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-2nd-Class
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Thermodynamics
Lecture 5 and 6
The First Law of Thermodynamics

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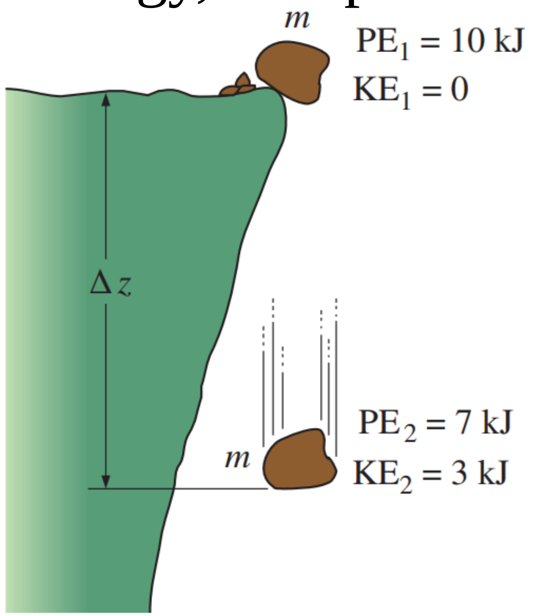
The First Law of Thermodynamics

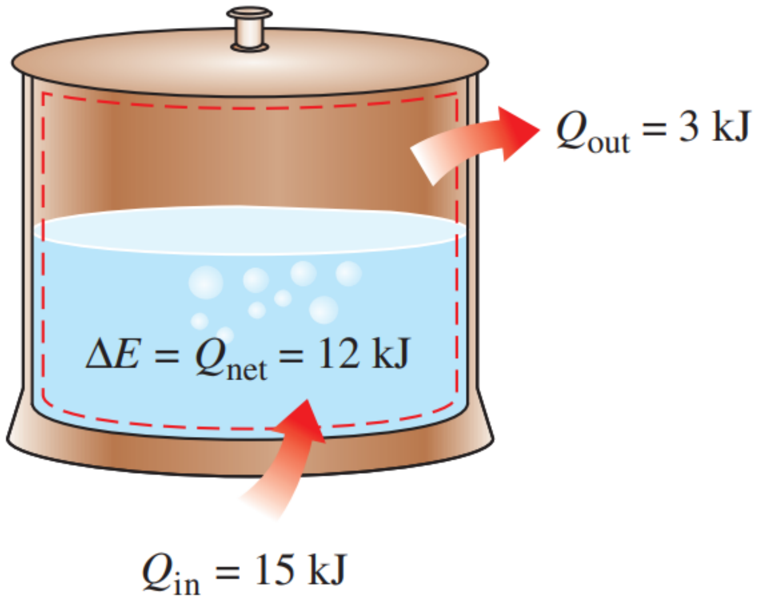
- The first law of thermodynamics states that the total energy of a system remains constant, even if it is converted from one form to another.

- Energy cannot be created or destroyed; it can only change forms.

