CAE 208 / MMAE 320: Thermodynamics

Fall 2023

September 14, 2023

Energy, energy transfer, and energy analysis (3)

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ANNOUNCEMENTS

Announcements

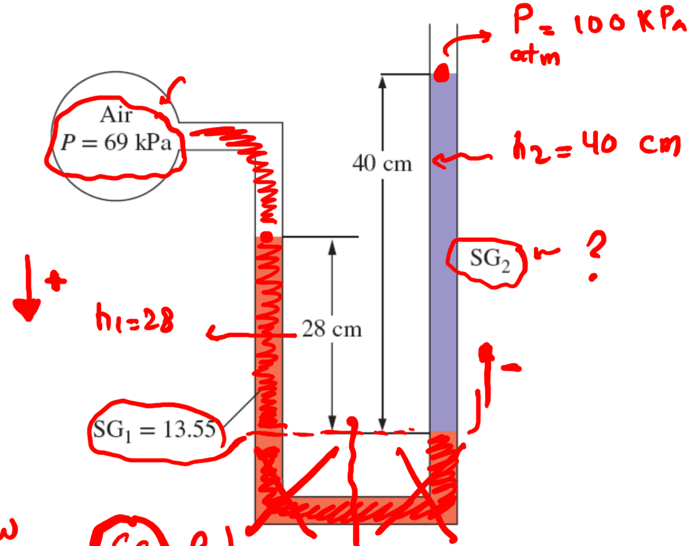
- Assignment 3 is posted
- How many of you reviewed the recording?

Announcements

- Pay attention to the units

Manometer

Solution:



$\rho_1 = (SG_1)\times\rho_w$, $\rho_2 = SG_2 \times \rho_w$

$$P_{air} + \rho_1 g h_1 - \rho_2 g h_2 = P_{atm} \rightarrow SG_2 = \frac{P_{air} - P_{atm}}{\rho_w g h_2} + \frac{SG_1 \times h_1}{h_2}$$

$$SG_2 = \frac{(69-100)\,KPa}{10^3 \frac{Kg}{m^3} \times 10\, m/s^2 \times 0.4\, m} + 13.55 \times \frac{0.28\, m}{0.4\, m} \approx 1.59 \leftarrow SG_2$$

RECAP

Recap

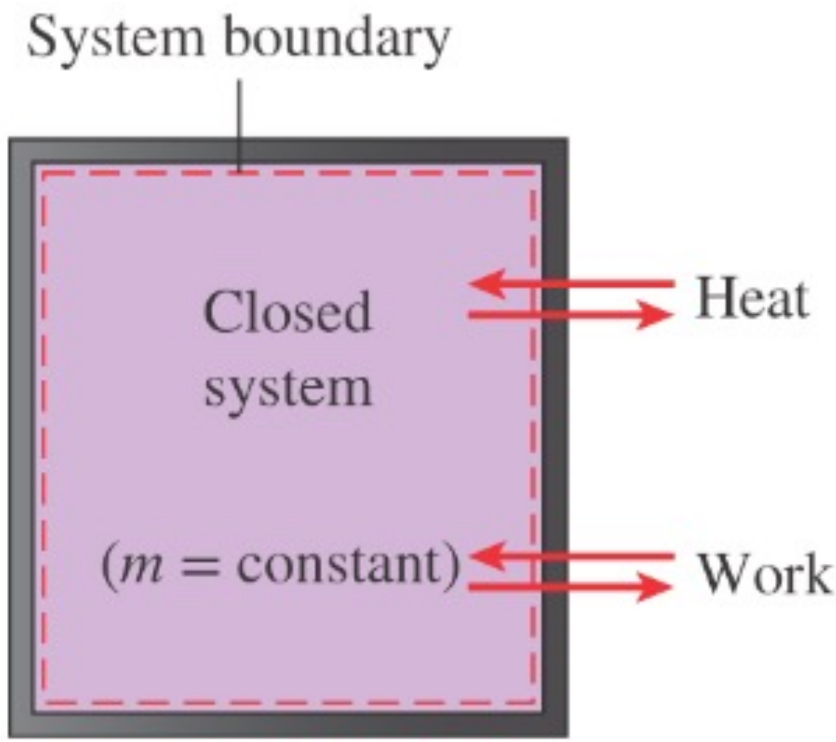
- Total energy of a system in the absence of magnetic, electric, and surface tension effects is

