CAE 208 Thermal-Fluids Engineering I
MMAE 320: Thermodynamics

Fall 2022

September 8, 2022

Energy, energy transfer, and energy analysis (II)

Built
Environment
Research
@ IIT

Advancing energy, environmental, and sustainability research within the built environment

www.built-envi.com

Dr. Mohammad Heidarinejad, Ph.D., P.E.
Civil, Architectural and Environmental Engineering
Illinois Institute of Technology
muh182@iit.edu

RECAP

Recap

- Total energy of a system in the absence of magnetic, electric, and surface tension effects is

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

$$e = u + ke + pe = u + \frac{V^2}{2} + gz \quad (kJ/kg)$$

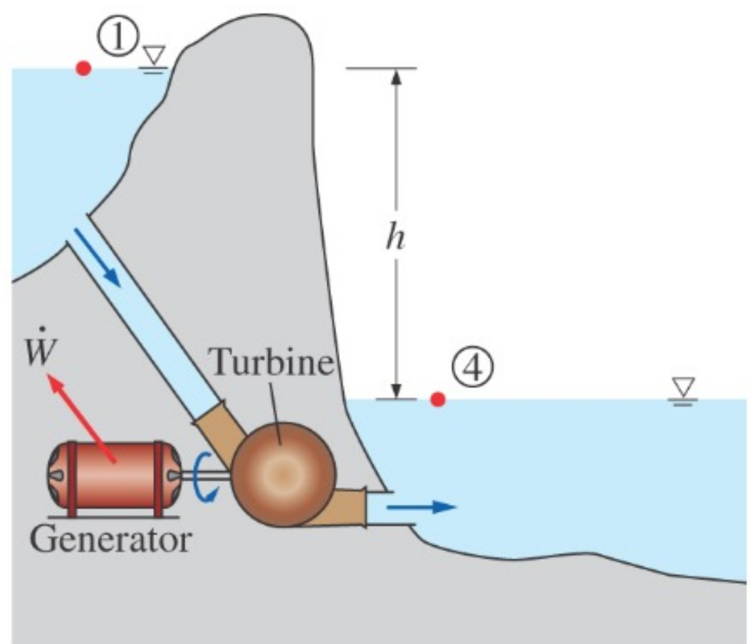
Forms of Energy

- Mechanical energy can be defined as the form of energy that can be converted to mechanical work completely and directly by an ideal mechanical device such as an ideal turbine

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

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

$$\Delta\dot{E}_{mech} = \dot{m}\mathrm{e}$$

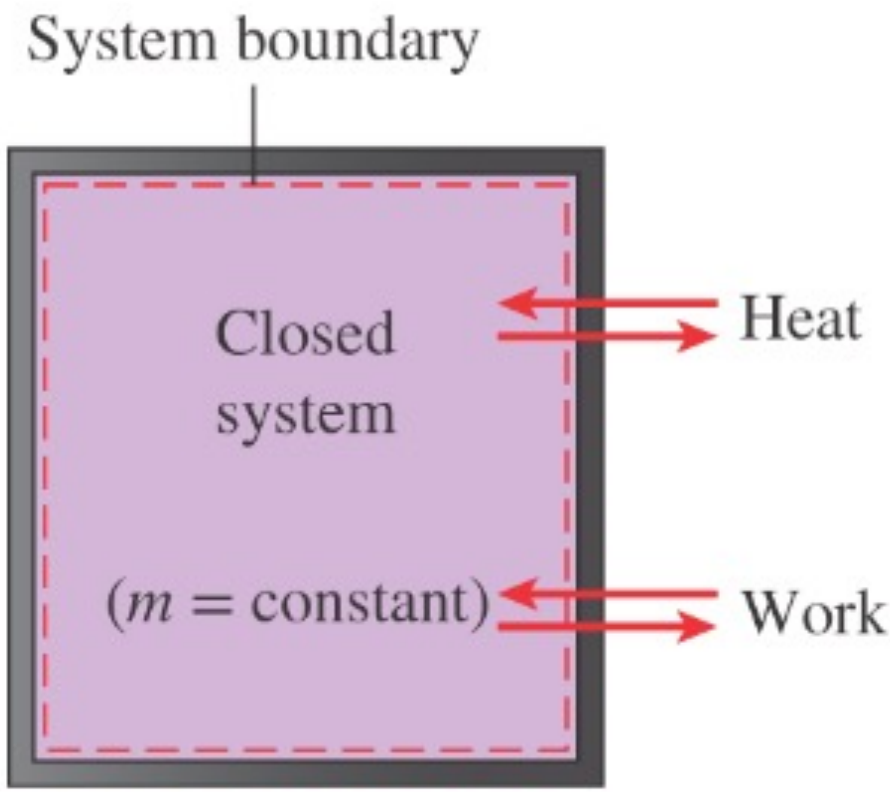


$\dot{W}_{max} = \dot{m}\Delta e_{mech} = \dot{m}g(z_1 - z_4) = \dot{m}gh$
since $P_1 \approx P_4 = P_{atm}$ and $V_1 = V_4 \approx 0$

$\frac{P}{\rho}$: flow work (it is per unit mass)