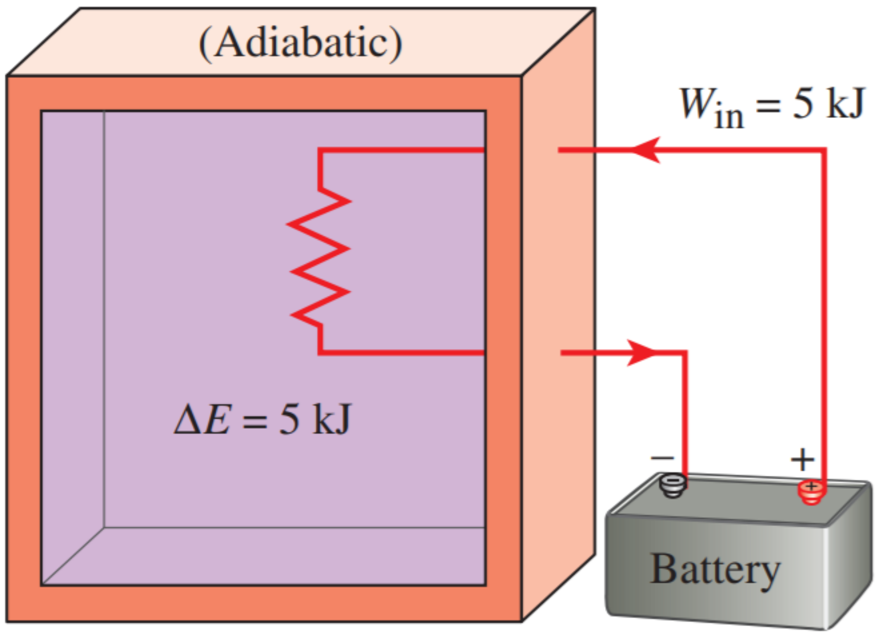
- We all know that a rock at some elevation possesses some potential energy, and part of this potential energy is converted to kinetic energy as the rock falls.



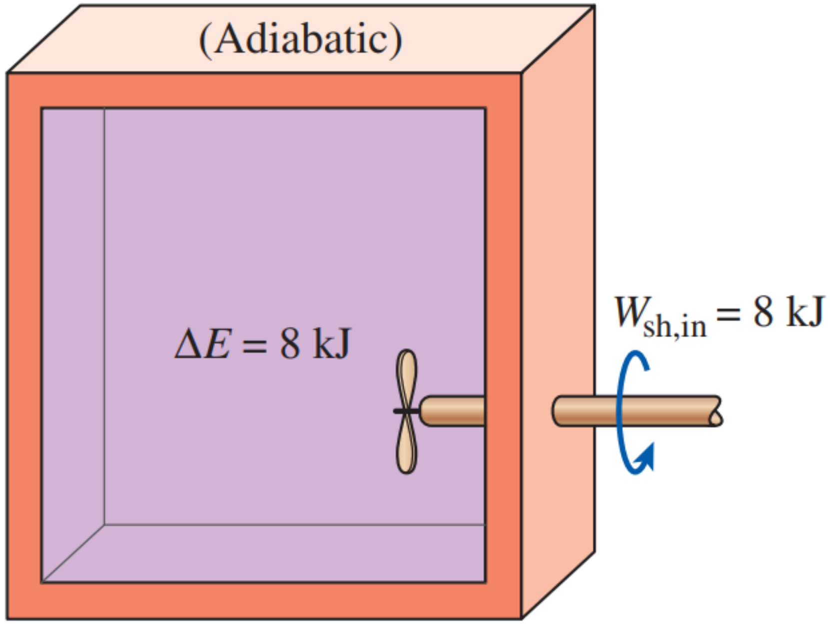
The development of the first law or the conservation of energy relation with the help of some familiar examples

