Thermodynamics

Chem 211: Lecture 3

Energy Forms & Transfer

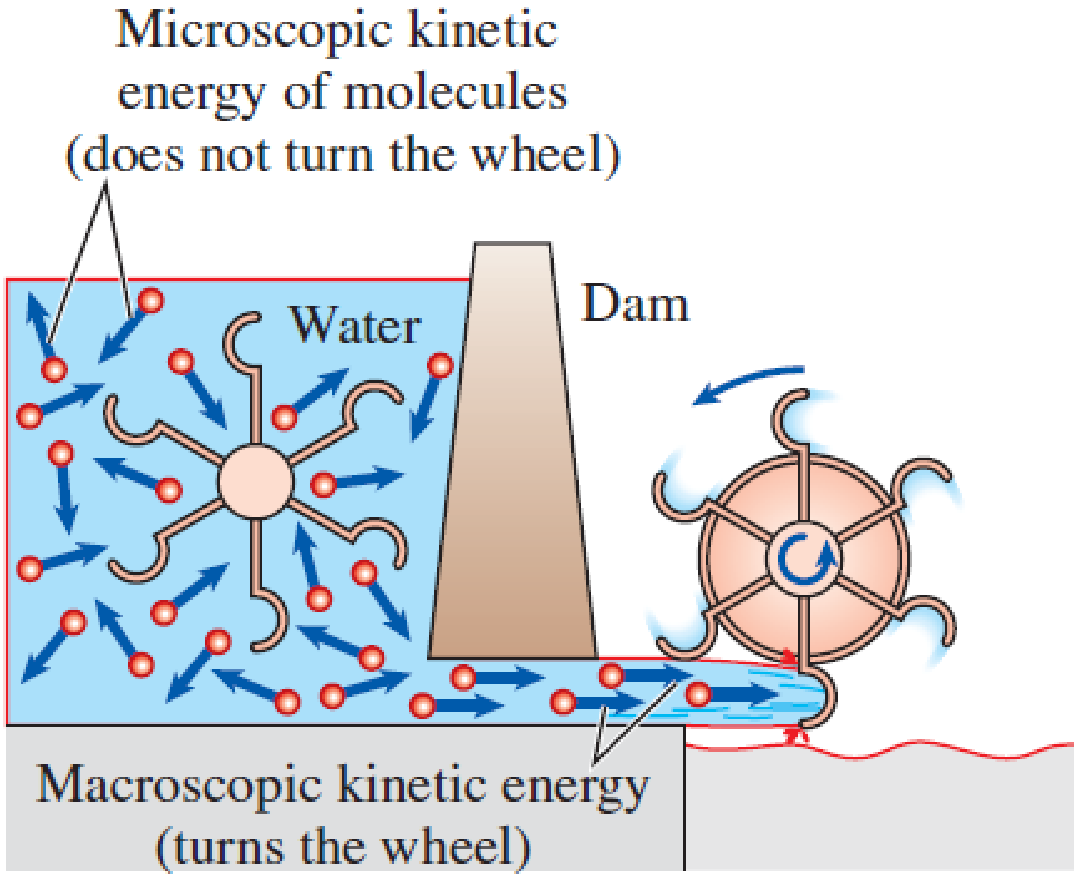
Ahmad Alakraa

Macroscopic/Microscopic KE

- The macroscopic kinetic energy of an object is an ***organized*** form of energy associated with the **orderly** motion of all molecules in one direction in a straight path or around an axis.

- In contrast, the microscopic kinetic energies of the molecules are completely ***random*** and highly ***disorganized***.

- The organized energy is much more valuable than the disorganized energy, and a major application area of thermodynamics is the conversion of disorganized energy (**heat**) into organized energy (**work**).



Organized energy can be converted to **disorganized** energy completely, but only a fraction of **disorganized** energy can be converted to **organized** energy by **heat engines**.

Total Energy, E

- In absence of magnetic, electric, and surface tension effects, E of a system consists of KE (**macroscopic**), PE (**macroscopic**), and internal energies, U.

$$E = U + KE + PE$$

$$E = U + \frac{1}{2}mV^2 + mgz \quad (kJ)$$

on a unit mass basis,

$$e = u + \frac{1}{2}V^2 + gz \quad (kJ/kg)$$

Stationary Systems

- Most closed systems remain stationary (i.e., their macroscopic velocity and elevation of the center of gravity remain constant during a process).

- In absence of other external influences, **stationary systems** experience no change in their macroscopic KE and PE.

$$\Delta E = \Delta U$$

A closed system is assumed to be stationary unless stated otherwise.

Control Volume Systems

- involve fluid flow for long periods of time.
- is convenient to express the energy flow in the rate form.
- The **mass flow rate** $\dot{m}$ is the amount of mass flowing through a cross section per unit time.
- The **volume flow rate** $\dot{V}$ is the volume of a fluid flowing through a cross section per unit time.

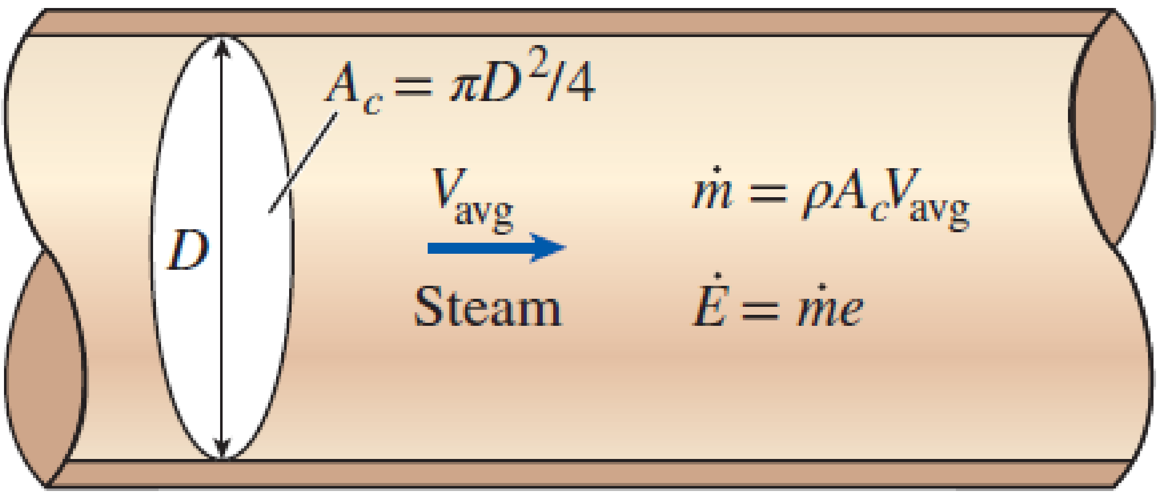
$$\dot{m} = \rho\dot{V} = \rho A_c V_{avg} \qquad \text{(kg/s)}$$

ρ is the fluid density, A_c is the cross-sectional area of flow, and V_{avg} is the average flow velocity normal to A_c. The dot over a symbol is used to indicate time rate.

- The energy flow rate associated with a fluid flowing at a rate of $\dot{m}$ is

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

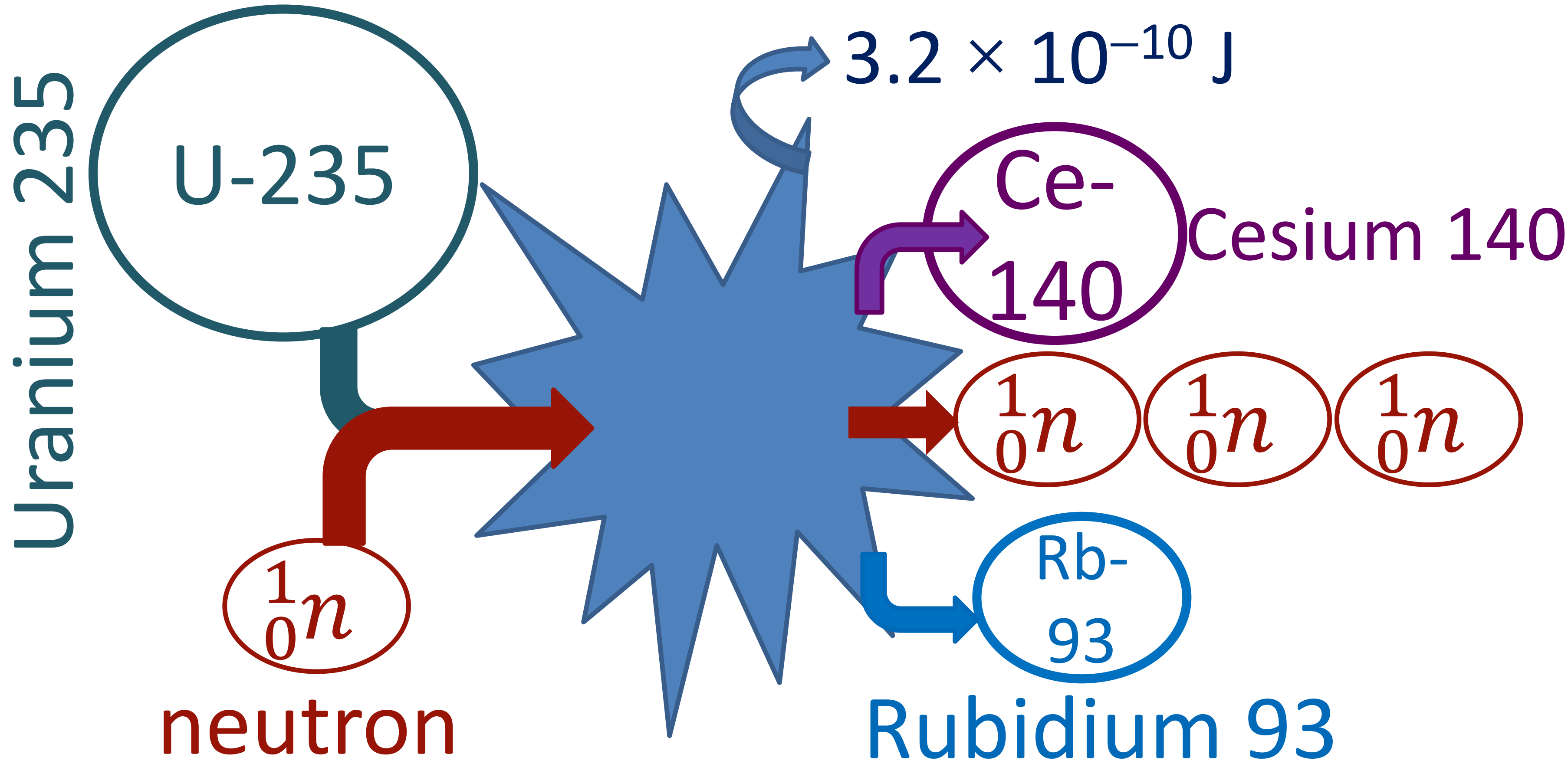
e : **energy per unit mass**



Mass and energy flow rates associated with the flow of steam in a pipe of inner diameter *D* with an average velocity of V_{avg}.