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

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

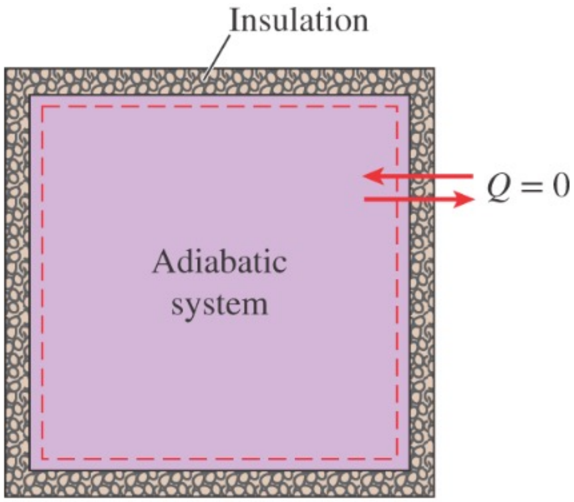
Recap

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



Recap

- 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

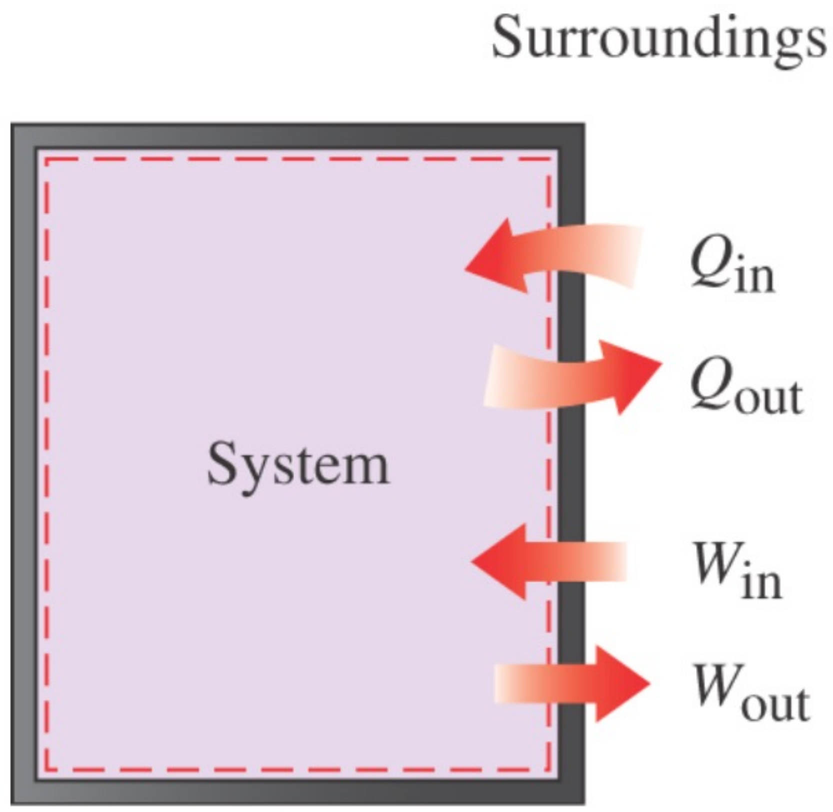


Recap

- 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

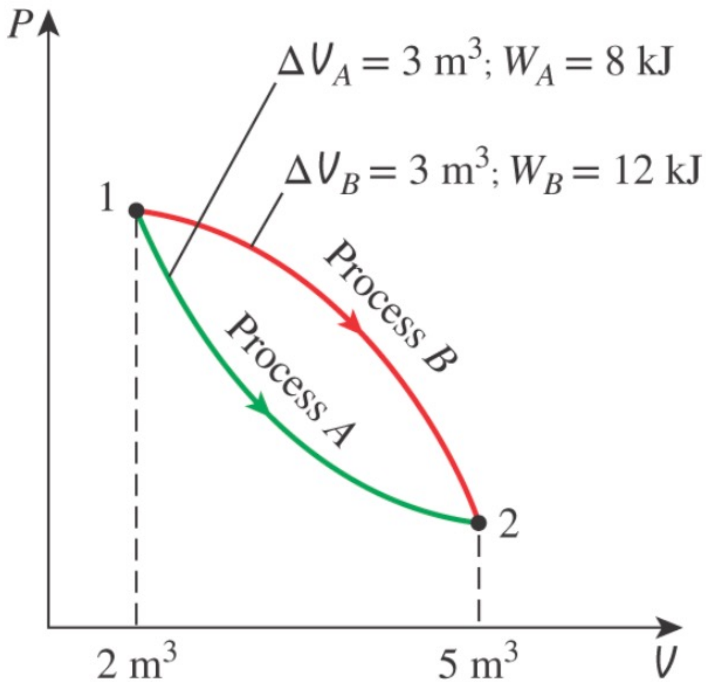
Recap

- Heat and work are directional quantities



Recap

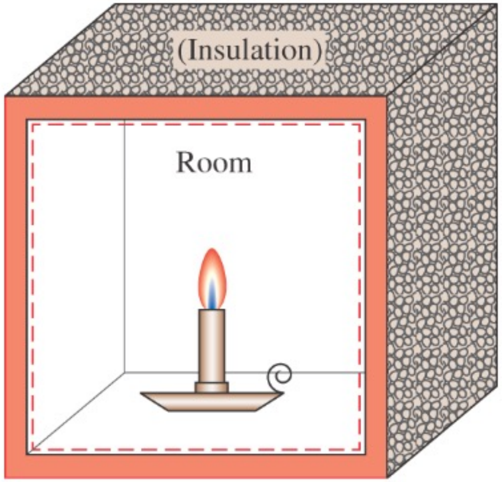
- Systems do not posses work at a state



CLASS ACTIVITY

Class Activity

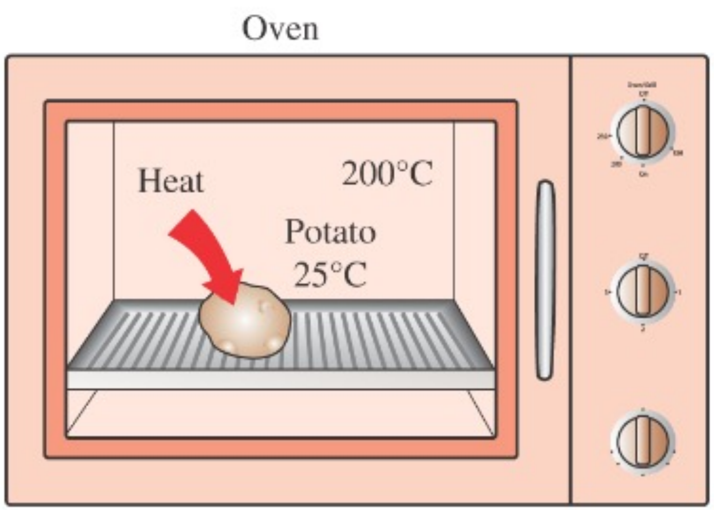
- A candle is burning in a well-insulated room. Taking the room (the air plus the candle) as the system, determine
  - ❑ If there is any heat transfer during the burning process
  - ❑ If there is any change in the internal energy of the system



CLASS ACTIVITY

Class Activity

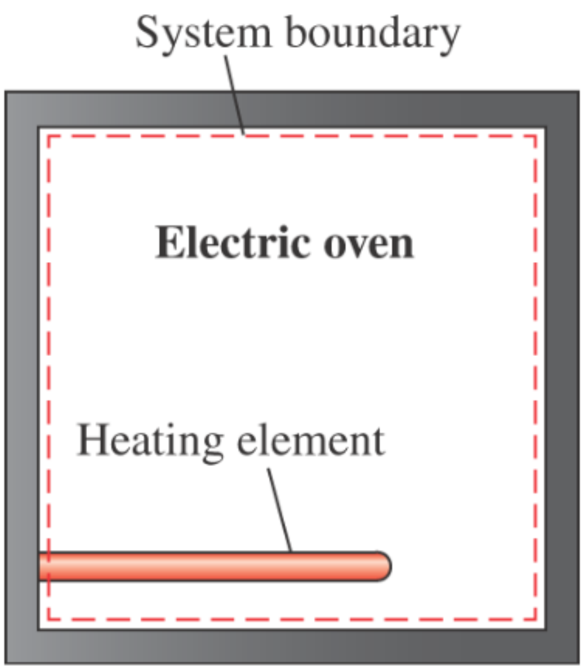
- A potato initially at room temperature (25 °C) is being baked in an oven that is maintained at 200 °C. Is there any heat transfer during this baking process.



