

# Thermodynamics I

## Lecture 6

### **Energy, Energy Transfer Heat and Work Interactions (Ch-2)**

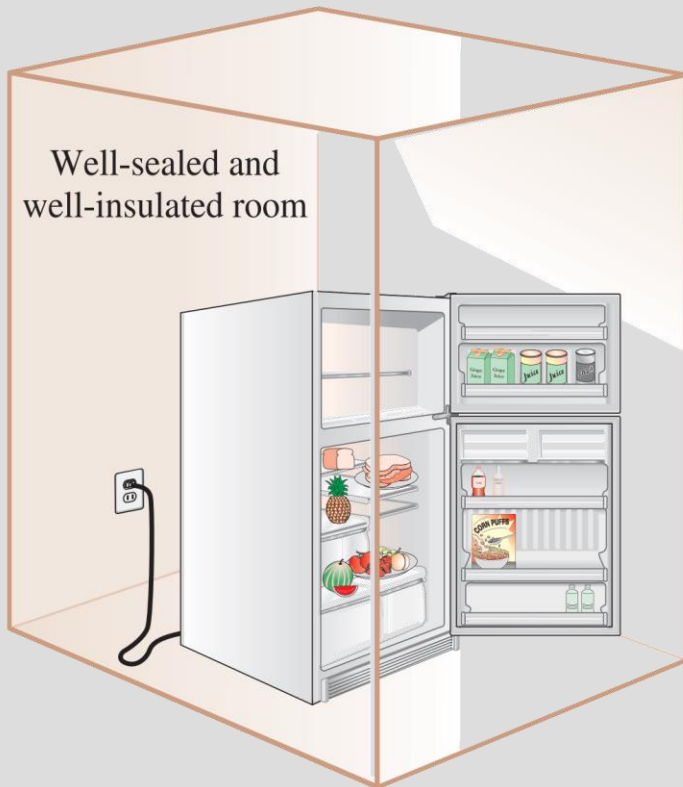
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# Objectives

- Introduce the concept of energy and define its various forms.
- Discuss the nature of internal energy.
- Define the concept of heat and the terminology associated with energy transfer by heat.
- Discuss the three mechanisms of heat transfer: conduction, convection, and radiation.
- Define the concept of work, including electrical work.
- Introduce the first law of thermodynamics, energy balances, and mechanisms of energy transfer to or from a system.
- Determine that a fluid flowing across a control surface of a control volume carries energy across the control surface in addition to any energy transfer across the control surface that may be in the form of heat and/or work.
- Define energy conversion efficiencies.
- Discuss the implications of energy conversion on the environment.

