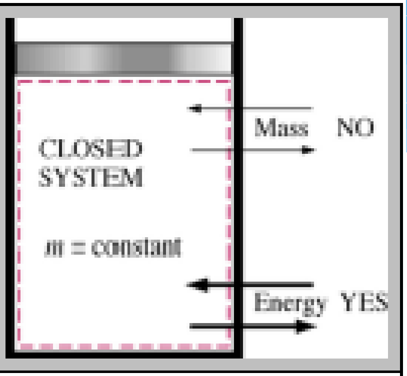
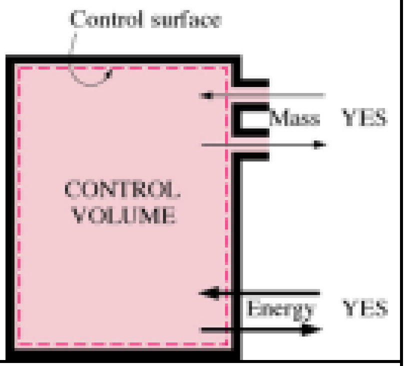
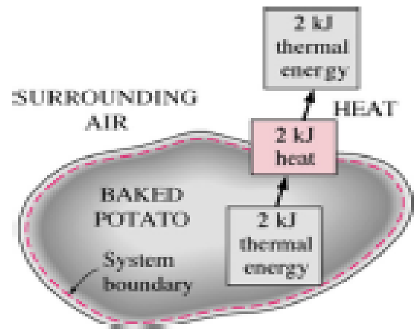
Lecture 3

Energy Transfer

Energy Transfer

Closed System	Heat Work	
Open System	**Heat,Work ,Mass**	

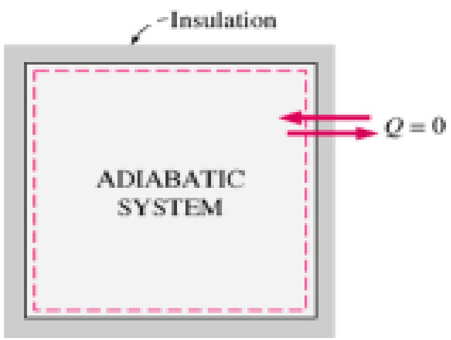
Energy Transfer by Heat



- Heat is energy in transition across the ***system boundary solely due to the*** temperature difference between the system and its surroundings.

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

  There are two ways a process can be adiabatic:
  - ✓ The system is well insulated.
  - ✓ The system and the surroundings are at the same temperature.



- The amount of heat transferred during a process between two states (1 and 2) is denoted by *Q12 or Q (in J or kJ).*

$$Q = m \times C \times \Delta T$$

  - ✓ Heat transfer per unit mass of a system is denoted by *q (= Q/m)*

- For a system with a *source heat* and a *heat sink*:

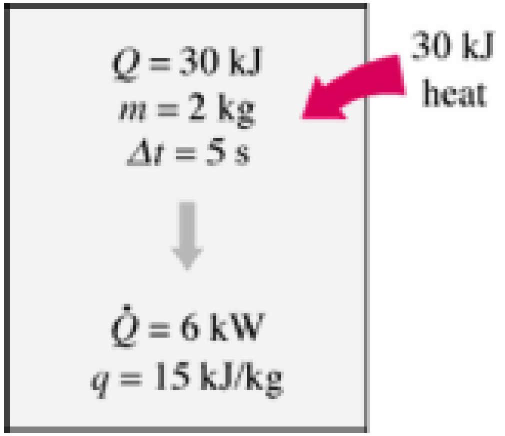
$$Q_{net} = \sum Q_{in} - \sum Q_{out}$$

