CAE 208 / MMAE 320: Thermodynamics

Fall 2023

September 7, 2023

Energy, energy transfer, and energy analysis (2)

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ANNOUNCEMENTS

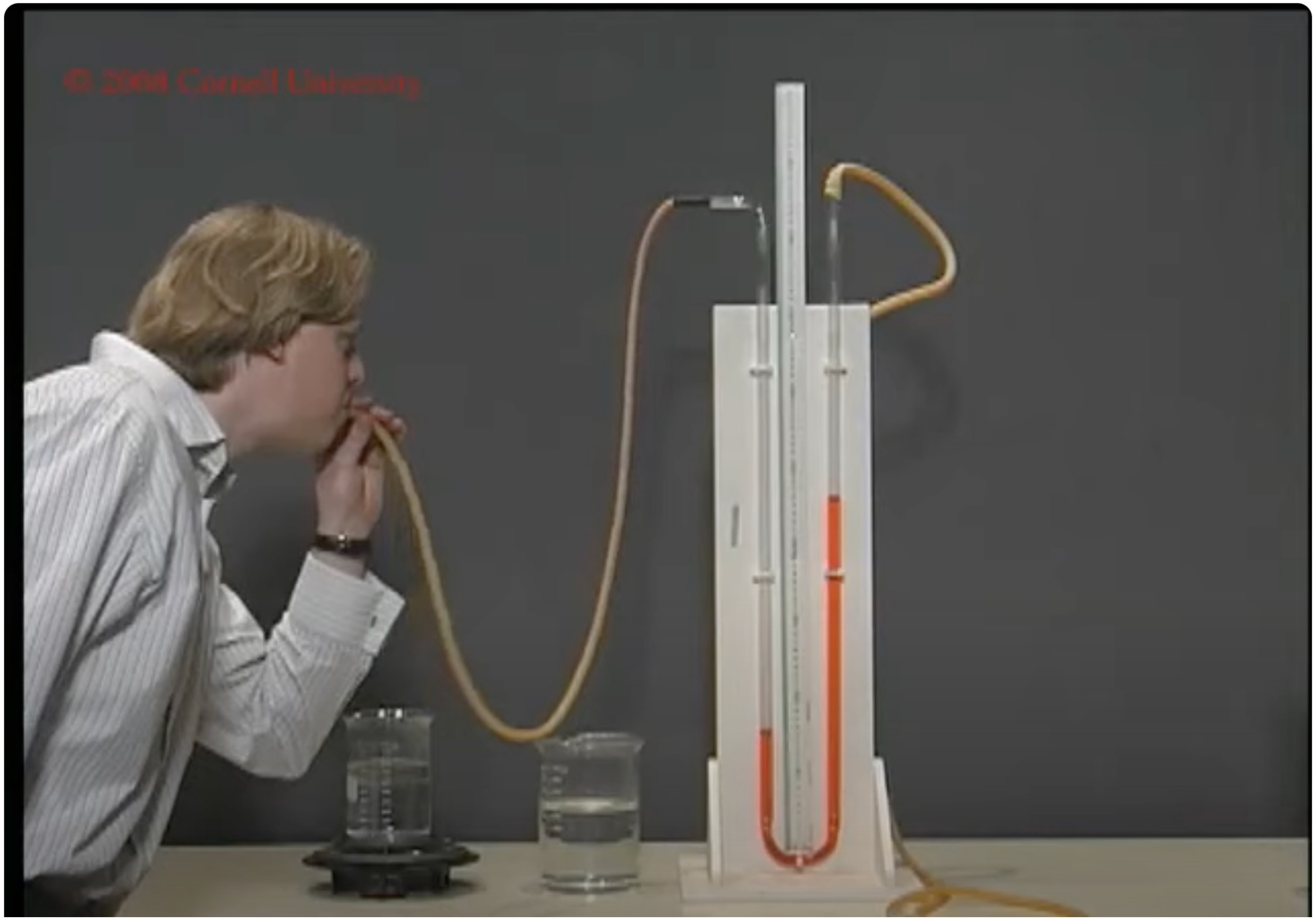
Announcements

- Assignment 2 is due tonight
- No lecture on Tuesday (I will upload a problem-solving session on Blackboard)
- No homework will be posted today (Assignment 3 will be posted next Thursday)