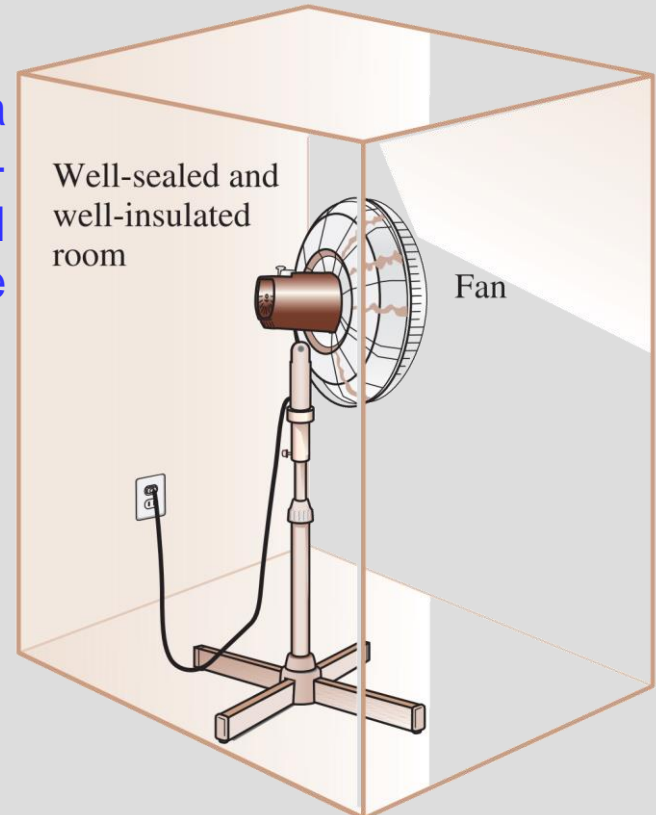
# INTRODUCTION

- If we take the entire room—including the air and the refrigerator (or fan)—as the system, which is an adiabatic closed system since the room is well-sealed and well-insulated, the only energy interaction involved is the electrical energy crossing the system boundary and entering the room.
- As a result of the conversion of electric energy consumed by the device to heat, **the room temperature will rise.**



A fan running in a well-sealed and well-insulated room will raise the temperature of air in the room.

A refrigerator operating with its door open in a well-sealed and well-insulated room



# FORMS OF ENERGY

- Energy can exist in numerous forms such as thermal, mechanical, kinetic, potential, electric, magnetic, chemical, and nuclear, and their sum constitutes the **total energy,  $E$**  of a system.
- Thermodynamics deals only with the **change** of the total energy.
- **Macroscopic forms of energy:** Those a system possesses as a whole with respect to some outside reference frame, such as kinetic and potential energies.
- **Microscopic forms of energy:** Those related to the molecular structure of a system and the degree of the molecular activity.
- **Internal energy,  $U$ :** The sum of all the microscopic forms of energy.
- **Kinetic energy, KE:** The energy that a system possesses as a result of its motion relative to some reference frame.
- **Potential energy, PE:** The energy that a system possesses as a result of its elevation in a gravitational field.



The macroscopic energy of an object changes with velocity and elevation.

$$\text{KE} = m \frac{V^2}{2} \quad (\text{kJ}) \quad \text{Kinetic energy}$$

$$\text{ke} = \frac{V^2}{2} \quad (\text{kJ/kg}) \quad \text{Kinetic energy per unit mass}$$

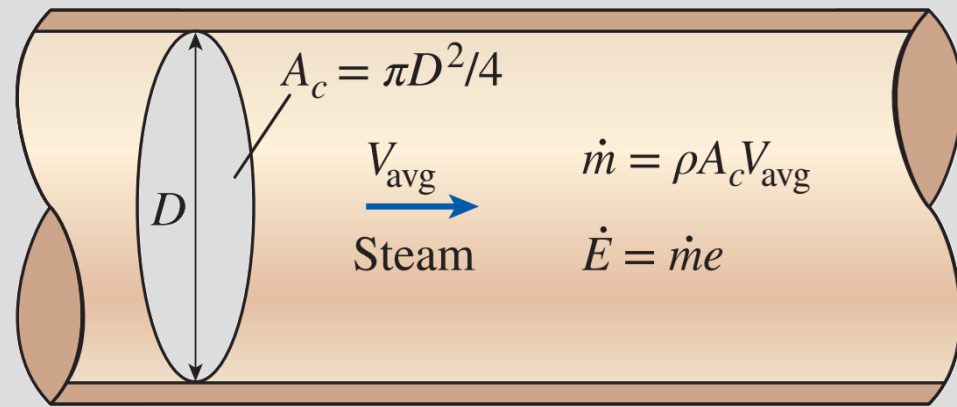
$$\text{PE} = mgz \quad (\text{kJ}) \quad \text{Potential energy}$$

$$\text{pe} = gz \quad (\text{kJ/kg}) \quad \text{Potential energy per unit mass}$$

$$E = U + \text{KE} + \text{PE} = U + m \frac{V^2}{2} + mgz \quad (\text{kJ}) \quad \text{Total energy of a system}$$