CLASS ACTIVITY

Class Activity

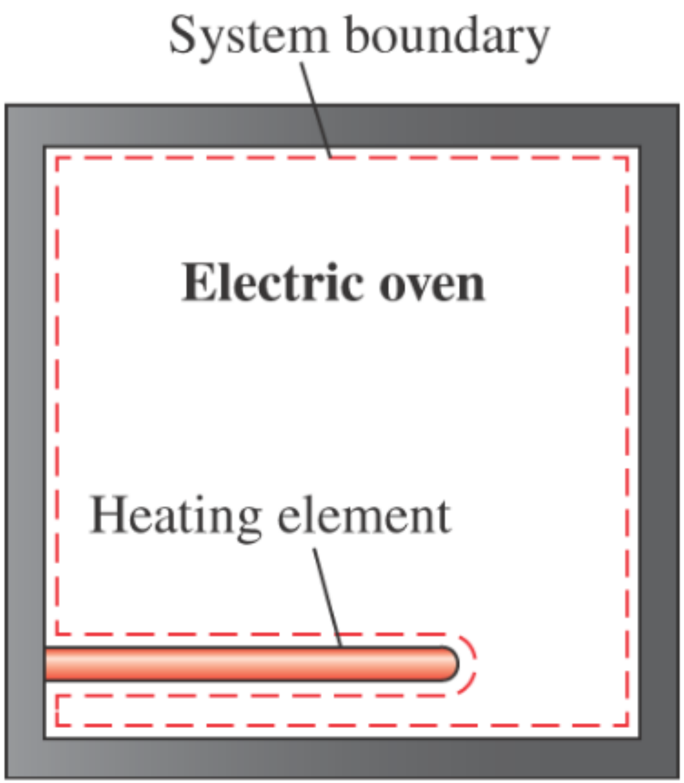
- A well-insulated electric oven is being heated through its heating element. If the entire oven, including the heating element is taken to be the system, determine whether there is a heat or work interaction.



CLASS ACTIVITY

Class Activity

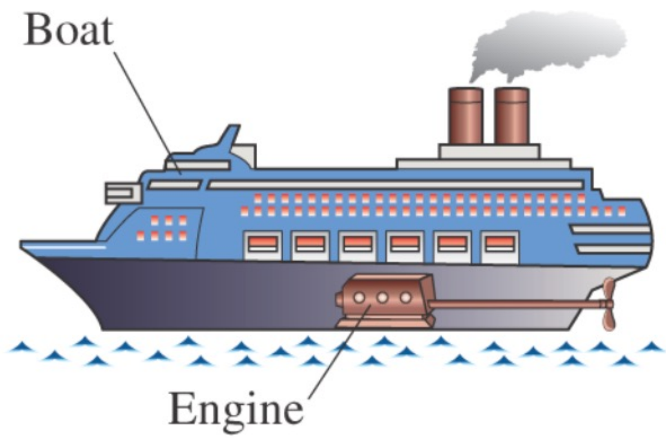
- Answer the previous class activity is the air is considered without the heating element.

