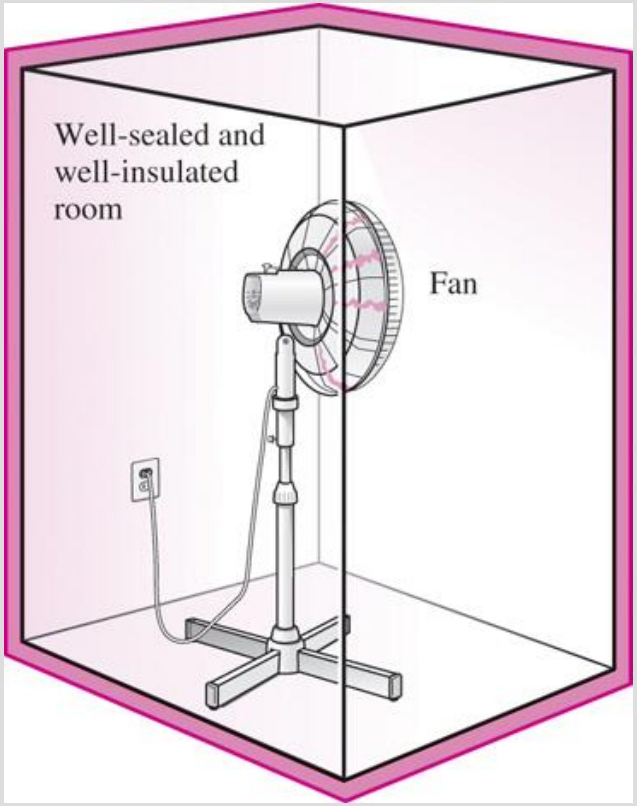
Chapter 2

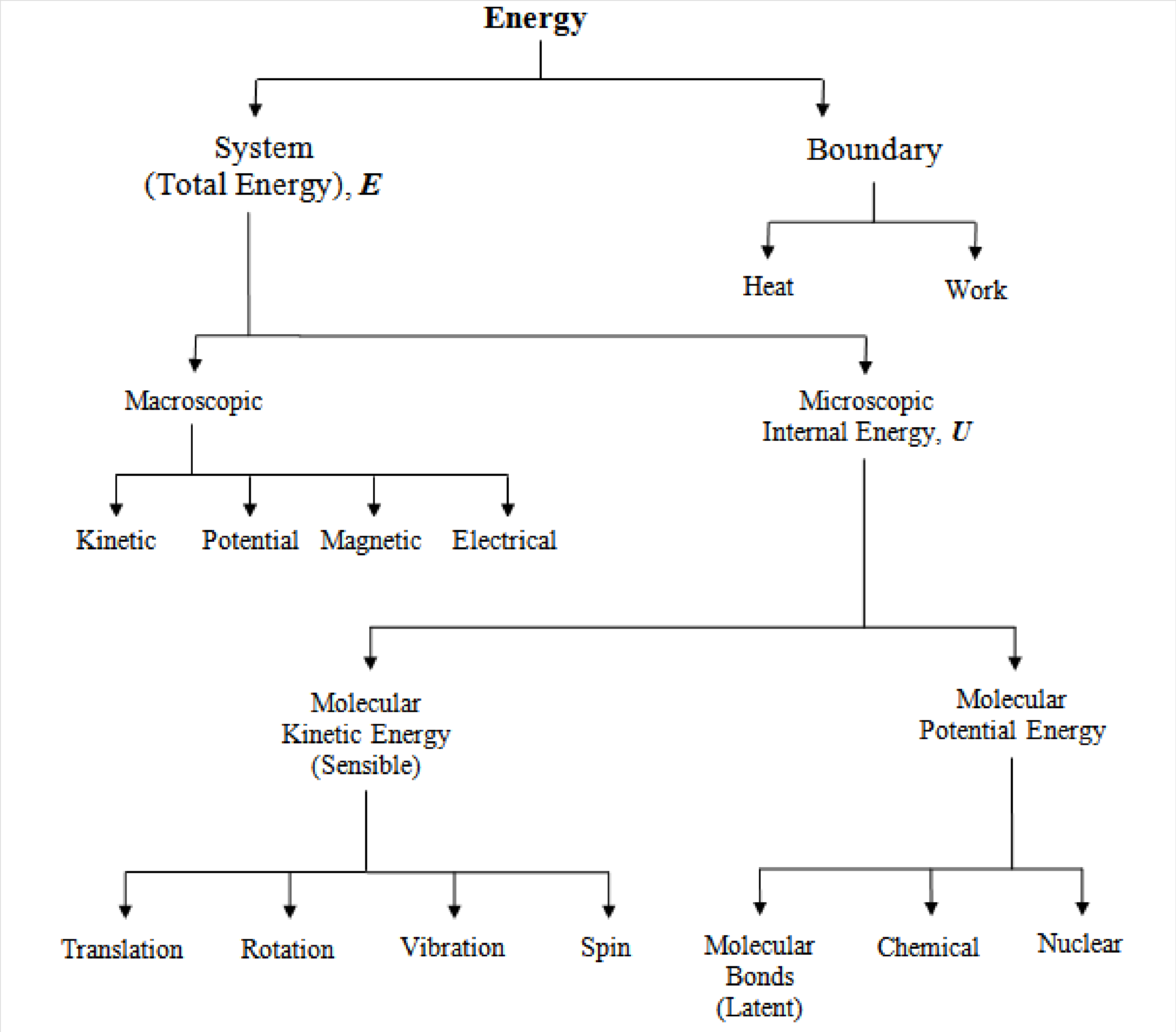
ENERGY, ENERGY TRANSFER, AND GENERAL ENERGY ANALYSIS