RECAP

Recap

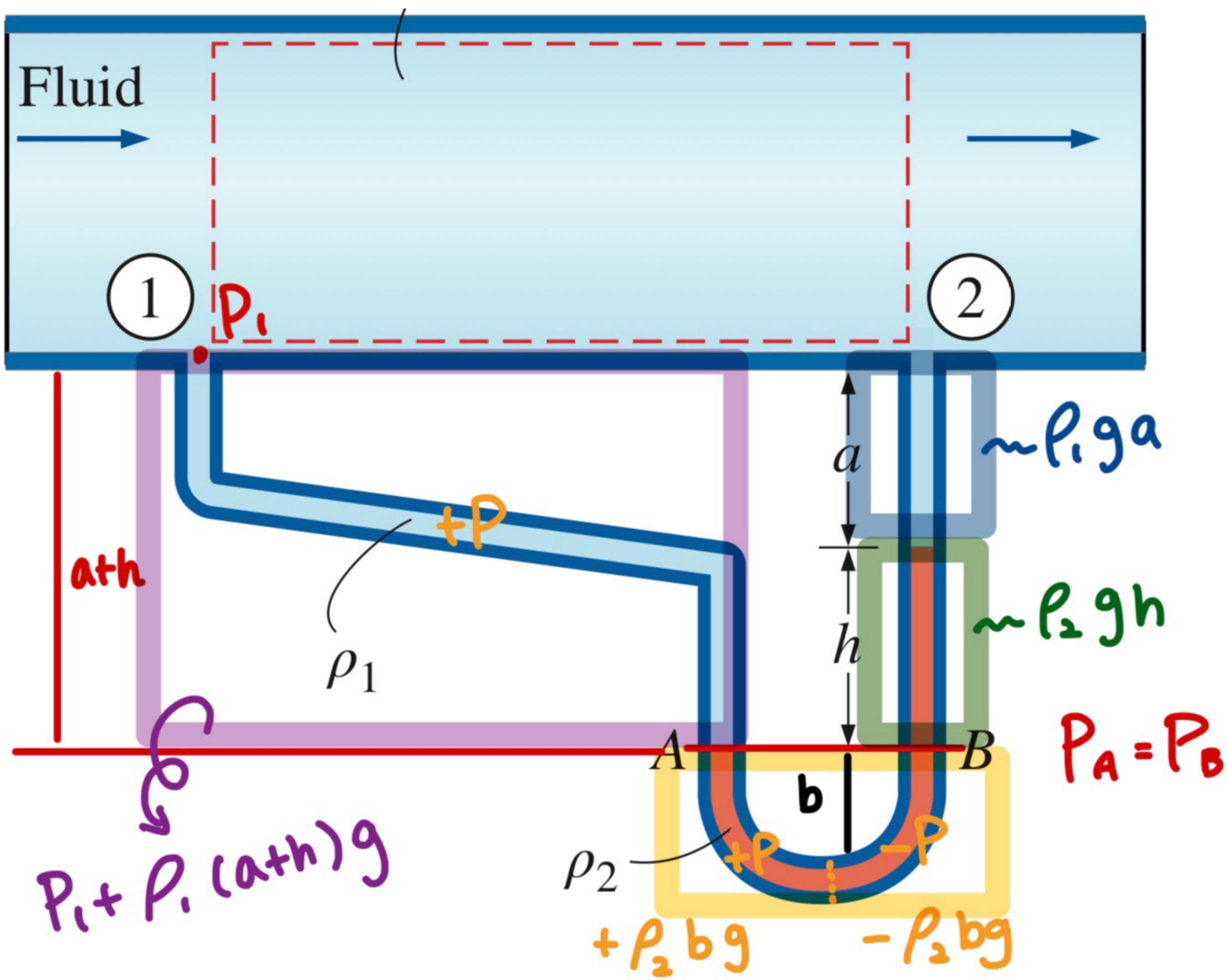
- Manometer



https://www.youtube.com/watch?v=2P5_J5JEHTQ

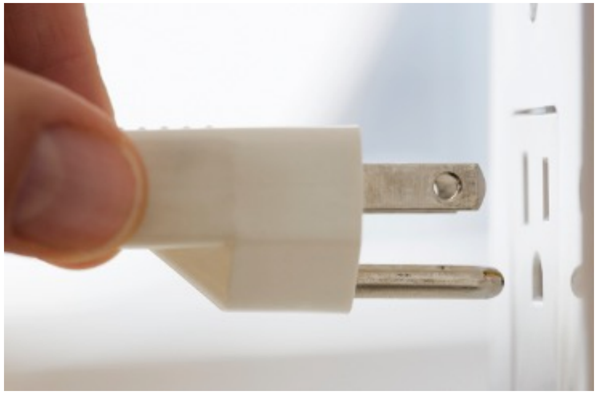
Recap

- Manometer (thanks for catching typos)



Recap

- Energy can exist in numerous forms:
  - ❑ Thermal
  - ❑ Mechanical
  - ❑ Kinetic
  - ❑ Potential
  - ❑ Electric
  - ❑ Magnetic
  - ❑ Chemical
  - ❑ Nuclear



Energy is conserved during the process

Recap

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

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

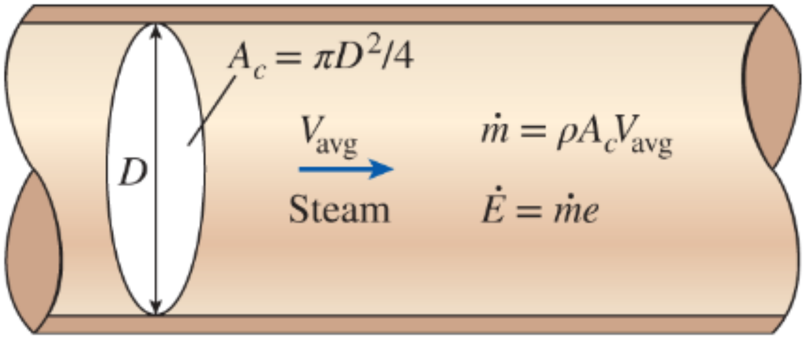
$$e = u + ke + pe = u + \frac{V^2}{2} + gz \quad (kJ/kg)$$

FORMS OF ENERGY

Forms of Energy

- Mass flow rates

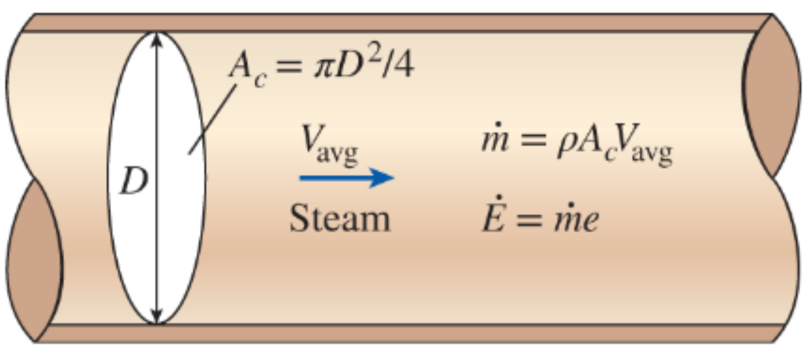
$$\dot{m} = \rho\dot{V} = \rho A_C V_{avg} \qquad (\frac{kg}{s})$$



Forms of Energy

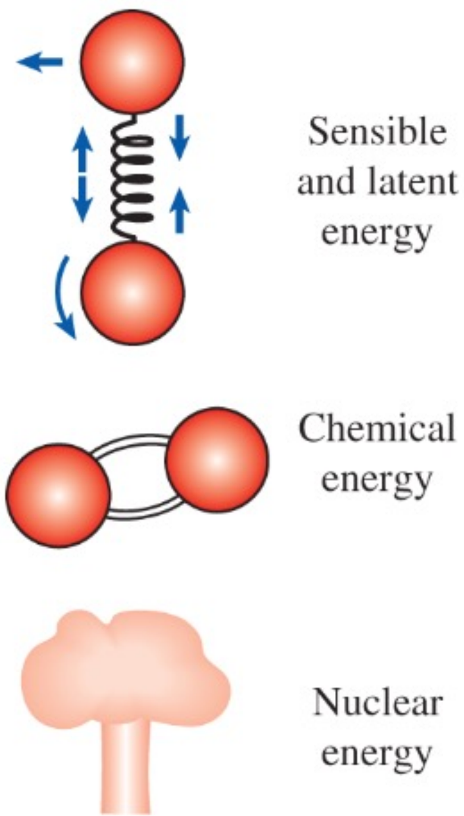
- Energy flow rates

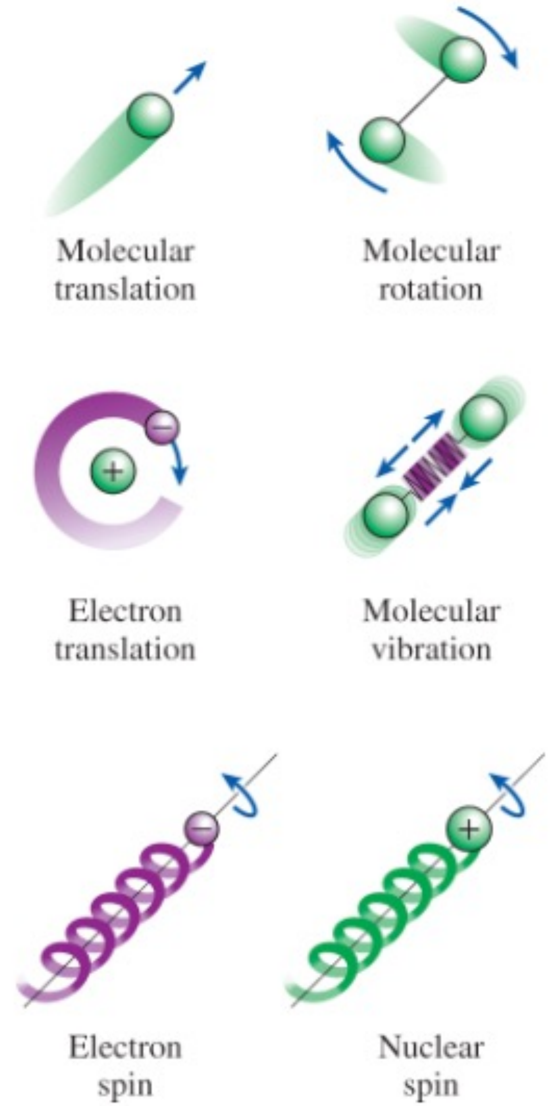
$$\dot{E} = \dot{m}e \qquad \left(\frac{kJ}{s}\right) \; or \; kW$$