- The *heat transfer rate* is denoted by (*kJ/s* = *kW*).
  - ✓When Q *varies with time*

$$Q = \int_{t_1}^{t_2} \dot{Q} dt$$

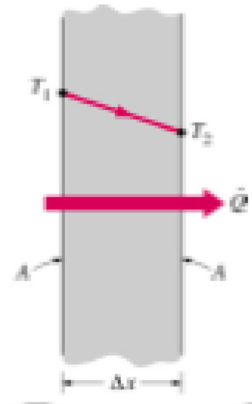
  - ✓When Q *remains constant*

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

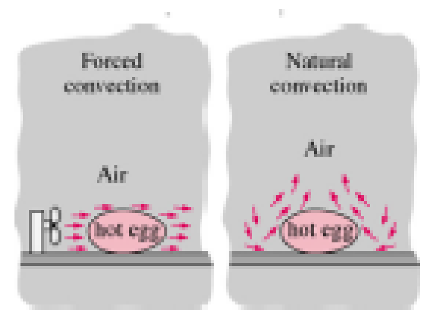


Mechanisms of Heat Transfer

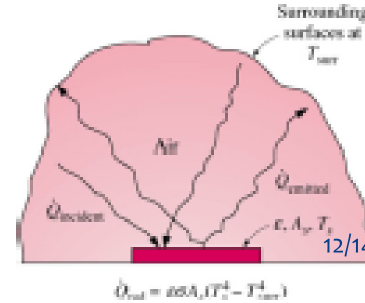
- ***Conduction:*** Transfer of energy from the more energetic particles of a substance to the adjacent less energetic one as a result of interaction between particles.



- ***Convection:*** Transfer of energy between a solid surface and adjacent fluid that is in motion and it involves the combined effects of conduction and fluid motion.



- ***Radiation:*** Transfer of energy due to the emission of electromagnetic waves (or photons)



Energy Transfer by Work:

- *Work* is *the energy transfer associated with force acting through a distance*.

$$Work = \int_{x_1}^{x_2} F\,dx \qquad \text{Unit}: \ \text{N.m} = \text{J (Joule)}$$

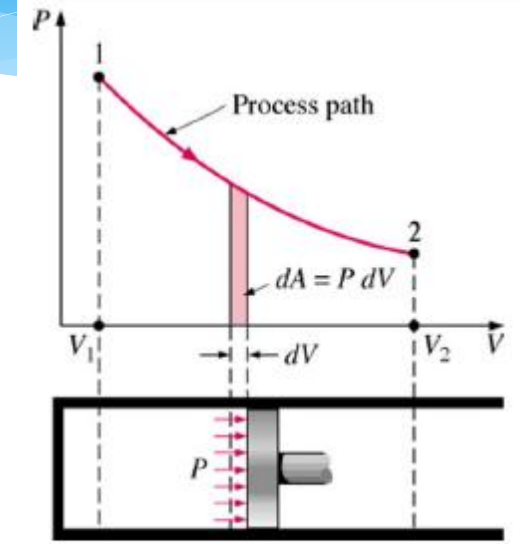
- *Power* = *the work done per unit time*.

- There are two requirements for a work interaction between a system and its surroundings to exist:

  1- There must be force acting on a boundary

  2- The boundary must move

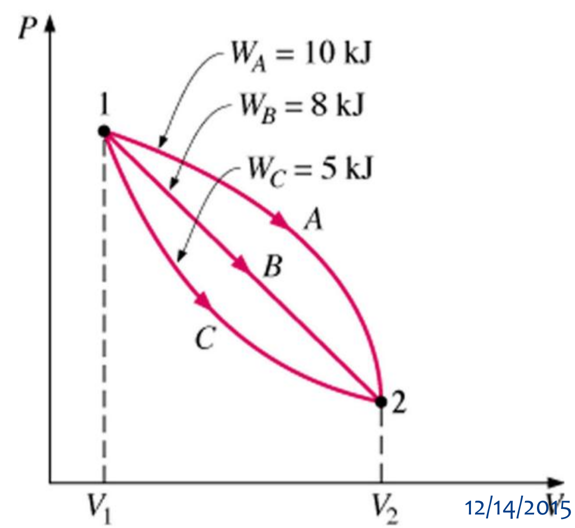
Moving Boundary Work:



- The area under the process curve on a *P-V* diagram is equal, in magnitude, to the work done during expansion or compression process of a closed system.

$$W = \int_{x_1}^{x_2} F dx = \int_{x_1}^{x_2} PA dx = \int_{V_1}^{V_2} P dV$$

Significance of the Path:



- Each path will have a different area underneath it.
- The boundary work done during a process *depends* ***on the path*** followed as well as ***the end states***.