INTRODUCTION

- Consider the two examples below.
- The two rooms are well insulated and sealed.
- The only energy interaction involved is the electrical energy crossing the system boundary and entering the room.
- The amount of energy in the room will increase.
- **The room temperature will rise**.



Energy of a System



Total Energy of a System

$$\mathrm{KE} = m\frac{V^2}{2} \qquad (\mathrm{kJ})$$

$$\mathrm{PE} = mgz \qquad (\mathrm{kJ})$$

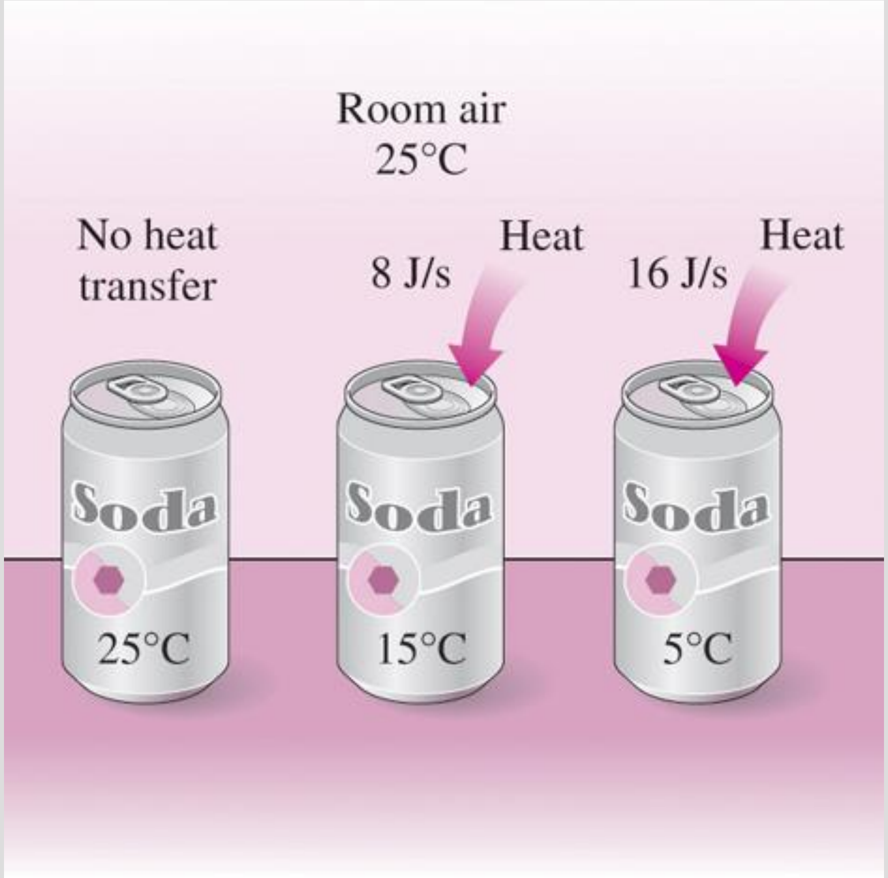
$$E = U + \mathrm{KE} + \mathrm{PE} = U + m\frac{V^2}{2} + mgz \qquad (\mathrm{kJ})$$