Forms of Energy

- Internal energy





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

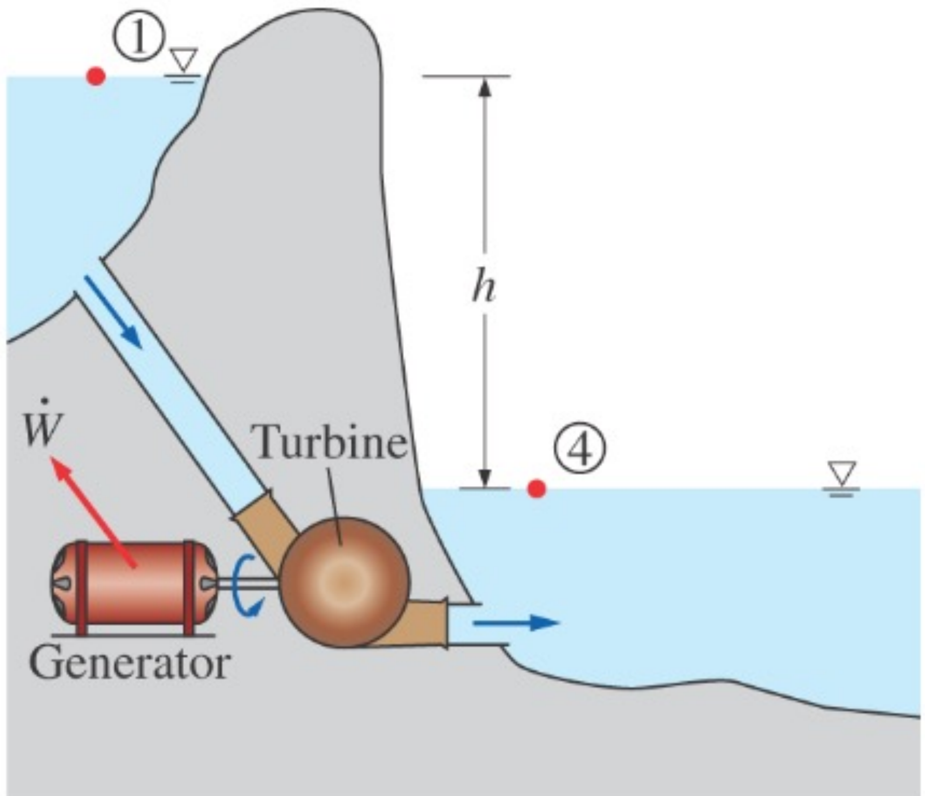
$$e_{mech} = \frac{P}{\rho} + \frac{V^2}{2} + gz$$

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

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

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

Forms of Energy



$$\dot{W}_{max} = \dot{m}\Delta e_{mech} = \dot{m}g\,(z_1 - z_4) = \dot{m}gh$$

since $P_1 \approx P_4 = P_{atm}$ and $V_1 = V_4 \approx 0$

Forms of Energy

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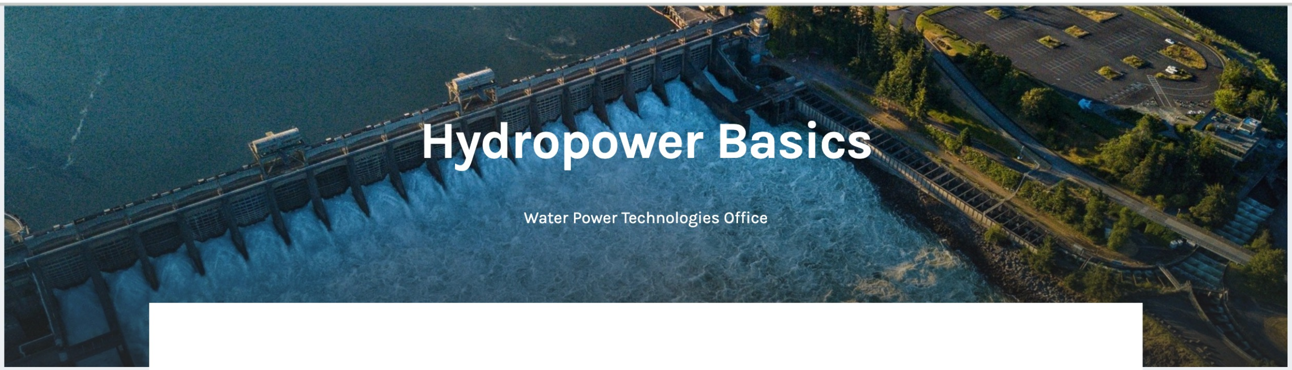
Office of
ENERGY EFFICIENCY & RENEWABLE ENERGY

ABOUT EERE | RESOURCES | BUILDINGS & INDUSTRY | RENEWABLE ENERGY | SUSTAINABLE TRANSPORTATION

WATER POWER TECHNOLOGIES OFFICE



Water Power Technologies Office » Hydropower Program » Hydropower Basics

WHAT IS HYDROPOWER?

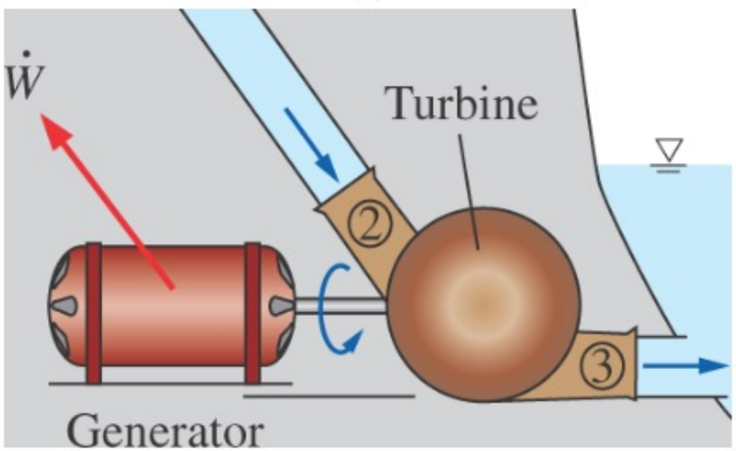
Hydropower, or hydroelectric power, is one of the oldest and largest sources of renewable energy, which uses the natural flow of moving water to generate electricity. Hydropower **currently accounts** for 28.7% of total U.S. renewable electricity generation and about 6.2% of total U.S. electricity generation.

While most people might associate the energy source with the Hoover Dam—a huge facility harnessing the power of an entire river behind its wall—**hydropower facilities come in all sizes**. Some may be very large, but they can be tiny, too, **taking advantage of water flows** in municipal water facilities or irrigation ditches. They can even be "damless," with diversions or run-of-river facilities that channel part of a stream through a powerhouse before the water rejoins the main river. Whatever the method, hydropower is much easier to obtain and more widely used than most people realize. In fact, all but two states (Delaware and Mississippi) use hydropower for electricity, some more than others. For example, in 2020 **about 66%** of the state of Washington's electricity came from hydropower.

LEARN MORE

- Hydropower Program
- How Hydropower Works
- Benefits of Hydropower
- History of Hydropower
- Hydropower Turbines

Forms of Energy



$$\dot{W}_{max} = \dot{m}\Delta e_{mech} = \dot{m}\frac{P_2 - P_3}{\rho} = \dot{m}\frac{\Delta P}{\rho}$$