$$e = u + \text{ke} + \text{pe} = u + \frac{V^2}{2} + gz \quad (\text{kJ/kg}) \quad \text{Energy of a system per unit mass}$$

$$e = \frac{E}{m} \quad (\text{kJ/kg}) \quad \text{Total energy per unit mass}$$



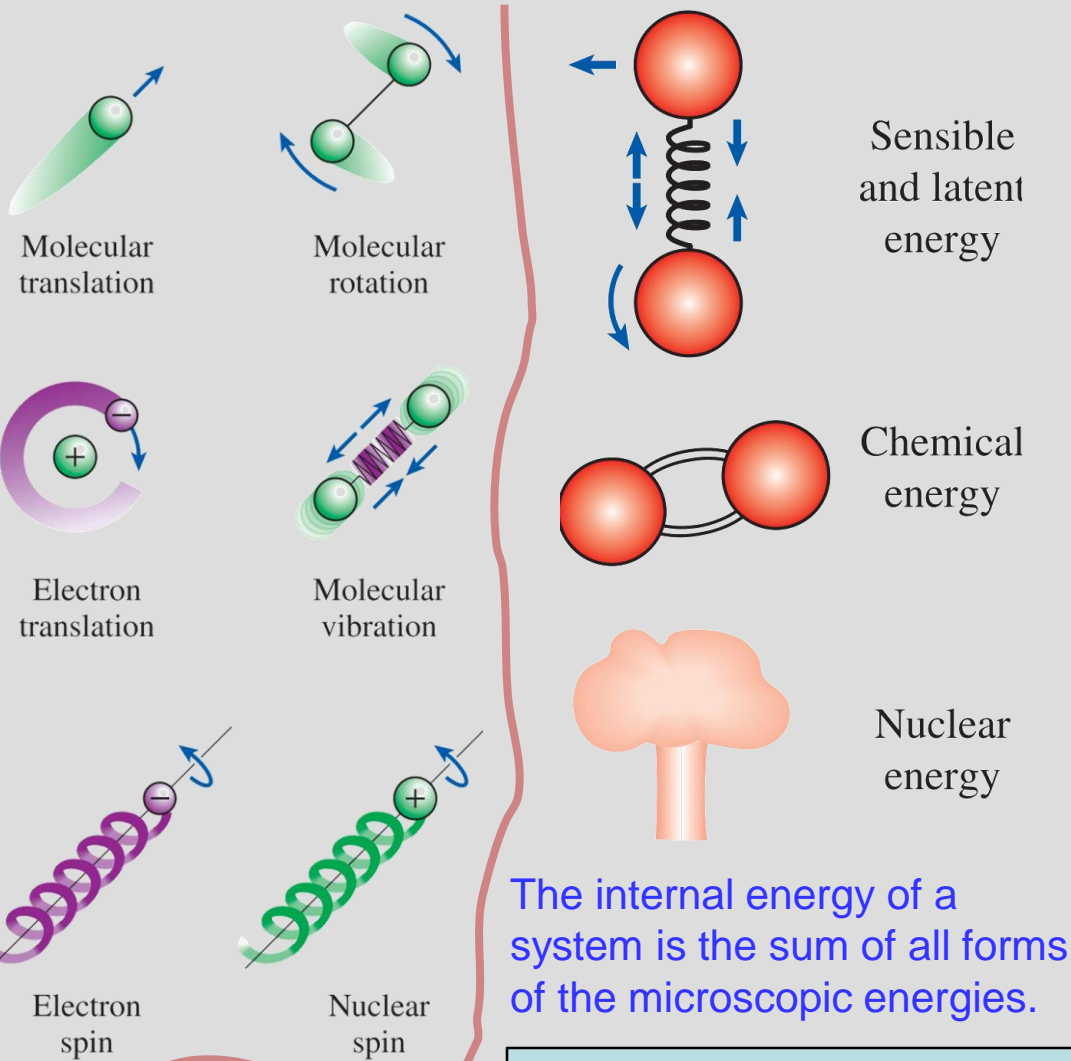
Mass flow rate

$$\dot{m} = \rho \dot{V} = \rho A_c V_{\text{avg}} \quad (\text{kg/s})$$

Energy flow rate

$$\dot{E} = \dot{m}e \quad (\text{kJ/s or kW})$$

# Some Physical Insight to Internal Energy



**Sensible energy:** The portion of the internal energy of a system associated with the kinetic energies of the molecules.