Energy Transfer

- The total energy of a system is the energy *contained* or *stored* in a system
- The forms of energy not stored in a system can be viewed as ***energy transfer***.
- Energy transfer is recognized at the system boundary as it crosses that boundary.
- Energy transfer represents the energy gained or lost by a system during a process.
- Energy can be transferred to/from a system by **heat**, **work**, and **mass**.
- In a closed system, energy can only be transferred by heat and work (since mass is not allowed to cross the system boundary)

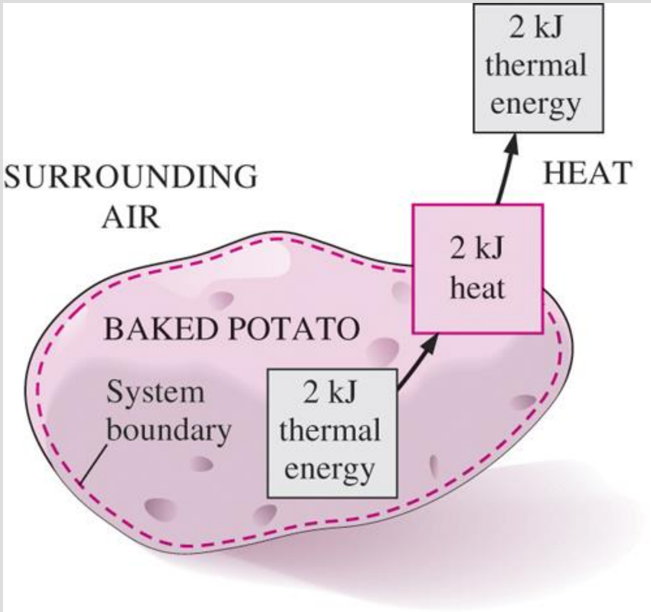
Energy Transfer By Heat

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



Energy Transfer By Heat

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

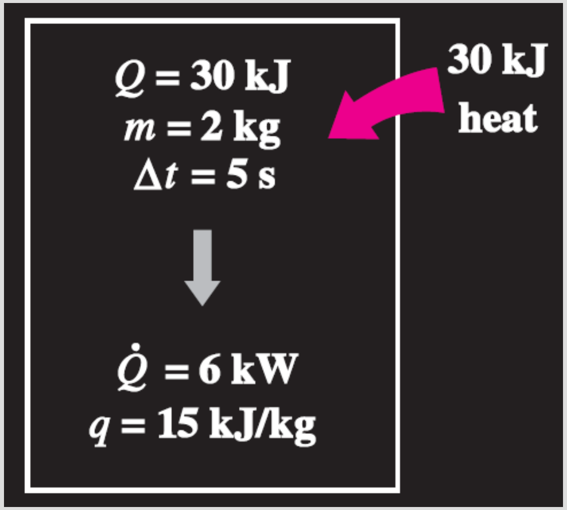


$$Q = \dot{Q}\ \Delta t \qquad \text{(kJ)}$$

Amount of heat transfer when heat transfer rate is constant

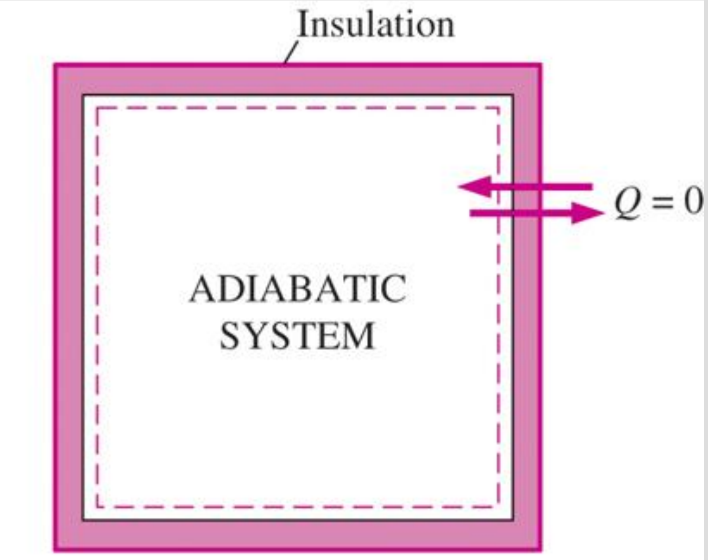
$$Q = \int_{t_1}^{t_2} \dot{Q}\ dt \qquad \text{(kJ)}$$