The work due to the relations between pressure and volume:

❑ Polytrophic process: $PV^n = C$

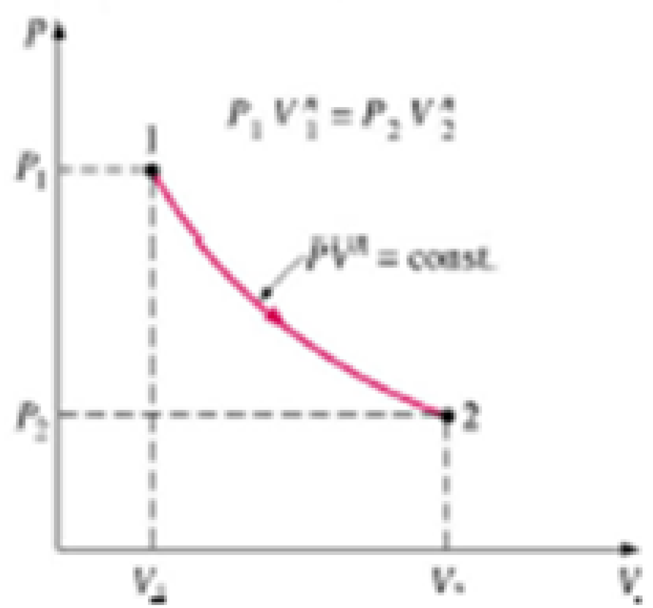
$$PV^n = C \Rightarrow P_1V_1^n = P_2V_2^n \Rightarrow P = \frac{C}{V^n}$$

$$W = \int_1^2 PdV = \int_1^2 CV^{-n}dV = C\int_1^2 V^{-n}dV$$

$$W = C\left.\frac{V^{-n+1}}{-n+1}\right|_{V_1}^{V_2} = C\frac{V_2^{-n+1} - V_1^{-n+1}}{-n+1}$$

$$W = \frac{P_2V_2^nV_2^{-n+1} - P_1V_1^nV_1^{-n+1}}{-n+1}$$

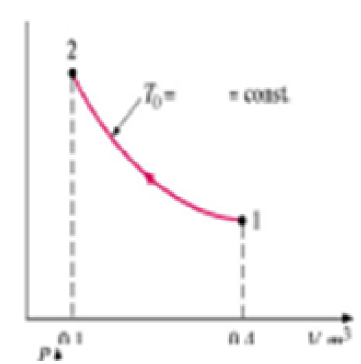
$$\therefore W = \frac{P_1V_1 - P_2V_2}{n-1}$$



❑ Isothermal process: *PV =C*

$$PV = mRT = C \text{ or } P = C/V \quad (T = \text{Constant})$$

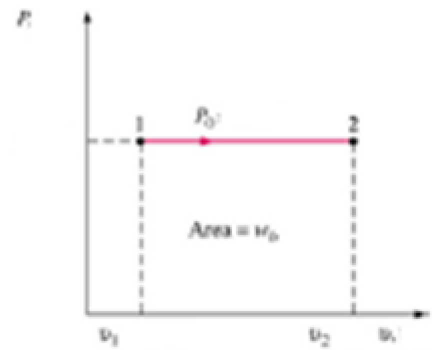
$$W = \int_1^2 P dV = \int_1^2 \frac{C}{V} dV = C\int_1^2 \frac{dV}{V} = C \ln\frac{V_2}{V_1} = P_1V_1 \ln\frac{V_2}{V_1} = mRT\frac{V_2}{V_1}$$



❑ Constant pressure process:

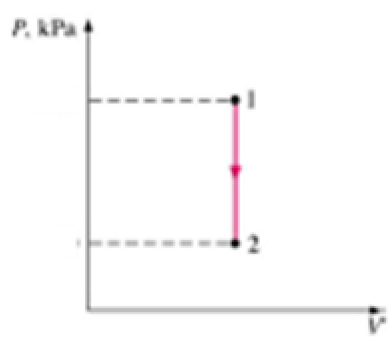
$$W = \int_1^2 P dV = P_0 \int_1^2 dV =$$

$$P_0(V_2 - V_1) = mP_0(v_2 - v_1)$$



❑ Constant Volume process

$$W = \int_1^2 P d\cancel{V}^{\,0} = 0$$



The Work:

Work is the force acting through a displacement and the displacement being in the direction of force.

$$W = \int_1^2 P.dV$$

- For Polytropic process:

$$W = \frac{P_1V_1 - P_2V_2}{n-1}$$

- For Isothermal process

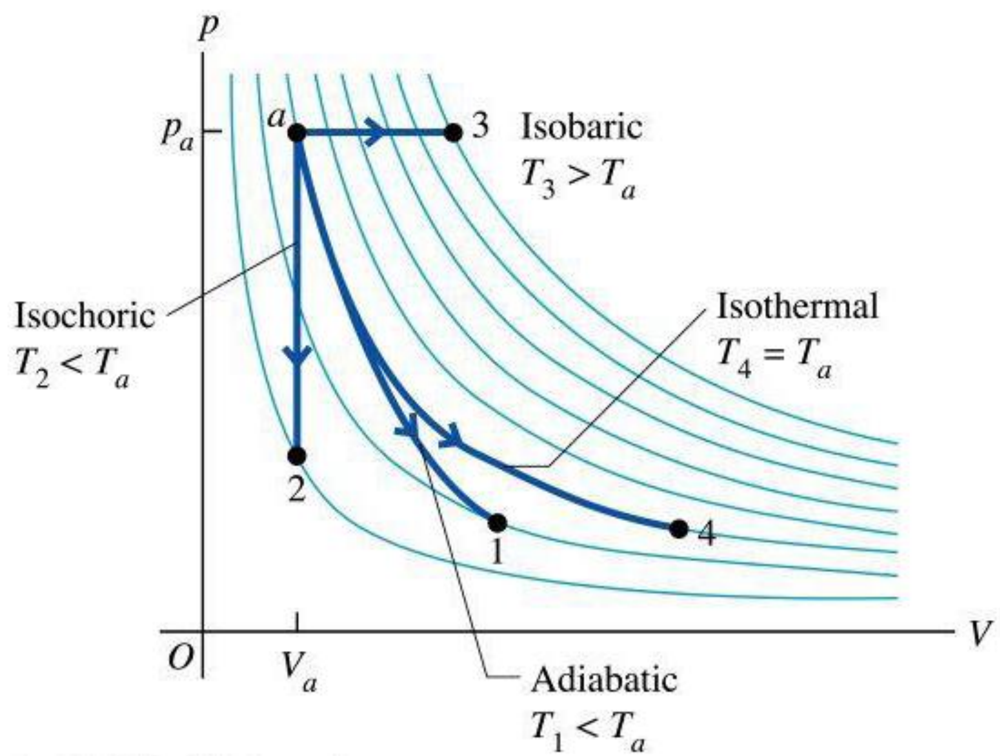
$$W = P_1V_1 \ln\frac{V_2}{V_1} = P_1V_1 \ln\frac{P_1}{P_2}$$

- For Isobaric process:

$$W = P_1 \times (V_2 - V_1)$$

- For Isochoric process:

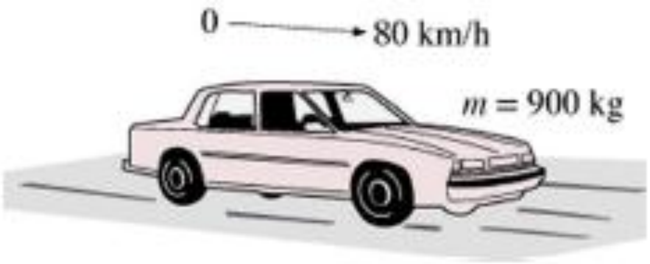
$$W = Zero$$



Example

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

Solution



$$W = 1/2m(V_2^2 - V_1^2)$$

$$W = 1/2(900\text{kg})\left[\left(\frac{80{,}000\text{m}}{3{,}600\text{s}}\right)^2 - 0\right]\left(\frac{1\text{kJ}}{1000\text{kgm}^2/\text{s}^2}\right)$$

$$W = 222\text{kJ}$$

The average Power

$$\dot{W} = \frac{W}{\Delta t} = \frac{222\text{kJ}}{20\text{s}} = 11.1\text{kW}$$