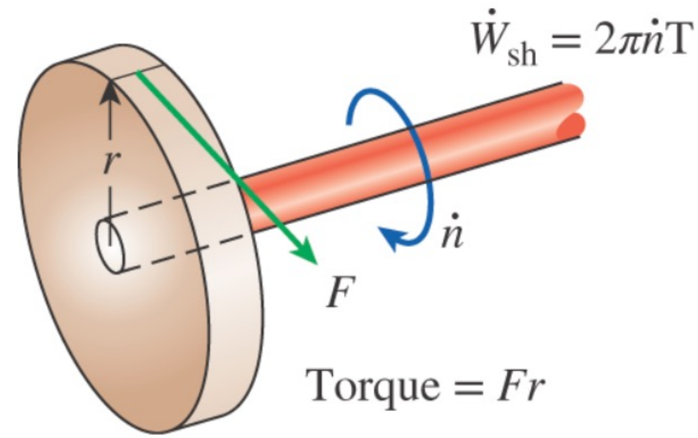


MECHANICAL FORMS OF WORK

Mechanical Forms of Work

- Shaft work





$$T = Fr$$

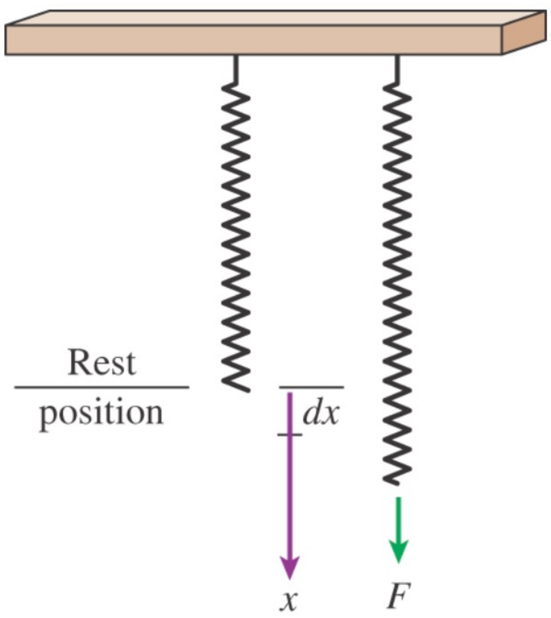
$$s = (2\pi r)n$$

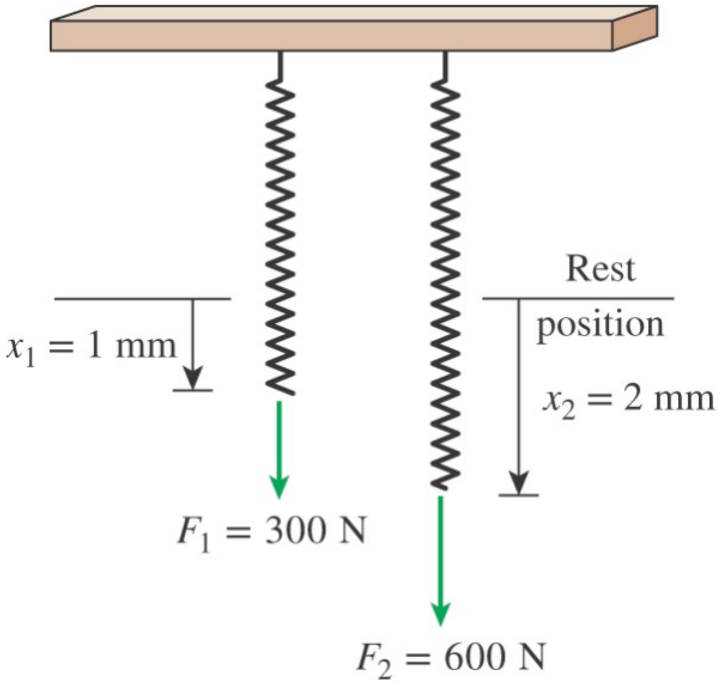
$$W_{sh} = Fs = \left(\frac{T}{r}\right)(2\pi r)n = 2\pi nT \qquad (kJ)$$

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

Mechanical Forms of Work

- Spring work



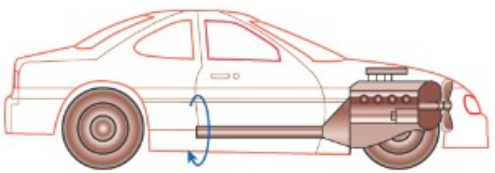


$$W_{spring} = \frac{1}{2}k(x_2^2 - x_1^2)$$

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

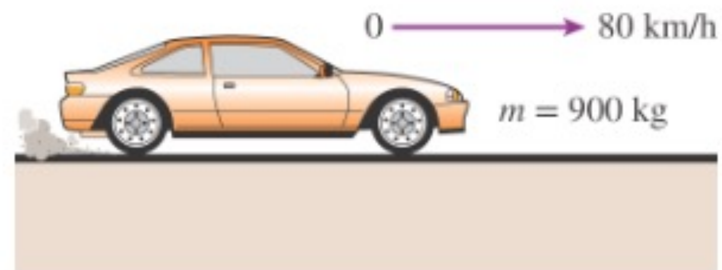
Class Activity

- 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

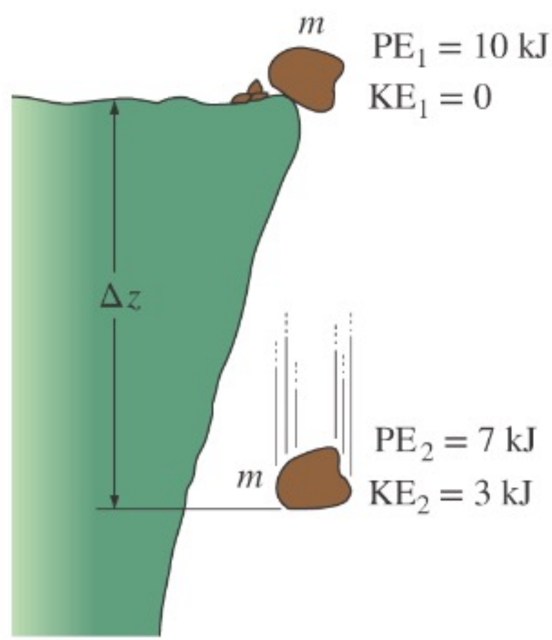


THE FIRST LAW OF THERMODYNAMICS

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



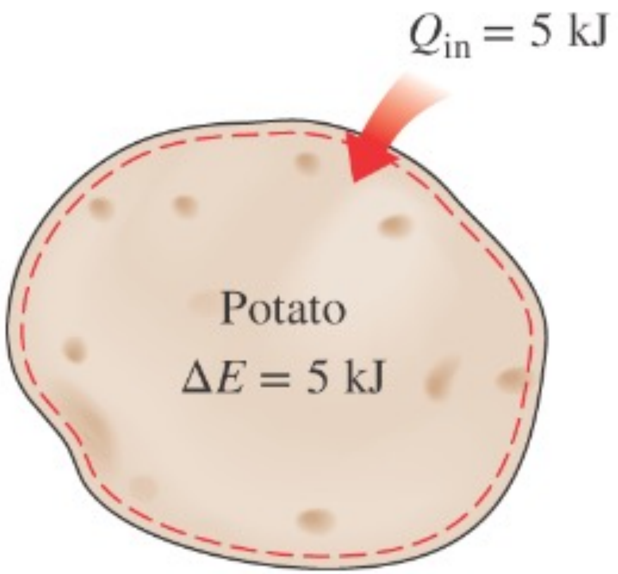
The First Law of Thermodynamics

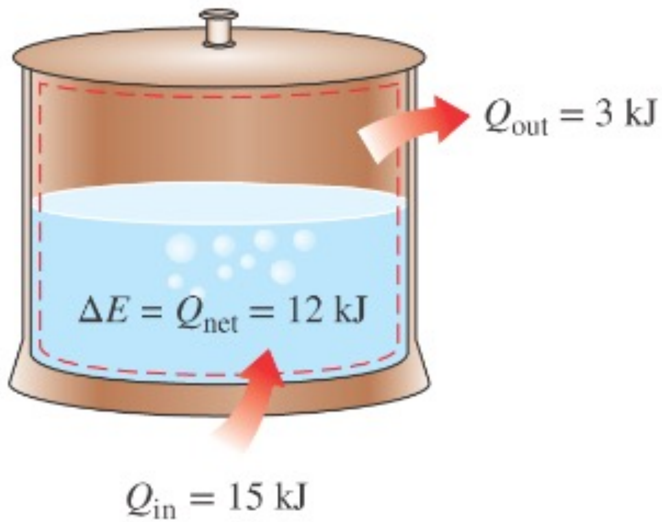
- Consider a system undergoing a series of adiabatic processes from a specified state 1 to another specified state 2.