Amount of heat transfer when heat transfer rate changes with time



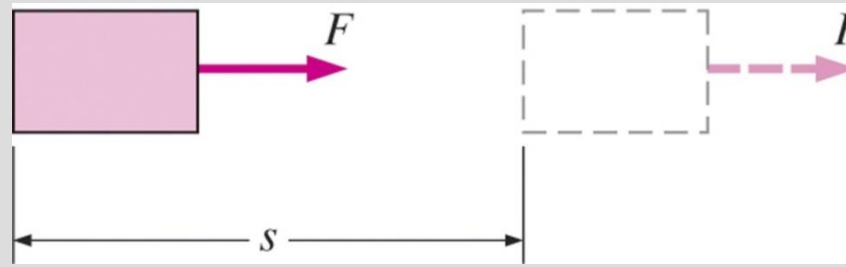
Adiabatic Process/System

- An ***adiabatic*** process is a process in which the system exchanges **NO** heat with its surroundings, i.e. $Q = 0$



Energy Transfer by Work

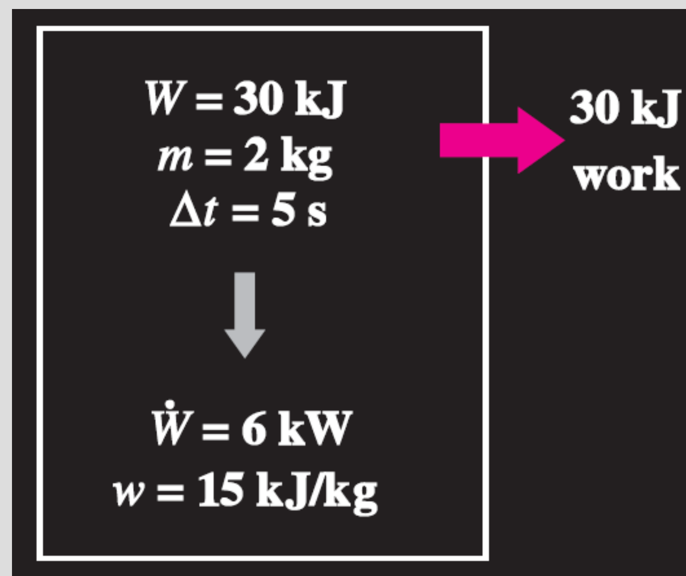
Work (*W*) is the energy transfer associated with a ***force*** acting through a ***distance***.



$$W = \int_1^2 F\, ds$$

- **Examples**: a rising piston, a rotating shaft, and an electric wire crossing the system boundaries

Power ($\dot{W}$) is the rate of energy transfer by work.