**Latent energy:** The internal energy associated with the phase of a system.

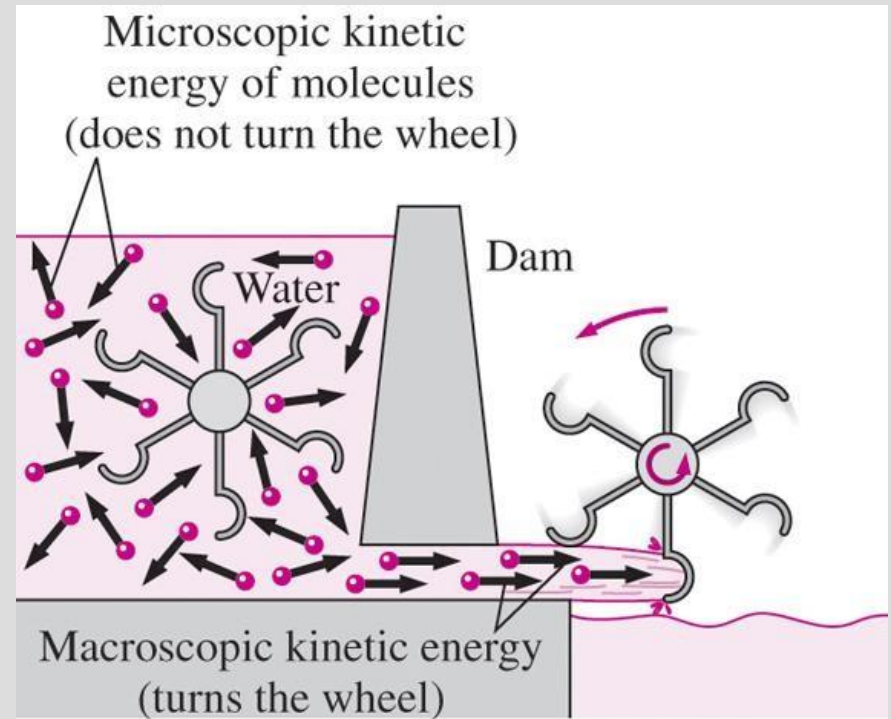
**Chemical energy:** The internal energy associated with the atomic bonds in a molecule.

**Nuclear energy:** The tremendous amount of energy associated with the strong bonds within the nucleus of the atom itself.

**Thermal = Sensible + Latent**

**Internal = Sensible + Latent + Chemical + Nuclear**

- The total energy of a system, can be *contained* or *stored* in a system, and thus can be viewed as the **static forms of energy**.
- The forms of energy not stored in a system can be viewed as the **dynamic forms of energy** or as **energy interactions**.
- The dynamic forms of energy are recognized at the system boundary as they cross it, and they represent the energy gained or lost by a system during a process.
- The only two forms of energy interactions associated with a closed system are **heat transfer** and **work**.
- **The difference between heat transfer and work:** An energy interaction is heat transfer if its driving force is a temperature difference. Otherwise it is work.



The *macroscopic* kinetic energy is an organized form of energy and is much more useful than the disorganized *microscopic* kinetic energies of the molecules.

# Mechanical Energy

**Mechanical energy:** The form of energy that can be converted to mechanical work completely and directly by an ideal mechanical device such as an ideal turbine.