Nuclear fission (splitting of U-235 isotope)

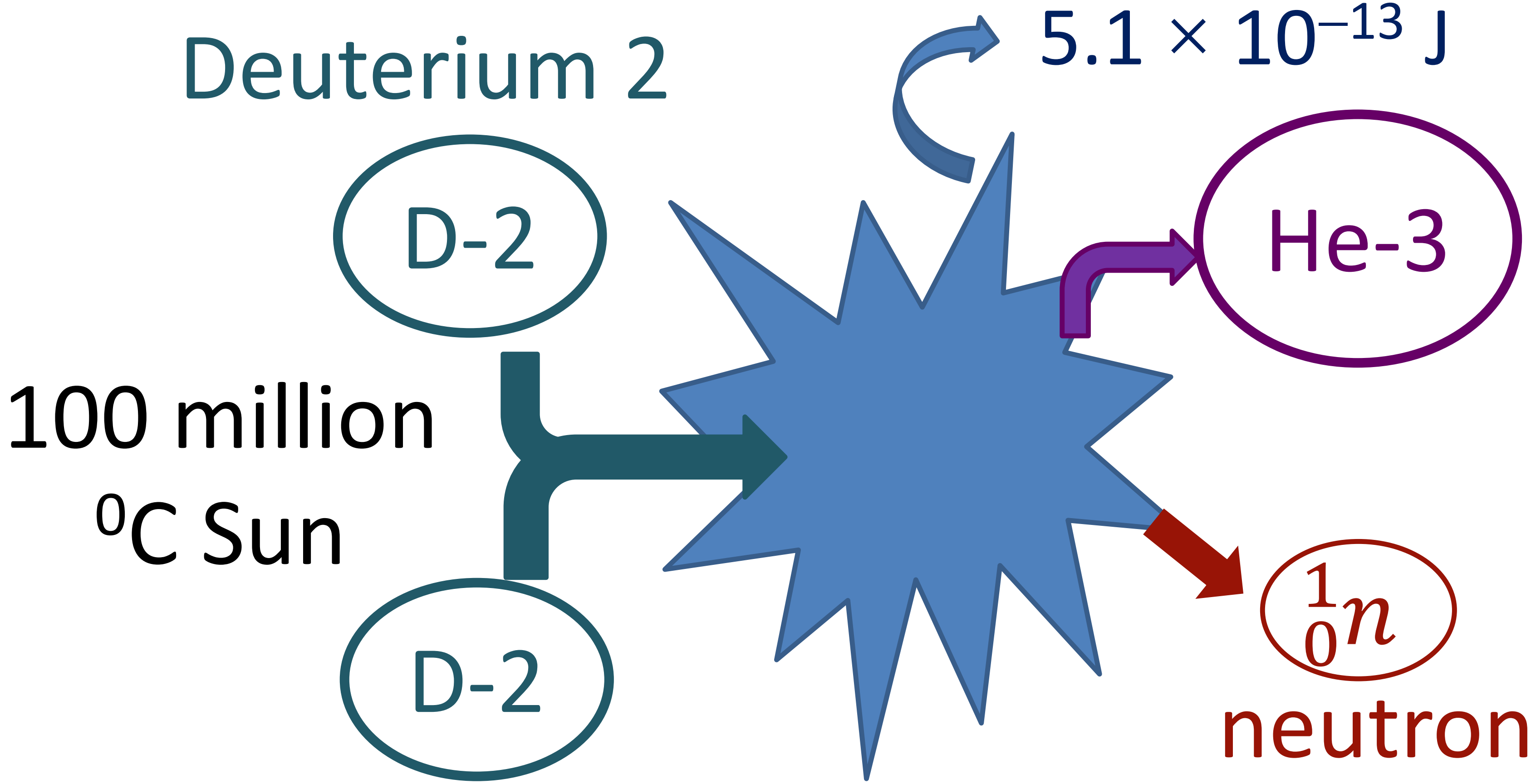
$$^{235}_{92}U + ^{1}_{0}n \rightarrow ^{140}_{55}Ce + ^{93}_{37}Rb + 3\,^{1}_{0}n + (3.2 \times 10^{-10} J)$$



1 kg of U-235 releases **8.314×10^{10} kJ of heat** >>> **Q** released when 3700 tons of coal are burned.

Nuclear fusion (H-2 isotope/Deuterium)

$$^{2}_{1}D + ^{2}_{1}D \rightarrow ^{3}_{2}He + ^{1}_{0}n + (5.1 \times 10^{-13} J)$$



Difficult because of strong repulsion between the positively charged nuclei.

A gasoline-powered Car

- An average car consumes about 5 L of gasoline a day, and the capacity of the fuel tank of a car is about 50 L. Therefore, a car needs to be refueled once every 10 days. Also, the density of gasoline ranges from 0.68 to 0.78 kg/L, and its lower heating value is about 44,000 kJ/kg (that is, 44,000 kJ of heat is released when 1 kg of gasoline is completely burned). Suppose a car is equipped with 0.1 kg of U-235, determine if this car will ever need refueling? (1 kg of U-235 = 8.314×10^{10} kJ)

Answer

Nuclear Fuel

Mass of gasoline used per day

Solution

$$m_{gasoline} = (\rho V)_{gasoline} = \left(\frac{0.75\ kg}{L}\right)\left(\frac{5\ L}{day}\right)$$
$$= 3.75\ kg/day$$

E supplied to the car per day

$$E = \left(m_{gasoline}\right)(Heating\ \ value)$$
$$= \left(\frac{3.75\ kg}{day}\right)\left(\frac{44{,}000\ kJ}{kg}\right) = \left(\frac{165{,}000\ kJ}{day}\right)$$

Complete fission of 0.1 kg of uranium-235 releases

$$(8.314 \times 10^{10}\ \text{kJ/kg})(0.1\ \text{kg}) = 8.314 \times 10^{9}\ \text{kJ}$$

$$No.\ \text{of days} = \frac{\text{Energy content of fuel}}{\text{Daily energy use}} = \frac{8.314 \times 10^{9}\ \text{kJ}}{165{,}000\ kJ/day}$$

$$= 50{,}390\ day = 138\ years$$

Mechanical Energy

- Concerns with the transportation of a fluid from one location to another at a specified flow rate, velocity, and elevation difference, and the system may generate mechanical work in a **turbine** or it may consume mechanical work in a **pump** or **fan** during this process.

- These systems do not involve the conversion of **nuclear**, **chemical**, or **thermal** energy to **mechanical** energy.

- Also, they do not involve any **heat transfer** in any significant amount, and they operate essentially at constant temperature.

- **Frictional effects** may cause the mechanical energy to be lost (i.e., to be converted to **thermal energy** (is a random or internal KE that usually cannot be used for any useful purpose).

Mechanical Energy

- The form of energy that can be converted to mechanical work completely and directly by an ideal mechanical device (turbine, pump).

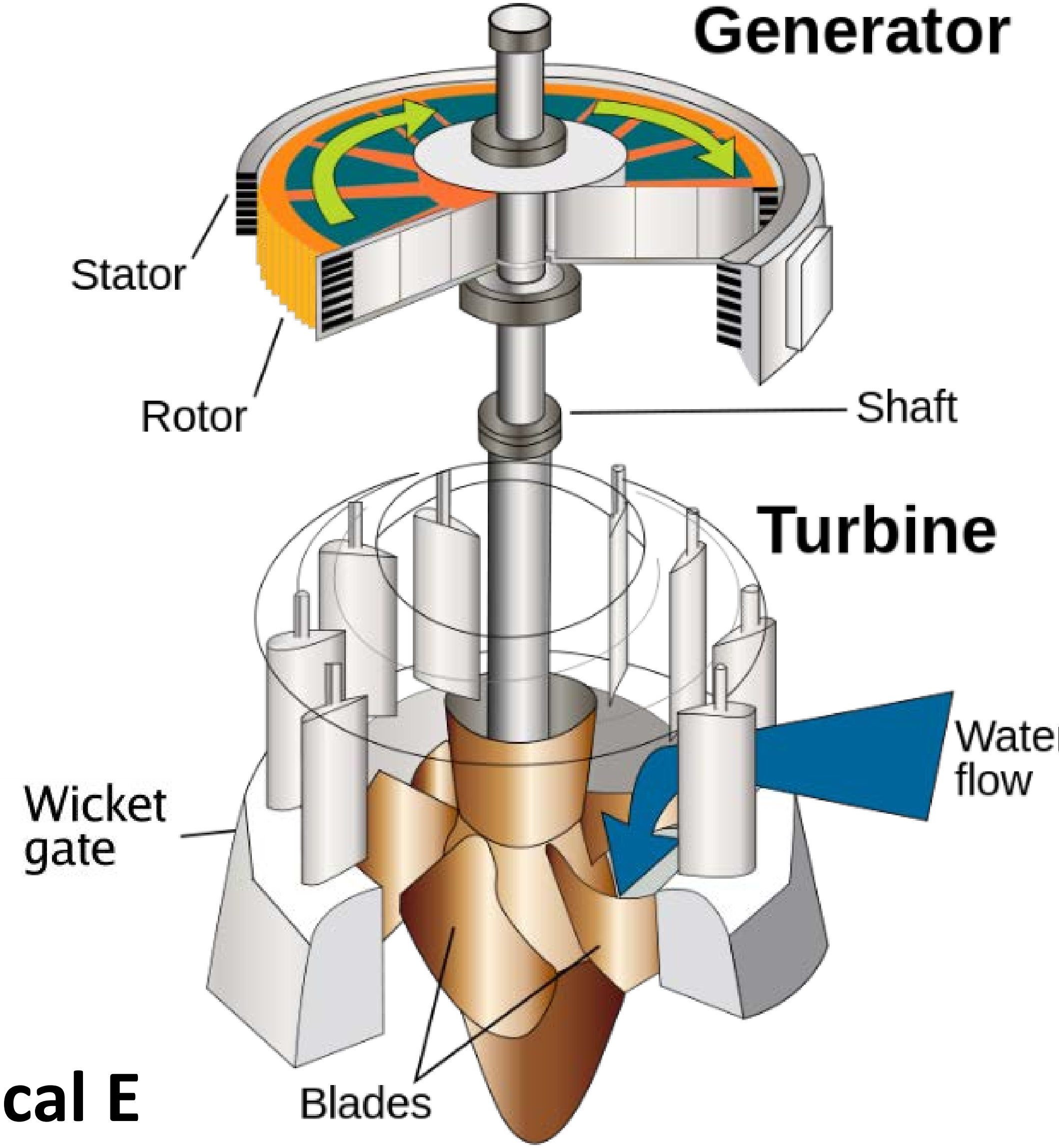
- A pump transfers mechanical energy to a fluid by raising its pressure, and a turbine extracts mechanical energy from a fluid by dropping its pressure.

- KE and PE are the familiar forms of mechanical energy.

- Thermal (although being a form of KE) energy is not mechanical energy, however, since it cannot be converted to work directly and completely (the second law of thermodynamics).

Hand water pump

A pump converts mechanical E (Torque on shaft) to Hydraulic E (Water Under Pressure)



Water turbine
operates oppositely

Pump/Flow Energy

$$P(Pa) = \frac{N}{m^2} = \frac{N\,m}{m^3} = \frac{J}{m^3}$$

$$\frac{P}{\rho} = \frac{Pa}{kg\,m^{-3}} = \frac{J\,m^{-3}}{kg\,m^{-3}} = \frac{J}{kg}$$

- The pressure of a flowing fluid is associated with its mechanical energy.
- Pressure itself is not a form of energy, but the pressure force acting on a fluid through a distance producing work is called ***flow work***, in the amount of P/ρ per unit mass.
- **Flow work** is expressed in terms of fluid properties, and it is convenient to view it as part of the energy of a flowing fluid and call it ***flow energy***.