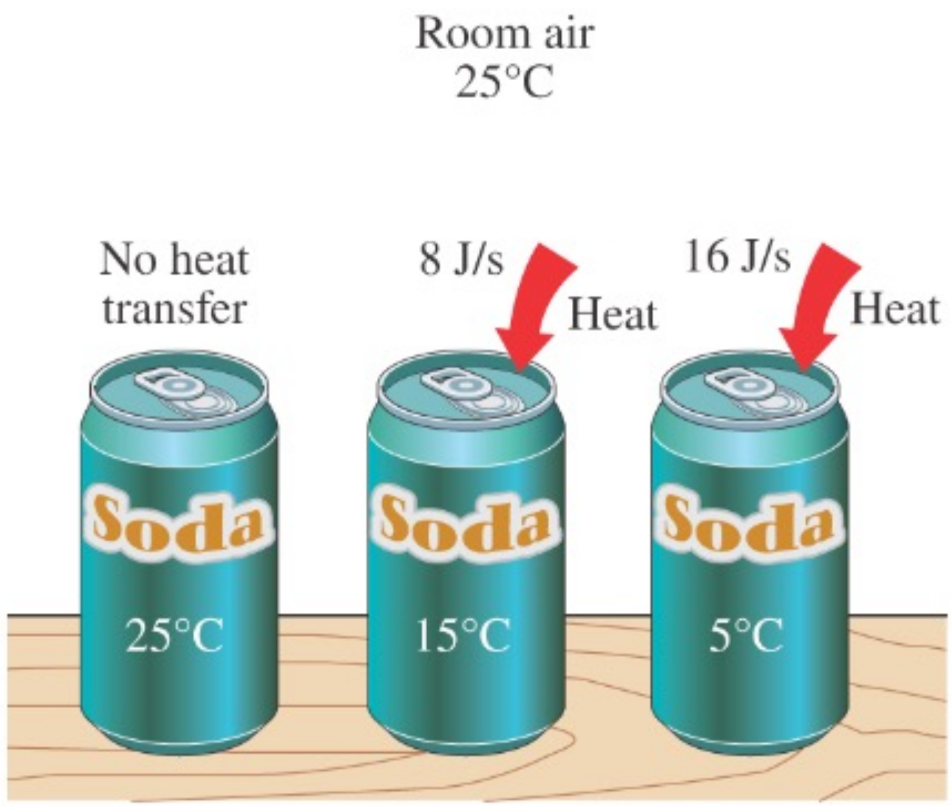
Recap

- Energy can cross the boundary of a closed system in two distinct forms:
  - ❑ Heat
  - ❑ Work



Recap

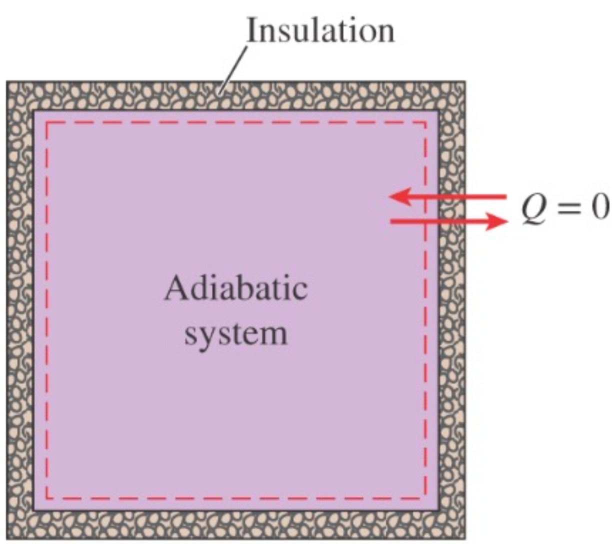
- Heat is defined as the form of energy that is transferred between two systems (or a system and its surrounding) by virtue of a temperature difference



Recap

- A process during which there is no heat transfer is called an adiabatic process.

- Two ways for a system to be adiabatic:
  - ❑ The system is well insulated so that only a negligible amount of heat can pass through the boundary
  - ❑ Both the system and the surroundings are at the same temperature and therefore there is no driving force for heat transfer



Recap

- Work like heat is an energy interaction between a system and its surrounding

- Remember heat is associated with temperature difference

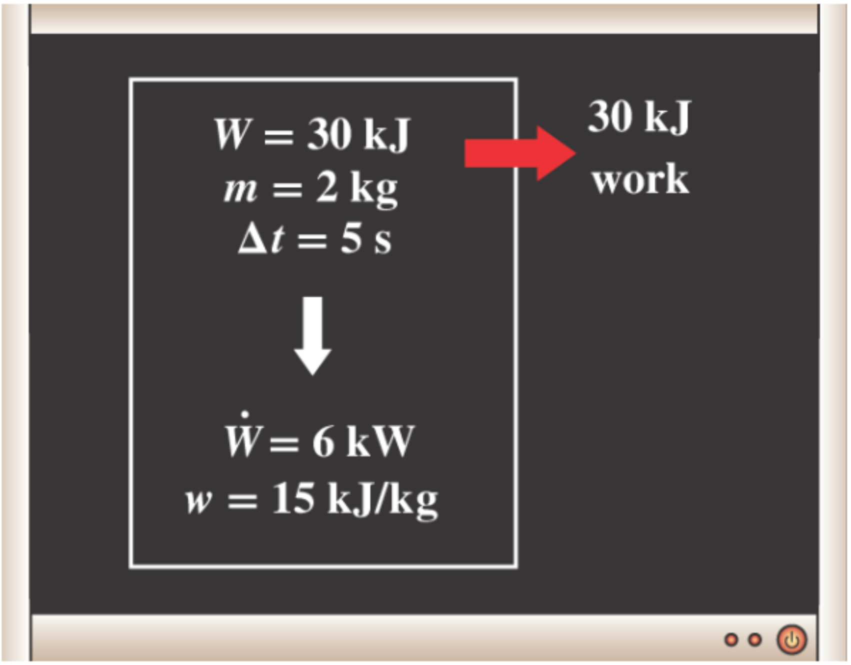
- Work is the energy transfer associated with a force acting through a distance (e.g., a rising piston, rotating shaft, electric wire crossing the system boundaries)