**Kinetic and potential energies:** The familiar forms of mechanical energy.

$$e_{\text{mech}} = \frac{P}{\rho} + \frac{V^2}{2} + gz$$

Mechanical energy of a flowing fluid per unit mass

$$\dot{E}_{\text{mech}} = \dot{m}e_{\text{mech}} = \dot{m}\left(\frac{P}{\rho} + \frac{V^2}{2} + gz\right)$$

Rate of mechanical energy of a flowing fluid

Mechanical energy change of a fluid during incompressible flow per unit mass

$$\Delta e_{\text{mech}} = \frac{P_2 - P_1}{\rho} + \frac{V_2^2 - V_1^2}{2} + g(z_2 - z_1) \quad (\text{kJ/kg})$$

Rate of mechanical energy change of a fluid during incompressible flow

$$\Delta \dot{E}_{\text{mech}} = \dot{m}\Delta e_{\text{mech}} = \dot{m}\left(\frac{P_2 - P_1}{\rho} + \frac{V_2^2 - V_1^2}{2} + g(z_2 - z_1)\right) \quad (\text{kW})$$



# Exercise Example 2-2

## EXAMPLE 2-2 Wind Energy

A site evaluated for a wind farm is observed to have steady winds at a speed of 8.5 m/s (Fig. 2–10). Determine the wind energy (a) per unit mass, (b) for a mass of 10 kg, and (c) for a flow rate of 1154 kg/s for air.

**Solution** A site with a specified wind speed is considered. Wind energy per unit mass, for a specified mass, and for a given mass flow rate of air are to be determined.

**Assumptions** Wind flows steadily at the specified speed.

**Analysis** The only harvestable form of energy of atmospheric air is the kinetic energy, which is captured by a wind turbine.

(a) Wind energy per unit mass of air is

$$e = ke = \frac{V^2}{2} = \frac{(8.5 \text{ m/s})^2}{2} \left( \frac{1 \text{ J/kg}}{1 \text{ m}^2/\text{s}^2} \right) = \mathbf{36.1 \text{ J/kg}}$$

## Exercise Example 2-2

(b) Wind energy for an air mass of 10 kg is

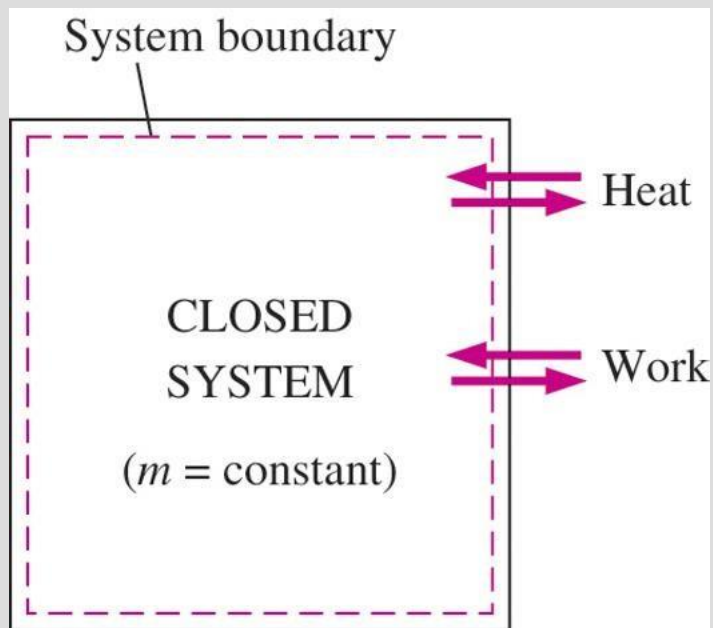
$$E = me = (10 \text{ kg})(36.1 \text{ J/kg}) = \mathbf{361 \text{ J}}$$