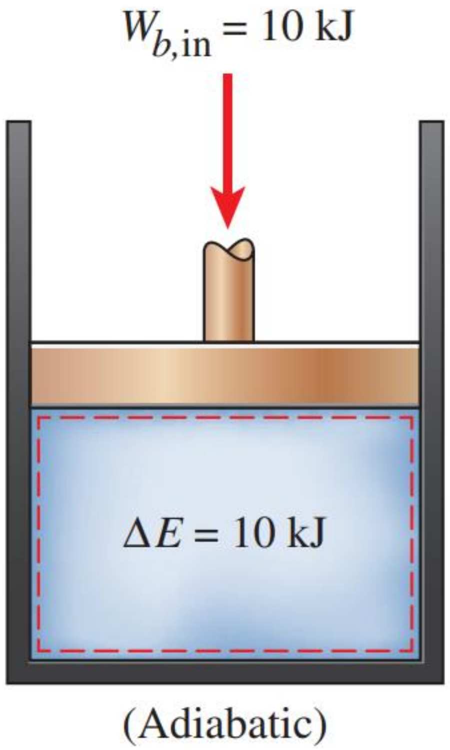


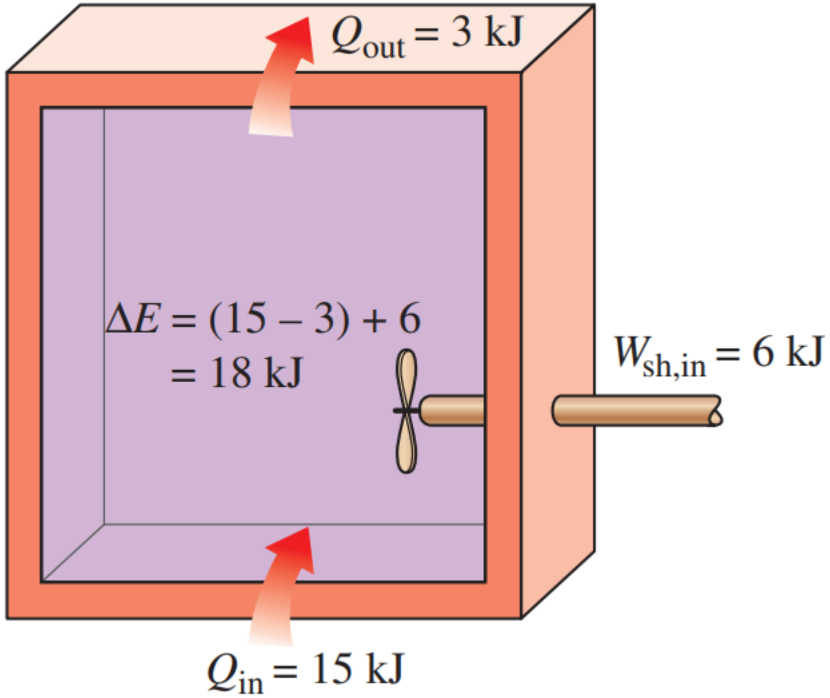
In the absence of any work interactions, the energy change of a system is equal to the net heat transfer.



The work (electrical) done on an adiabatic system is equal to the increase in the energy of the system.







The work (boundary) done on an adiabatic system is equal to the increase in the energy of the system.

The work (boundary) done on an adiabatic system is equal to the increase in the energy of the system.

The energy change of a system during a process is equal to the net work and heat transfer between the system and its surroundings.

Energy Balance

- 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 that process. That is,

$$\begin{pmatrix}\text{Total energy}\\ \text{entering the system}\end{pmatrix} - \begin{pmatrix}\text{Total energy}\\ \text{leaving the system}\end{pmatrix} = \begin{pmatrix}\text{Change in the total}\\ \text{energy of the system}\end{pmatrix}$$

or

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

Energy Balance for Closed System

$$Q_{12} = W_{12} + \Delta P.E_{12} + \Delta K.E_{12} + \Delta F.E_{12} + \Delta U_{12}$$

$$Q_{12} = W_{12} + \Delta E_{12}$$

where

$$\Delta E_{12} = Stored\ Energy$$

$$\Delta E_{12} = \Delta P.E_{12} + \Delta K.E_{12} + \Delta F.E_{12} + \Delta U_{12}$$

$\Delta P.E_{12} = 0,\quad If\ there\ is\ no\ considered\ difference\ in\ height$

$\Delta F.E_{12} = 0,\quad If\ there\ is\ no\ flow$

$\Delta K.E_{12} = 0,\quad If\ there\ is\ no\ movement$

$$\therefore Q_{12} = W_{12} + \Delta U_{12}$$

The above equation represents the non-flow energy equation

Ex (1): In the compression stroke of an internal combustion engine, the heat rejected to the cooling water is 45 kJ/kg and the work input is 90 kJ/kg. Calculate the change in internal energy.