- The mechanical energy of a flowing fluid can be expressed on a unit mass basis as

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

all per unit mass

Flow energy ($\frac{P}{\rho}$), KE ($\frac{V^2}{2}$), PE (gz)

$\dot{m}$:mass flow rate of a fluid

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

- The mechanical energy change of a fluid during incompressible (ρ = constant) flow becomes:

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

$$\Delta \dot{E}_{mech} = \dot{m}\Delta e_{mech}$$

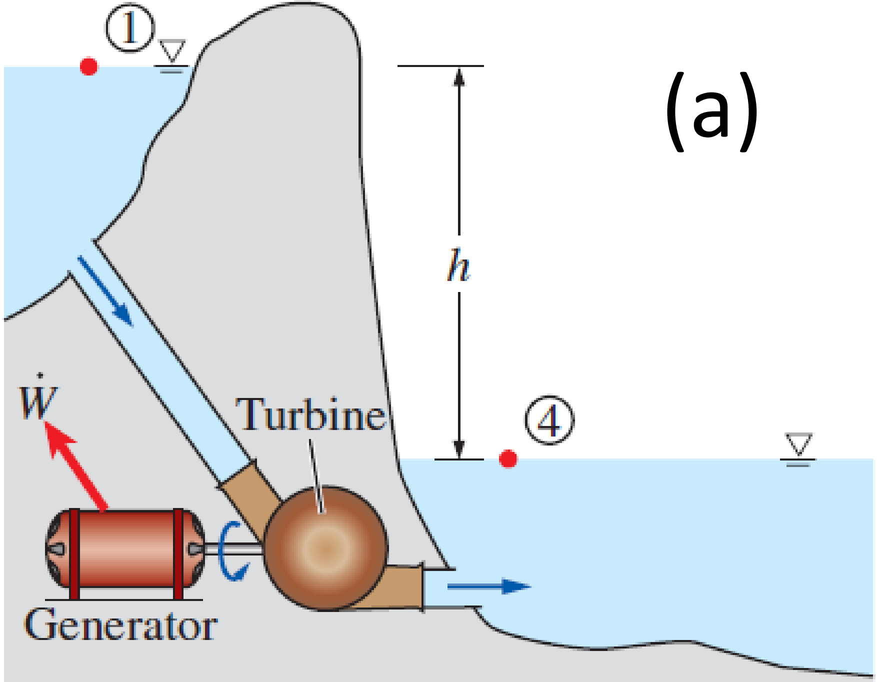
$$= \dot{m}\left(\frac{P_2 - P_1}{\rho} + \frac{V_2^2 - V_1^2}{2} + g(z_2 - z_1)\right) \quad \text{(kW)}$$

- The mechanical energy of a fluid does not change during flow if its pressure, density, velocity, and elevation remain **constant**.

- In the absence of any irreversible losses, the mechanical energy change represents the **mechanical work** supplied to the fluid (if $\Delta e_{mech} > 0$, **pump**) or extracted from the fluid (if $\Delta e_{mech} < 0$, **turbine**).

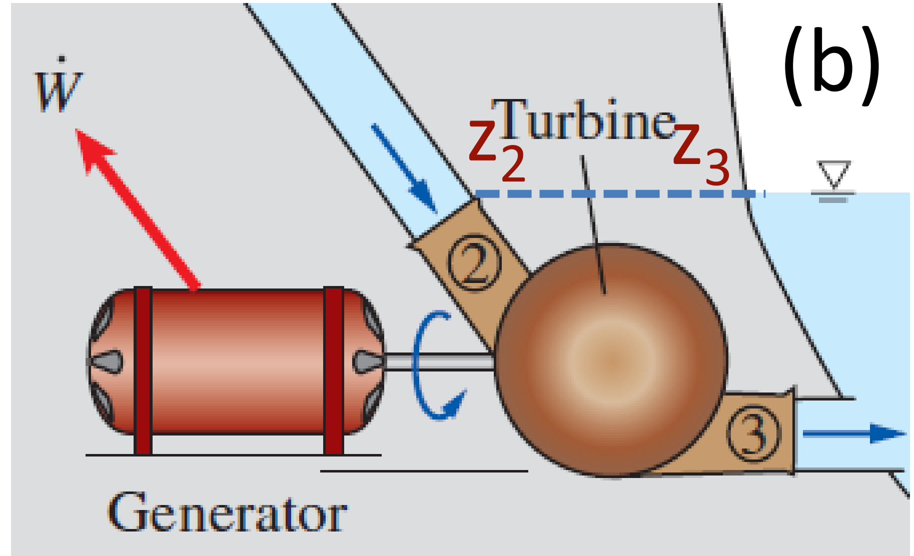
- The maximum (ideal) power generated by a **turbine**, for example, is

$$\dot{W}_{max} = \dot{m}\Delta e_{mech}$$



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

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



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

Since $V_2 \approx V_3$ and $z_2 = z_3$

An ideal hydraulic turbine coupled with an ideal generator. In the absence of irreversible losses (heat), the maximum produced power is proportional to (a) the change in water surface elevation from the upstream to the downstream reservoir or (b) (close-up view) the drop in water pressure from just upstream to just downstream of the turbine.

Example: Wind Energy

- 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 (*a*) per unit mass, (*b*) for a mass of 10 kg, and (*c*) for a flow rate of 1154 kg/s for air.

Answer

Assumption: 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

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

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

$$\boldsymbol{E_{mech}} = m e_{mech} = m\left(\frac{V^2}{2}\right)$$

$$= 10\ kg \times (36.1\ J/kg) = 361\ J$$

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

$$\dot{\boldsymbol{E}}_{\boldsymbol{mech}} = \dot{m} e_{mech} = \dot{m}\left(\frac{V^2}{2}\right)$$

$$= (1154\ kg/s) \times (36.1\ J/kg) \times \frac{1\ kW}{1000\ J/s} = 41.7\ kW$$

- This specified mass flow rate (1154 kg/s) corresponds to a 12-m-diameter flow section when the air density is 1.2 kg/m^3.

- Therefore, a wind turbine with a span diameter of 12 m has a power generation potential of 41.7 kW.

- Real wind turbines convert about one-third of this potential to electric power.

CYU

- Select the correct list of energy forms that constitute internal energy:

  (A) Sensible, chemical, and kinetic

  (B) Sensible, latent, chemical, and nuclear

  (C) Sensible, chemical, and nuclear

  (D) Sensible and latent

  (E) Potential and kinetic

Answer

√ **(B) Sensible, latent, chemical, and nuclear**

CYU

- To what velocity (m/s) do we need to accelerate a car at rest to increase its kinetic energy by 1 kJ/kg?

(A) 1 (B) 1.4 (C) 10 (D) 44.7 (E) 90

Answer

√ **(D) 44.7**

$$e_{mech} = ke = \frac{V^2}{2} = 1000\ J/kg$$

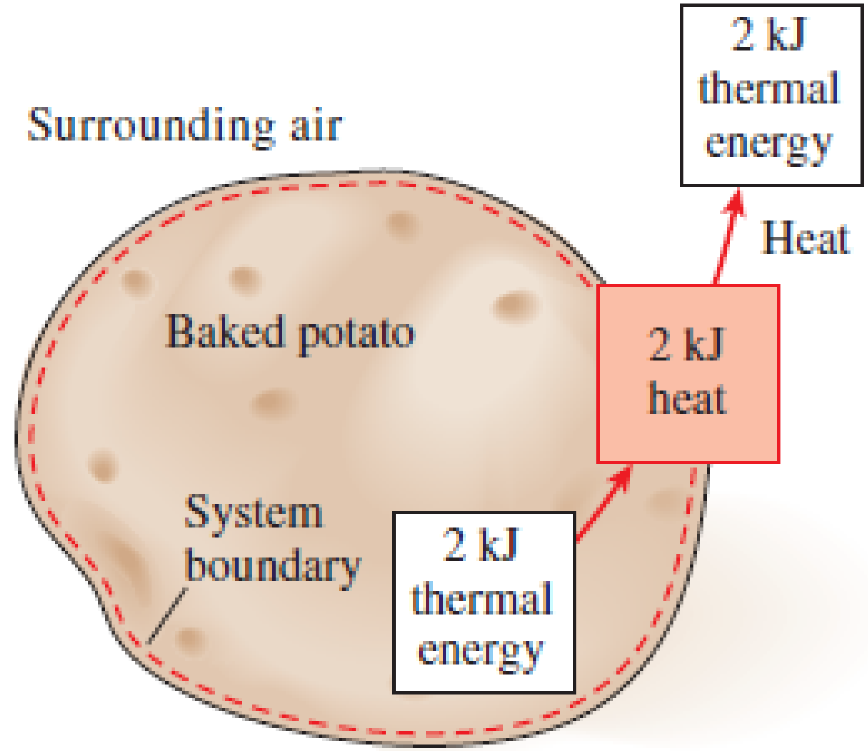
$$V = 44.7\ \mathrm{m/s}$$

Energy Transfer by Heat

- **Heat** is defined as the form of energy that is transferred between two systems (or a system and its surroundings) by virtue of a temperature difference.
- The direction of energy transfer is always from the higher temperature body to the lower temperature one.
- Once the temperature equality is established, energy transfer stops.
- The **thermal energy** of a given system is recognized inside the system as a consequence of the KE of its particles but **heat** (heat transfer) is recognized at interfaces.
- Therefore, terms as "**body heat**", "**heat rejection**", "**heat of reaction**" & "**specific heat**" are misleading.

Heat is an Energy in Transition

- **Heat** is recognized only as it crosses the boundary of a system.
- A hot baked potato contains energy, but this energy is heat transfer only as it passes through the skin of the potato (the system boundary) to reach the air.
- Once in the surroundings, the transferred heat becomes part of the internal energy of the surroundings.



Heat is recognized when crossing a boundary

Heating Rate, $\dot{Q}$ (kW)

- amount of heat transferred per unit time.
- The larger ΔT, the higher is the rate of heat transfer.