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

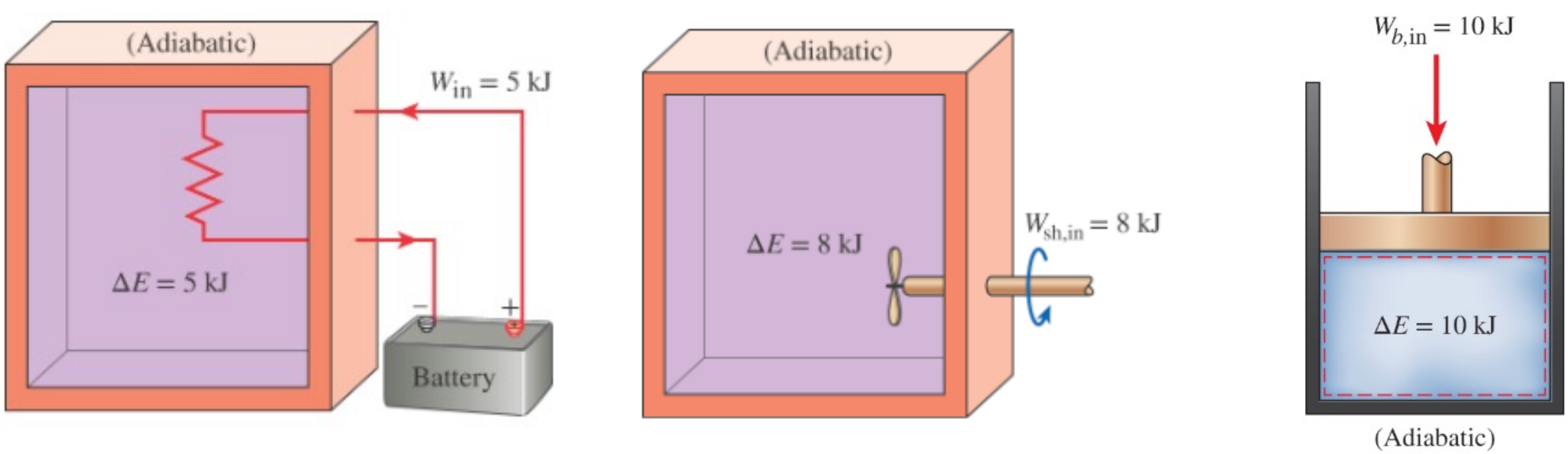
- Example processes that involve heat transfer but no work interactions:





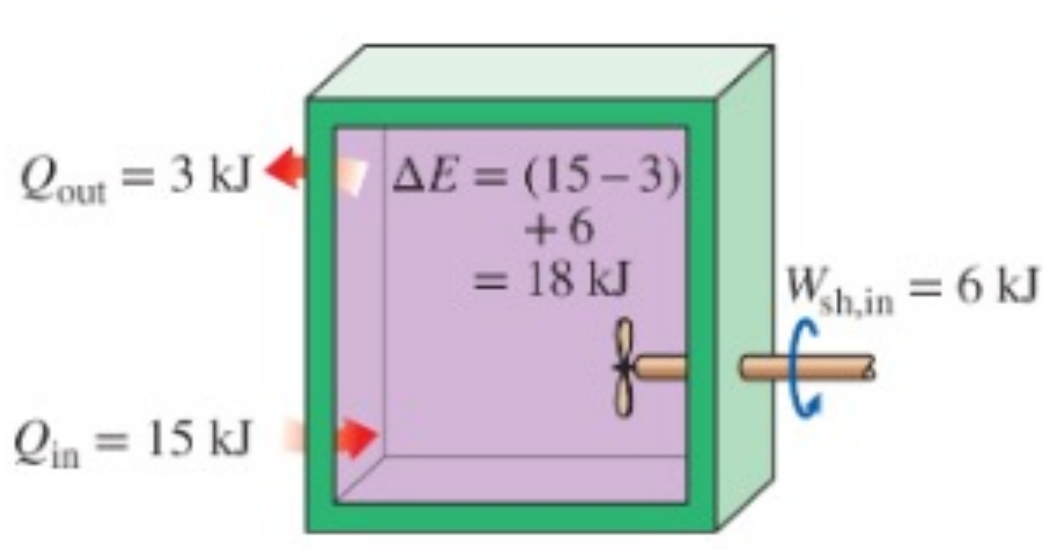
The First Law of Thermodynamics

- 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}

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

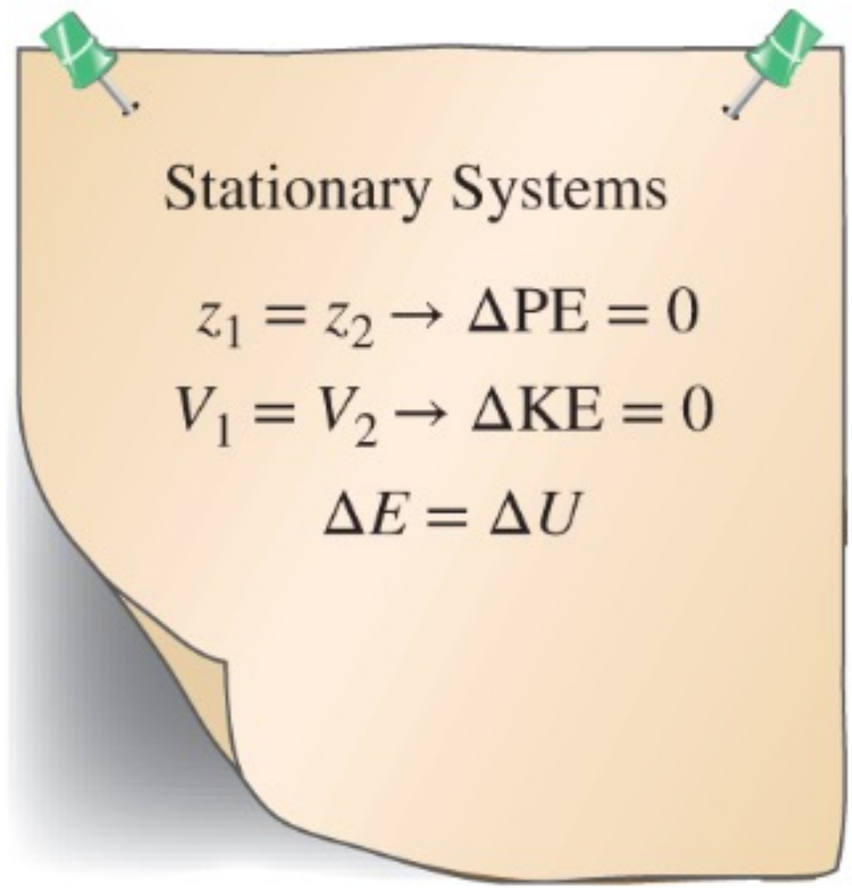
$$\Delta U = m(u_2 - u_1)$$

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

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

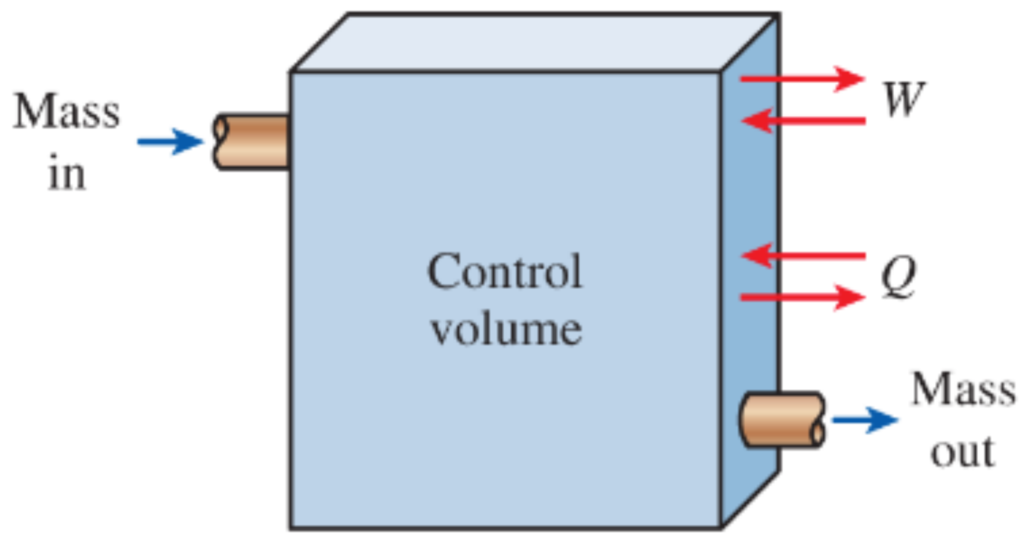
The First Law of Thermodynamics

- Most systems encountered in practice are stationary:



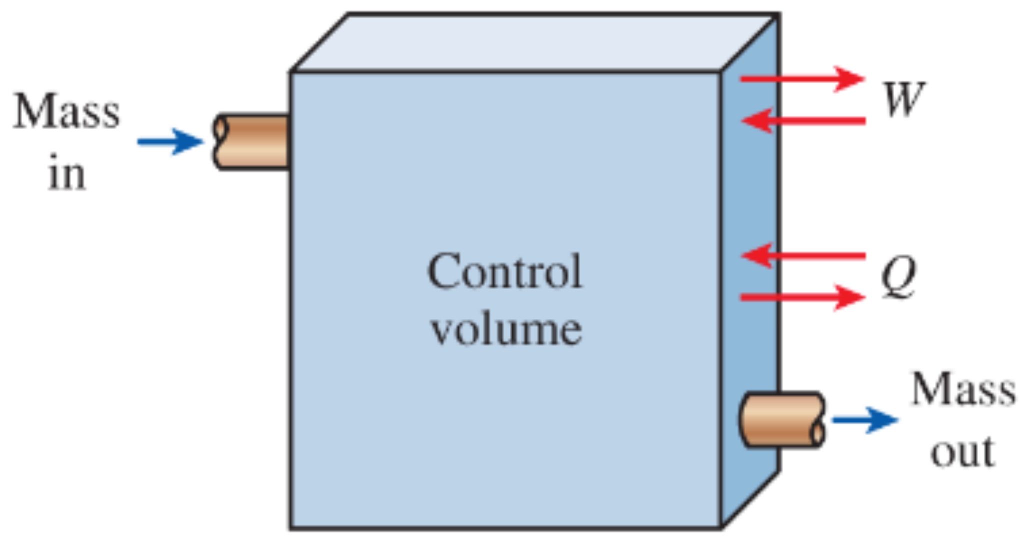
The First Law of Thermodynamics

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



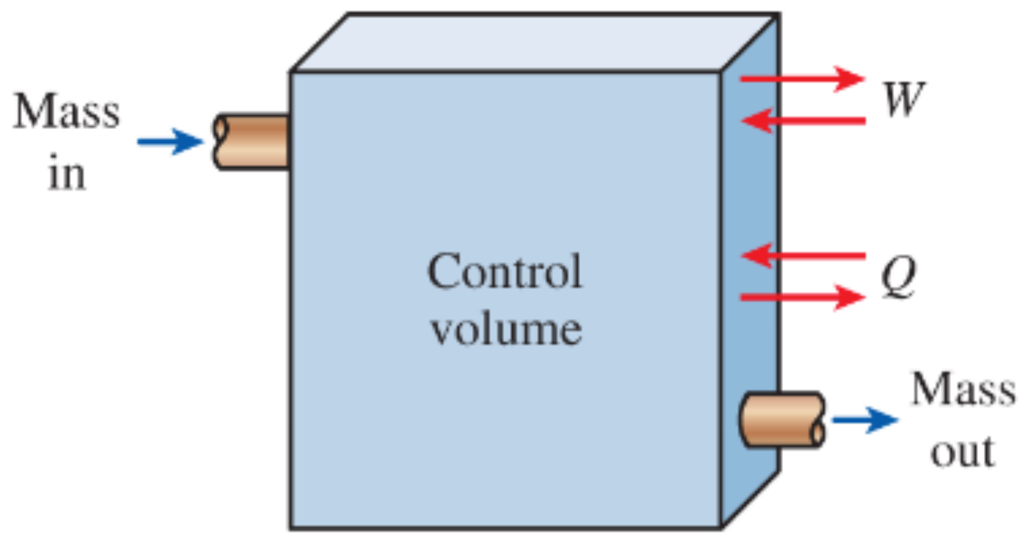
The First Law of Thermodynamics

- Mechanisms of energy transfer, E_{in} and E_{out}:
  - ❑ 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 First Law of Thermodynamics

- Mechanisms of energy transfer, E_{in} and E_{out}:
  - ❑ 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