since $V_1 \approx V_3$ and $z_2 = z_3$

$\Delta e_{mech} > 0$ mechanical work supplied to the fluid

$\Delta e_{mech} < 0$ mechanical work extracted from the fluid

CLASS ACTIVITY

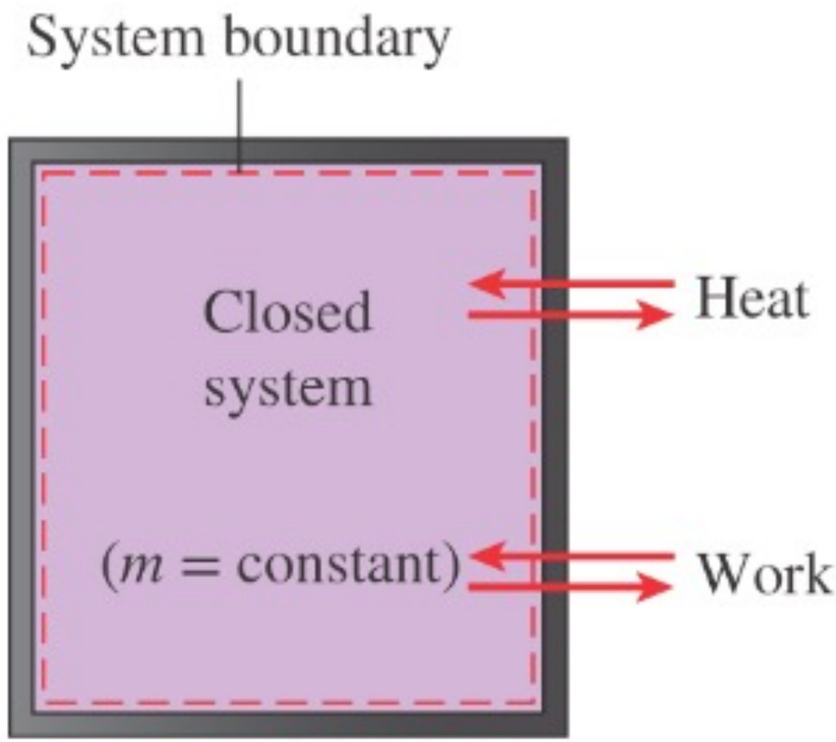
Class Activity

- A site evaluated for a wind farm is observed to have steady winds at a speed of 8.5 m/s. Determine the wind energy
  - ❑ Per unit mass
  - ❑ For a mass of 10 kg
  - ❑ For a flow rate of 1154 kg/s of air

ENERGY TRANSFER BY HEAT

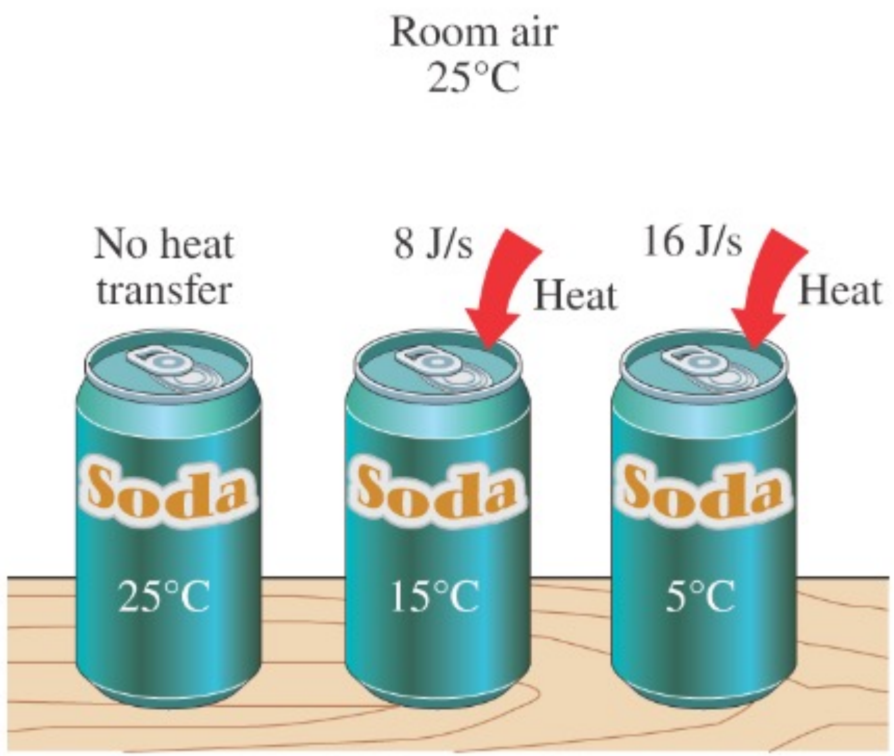
Energy Transfer by Heat

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



Energy Transfer by Heat

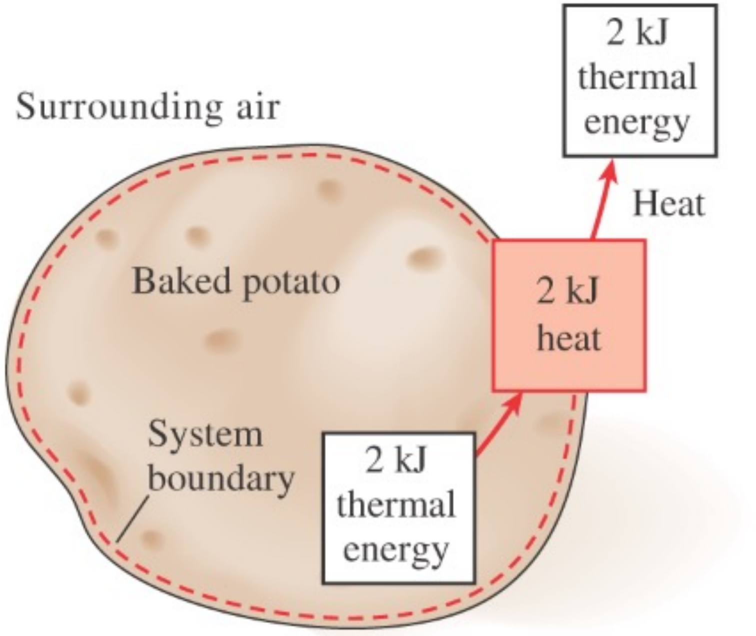
- Heat is defined as the form of energy that is transferred between two systems (or a system and its surrounding) by virtue of a temperature difference