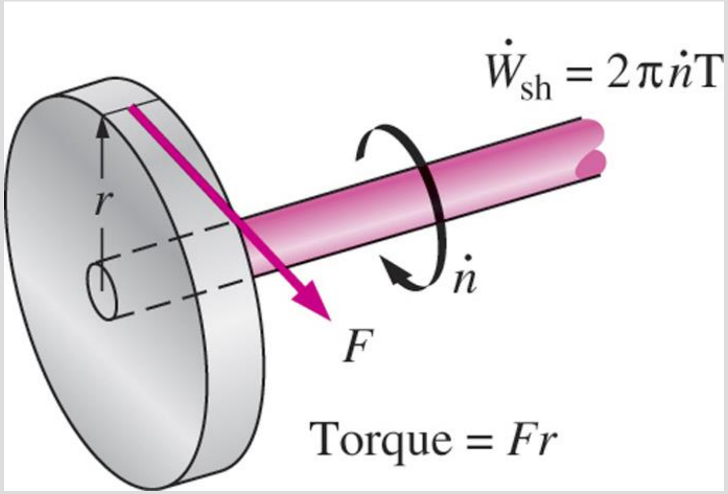
Examples of Types of Work

- Shaft work
- Spring work
- Electrical work

Shaft Work

- A force *F* acting through a moment arm *r* generates a torque T

$$\mathrm{T} = Fr \quad \rightarrow \quad F = \frac{\mathrm{T}}{r}$$

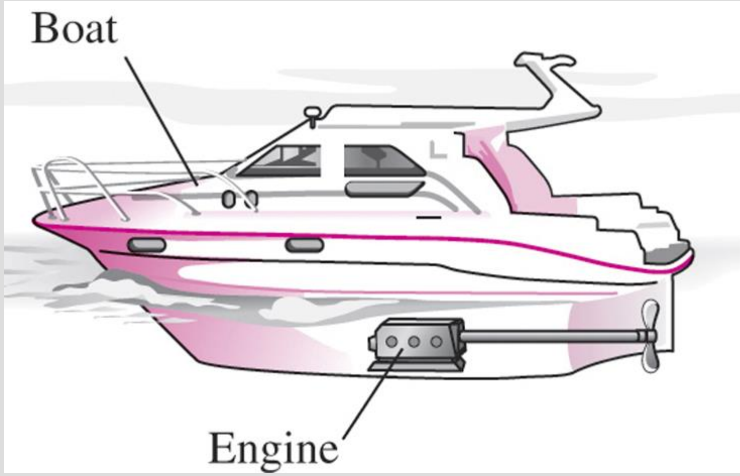


- This force acts through a distance *s*

$$s = (2\pi r)n$$

- The work done is:

$$W_{sh} = Fs = \left(\frac{\mathrm{T}}{r}\right)(2\pi rn) = 2\pi n\mathrm{T}$$



- The power transmitted through the shaft is the shaft work done per unit time

$$\dot{W}_{sh} = 2\pi\dot{n}\mathrm{T}$$

Spring Work

- When the length of the spring changes by a differential amount *dx* under the influence of a force *F*, the work done is:

$$\delta W_{\text{spring}} = F\,dx$$

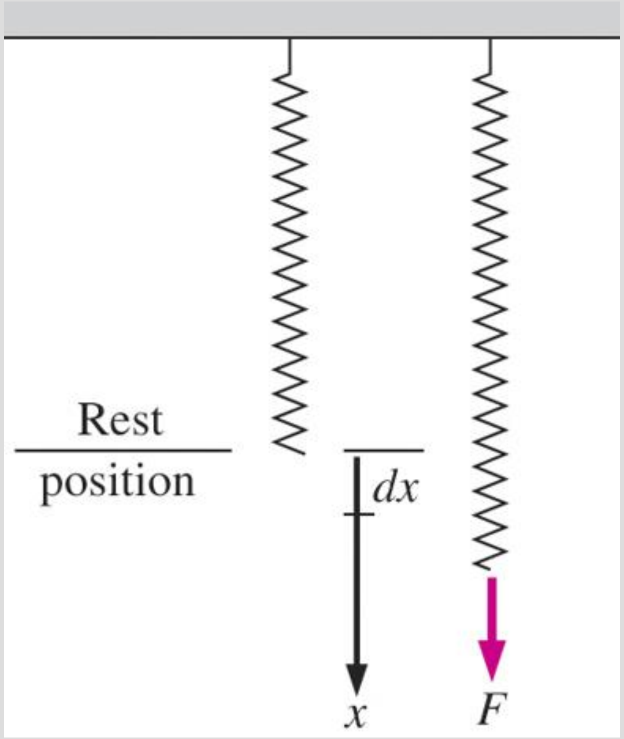
- For linear elastic springs, the displacement *x* is proportional to the force applied

$$F = kx$$, *k:* spring constant (kN/m)

