh

$$\Delta h = h_2 - h_1 \quad \leftarrow \text{from tables}$$

$$\Delta h = \int_1^2 c_p(T)\, dT$$

$$\Delta h \cong c_{p,avg} \Delta T$$



Similarly:

$$\Delta u = u_2 - u_1 \quad \text{(table)}$$

$$\Delta u = \int_1^2 c_v(T)\, dT$$

$$\Delta u \cong c_{v,\text{avg}} \Delta T$$

$$\Delta u = u_2 - u_1 = \int_1^2 c_v(T)\, dT$$

$$\Delta h = h_2 - h_1 = \int_1^2 c_p(T)\, dT$$

$$h = u + RT \xrightarrow{\textbf{differentiate}} dh = du + R\, dT$$

$$\longrightarrow \quad c_p dT = c_v dT + R dT$$

$$\div\, dT \quad \longrightarrow \quad c_p = c_v + R \qquad (\mathrm{kJ/kg \cdot K})$$

On a molar basis $\longrightarrow \quad \bar{c}_p = \bar{c}_v + R_u \qquad (\mathrm{kJ/kmol \cdot K})$

Specific heat ratio $\quad k = \dfrac{c_p}{c_v}$

Solids and Liquids:

Can be approximated as incompressible: $c_p \cong c_v = c$

Again, specific heats depend on temperature only.

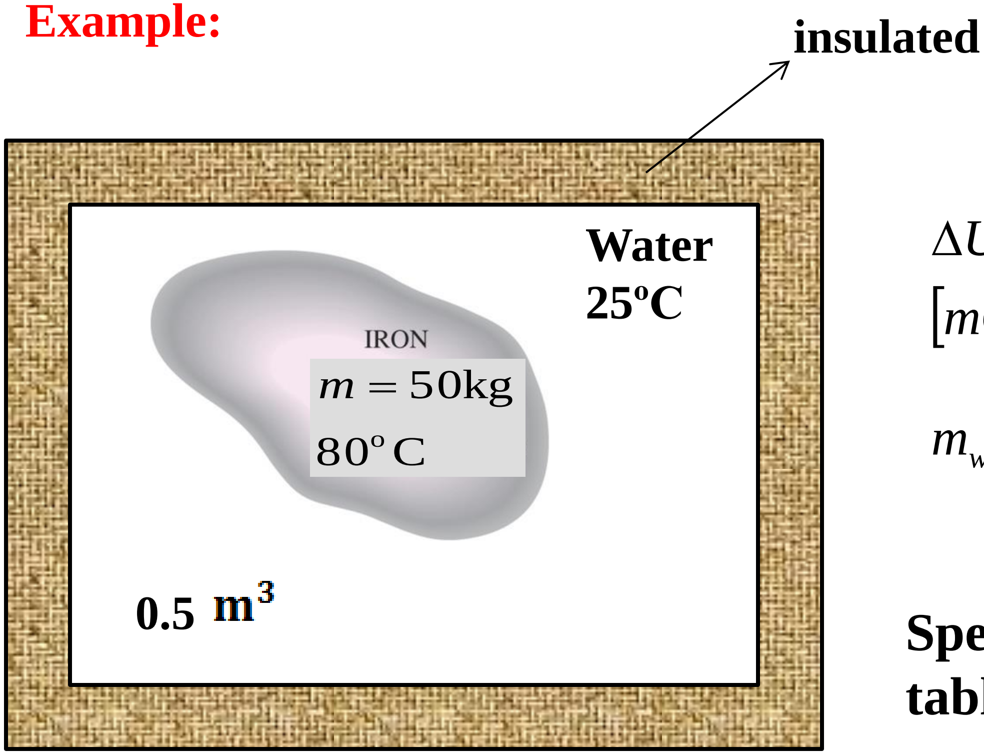
$$\mathbf{du = C_v dT = C(T) dT}$$

The change in internal energy between states 1 and 2:

$$\Delta u = u_2 - u_1 = \int_1^2 c(T)\, dT$$

$$\Delta u = c_{avg}(T_2 - T_1)$$

Example:



Q-W=ΔU or ΔU=0

$$\Delta U = \Delta U_{iron} + \Delta U_{water} = 0$$

$$[mC(T_2 - T_1)]_{iron} + [mC(T_2 - T_1)]_{water} = 0$$

$$m_{water} = \frac{V}{v_{25\ C}} = \frac{0.5\,\text{m}^3}{0.001\text{m}^3/\text{kg}} = 500\,\text{kg}$$

Specific heats are determined from table A-3.

$$50\,\text{kg}(0.45\,{}^{\text{kJ}}\!/\!_{\text{kg}^\circ\text{C}})(T_2 - 80^\circ\text{C}) + 500\text{kg}(4.18\,{}^{\text{kJ}}\!/\!_{\text{kg}^\circ\text{C}})(T_2 - 25^\circ\text{C}) = 0$$

$$T_2 = 25.6\ ^\circ\text{C}$$

Example 1 – Class Work

- **Radon** gas initially at 65 kPa, 200^{o}C is **to be heated** in a **closed , rigid container** until it is at 400^{o}C. The mass of the radon is 0.393 kg.
- A table of properties shows that at 200^{o}C, the internal energy of radon is 26.6 kJ/kg; at 400^{o}C it is 37.8 kJ/kg.
- Determine the amount of heat required.
- Determine the final pressure

(Draw a simple diagram and put the information on it)

Example 2

Air at a temperature of 500^{o}C is **compressed** in a piston-cylinder arrangement at a **constant pressure** of 1.2 MPa from a volume of 2 m^3 to a volume of 0.4 m^3. if the internal energy decrease is 4820 kJ, find

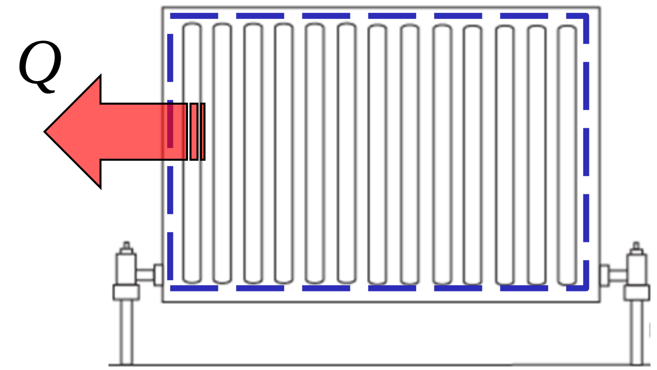
a. the work done during the reversible compression
b. The heat transferred
c. The change of enthalpy
d. The average specific heat at constant pressure.

a) $W_{1-2} = P(V_2 - V_1) = 1.2\times10^3\,\mathrm{kPa}\left[(0.4 - 2)\,\mathrm{m}^3\right] = -1920\mathrm{kJ}$

b) $Q_{1\text{-}2} - W_{1-2} = U_2 - U_1 \rightarrow Q_{1-2} - (-1920\mathrm{kJ}) = -4820\mathrm{kJ} \rightarrow Q_{1-2} = -6740\mathrm{kJ}$

Example 3

The radiator of a steam heating system is filled with superheated vapor. The volume of the radiator is 15 L and the inlet and outlet valves are closed. The pressure inside the radiator drops from 200 kPa to 100 kPa while dissipating heat into a room. If the initial temperature of the steam is 200°C determine the heat transferred to the room.



$$Q - W = \Delta U$$

$$Q = m(u_2 - u_1) = \frac{V}{v}(u_2 - u_1)$$

$$Q = \frac{15\times10^{-3}\,\mathrm{m}^3}{1.0803\,\mathrm{m}^3/\mathrm{kg}}(u_2 - 2654.4\,\mathrm{kj/kg})$$

In order to find u_2 we need to find the quality at state 2

$$\rightarrow x = \frac{v - v_f}{v_{fg}} \quad \text{then use} \quad u_2 = u_f + x u_{fg}$$