$$w = \frac{W}{m} \qquad (\frac{kJ}{kg})$$

ENERGY TRANSFER BY WORK

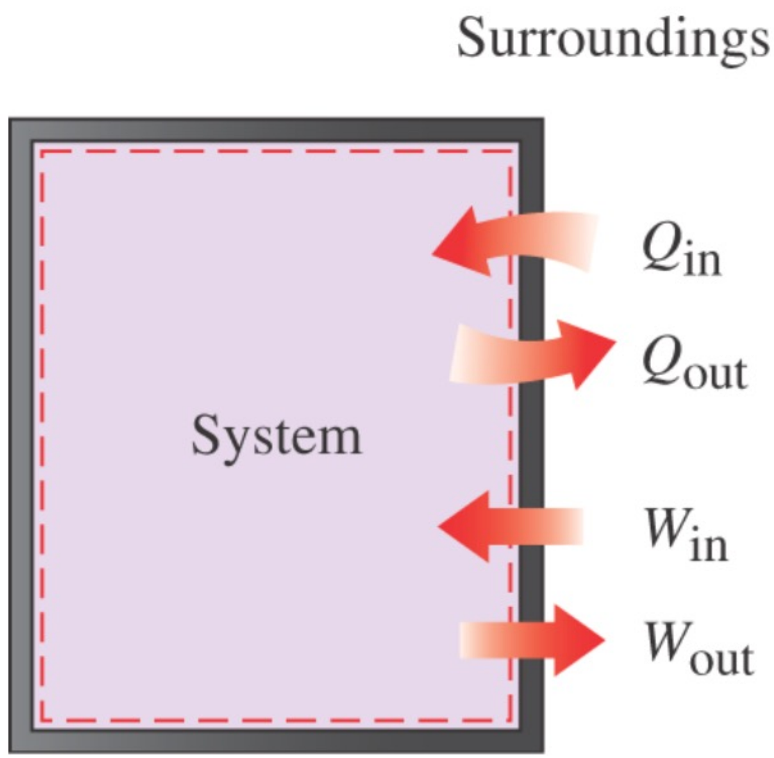
Energy Transfer by Work

- Work done per unit time is called power and is donated with $\dot{W}$
- The unit of power is kJ/kg or kW



Energy Transfer by Work

- Heat and work are directional quantities



Heat transfer to a system and work done any a system are positive, heat transfer from a system and work done on a system are negative

Energy Transfer by Work

- A quantity that is transferred to or from a system (e.g., heat and work) during an interaction is not a property since the amount of such a quantity depends on more than just the state of the system

Energy Transfer by Work

- Work and heat have similarities:
  - ❑ Both are recognized at the boundaries of a system as they cross the boundaries
  - ❑ Systems possess energy but not heat or work
  - ❑ Both are associated with a process not a state (unlike properties heat and work has not meaning at a state)
  - ❑ Both are *path functions* (i.e., their magnitudes depend on the path followed during a process as well as the ends states)

Energy Transfer by Work

- Path functions have inexact differentials designated by the symbol δ (e.g., δW or δQ not $\mathrm{d}W$ or $\mathrm{d}Q$)

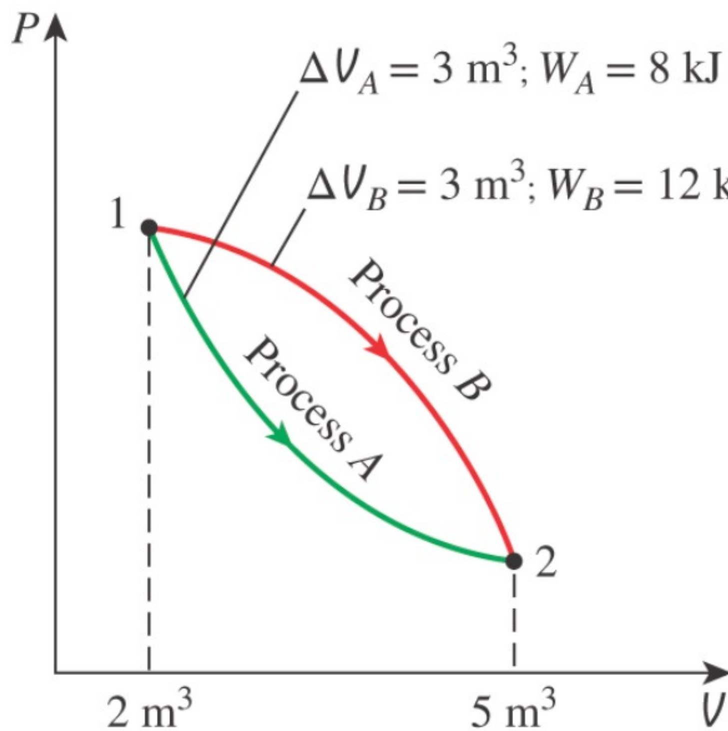
- Properties are point functions (i.e., they depend on the state only and not on how a system reaches the state), meaning they have exact differentials

$$\int_1^2 dV = V_2 - V_1 = \Delta V$$

$$\int_1^2 \delta W = W_{12} \; (not \; \Delta W)$$

Energy Transfer by Work

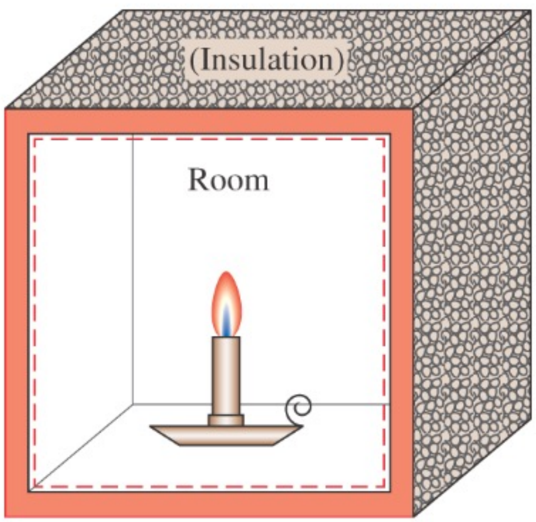
- Total work is obtained by following the process path and adding differential amounts of work (δW) done along the way
- The integral of δW is not $W_2 - W_1$ (Work is not a property!)
- Systems do not posses work at a state



CLASS ACTIVITY

Class Activity

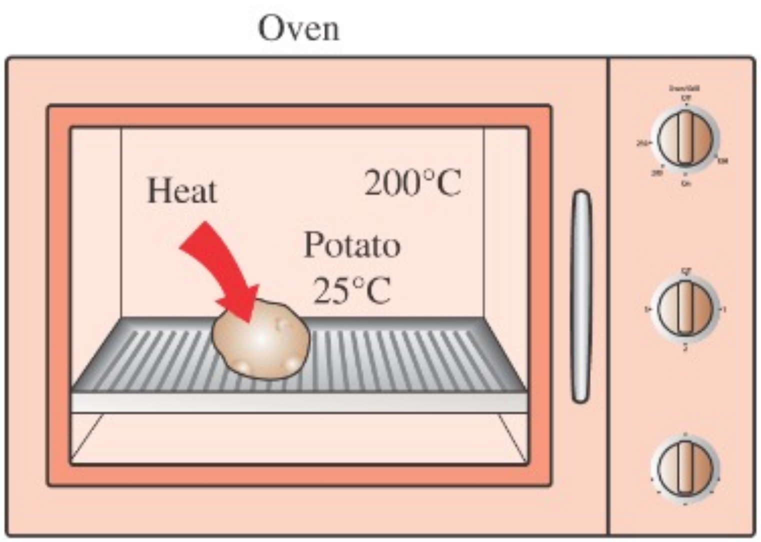
- A candle is burning in a well-insulated room. Taking the room (the air plus the candle) as the system, determine
  - ❑ If there is any heat transfer during the burning process
  - ❑ If there is any change in the internal energy of the system