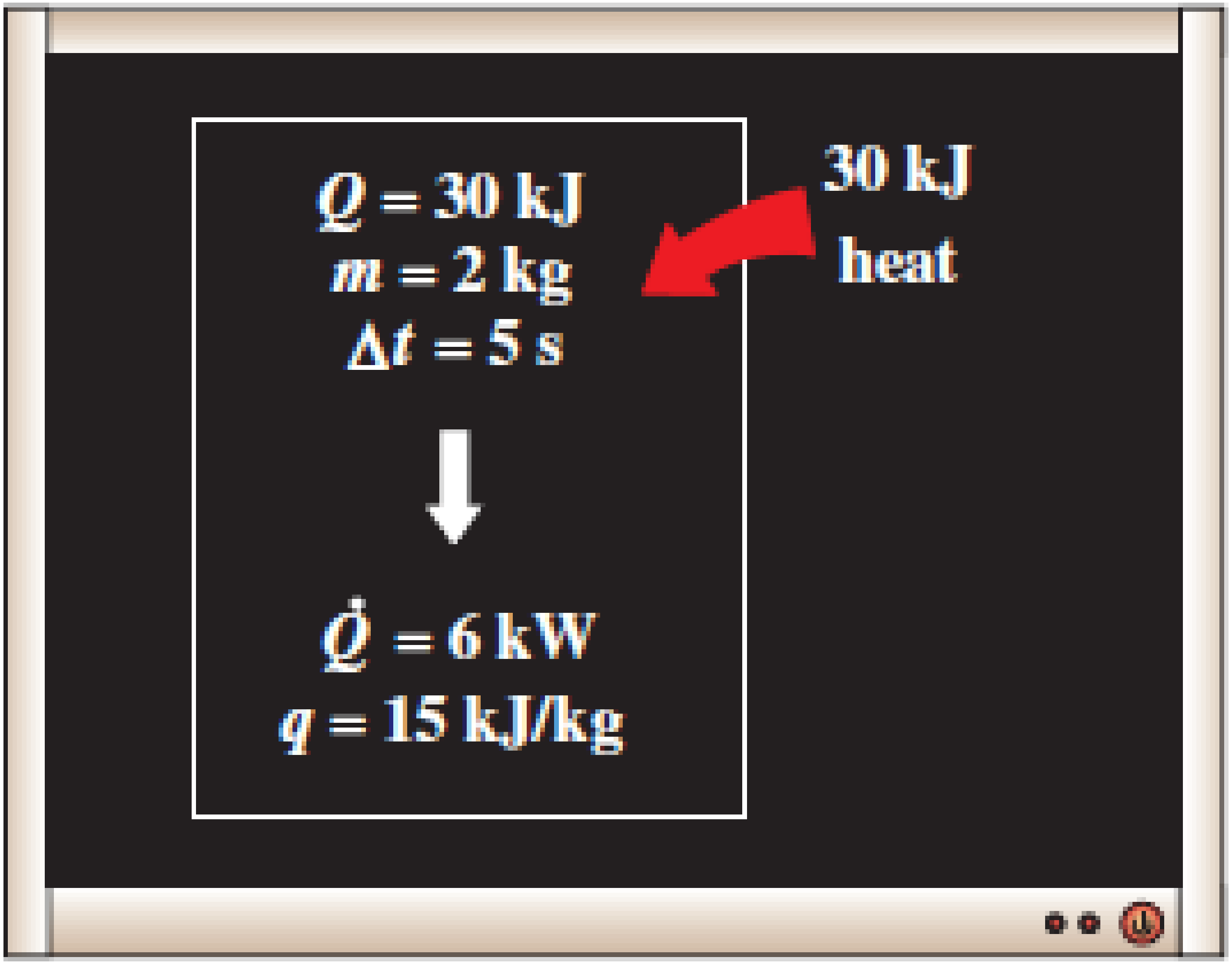
Room air 25°C

No Heat Transfer

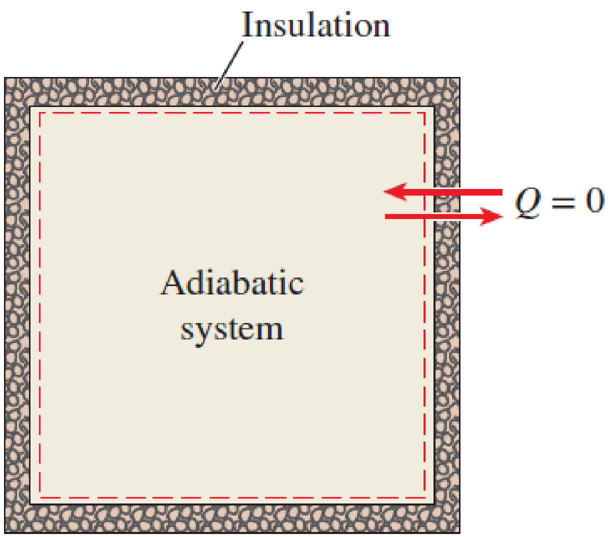
8 J/s

16 J/s

Heat per mass, q (kJ/kg)



Adiabatic process, q=0



Occurs if:

- System is well-insulated, **or**
- Both system and surroundings are at same T. (Nothing driving q.)

- For adiabatic processes, q=0 but the energy content and thus T of system can still be changed (e.g., by **work**). The work done is because of the change in the internal energy.
- In an isothermal process, there is no change in the system's temperature.

CYU

- If an energy transfer between a closed system and its surroundings is not heat, it must be

(A) Mechanical energy

(B) Energy transfer by mass

(C) Work or energy transfer by mass

(D) Work

(E) Thermal energy

Answer

√ **(D) Work**

CYU

- A 2-kg closed system receives 6 kJ heat from a source for a period of 10 min. The rate of heat transfer and the heat transfer per unit mass are

(A) 3 W, 10 kJ/kg

(B) 10 W, 3 kJ/kg

(C) 3 kW, 10 kJ/kg

(D)) 0.6 kW, 3 kJ/kg

(E) 0.6 W, 3 kJ/kg

Answer

√ **(B) 10 W, 3 kJ/kg**

Energy Transfer by Work

- An energy interaction (*exchange*) that is not caused by a temperature difference between a **closed** system and its surroundings is work.
- Work is the energy transfer associated with a force acting through a distance. A rising piston, a rotating shaft, and an electric wire crossing the system boundaries are all associated with work interactions.
- The unit of work is kJ and the work done per unit time is called **power** ($\dot{W}$) which has the unit kJ/s, or kW.

- Work transfer to a system (work done on a system) increases the system's E.

- Work transfer from a system (work done by system) decreases the system's E.

- Car engines and hydraulic, steam, or gas turbines **produce** work while compressors, pumps, and mixers consume work.

Formal sign convention

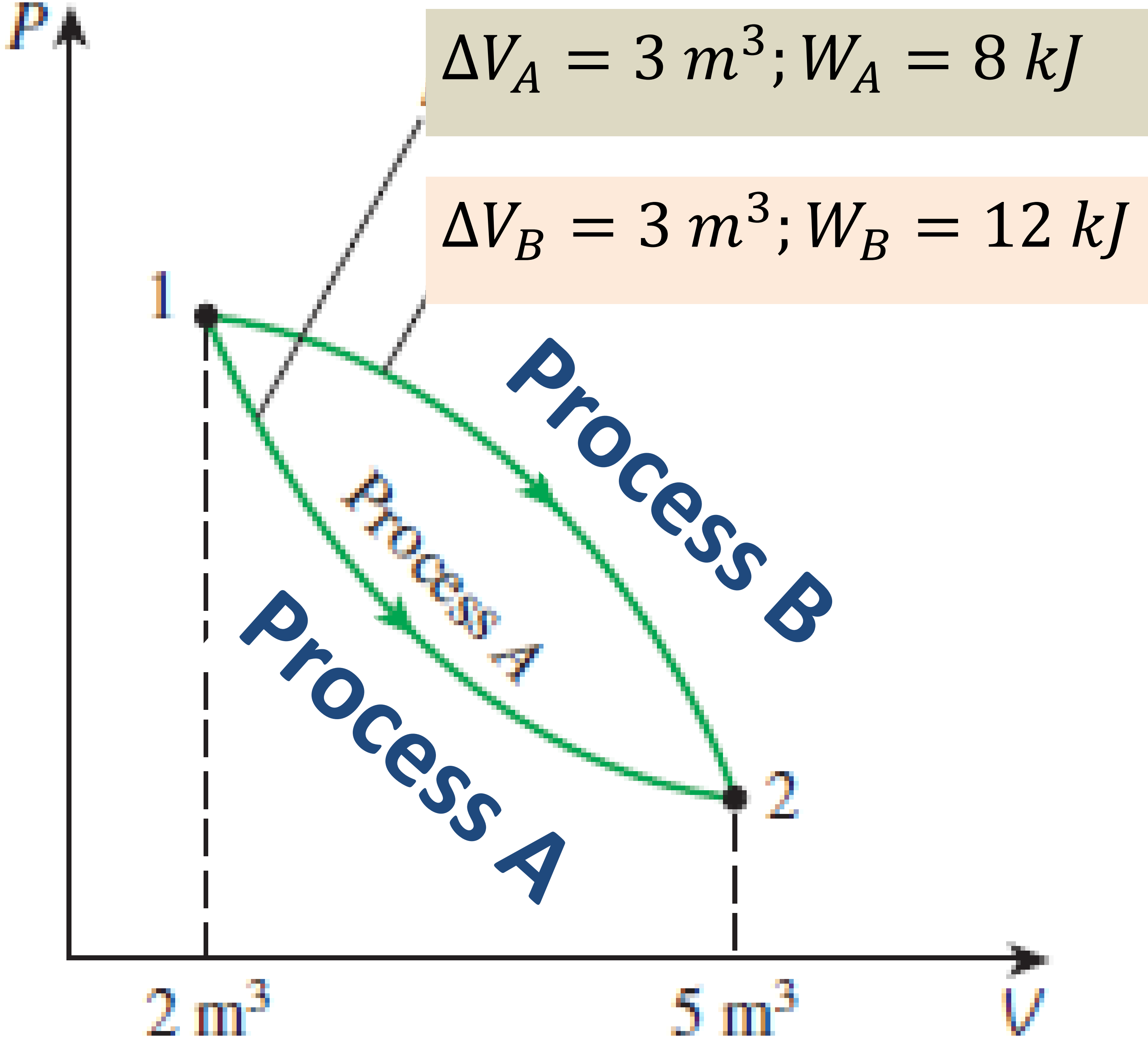
- Heat and work are ***directional quantities***, and their interaction requires the specification of both the *magnitude* and *direction.*
- The generally accepted **formal sign convention** for heat and work interactions is as follows:
  - heat transfer **to** a system and work done **by** a system are **positive**; heat transfer **from** a system and work done **on** a system are **negative**.
  - use the subscripts *in* and *out* to indicate direction, e.g., a work input of 5 kJ can be expressed as W_{in} = 5 kJ, while a heat loss of 3 kJ can be expressed as Q_{out} = 3 kJ.
  - If the direction is not specified, **assume** a direction and try to verify it.

Adopting a method

- The third method is adopted by the reference book.
- When the direction of a heat or work interaction is not known, we can simply *assume* a direction for the interaction (using the subscript *in* or *out*) and solve for it.
- A positive result indicates the assumed direction is right.
- A negative result indicates that the direction of the interaction is the opposite.
- This book used this ***intuitive approach*** to eliminate the need to adopt a formal sign convention and the need to carefully assign negative values to some interactions.

Heat & Work

- Both are recognized at the boundaries of a system as they cross the boundaries (*boundary* phenomena).
- Systems possess energy, but not heat or work.
- Both are associated with a ***process***, not a **state**. Unlike **properties**, heat or work has no meaning at a **state**.
- Both are ***path functions*** (i.e., their magnitudes depend on the path followed during a process as well as the end states).