- Substituting and integrating yield

$$W_{\text{spring}} = \tfrac{1}{2}k\left(x_2^2 - x_1^2\right)$$

x_1 and x_2: the initial and the final displacements



Electrical Work

Electrical work

$$W_e = \mathbf{V}N$$

Electrical power

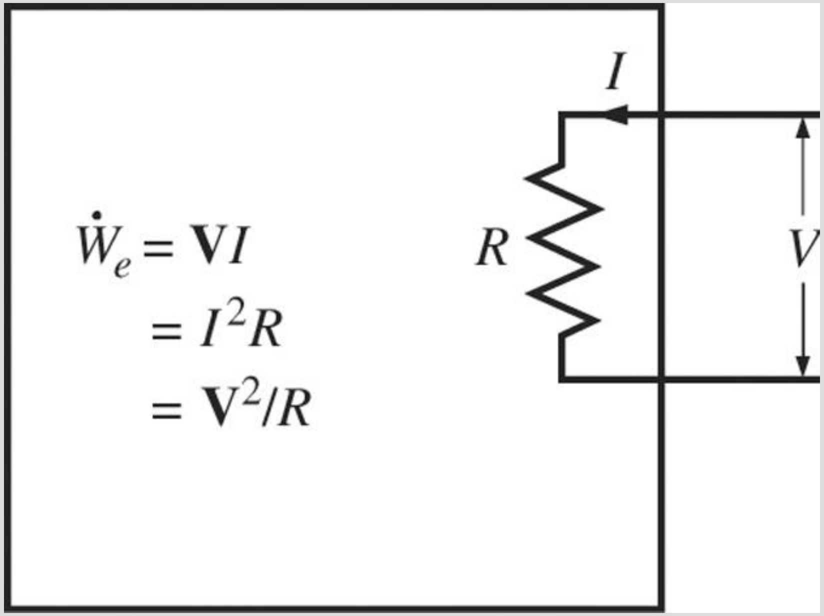
$$\dot{W}_e = \mathbf{V}I \qquad \text{(W)}$$

When potential difference and current change with time

$$W_e = \int_1^2 \mathbf{V}I\, dt$$

When potential difference and current remain constant

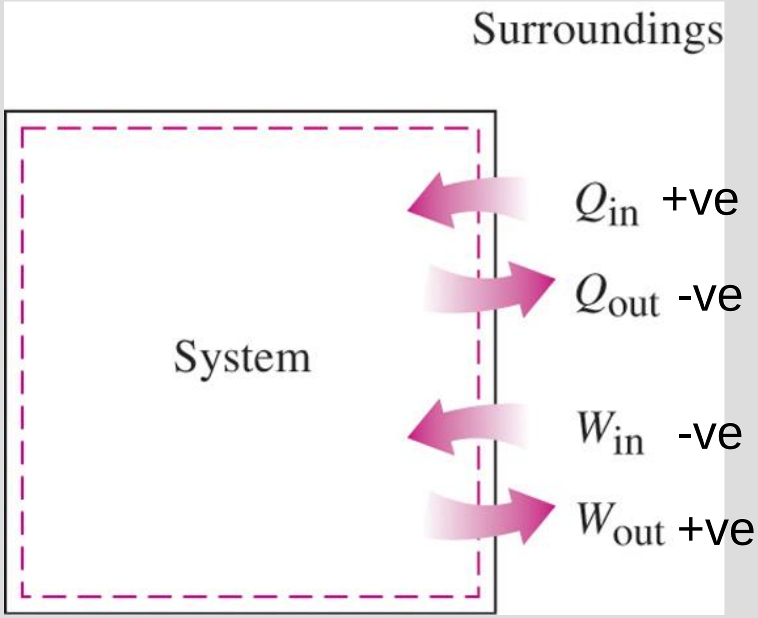
$$W_e = \mathbf{V}I\ \Delta t \qquad \text{(kJ)}$$



Sign Convention for Heat and Work

Formal sign convention

- Heat transfer to a system and work done by (out of) a system are positive
- Heat transfer from (out of) a system and work done on a system are negative



Alternative

- Use the subscripts ***in*** and ***out*** to indicate direction ***(preferred)***

Nature of Heat and Work

- Heat and work are recognized at the boundaries of a system as they cross the boundaries.
- Heat and work are ***boundary*** phenomena.
- Systems possess energy, but not heat or work.
- Heat and work are associated with a ***process***, not a state.
- Unlike properties, heat or work has no meaning at a state.