CLASS ACTIVITY

Class Activity

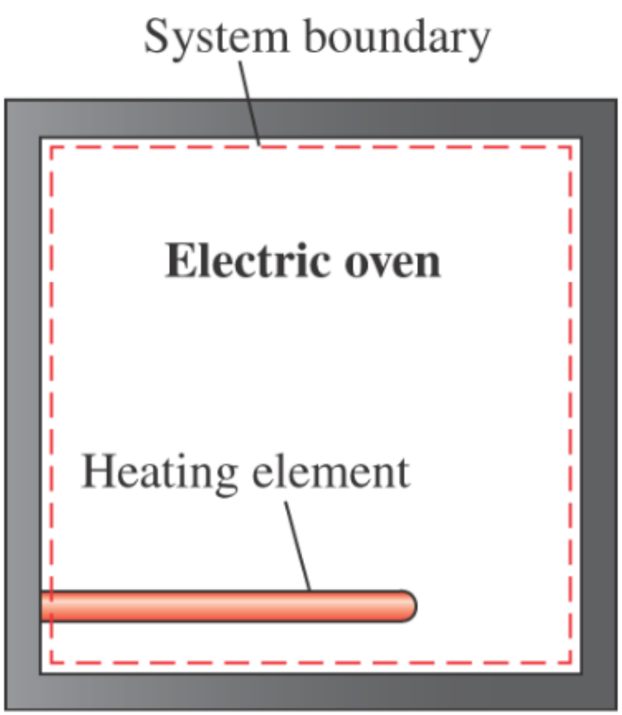
- A potato initially at room temperature (25 °C) is being baked in an oven that is maintained at 200 °C. Is there any heat transfer during this baking process.



CLASS ACTIVITY

Class Activity

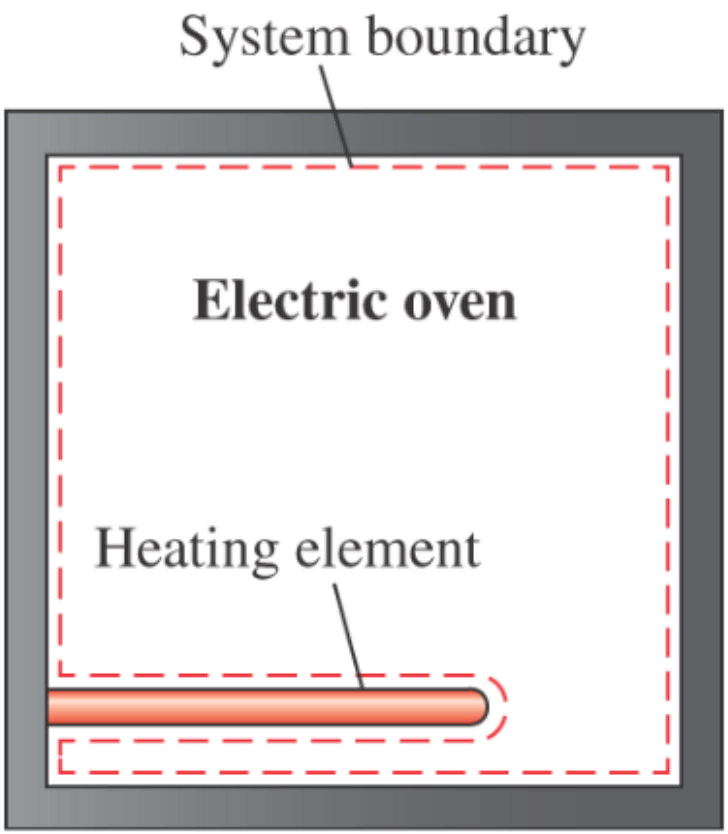
- A well-insulated electric oven is being heated through its heating element. If the entire oven, including the heating element is taken to be the system, determine whether there is a heat or work interaction.



CLASS ACTIVITY

Class Activity

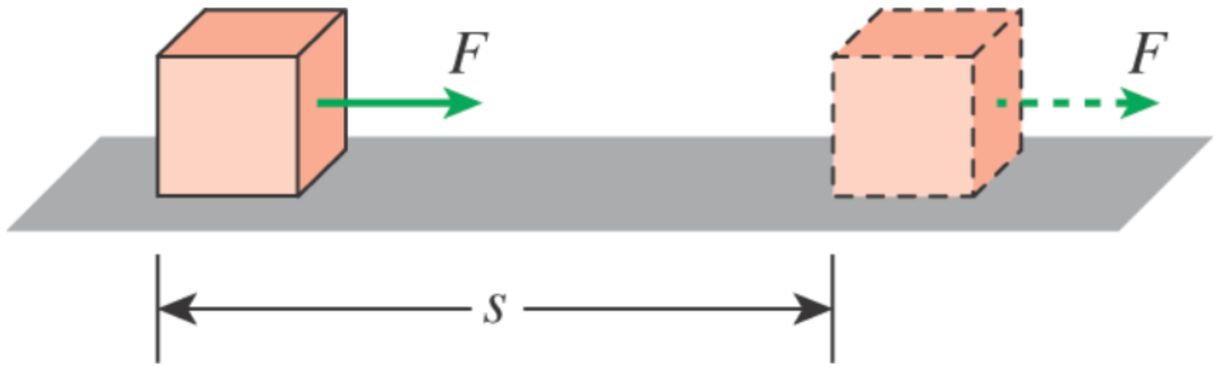
- Answer the previous class activity is the air is considered without the heating element.