Solution:

$$Q_{12} = -45 \frac{kJ}{kg}$$

$$W_{12} = -90 \frac{kJ}{kg}$$

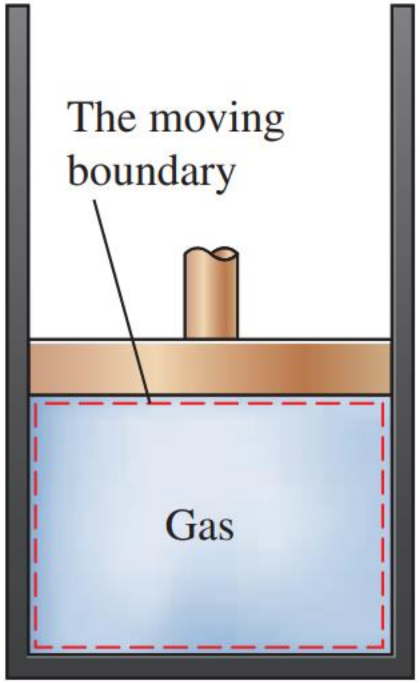
$$Q_{12} = W_{12} + \Delta U_{12}$$

$$-45 = -90 + \Delta U_{12}$$

$$\therefore \Delta U_{12} = 45 \frac{kJ}{kg}$$

Work done at a moving Boundary of a closed system

- P=f(V) is simply the equation of the process path on P-V diagram. The quasi-equilibrium expansion process described above is shown in a below P-V diagram.

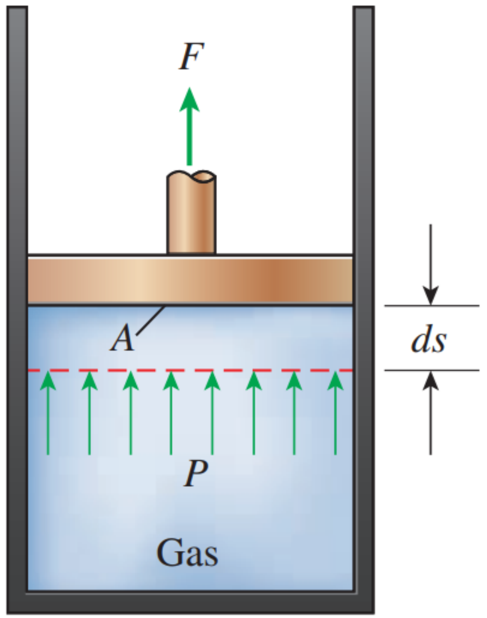


The work associated with a moving boundary is called boundary work.

Work done at a moving Boundary of a closed system

❖ Consider the gas enclosed in the piston–cylinder device. The initial pressure of the gas is P, the total volume is V, and the cross-sectional area of the piston is A. If the piston is allowed to move a distance ds in a quasi-equilibrium manner, the differential work done during this process is

$$\delta W_b = F\,ds = PA\,ds = P\,dV$$



A gas does a differential amount of work δW_b as it forces the piston to move by a differential amount *ds*.

Work done at a moving Boundary of a closed system

- The total boundary work done during the entire process as the piston moves is obtained by adding all the differential works from the initial state to the final state:

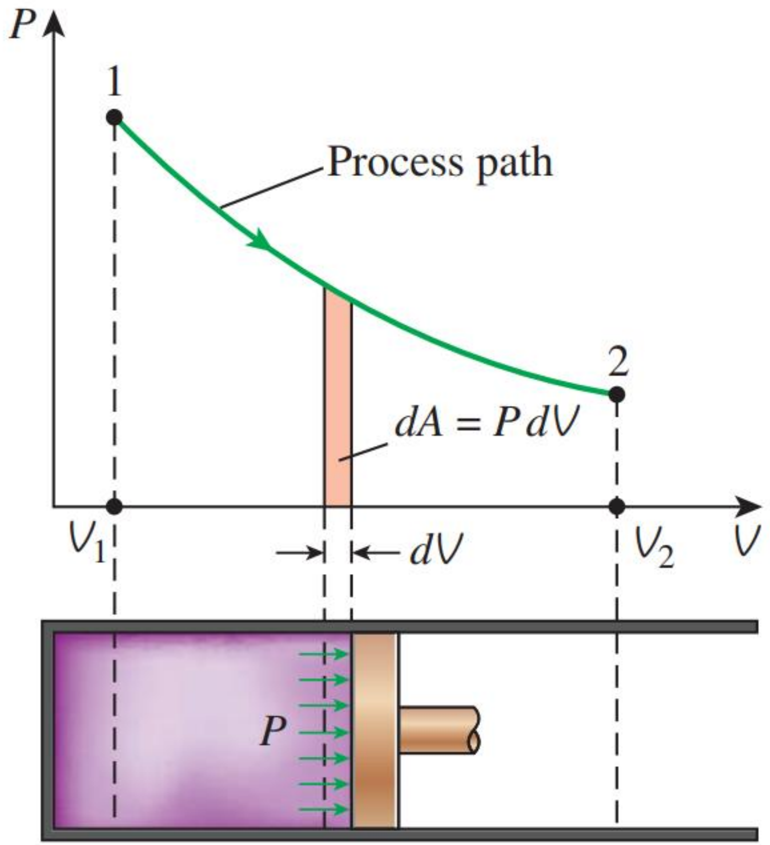
$$W_b = \int_1^2 P\,dV \qquad \text{(kJ)}$$

- The total area A under the process curve 1–2 is obtained by adding these differential areas:

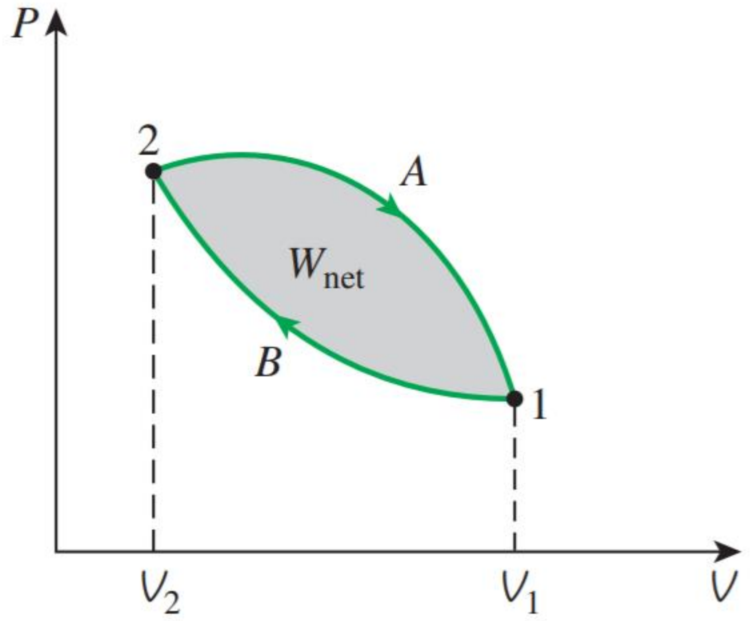
$$\text{Area} = A = \int_1^2 dA = \int_1^2 P\,dV$$

- we can generalize the boundary work relation by expressing it as:

$$W_b = \int_1^2 P_i\,dV$$



The area under the process curve on a P-V diagram represents the boundary work.



The net work done during a cycle is the difference between the work done by the system and the work done on the system.