Energy Transfer by Heat

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

$$q = \frac{Q}{m} \quad \left(\frac{kJ}{kg}\right)$$



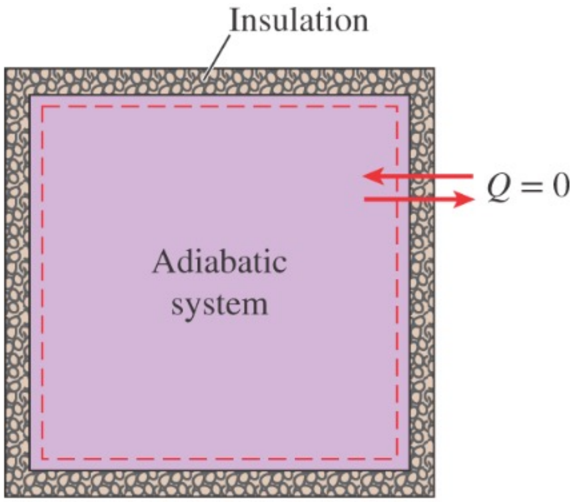
$$Q_{12}$$

Energy Transfer by Heat

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

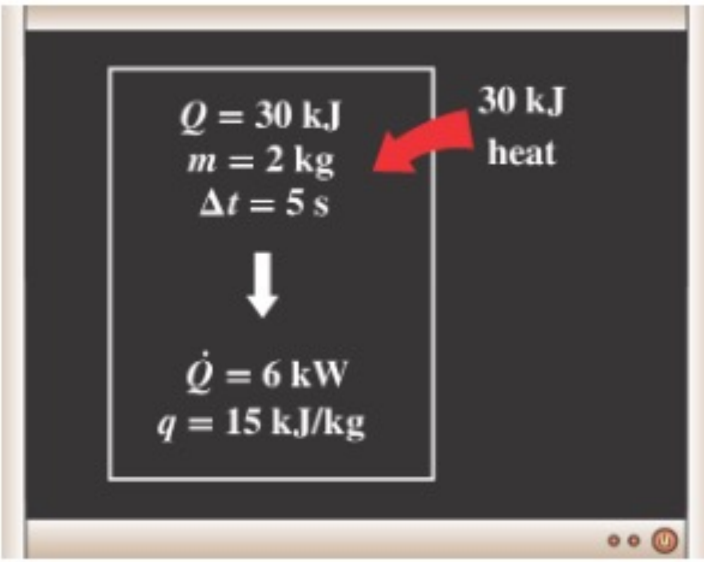
Energy Transfer by Heat

- 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



Energy Transfer by Heat

- Let's look at the relationship between the heat and heat transfer



$$q = \frac{Q}{m} \quad \left(\frac{kJ}{kg}\right)$$

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

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

ENERGY TRANSFER BY WORK

Energy Transfer by Work

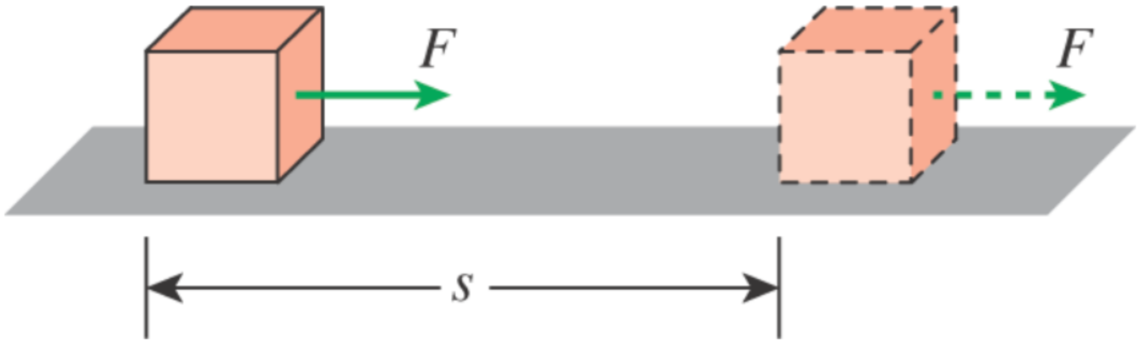
- Work like heat is an energy interaction between a system and its surrounding

- 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)

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

Energy Transfer by Work

- Work is a form of energy transferred like heat the energy units such as kJ

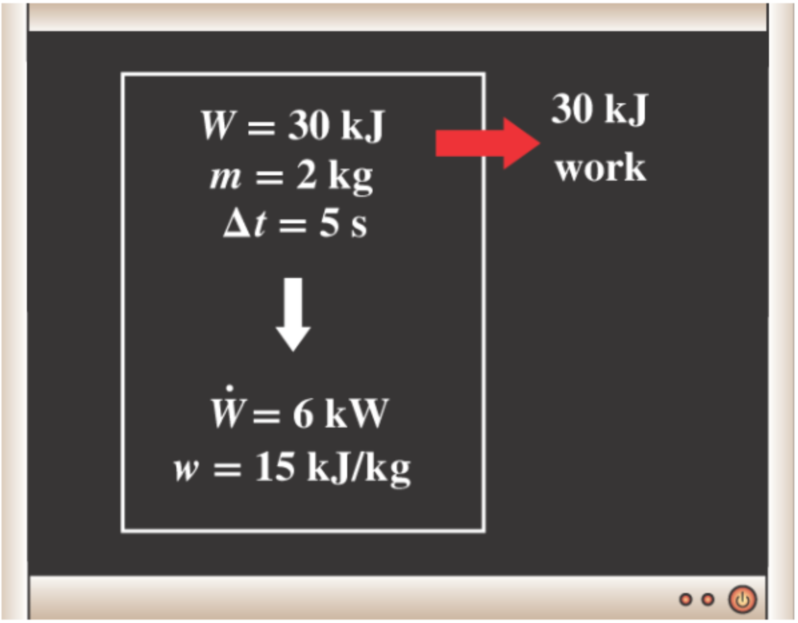
- Work done during a process between states 1 and 2 is donated by W_{12}

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

Energy Transfer by Work

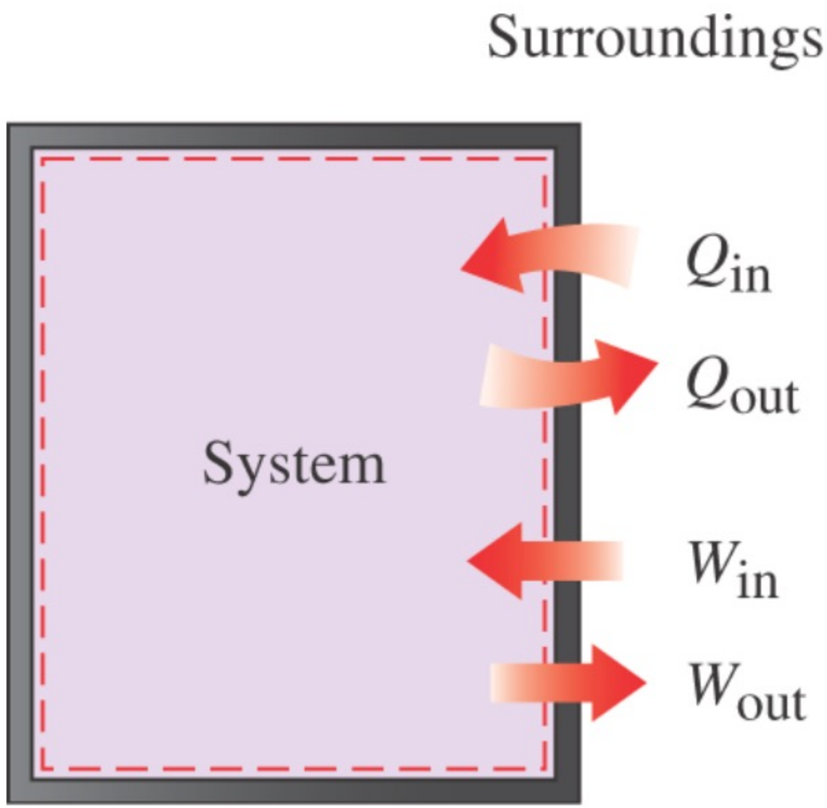
- Work done per unit time is called power (donated with $\dot{W}$)

- The unit of power is kJ/kg or kW



Energy Transfer by Work

- Heat and work are directional quantities



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

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

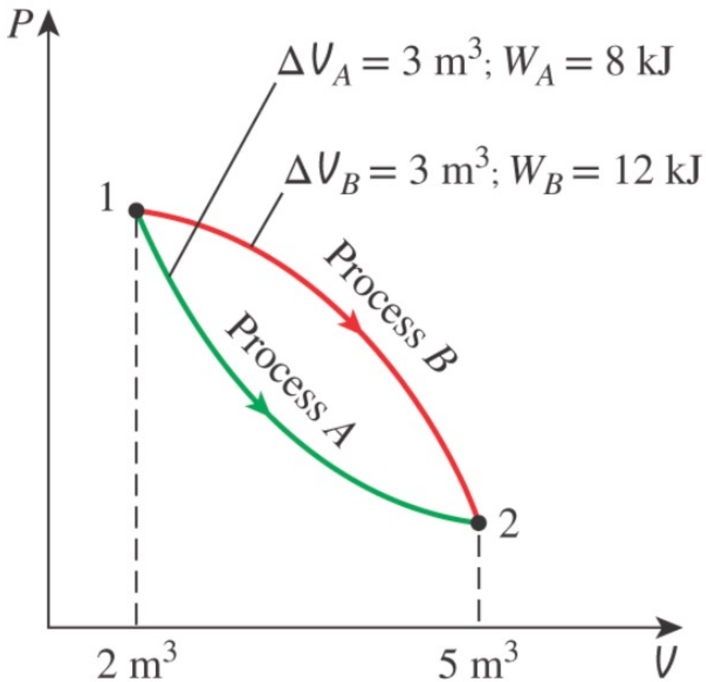
$$\int_1^2 \delta W = W_{12} \; (not \; \Delta W)$$

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!)