MECHANICAL FORMS OF WORK

Mechanical Forms of Work

- Work is related to a force acting through a distance



$$W = Fs \qquad (kJ)$$

$$W = \int_1^2 F ds \qquad (kJ)$$

Mechanical Forms of Work

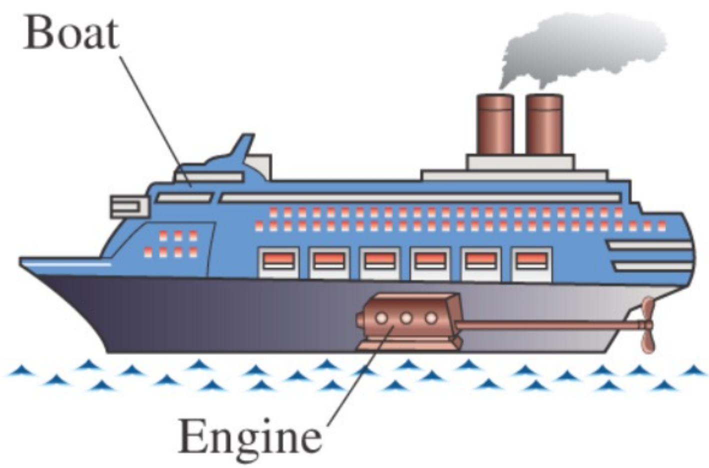
- The work done on a system by an external force acting in the direction of motion is negative and work done by a system against an external force acting in the opposite direction to motion is positive

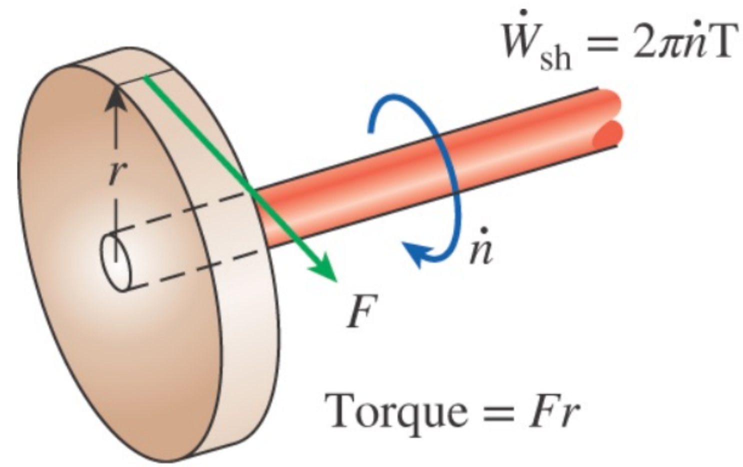
Mechanical Forms of Work

- Two requirements for a work interaction between a system and its surrounding to exist
  - ❑ There must be a force acting on the boundary
  - ❑ The boundary must move

Mechanical Forms of Work

- Shaft work





$$T = Fr$$

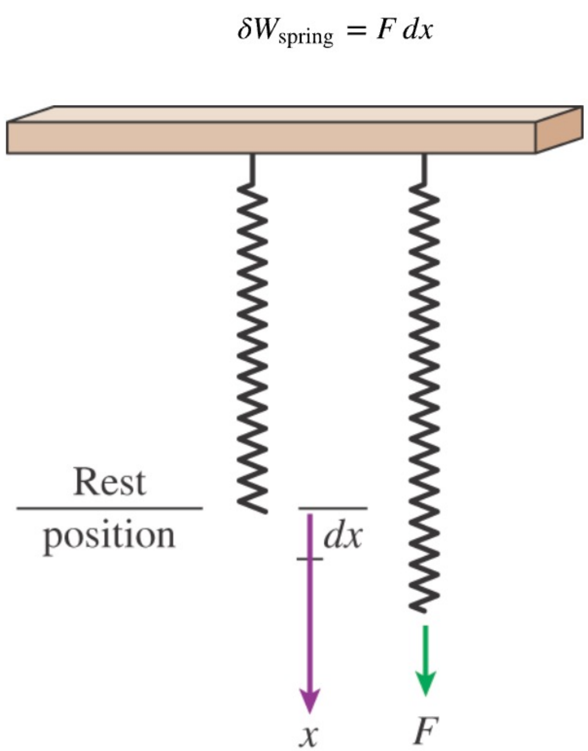
$$s = (2\pi r)n$$

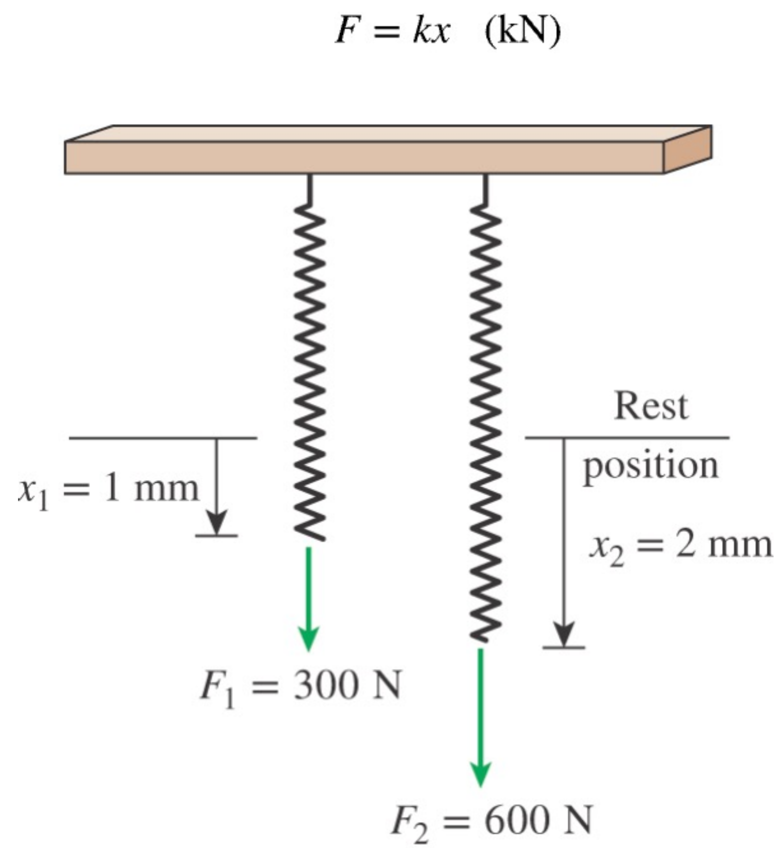
$$W_{sh} = Fs = \left(\frac{T}{r}\right)(2\pi r)n = 2\pi nT \qquad (kJ)$$