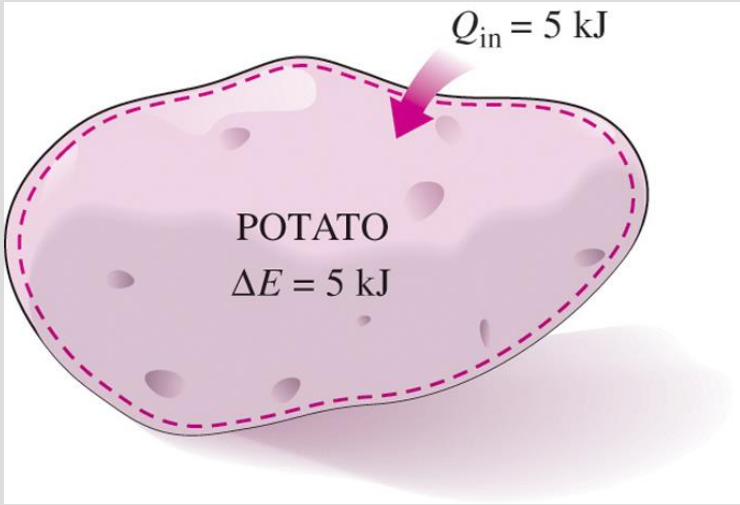
The First Law of Thermodynamics

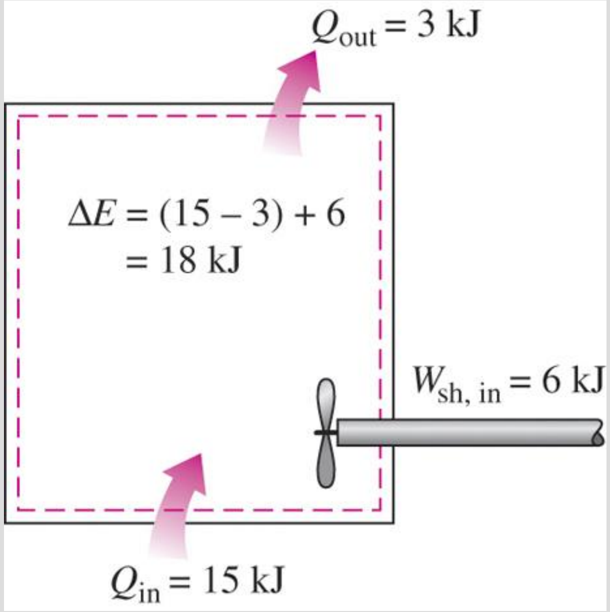
- Energy can be neither created nor destroyed during a process; it can only change forms.
- It is also called the ***First of Law of Thermodynamics***
- The same principle can also be expressed in the form of an energy balance.

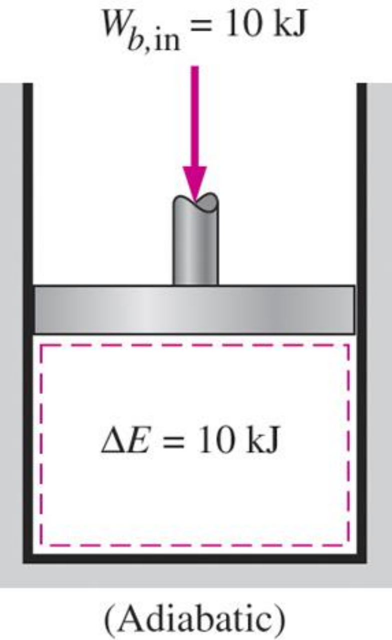
$$\begin{pmatrix} \text{Total energy} \\ \text{entering the system} \end{pmatrix} - \begin{pmatrix} \text{Total energy} \\ \text{leaving the system} \end{pmatrix} = \begin{pmatrix} \text{Change in the total} \\ \text{energy of the system} \end{pmatrix}$$

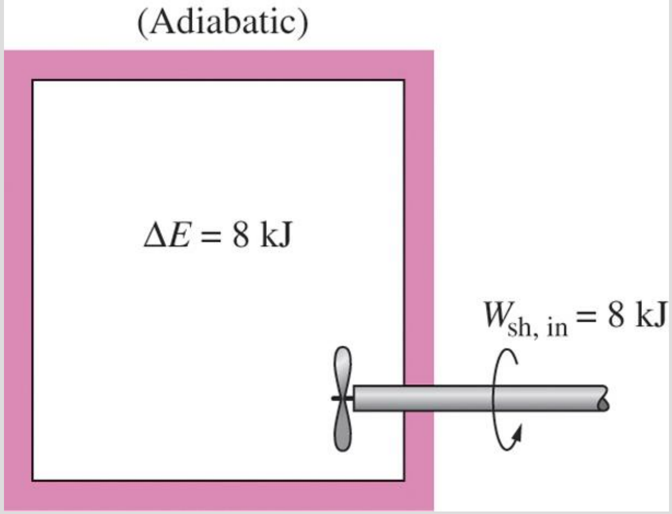
$$\Rightarrow \quad E_{\text{in}} - E_{\text{out}} = \Delta E_{\text{system}}$$