(c) Wind energy for a mass flow rate of 1154 kg/s is

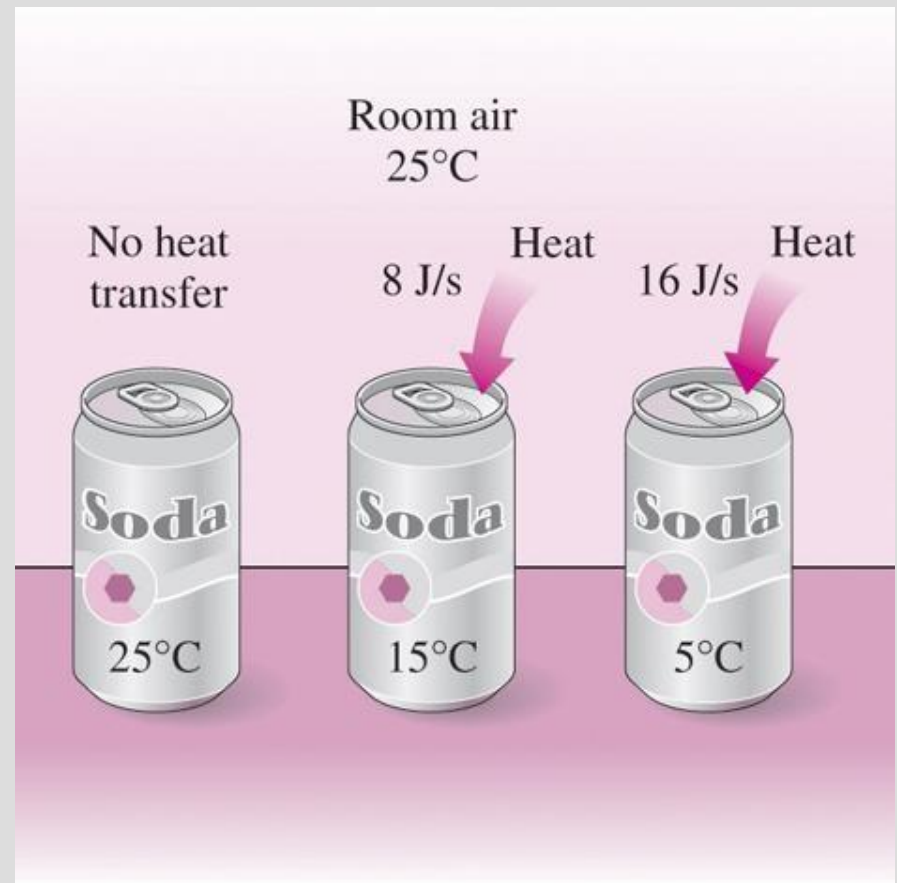
$$\dot{E} = \dot{m}e = (1154 \text{ kg/s})(36.1 \text{ J/kg}) \left( \frac{1 \text{ kW}}{1000 \text{ J/s}} \right) = \mathbf{41.7 \text{ kW}}$$

# 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.



Energy can cross the boundaries of a closed system in the form of heat and work.