$$\dot{W}\_sh = Fs = 2\pi\dot{n}T \qquad (kW)$$

Mechanical Forms of Work

- Spring work



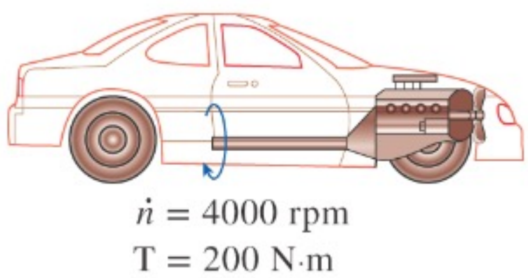


$$W_{spring} = \frac{1}{2}k(x_2^2 - x_1^2)$$

CLASS ACTIVITY

Class Activity

- Determine the power transmitted through the shaft a car when the torque applied is 200 N.m and the shaft rotates at a rate of 4000 revolutions per minute (rpm)



CLASS ACTIVITY

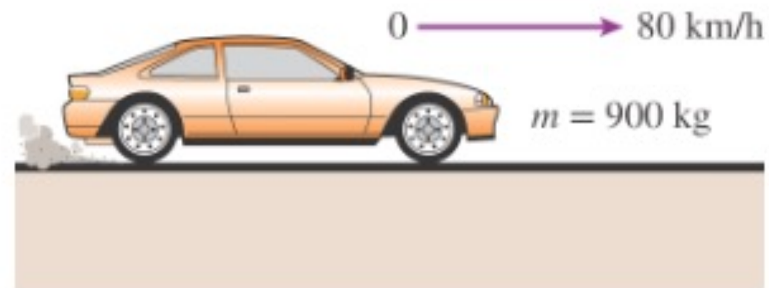
Class Activity

- A man whose mass is 100 kg pushes a cart whose mass, including its contents, is 100 kg up a ramp that is inclined at an angle of 20 from the horizontal. The local gravitational acceleration is 9.81 m/s^2. Determine the work in kJ needed to move along this ramp a distance of 100 m considering (a) the man and (b) the cart and its contents as the systems

CLASS ACTIVITY

Class Activity

- Determine the power required to accelerate a 900 kg car shown in the image from reset to a velocity of 80 km/h in 20 s on a level road

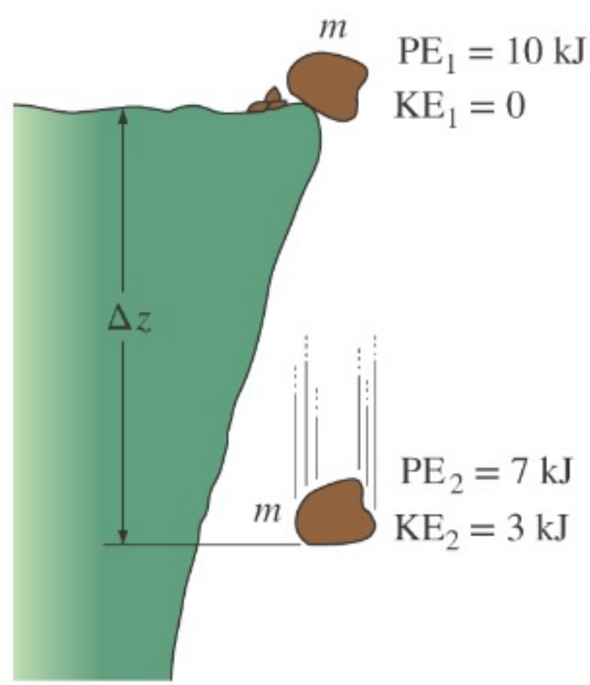


THE FIRST LAW OF THERMODYNAMICS

The First Law of Thermodynamics

- The first law of thermodynamics or also known as the conservation of energy principles:

Energy can be neither created nor destroyed during a process; it can only change forms



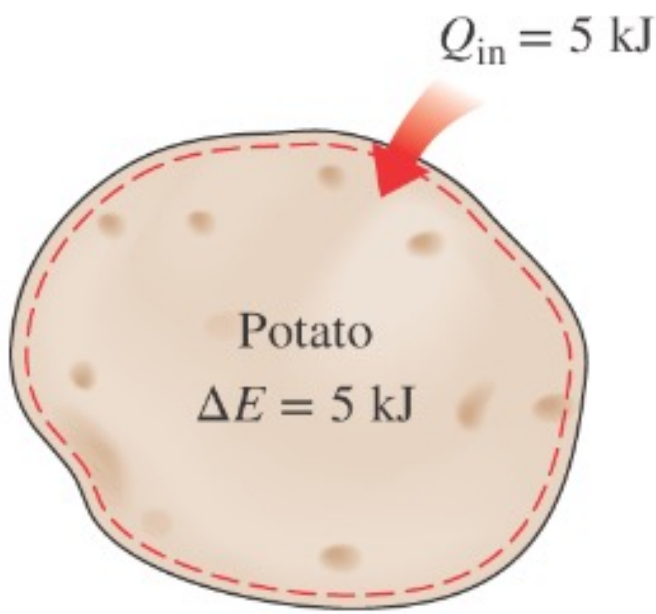
The First Law of Thermodynamics

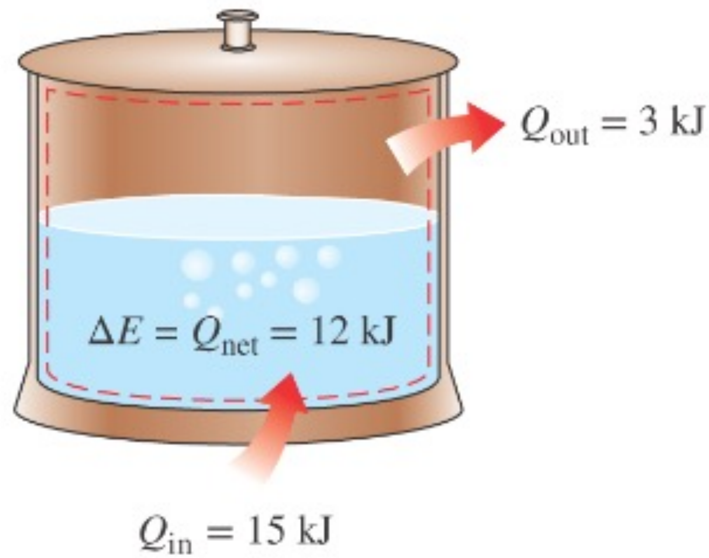
- Consider a system undergoing a series of adiabatic processes from a specified state 1 to another specified state 2.