Energy Transfer by Work

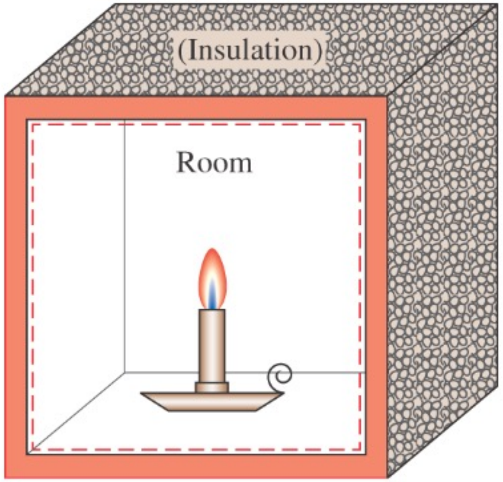
- Systems do not posses work at a state



CLASS ACTIVITY

Class Activity

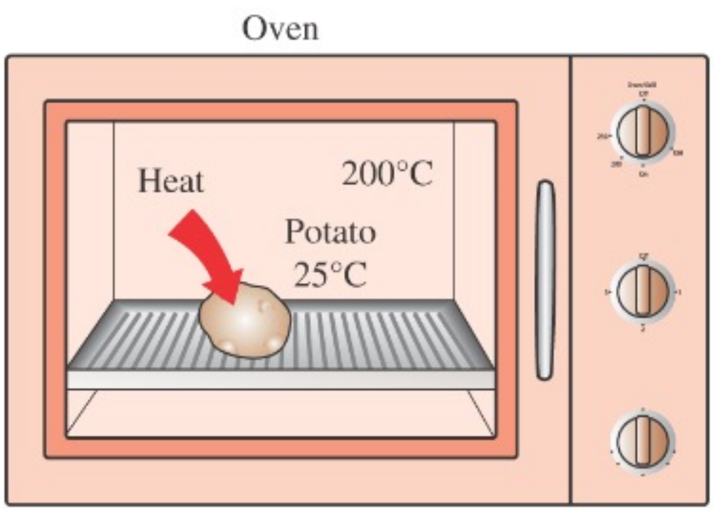
- A candle is burning in a well-insulated room. Taking the room (the air plus the candle) as the system, determine
  - ❑ If there is any heat transfer during the burning process
  - ❑ If there is any change in the internal energy of the system



CLASS ACTIVITY

Class Activity

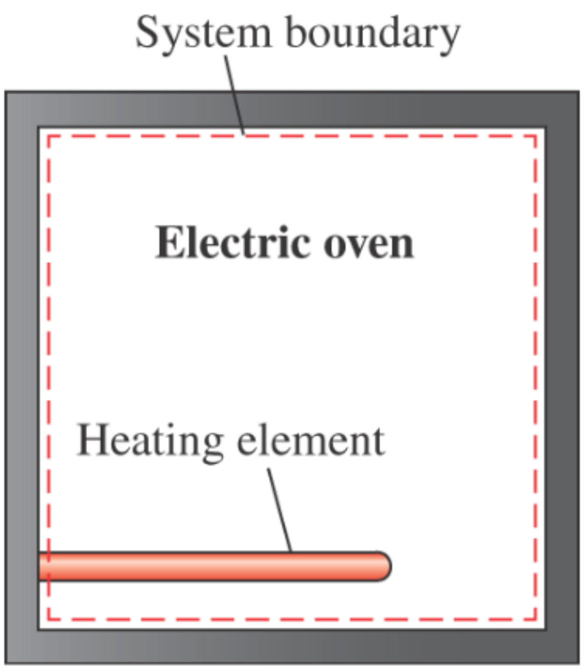
- A potato initially at room temperature (25 °C) is being baked in an oven that is maintained at 200 °C. Is there any heat transfer during this baking process.



CLASS ACTIVITY

Class Activity

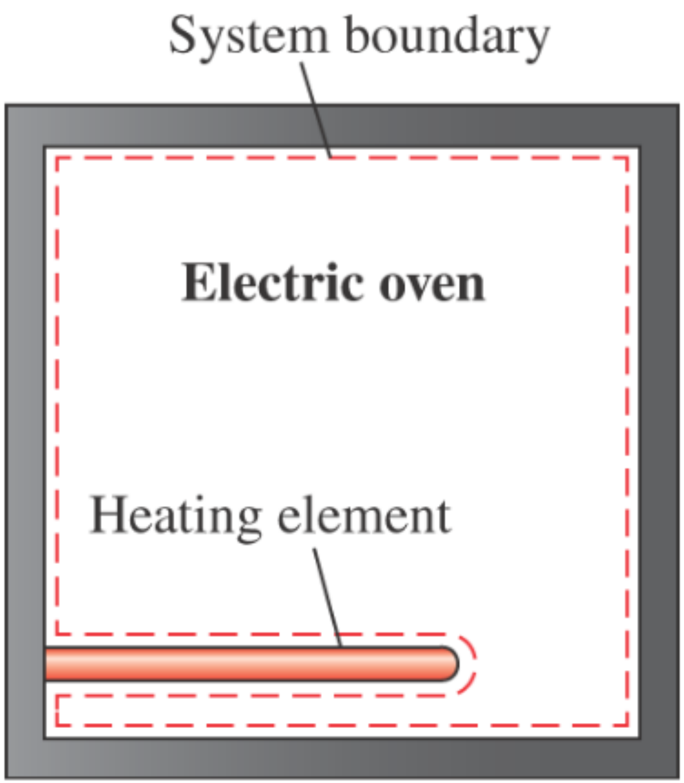
- A well-insulated electric oven is being heated through its heating element. If the entire oven, including the heating element is taken to be the system, determine whether there is a heat or work interaction.



CLASS ACTIVITY

Class Activity

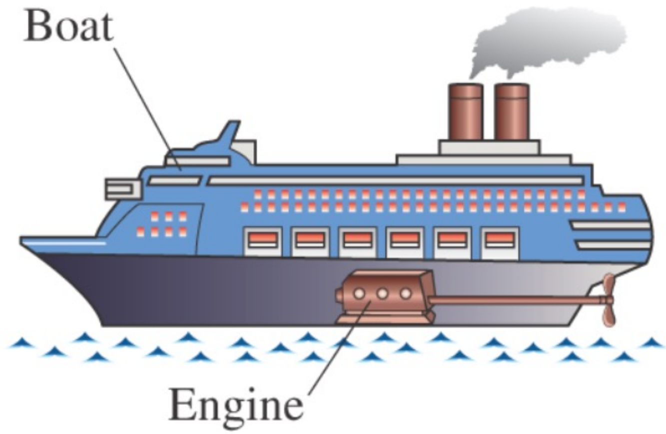
- Answer the previous class activity is the air is considered without the heating element.