$\Delta V_A = 3\ m^3; W_A = 8\ kJ$
$\Delta V_B = 3\ m^3; W_B = 12\ kJ$
P
1
2
Process A
Process B
Process A
2 m³
5 m³
V

Point "State" Functions

Properties as V are point functions (have exact differentials, dV, dE)

$$\int_1^2 dV = \Delta V$$

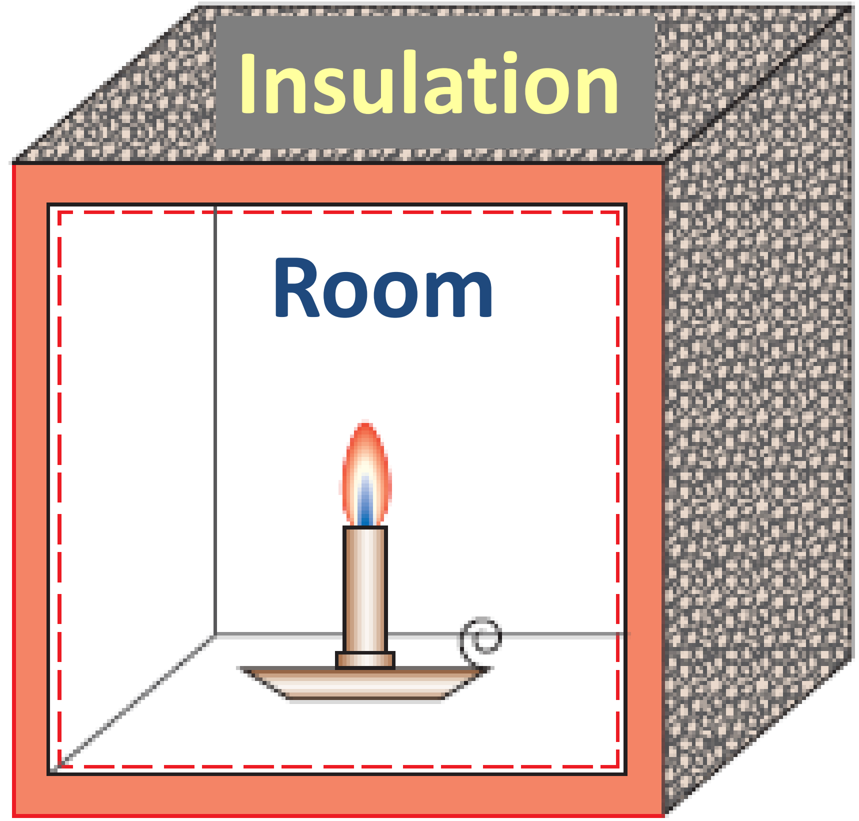
Path "non-State" Functions

Work and heat are path functions (have inexact differentials, δW, δQ)

$$\int_1^2 \delta W = W_{12} \neq \Delta W$$

Example

- A candle is burning in a well-insulated room. Taking the room (air + candle) as the system, determine:
  a) if there is any heat transfer during this burning process and
  b) if there is any change in the internal energy of the system.



$Q = ???$

$\Delta U = ???$

- Interior surfaces of the room form insulated boundary for adiabatic system

$$(Q = 0)$$

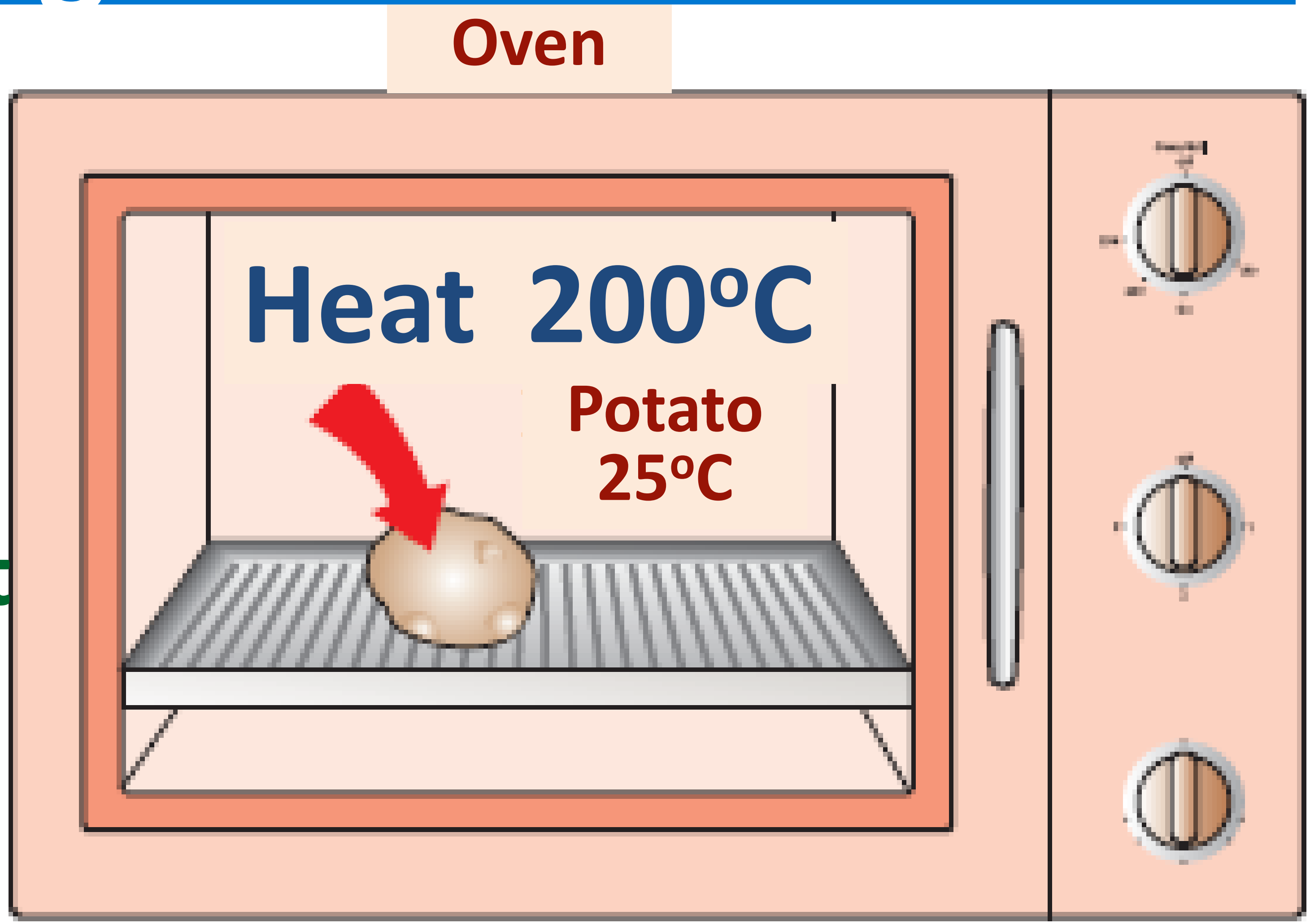
- During the process, part of chemical energy is converted to sensible energy but no change in total internal energy of the system.

$$\Delta U = 0$$

Heating Potato in an Oven

A potato initially at 25^0C

oven is at 200^0C



Q = ???

W = ???