1- Constant Volume (Isochoric or Iso-metric) Process

❖ In this process

$$V = constant$$

$$V_1 = V_2$$

$$dV = 0$$

$$W = \int_1^2 P\,dV = 0$$

$$Q_{12} = W_{12} + \Delta U_{12}$$

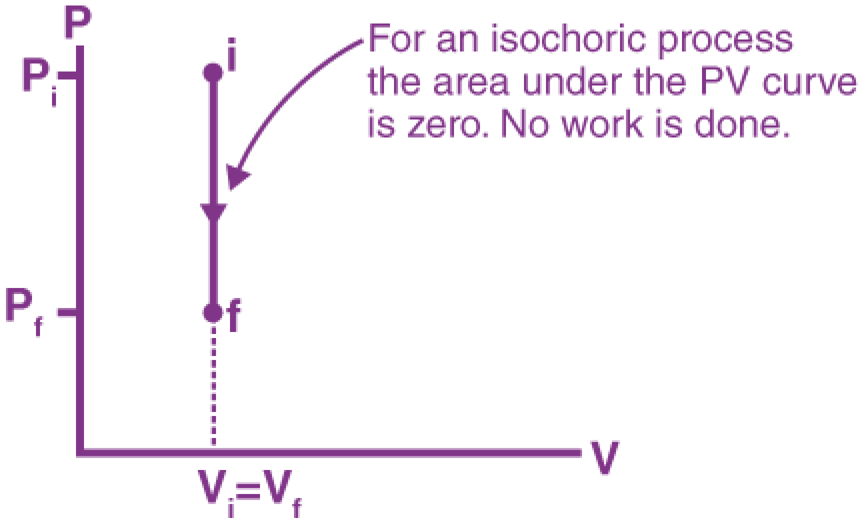
=0

$$\therefore Q_{12} = \Delta U_{12}$$

$$\Delta U_{12} = mC_v(T_1 - T_2)$$

$$\therefore Q_{12} = mC_v(T_1 - T_2)$$

$$Also\ \frac{P_1}{T_1} = \frac{P_2}{T_2}$$



Ex (2): A fluid in a closed vessel of a fixed volume of 0.14 m3, at pressure of 10 bar and temperature of 250 ^{o}C. If the vessel is cooled so that the pressure falls to 3.5 bar, determine the final temperature and the heat transferred
R=0.278 kJ/kg K, Cv=0.718 kJ/kg K

Solution:

2- Constant Pressure (Iso-baric) Process

❖ In this process

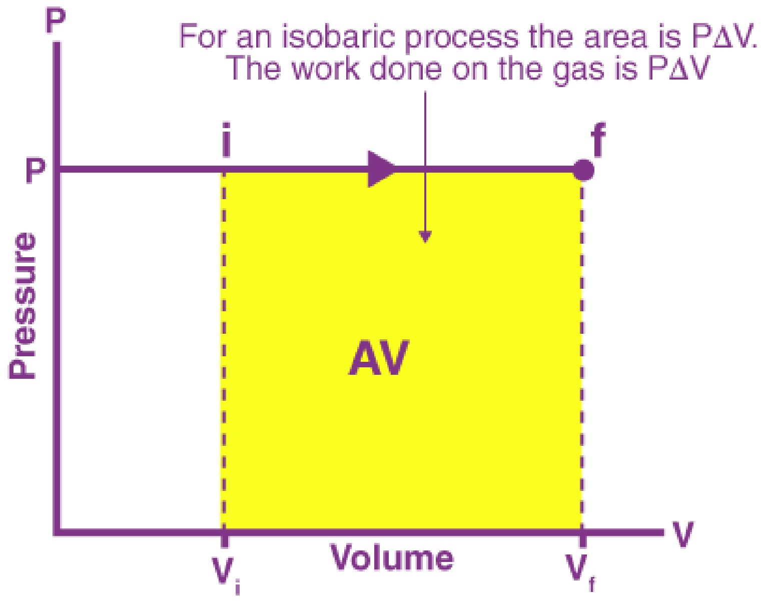
$$W_{12} = \int_1^2 P\, dV = P \int_1^2 dV$$

$$W_{12} = P\,(V_2 - V_1) = m\,R\,(T_2 - T_1)$$

$$Q_{12} = W_{12} + \Delta U_{12}$$

$$= P\,(V_2 - V_1) + \Delta U_{12}$$

$$= \Delta(PV)_{12} + \Delta U_{12} = \Delta H_{12}$$



<u>For ideal Gas:</u>

$$Q_{12} = W_{12} + \Delta U_{12}$$

$$= m\,R\,(T_2 - T_1) + m\,cv\,(T_2 - T_1)$$

$$= m\,(R + cv)\,(T_2 - T_1)$$

$$\therefore\ Q_{12} = \Delta H_{12} = m\,cp\,(T_2 - T_1)$$

Ex (3): 0.2 kg of fluid initially at a temperature of 165 ^oC, expands reversibly at a constant pressure of 7 bar until the volume is doubled. Find the final temperature, work done and heat transfer.