For all adiabatic processes between two specified states of a closed system the net work done is the same regardless of the nature of the closed system and the details of the process

The First Law of Thermodynamics

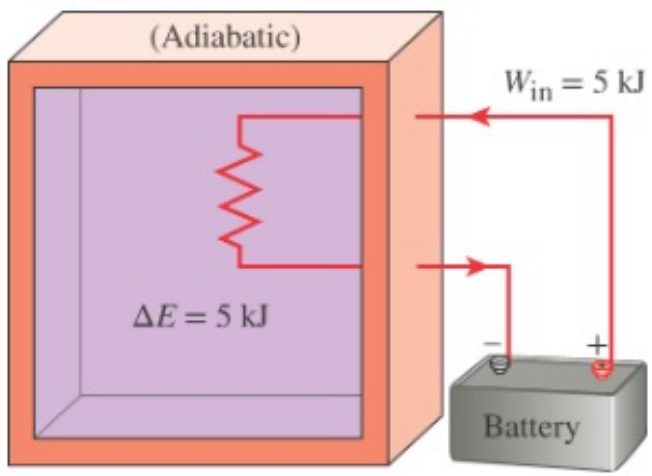
- Example processes that involve heat transfer but no work interactions:

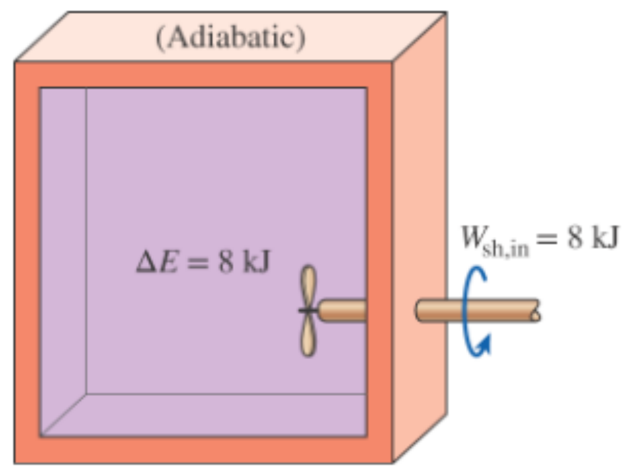


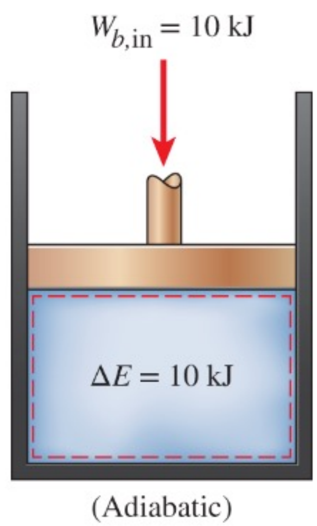


The First Law of Thermodynamics

- Example processes that involve work but no heat transfer interactions:

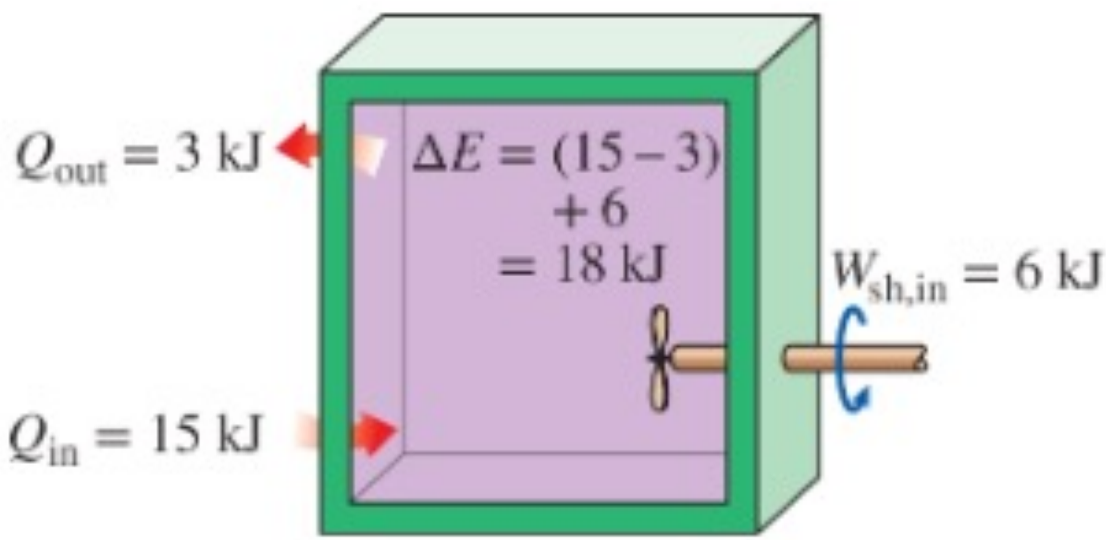






The First Law of Thermodynamics

- Example of heat and work:



The First Law of Thermodynamics

- The net change (increase or decrease) in the total energy of the system during a process is equal to the difference between the total energy entering and the total energy leaving the system during the process

$$(Total\ energy\ entering\ the\ system) - (Total\ energy\ leaving\ the\ system) = (Change\ in\ the\ total\ energy\ of\ the\ sysem)$$