System = Potato

Q = +Ve

Heat will flow under ΔT

W = 0

heat transfer process

System = Potato+ Chamber

Surrounding is doing work (electrical) on System

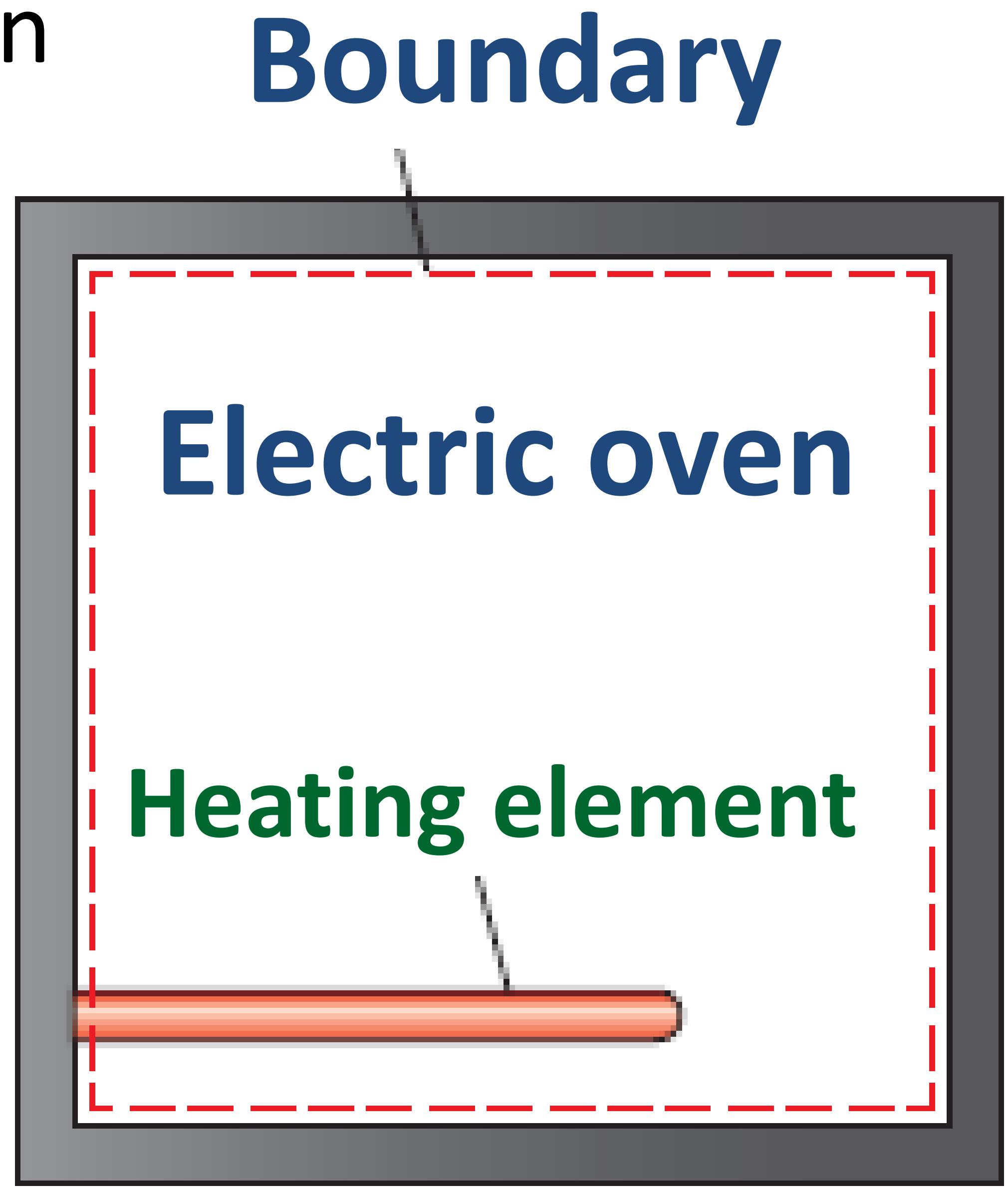
Q = 0 **W** = +Ve **Work Process**

Heating Oven by Work Transfer

System = entire oven + heating element

Q = 0 **W** = +Ve

Work process



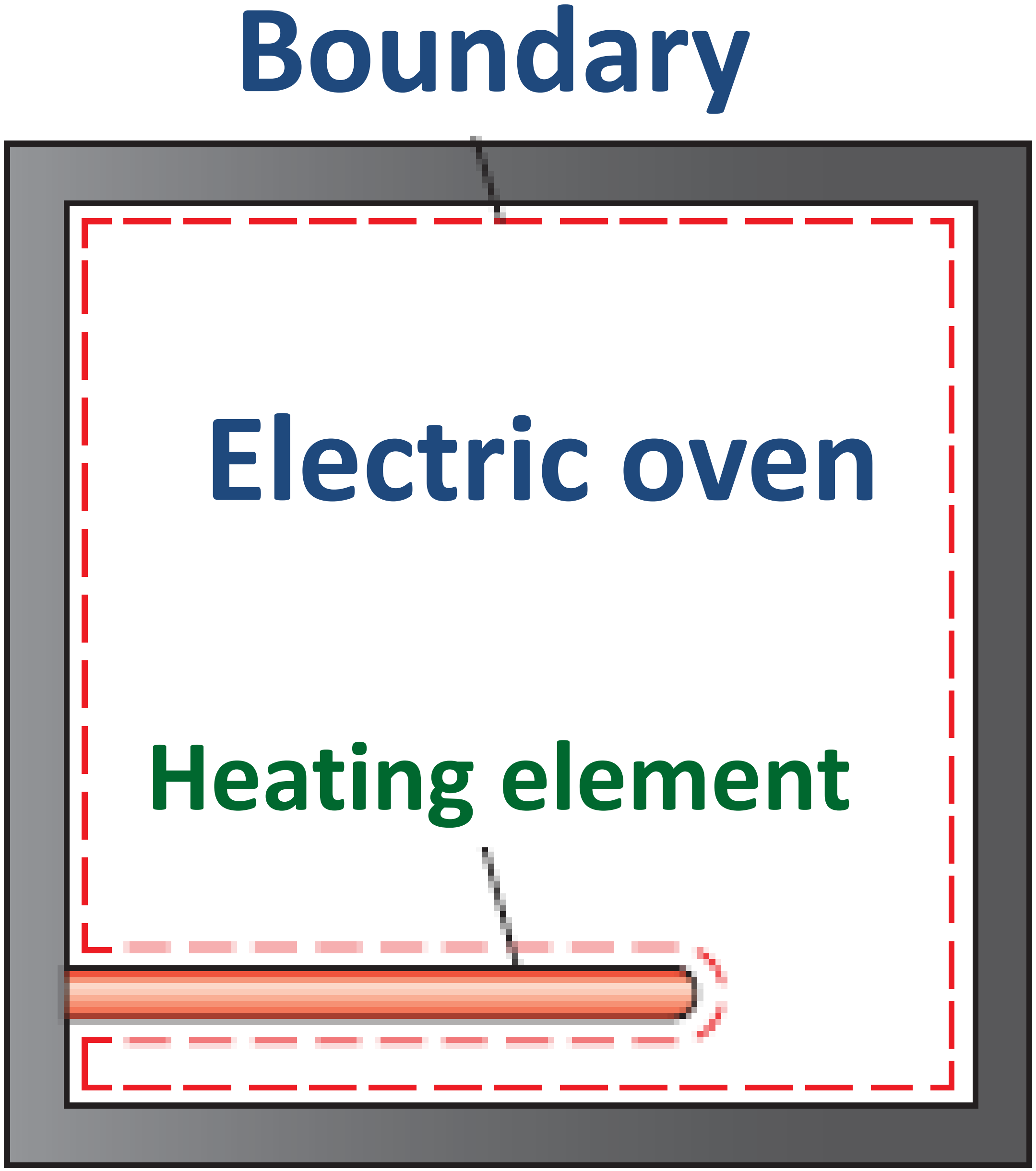
Heating Oven by Heat

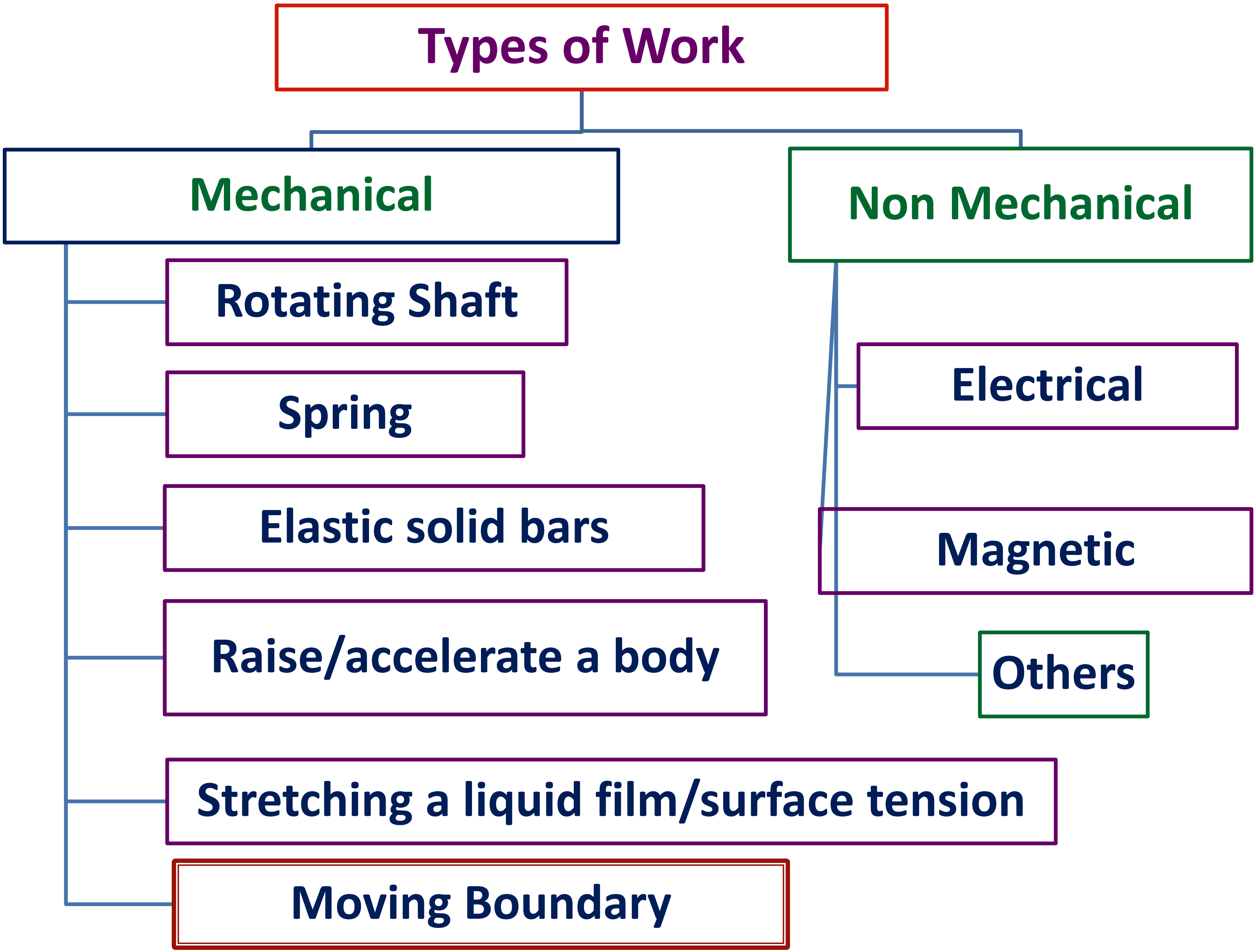
System = air in oven only

Q = +Ve

W = 0

Q is inspired by ΔT




Types of Work
Mechanical
Rotating Shaft
Spring
Elastic solid bars
Raise/accelerate a body
Stretching a liquid film/surface tension
Moving Boundary
Non Mechanical
Electrical
Magnetic
Others

Electrical Work

- In an electric field, electrons in a wire move under the effect of electromotive forces, doing work.
- When N coulombs of electrical charge move through a potential difference V, the electrical work, W_e, done is:

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

- It can also be expressed in the rate form as:

$$\dot{W}_e = \mathrm{V}I$$

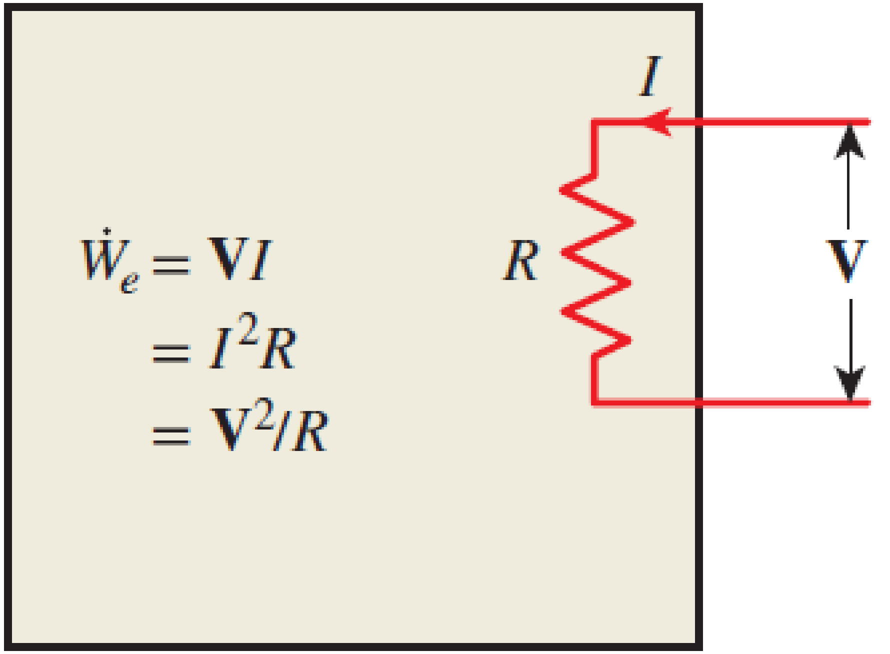
- where $\dot{W}_e$ is the **electrical power** and I is *the number of electrical charges flowing per unit time*, that is, the ***current***.

- In general, both V and I vary with time, and the electrical work done during a time interval Δt is expressed as:

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

- If V and I remain constant during the time interval Δt, it reduces to:

$$W_e = \mathrm{V} I \, \Delta t$$



CYU

- Select the ***wrong*** statement regarding heat and work interactions.

(A) Both heat and work are boundary phenomena.

(B) The magnitudes of heat and work depend on the path followed during a process.

(C) The magnitudes of heat and work depend on the initial and final states of a system.

(D) Heat and work are defined at a state of a system.

(E) The temperature of a well-insulated system can be changed by energy transfer as work.