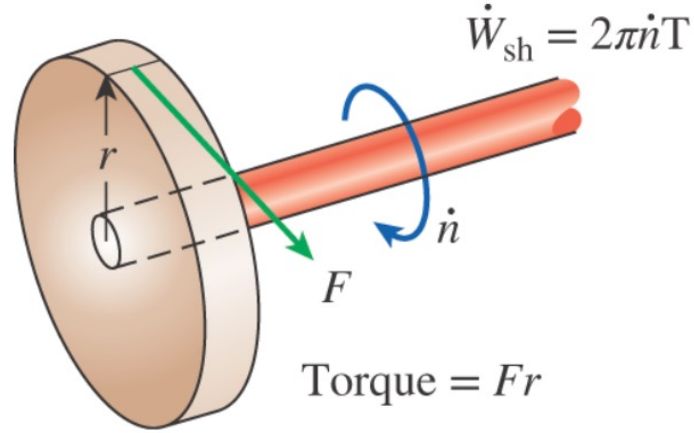


MECHANICAL FORMS OF WORK

Mechanical Forms of Work

- Shaft work





$$T = Fr$$

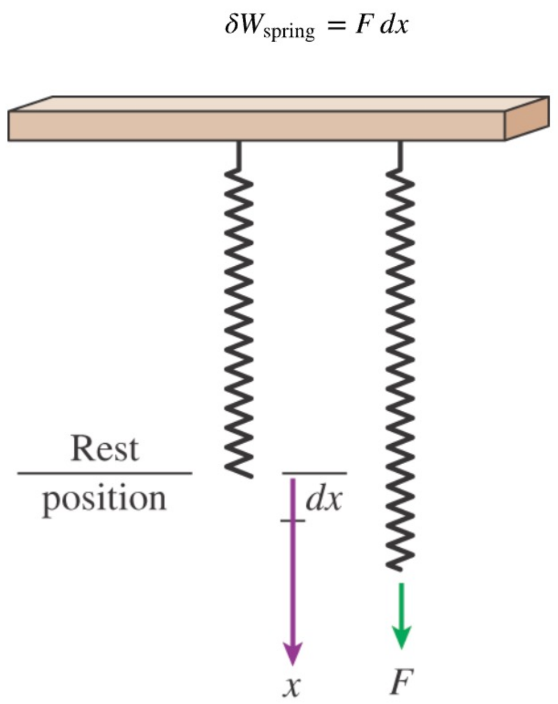
$$s = (2\pi r)n$$

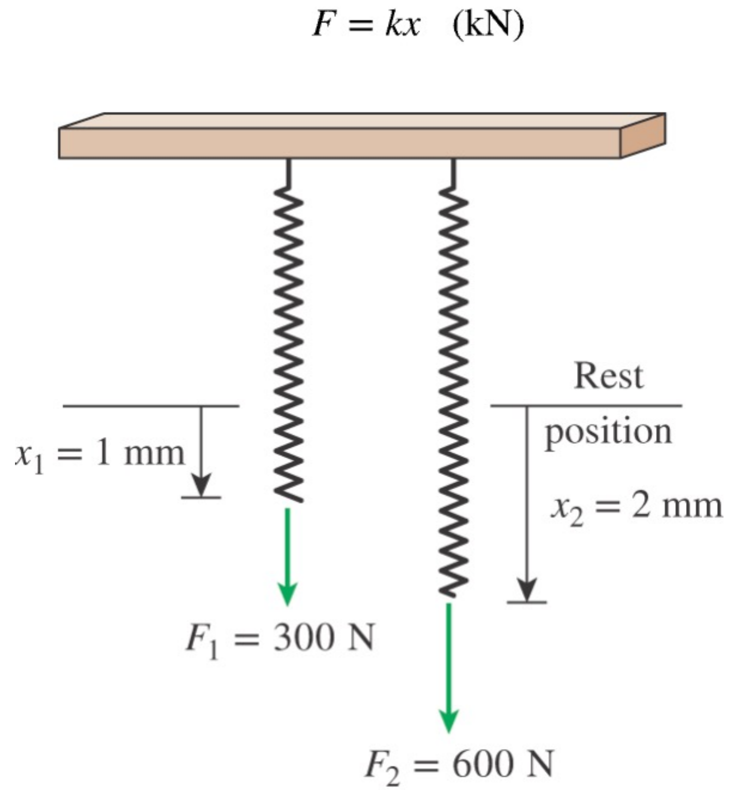
$$W_{sh} = Fs = \left(\frac{T}{r}\right)(2\pi r)n = 2\pi nT \qquad (kJ)$$

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

Mechanical Forms of Work

- Spring work



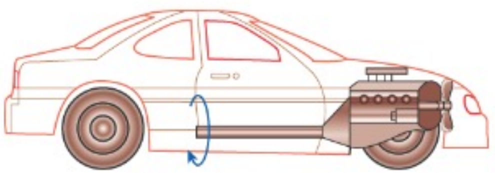


$$W_{spring} = \frac{1}{2}k(x_2^2 - x_1^2)$$

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

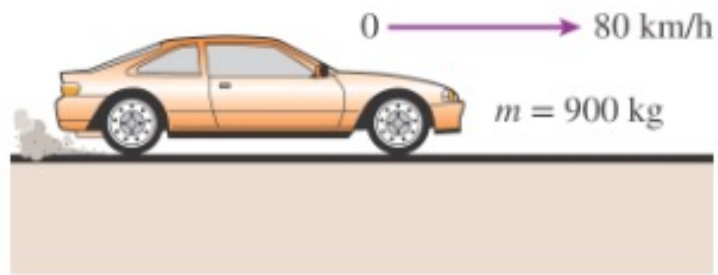
Class Activity

- 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

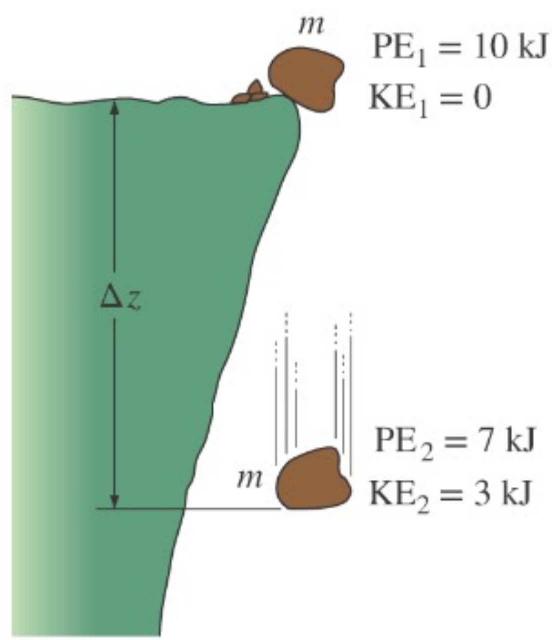


THE FIRST LAW OF THERMODYNAMICS

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



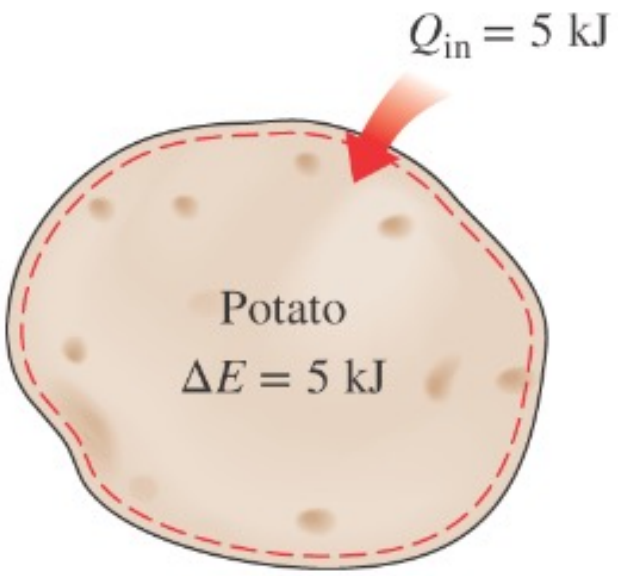
The First Law of Thermodynamics

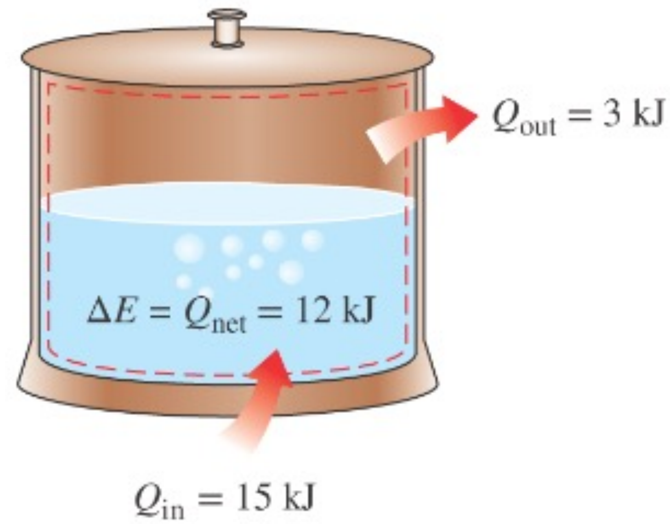
- Consider a system undergoing a series of adiabatic processes from a specified state 1 to another specified state 2.