The First Law of Thermodynamics

- The energy balance can be expressed on a per unit mass basis as

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

The First Law of Thermodynamics

- For constant rates, we can write:

$$Q = \dot{Q}\Delta t$$

$$W = \dot{W}\Delta t$$

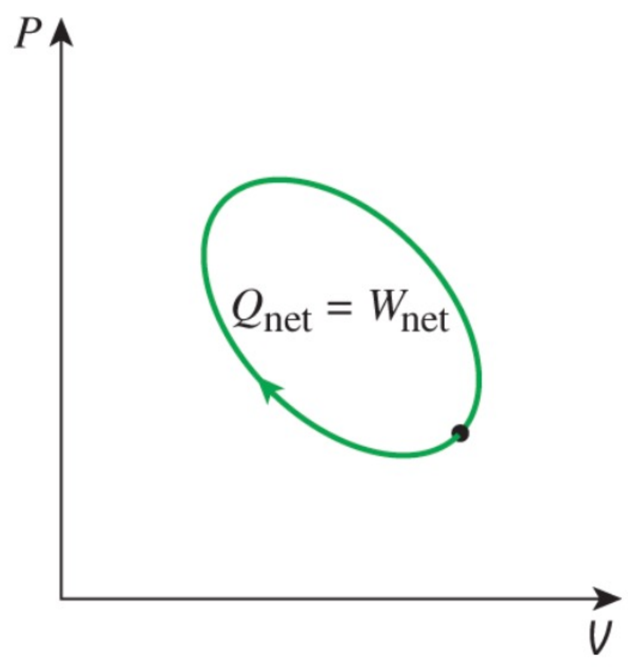
$$E = \left(\frac{dE}{dt}\right)\Delta t$$

The First Law of Thermodynamics

- For a closed system undergoing a cycle, the initial and final states are identical:

$$\Delta E = E_{in} - E_{out} = 0 \quad \rightarrow E_{in} = E_{out}$$

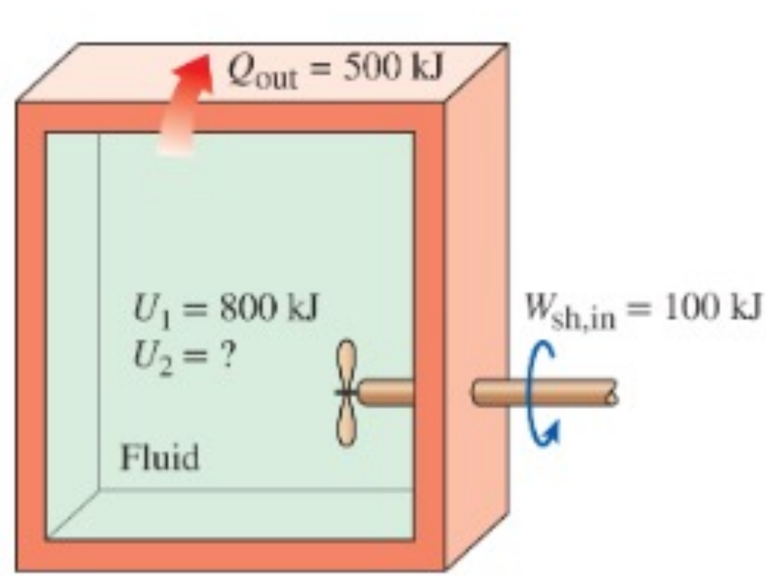
$$W_{net,out} = Q_{net,in} \quad \rightarrow \dot{W}_{net,out} = \dot{Q}_{net,in}$$



CLASS ACTIVITY

Class Activity

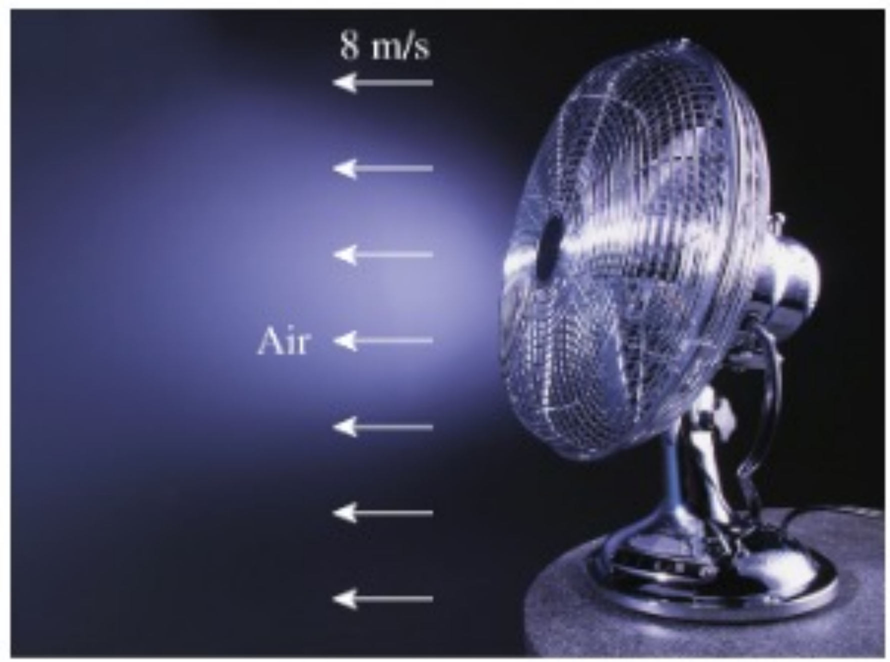
- A rigid tank contains a hot flid that is cooled while being stirred by a paddle wheel. Initially, the internal energy of the fluid is 800 kJ. During the cooling process, the fluid loses 500 kJ of heat, and the paddle wheel does 100 kJ of work on the fluid. Determine the final internal energy of the fluid. Neglect the energy stored in the paddle wheel



CLASS ACTIVITY

Class Activity

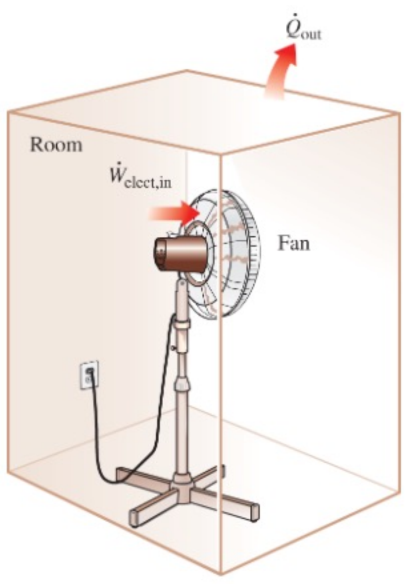
- A fan that consumes 20 W of electric power when operating is claimed to discharge air from a ventilated room at a rate of 1 kg/s at a discharge velocity of 8 m/s. Determine if this claim is reasonable