Answer √ **(D) Heat and work are defined at a state of a system.**

CYU

- Work is done on a 0.5-kg closed system by a rotating shaft in the amount of 10 kJ during a period of 20 s. The work per unit mass and the power are

(A) 10 kJ/kg, 5 kW

(B) 5 kJ/kg, 2 kW

(C) 20 kJ/kg, 0.5 kW

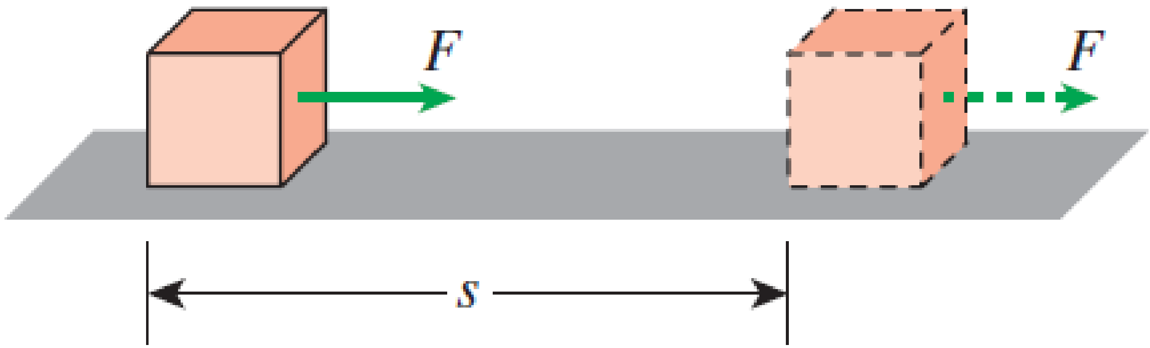
(D) 2000 J/kg, 50 W

(E) 2 kJ/kg, 5 kW

Answer √ **(C) 20 kJ/kg, 0.5 kW**

Mechanical Work

- There are several different ways of doing work, each in some way related to a force acting through a distance.



- The work done by a constant force F on a body displaced a distance s in the direction of the force is given by:

$$W = Fs$$

- If the force F is not constant

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

Conventions

- The work done on a system by an external force acting in the direction of motion is negative.

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

Mechanical work is associated with the movement of the **boundary** of a system or with the movement of the **entire system** as a whole

Moving boundary (mech.) work will be discussed later

Requirements of work interaction

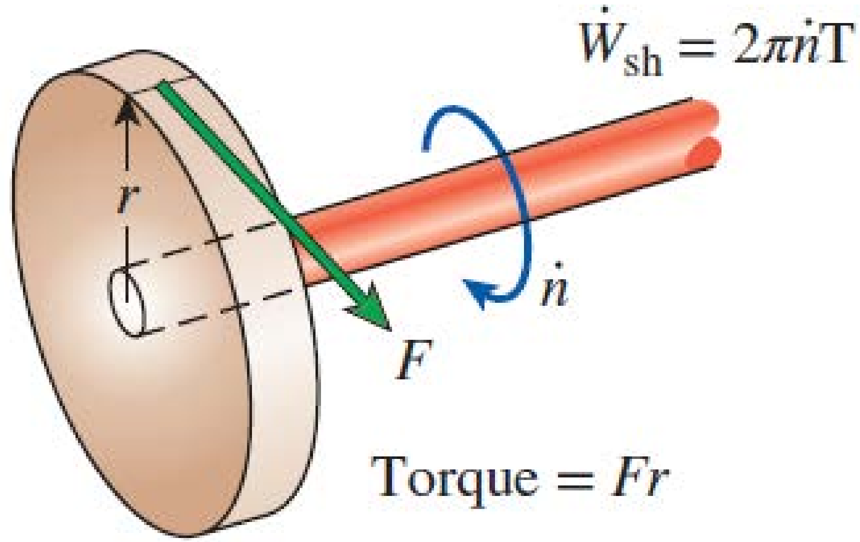
1) there must be a ***force*** acting on the boundary,
2) The boundary must ***move***.

- The presence of forces on the boundary without any displacement of the boundary **does not** constitute a **work interaction**.

- Likewise, the displacement of the boundary without any force to oppose or drive this motion **is not** a **work interaction** since no energy is transferred.
  - as the expansion of a gas into an evacuated space.

Shaft 1ƒ° 17 $117 Work

- Energy transmission with a rotating shaft.
- Often the torque T applied to the shaft is constant, *i.e.*, the force F applied is also constant.
- A constant force F acting through a moment arm r generates a torque T of:



$$T = Fr$$

$$F = \frac{T}{r}$$

- This force acts through a distance s, which is related to the radius r and to n revolutions by:

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

- Then the shaft work, W_{sh}, is determined from:

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

- The power, $\dot{W}_{sh}$, transmitted through the shaft is the shaft work done per unit time:

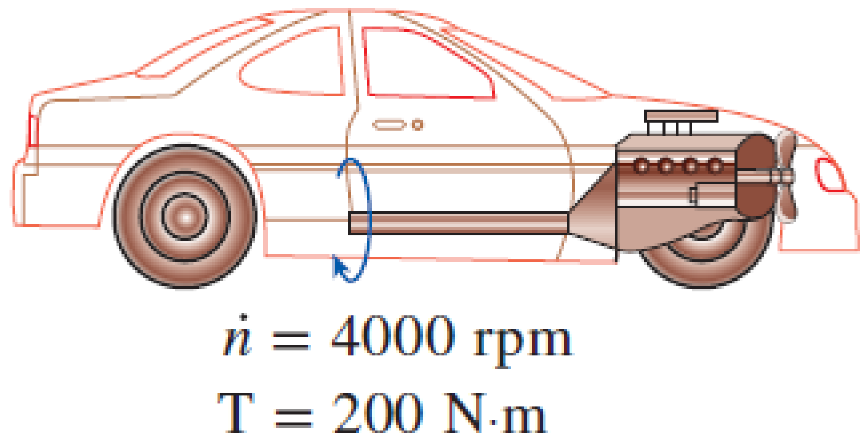
$$\dot{W}_{sh} = 2\pi \dot{n} \mathrm{T} \quad (\mathrm{kW})$$

where $\dot{n}$ is the **number of revolutions per unit time**.

Example: Power Transmission by the Shaft of a Car

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

Answer



The shaft power:

$$\dot{W}_{sh} = 2\pi \dot{n} \mathrm{T} \quad (\mathrm{kW})$$

$$\dot{W}_{sh} = 2\pi \times \frac{4000}{min} \times \frac{1\ min}{60\ s} \times 200\ Nm \times \frac{1\ kJ}{1000\ Nm}$$

$= 83.8$ kW $= 112$ hp

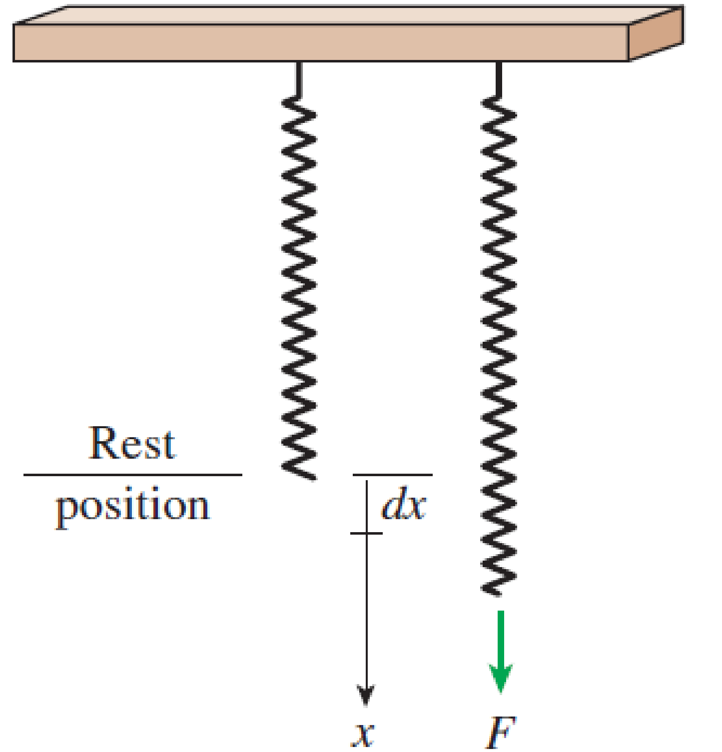
$1\ \mathrm{hp} \approx 0.748\ \mathrm{kW}$

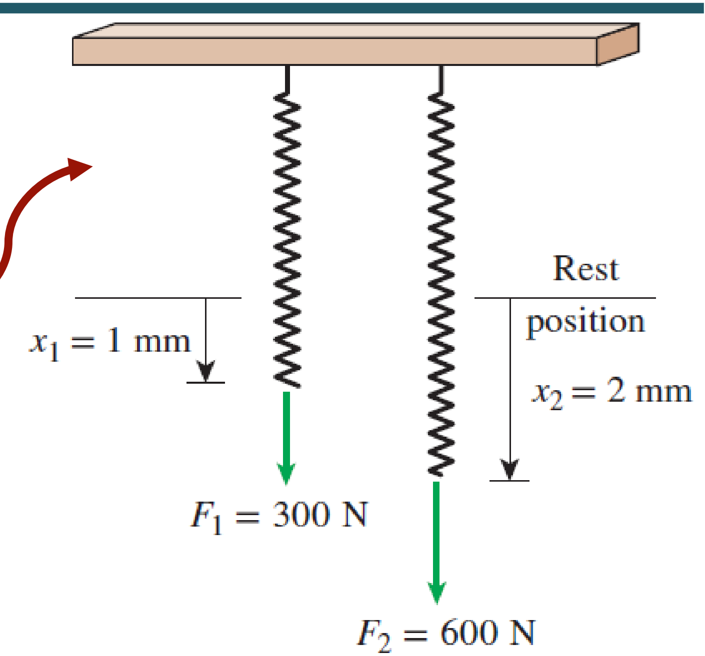
Spring 1 ƒ§¥ Work

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

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

- For linear elastic springs, the displacement x is proportional to F, $F = kx$
- k (kN/m) is the spring constant.





$$\int_0^{W_{spring}} \delta W_{spring} = \int_0^x F dx$$

$$\int_0^{W_{spring}} \delta W_{spring} = \int_0^x (kx) dx$$

$$W_{spring} = \frac{kx^2}{2}$$

$$\int_{W_1}^{W_2} \delta W_{spring} = \int_{x_1}^{x_2} (kx) dx$$

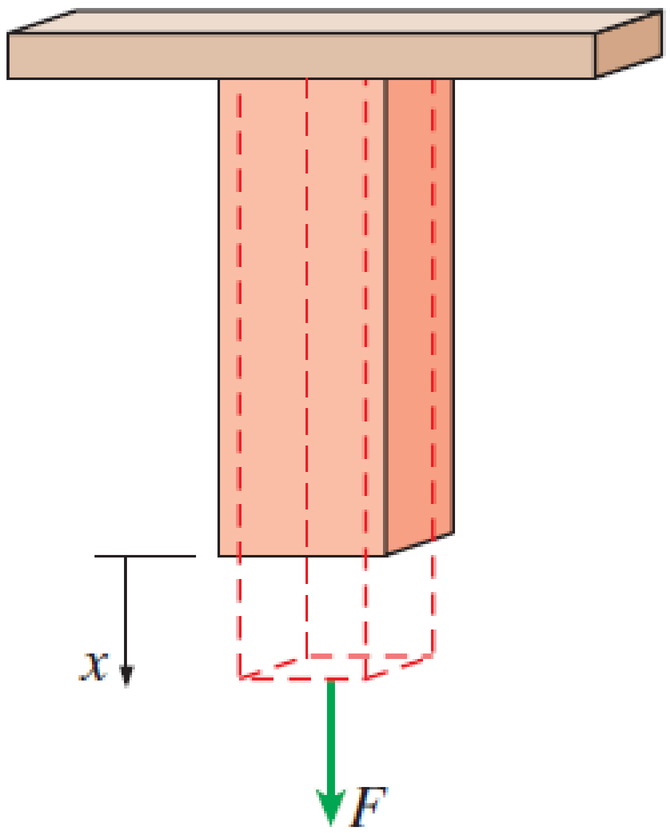
$$W_{spring} = \frac{k(x_2^2 - x_1^2)}{2}$$

Work done on elastic solid bars

- Solids are often modeled as linear springs because under the action of a force (not large enough to cause permanent (**plastic**) deformations) they contract or elongate, and when the force is lifted, they return to their original lengths, like a spring.

$$F = \sigma_n A$$

- σ_n is the normal stress (equiv. to P) and A is cross-sectional area of the bar.