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

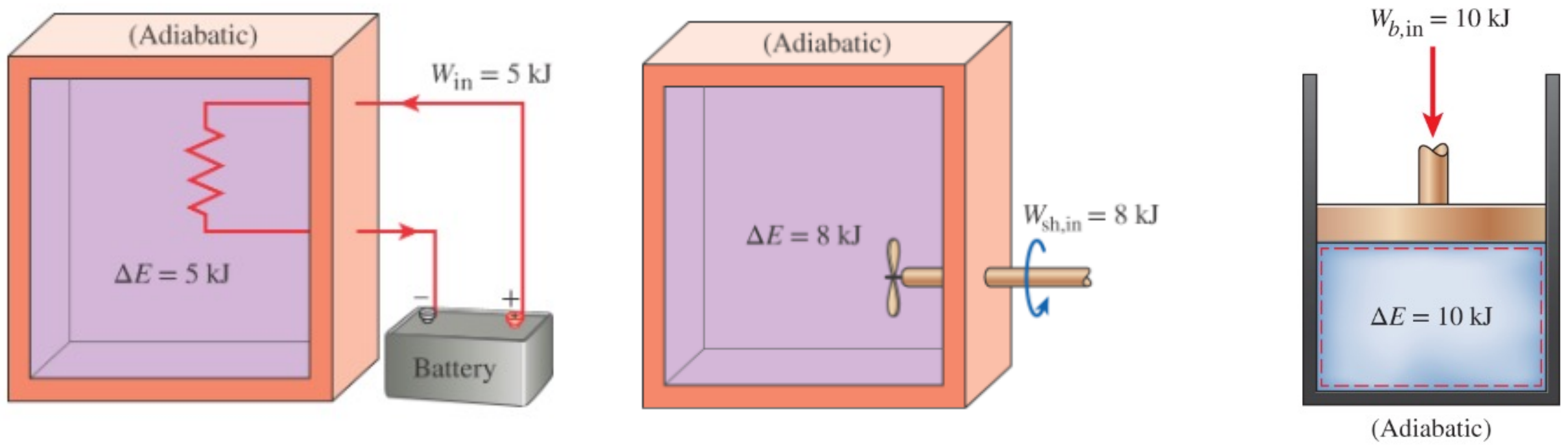
- Example processes that involve heat transfer but no work interactions:





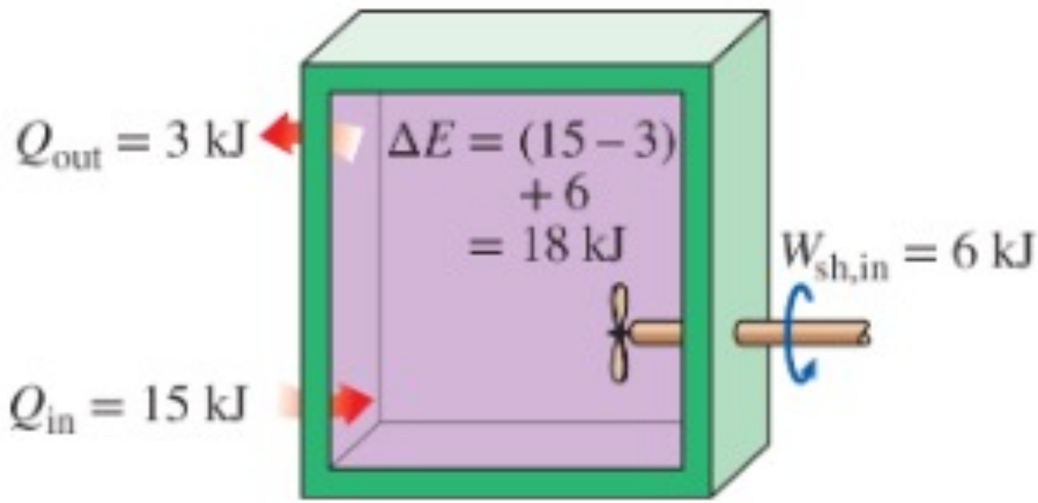
The First Law of Thermodynamics

- 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}

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

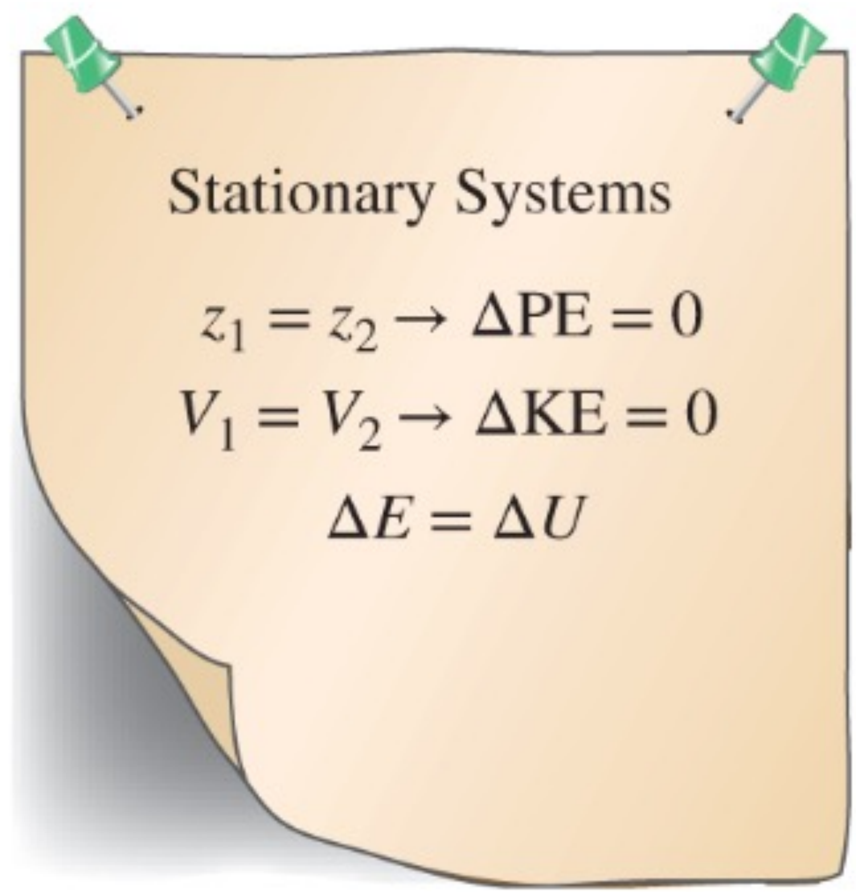
$$\Delta U = m(u_2 - u_1)$$

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

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

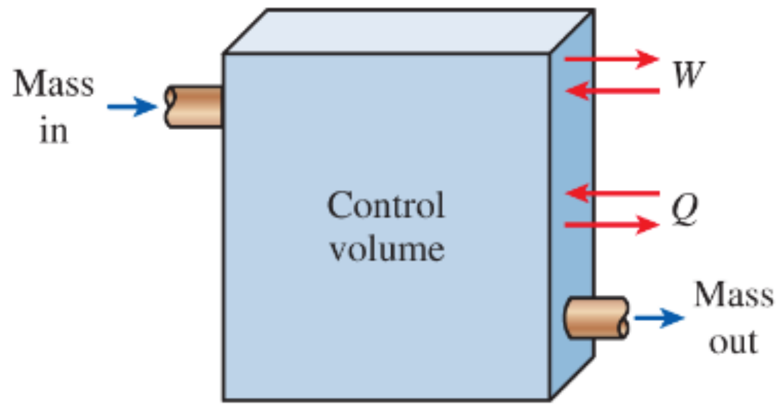
The First Law of Thermodynamics

- 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
  - ❑ 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