CLASS ACTIVITY

Class Activity

- A room is initially at the outdoor temperature of 25 °C. Now a large fan that consumes 200 W of electricity when running is turned on The heat transfer rate between the room and the outdoor air is given $\dot{Q} = UA(T_i - T_o)$ where U = 6 W/m2C is the overall heat transfer coefficient. A = 30 m2 is the exposed surface area of the room, Ti and To are the indoor and outdoor air temperatures, respectively. Determine the nd oor air temperature when steady operating are established



ENERGY CONVERSION EFFICIENCIES

Energy Conversion Efficiencies

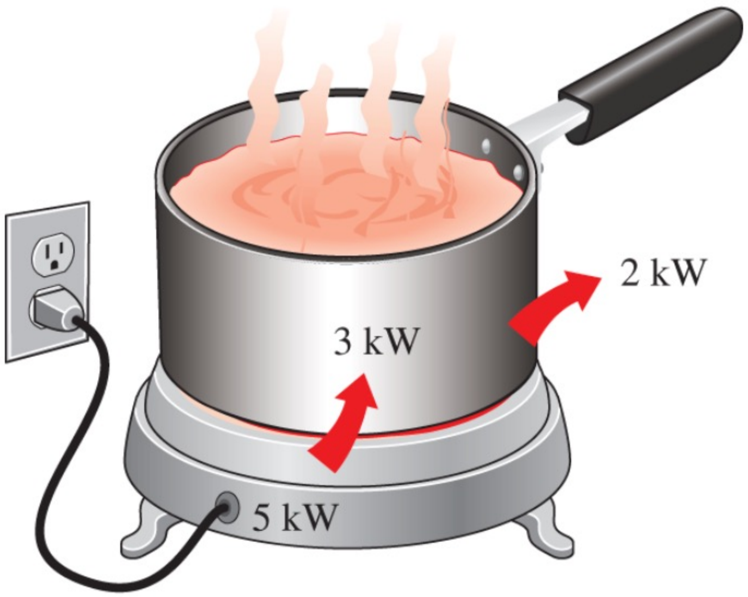
- Efficiency, in general, can be expressed in terms of the desired output and the required input as:

$$Efficiency = \frac{Desired\ output}{Required\ input}$$

Energy Conversion Efficiencies

- Efficiency of a cooking appliance

$$Efficiency = \frac{Energy\ Utilized}{Energy\ supplied\ to\ appliace}$$



Energy Conversion Efficiencies

- Summarize efficiencies:

$$\eta_{mech} = \frac{mechanical\ energy\ output}{Mechanical\ energy\ input} = \frac{E_{mech,out}}{E_{mech,in}} = 1 - \frac{E_{mech,loss}}{E_{mech,in}}$$

Energy Conversion Efficiencies

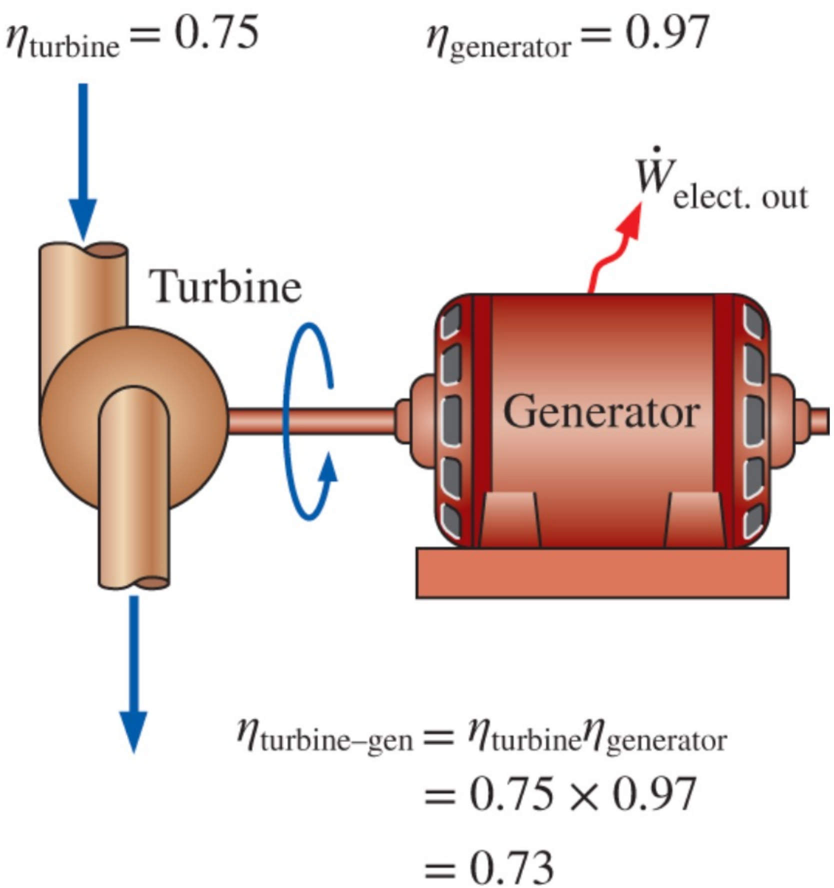
- Summarize efficiencies:

$$\eta_{pump} = \frac{mechanical\ energy\ increase\ of\ the\ fluid}{Mechanical\ energy\ input} = \frac{E_{mech,fluid}}{\dot{W}_{shaft,in}} = \frac{\dot{W}_{pump,u}}{\dot{W}_{pump}}$$

$$\eta_{turbine} = \frac{mechanical\ energy\ output}{Mechanical\ energy\ decrease\ of\ the\ fluid} = \frac{\dot{W}_{shaft,out}}{|\Delta\dot{E}_{mech,fluid}|} = \frac{\dot{W}_{turbine}}{\dot{W}_{turbine,e}}$$

Energy Conversion Efficiencies

- Summarize efficiencies:



CLASS ACTIVITY

Class Activity

- Can the combined pump–motor efficiency be greater than either the pump or the motor efficiency?