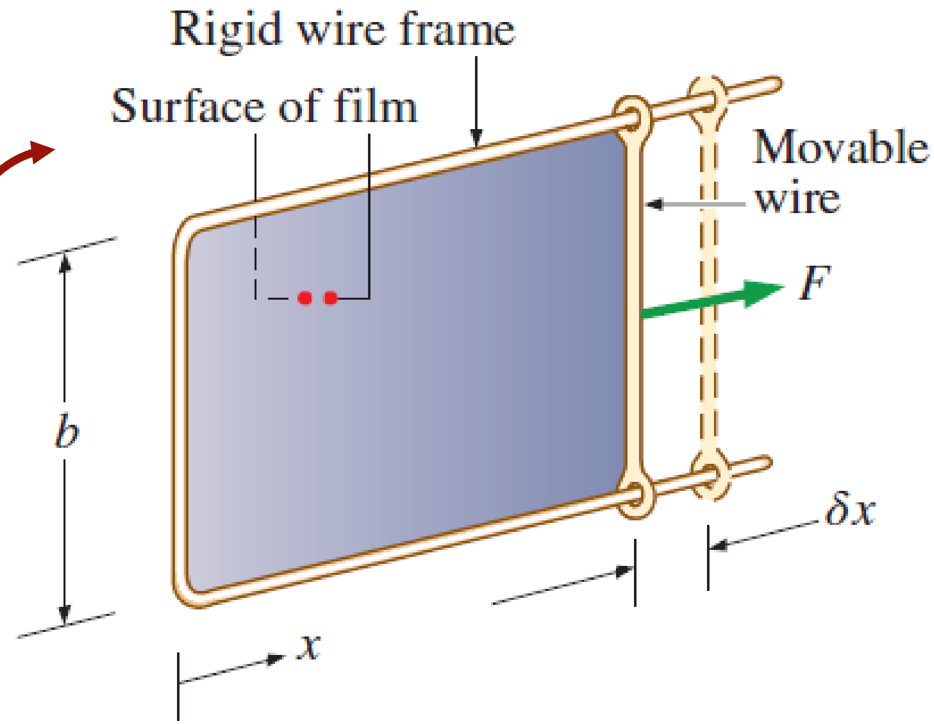


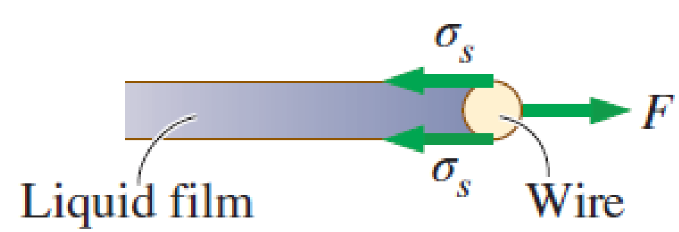
$$W_{elastic} = \int_1^2 \sigma_n A \, dx$$

Work of a stretched liquid film

- Consider a liquid film such as soap film suspended on a wire frame.

- A **force** is required to overcome the microscopic forces between molecules at the liquid–air interfaces to stretch this film by the movable portion of the wire frame.





σ_s surface tension force per unit length

- These microscopic forces are perpendicular to any line in the surface, and the force generated by these forces per unit length is called the **surface tension** σ_s, whose unit is N/m.
- Therefore, the work associated with the stretching of a film is also called ***surface tension work,*** $W_{surface}$.

$$W_{surface} = \int_1^2 \sigma_s dA \qquad \text{(kJ)}$$

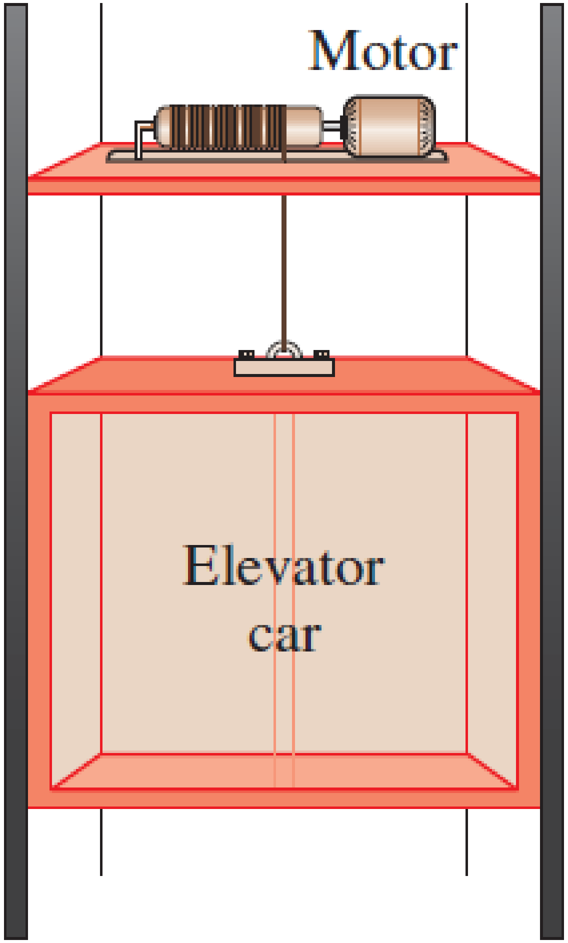
  - o $dA = 2b\,dx$ is the change in the surface area of the film.
  - o The factor 2 is due to the fact that the film has two surfaces in contact with air.

- The force acting on the movable wire as a result of surface tension effects is

$$F = 2b\sigma_s$$

Work of raising or accelerating a body

- When a body is raised in a gravitational field, its potential energy **increases**.
- Likewise, when a body is accelerated, its kinetic energy **increases**.
- The conservation of energy principle requires that an equivalent amount of energy must be transferred to the body being raised or accelerated.



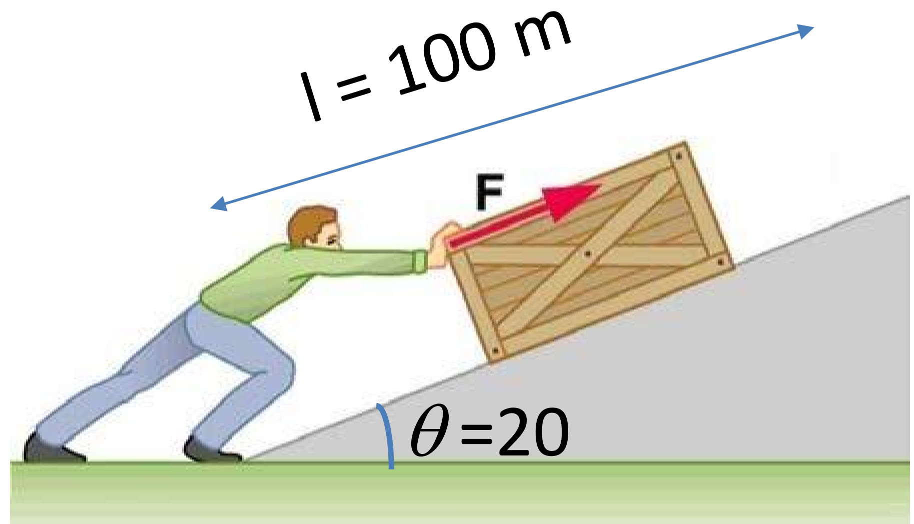
- Energy can be transferred to a given mass by heat (under **temp. difference** - not the case) and work (√).
- The work transfer needed to raise a body is equal to the change in the potential energy of the body.
- The work transfer needed to accelerate a body is equal to the change in the kinetic energy of the body.
- Similarly, the potential or kinetic energy of a body represents the work that can be obtained from the body as it is lowered to the reference level or decelerated "slowed" to zero velocity.
- This discussion together with the consideration for friction and other losses form the basis for determining the required power rating of motors and engines.

Example: Work Requirement to Push a Cart Uphill

- A person 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 9.8 m/s^2. Determine the work, in kJ, needed to move along this ramp a distance of 100 m considering (*a*) the person and the cart and (*b*) just the cart.

Answer

Considering the **(person + cart)** as the system, letting *l* be the displacement along the ramp, and letting θ be the inclination angle of the ramp,



$$W = F\,l\,sin\theta = \mathrm{mg}\,l\,sin\theta$$

$$= (100 + 100\ kg)(9.8\ m/s^2)(100\ m)\ (sin20)\left(\frac{1\ kJ/kg}{1000\ m^2/s^2}\right)$$

$$= 67.0\ kJ$$

Cart only

$$W = (100\ kg)(9.8\ m/s^2)(100\ m)\ (sin20)\left(\frac{1\ kJ/kg}{1000\ m^2/s^2}\right)$$

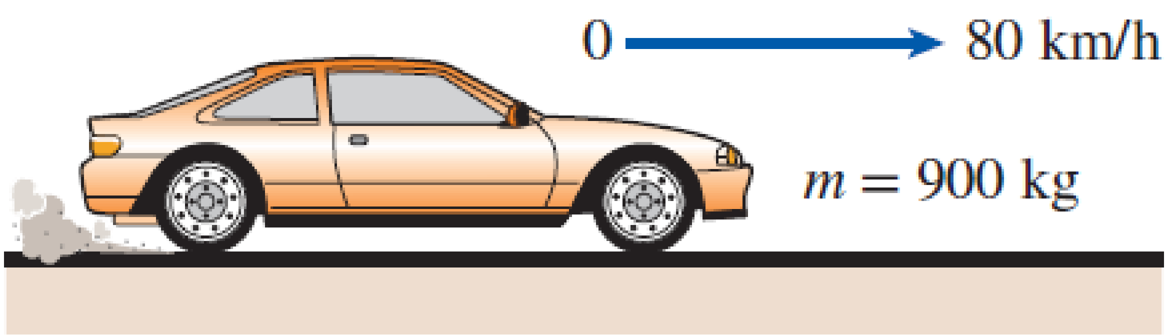
$$= 33.5\ kJ$$

Example: Power needed to accelerate a car

- Determine the power required to accelerate a 900-kg from rest to a velocity of 80 km/h in 20 s on a level road.

$$W_a = \frac{m\left(V_2^2 - V_1^2\right)}{2} = \frac{1}{2}(900\ kg)\left[\left(\frac{80{,}000\ m}{3600\ s}\right)^2 - 0^2\right]\left(\frac{1\ kJ/kg}{1000\ m^2/s^2}\right)$$

$$= 222\ kJ$$



Average power

$$\dot{W}_a = \frac{W_a}{\Delta t} = \frac{222\ kJ}{20\ s} = 11.1\ kW = 14.9\ hp$$