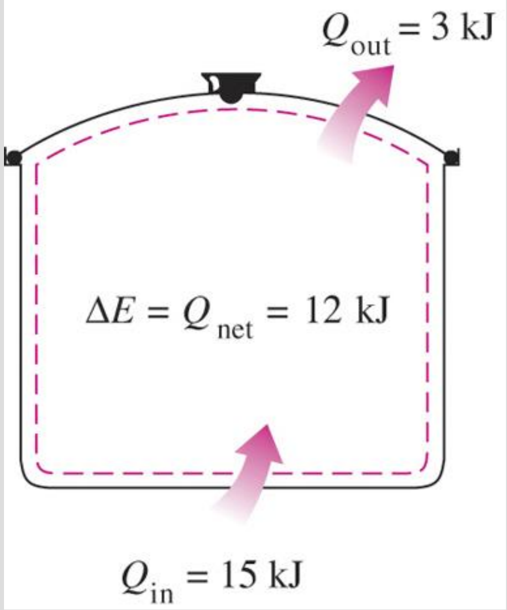
Energy Balance (Examples)











Energy Change of a System, ΔE_{system}

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

$$\Delta E_{system} = E_{final} - E_{initial} = E_2 - E_1$$

$$= \Delta U + \Delta KE + \Delta PE$$

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

$$\Delta KE = \tfrac{1}{2} m(V_2^2 - V_1^2)$$

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

Stationary Systems

$$z_1 = z_2 \rightarrow \Delta PE = 0$$

$$V_1 = V_2 \rightarrow \Delta KE = 0$$

$$\Delta E = \Delta U$$

Mechanisms of Energy Transfer, E_{in} and E_{out}

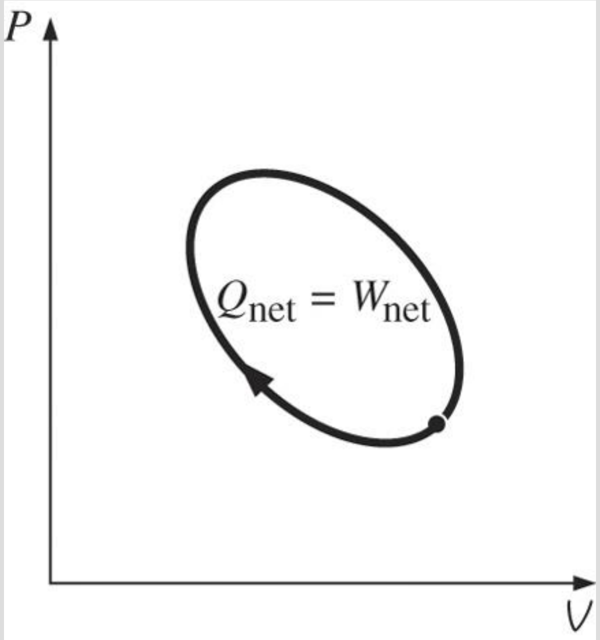
$$E_{\text{in}} - E_{\text{out}} = \underbrace{(Q_{\text{in}} - Q_{\text{out}})}_{\text{Heat Transfer}} + \underbrace{(W_{\text{in}} - W_{\text{out}})}_{\text{Work Transfer}} + \underbrace{(E_{\text{mass,in}} - E_{\text{mass,out}})}_{\text{Mass Transfer}} = \Delta E_{\text{system}}$$

$$E_{\text{in}} - E_{\text{out}} = (Q_{\text{in}} + W_{\text{in}} + E_{\text{mass,in}}) - (Q_{\text{out}} + W_{\text{out}} + E_{\text{mass,out}}) = \Delta E_{\text{system}}$$

$$\underbrace{\dot{E}_{\text{in}} - \dot{E}_{\text{out}}}_{\substack{\text{Rate of net energy transfer} \\ \text{by heat, work, and mass}}} = \underbrace{dE_{\text{system}}/dt}_{\substack{\text{Rate of change in internal,} \\ \text{kinetic, potential, etc., energies}}} \qquad \text{(kW)}$$

Energy Balance for a Cycle

- A cycle implies that the system is closed
- A cycle means that the system:
  - Starts at a certain initial state
  - Undergoes a number of processes
  - Returns at the end to the same initial state



$$\Delta E_{system} = \cancel{E_{final} - E_{initial}}^{\,0}$$

$$= (Q_{in} - Q_{out}) + (W_{in} - W_{out}) + \cancel{(E_{mass,in} - E_{mass,out})}^{\,0}$$

$$W_{net,out} = Q_{net,in} \Rightarrow \dot{W}_{net,out} = \dot{Q}_{net,in}$$