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

This is known as the energy balance

The First Law of Thermodynamics

- Energy change of a system ΔE_{system}

$$Energy\ change = Energy\ at\ final\ state\ - Energy\ at\ initial\ state$$

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

Energy is a property, and the value of a property does not change unless the state of the system changes

The First Law of Thermodynamics

- Energy change of a system ΔE_{system}

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

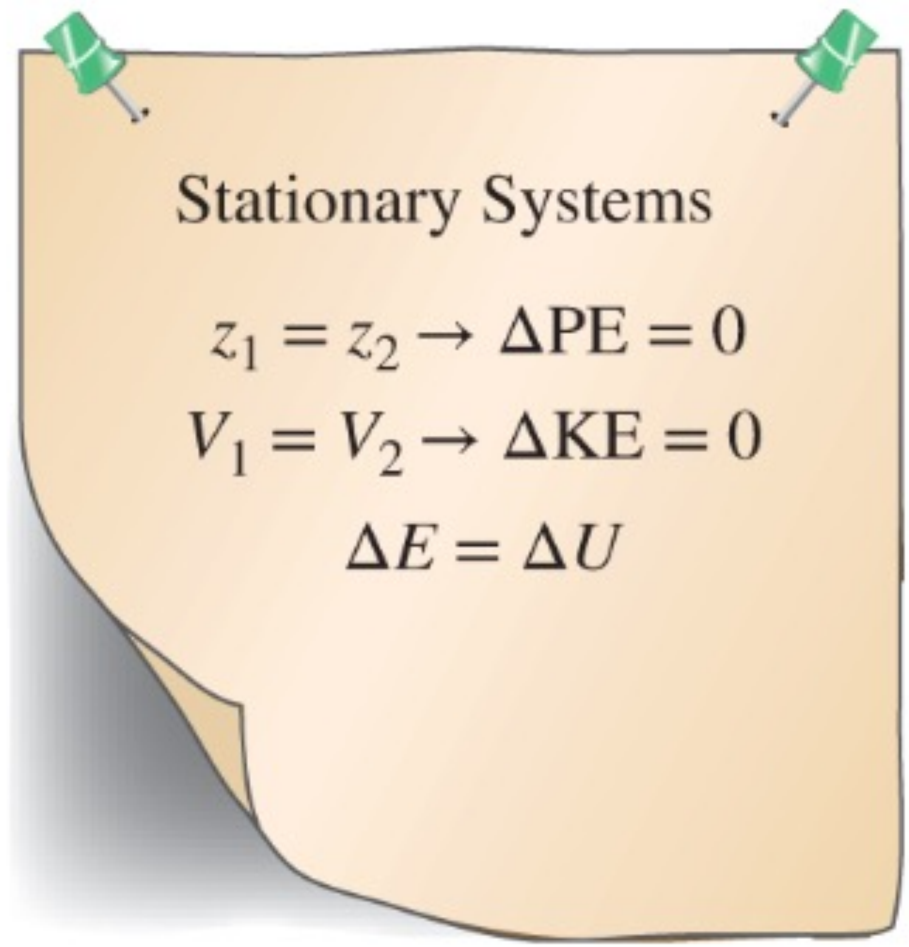
$$\Delta U = m(u_2 - u_1)$$

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

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

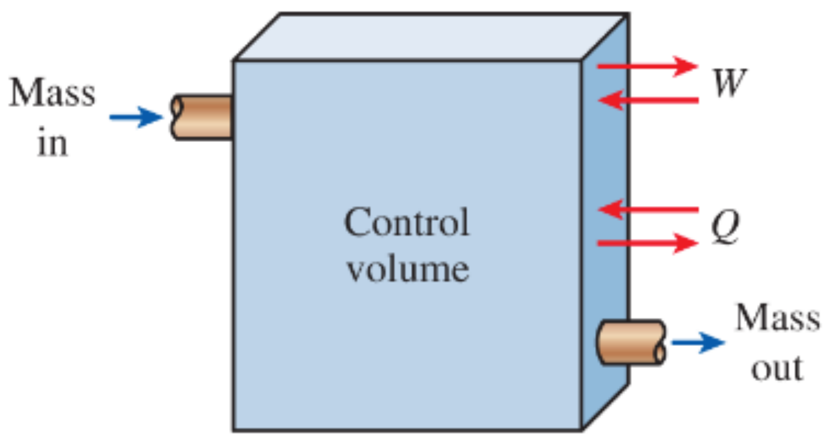
The First Law of Thermodynamics

- Most systems encountered in practice are stationary:



The First Law of Thermodynamics

- Mechanisms of energy transfer, E_{in} and E_{out}:
  - ❑ Energy can be transferred to or from in three forms: heat, work, and mass flow
  - ❑ Each energy interactions 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 fixed mass or closed system are heat transfer and work



The First Law of Thermodynamics

- Heat Transfer (Q):
  - Heat transfer to a system (heat gain) increases the energy of the molecules and thus the energy of the system
  - Heat transfer from a system (heat loss) decreases the energy since the energy transferred out as heat comes from the energy of the molecules of the system

The First Law of Thermodynamics

- Work (W):
  - An energy interaction that is not caused by a temperature different between a system and its surroundings (e.g., a rising piston, a rotating shaft, an electrical wire)
  - Work transfer to a system (i.e., work done on a system) increases the energy of the system
  - Work transfer from a system (i.e., work done by the system) decreases the energy of the system since the energy transferred out as work comes from the energy contained in the system
    - e.g., car engines, hydraulic, steam/gas turbines produce work
    - e.g., compressors, pumps, mixers consume work

The First Law of Thermodynamics

- Mass flow (m)
  - Mass flow in and out of the system serves as an additional mechanism of energy transfer
  - When mass enters a system, the energy of the system increases because mass carries energy with it (in fact, mass is energy)
  - When some mass leaves the system, the energy contained within the system decreases because the departing mass takes out some energy with it
  - When hot water is taken out a water heater and is replaced by the same amount of cold water, the energy content of the hot-water tank (the control volume) decreases as a result of this mass interaction

The First Law of Thermodynamics

- We can sum the heat, work, and mass, and the next transfer

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

Net energy transfer by heat, work, and mass

Change in internal, kinetic, potential, …, energies