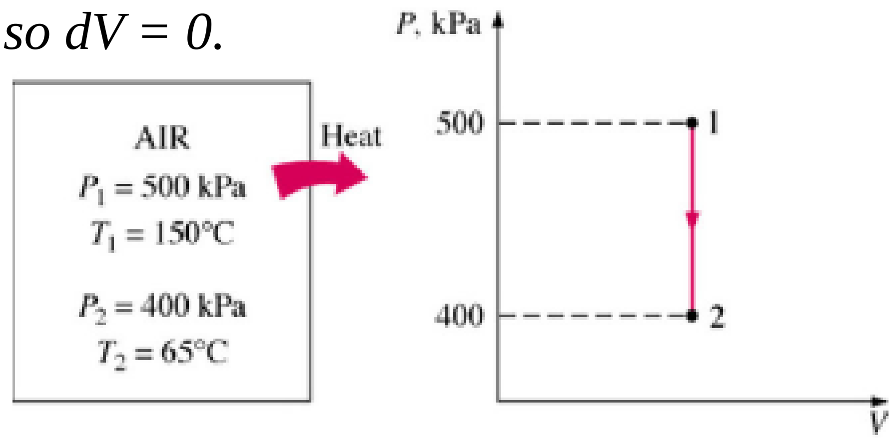
Example Constant Volume Process

A rigid tank contains air at 500 kPa and 150°C. As a result of heat transfer to surroundings, the temperature and pressure inside the tank drop to 65°C and 400 kPa, respectively. Determine the boundary work done during this process.

Solution

A rigid tank has a constant volume and so dV = 0.

$$W = \int_1^2 P\,d\overset{\nearrow 0}{V} = 0$$



Example Constant Pressure Process

A frictionless piston-cylinder device contains 10 kg of water vapor at 500 kPa and 250°C. Heat is now transferred to the steam until the temperature reached 350°C. Determine the work done by the steam during this process.

Solution

From the table

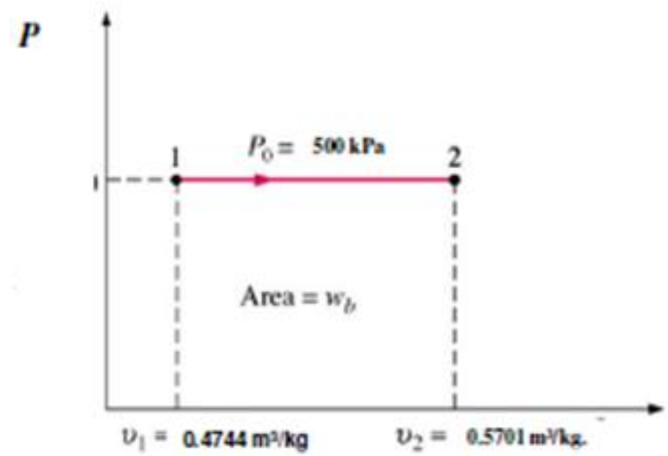
At $P = 500$ kPa $= 0.5$ MPa

and $T_1 = 250$ °C:

$v_1 = 0.4744$ m³/kg

and $T_2 = 350$ °C

$v_2 = 0.5701$ m³/kg.



$$W = \int_1^2 P\,dV = P_0 \int_1^2 dV =$$

$$P_0(V_2 - V_1) = mP_0(v_2 - v_1)$$

$W = 10$ kg$\times$500 kPa$\times$(0.5701-0.4744) m³/kg$\times$(1 kJ/kPa.m³)

$W = 479$ kJ