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

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

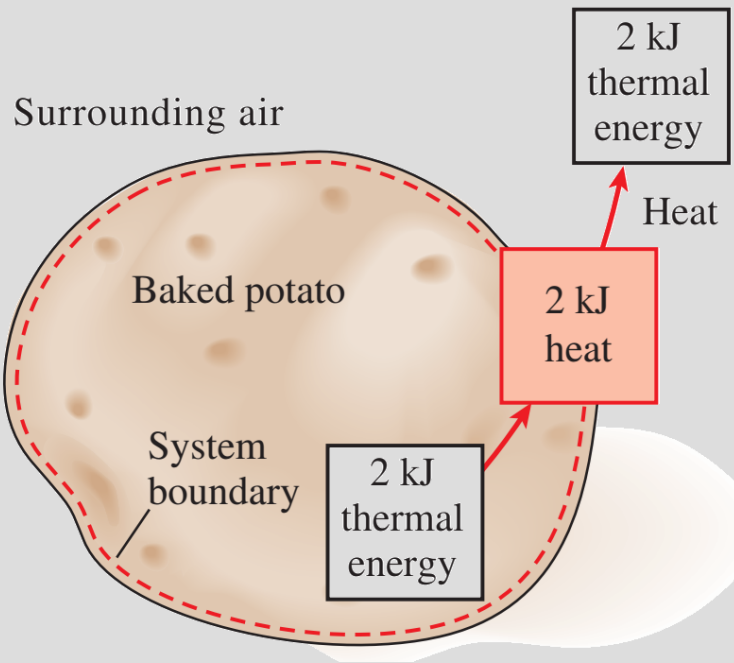
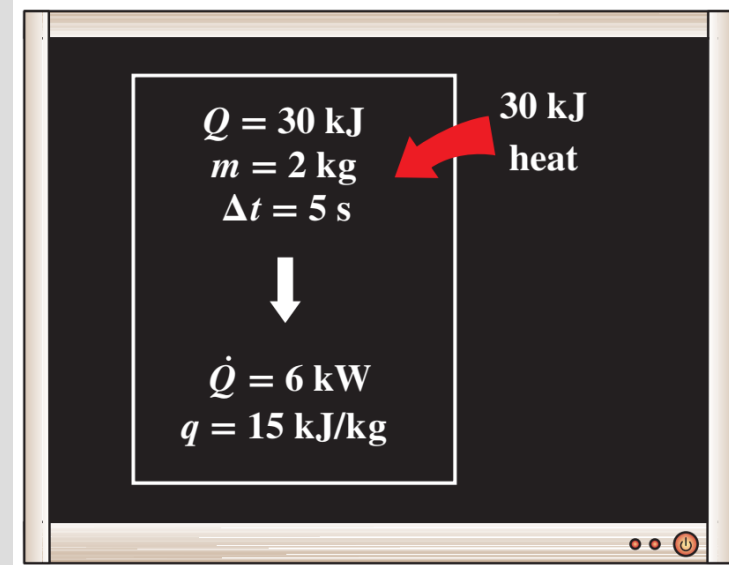
Heat transfer per unit mass

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

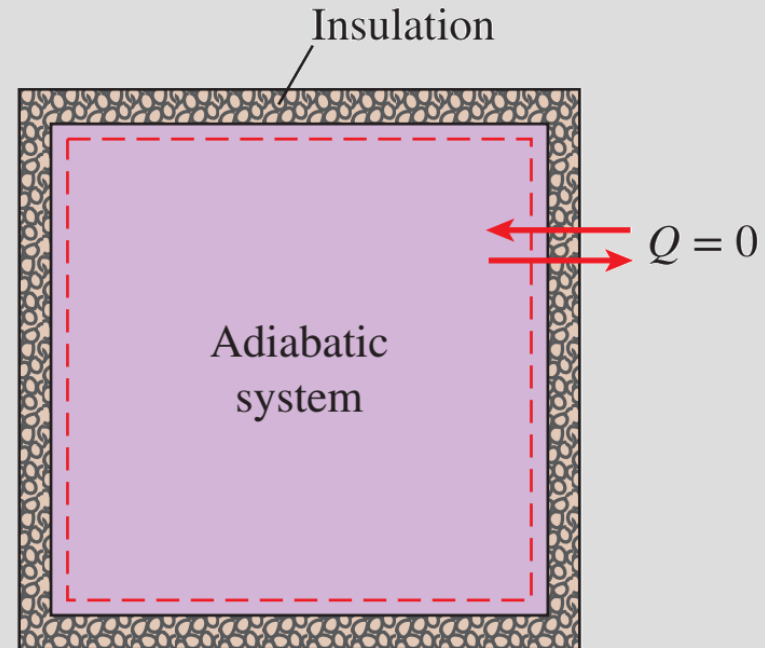
Amount of heat transfer when heat transfer rate is constant

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

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.

**End of Lecture**