A- When the fluid is air take R=0.278 kJ/kg K and Cp=1.005 kJ/kg K.

B- When the fluid is steam take the initial dryness fraction of 0.7.

Solution:

3- Constant Temperature (Iso-thermal) Process

❖ In this process

$$T_1 = T_2 = T$$

$$m, R \text{ and } T = constants$$

$$\therefore P\,V = constant \rightarrow \frac{P_1}{P_2} = \frac{V_2}{V_1}$$

$$Since\ T_1 = T_2 \rightarrow \ (T_2 - T_1) = 0$$

$$\therefore \Delta U_{12} = m\,cv\,(T_2 - T_1) = 0 \quad (=0)$$

$$Q_{12} = W_{12} + \Delta U_{12} \quad (\Delta U_{12} = 0)$$

$$\therefore Q_{12} = W_{12}$$

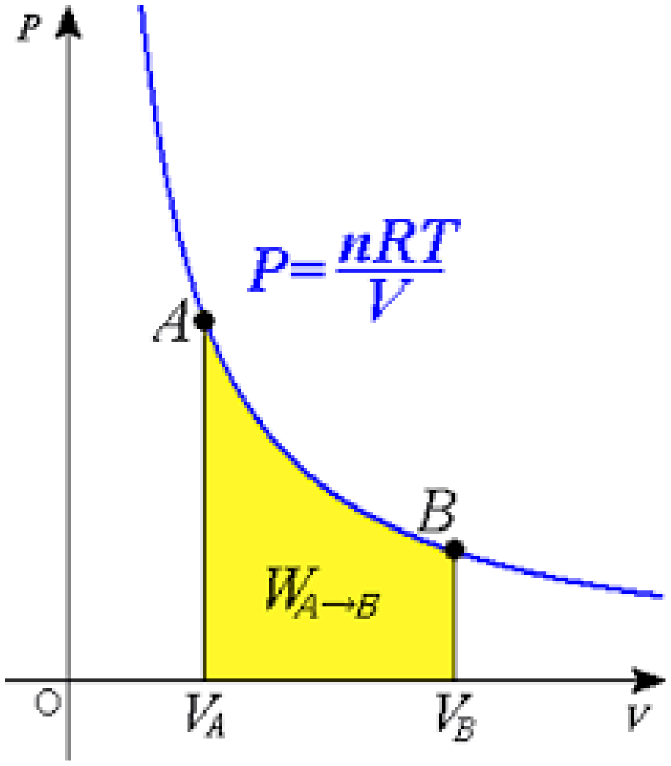
$$W_{12} = \int_1^2 P\,dV$$

$$Since\ PV = m\,R\,T \ \rightarrow P = \frac{m\,R\,T}{V}$$

$$\therefore W_{12} = m\,R\,T \int_1^2 \frac{dV}{V}$$

$$= m\,R\,T\,[\ln V]_1^2 = m\,R\,T\,[\ln V_2 - \ln V_1]$$

$$\therefore W_{12} = m\,R\,T \ln \frac{V_2}{V_1} \quad OR \quad W_{12} = m\,R\,T\,ln \frac{P_1}{P_2}$$



Ex (4): A quantity of O_2 gas at a pressure of 5 bar, volume of 0.1 m^3 and temperature of 1227 ^oC expands isothermally until its pressure reduces to 1 bar. It is then cooled isobarically to the original volume. Find the change in internal energy, work done and heat rejected during each process.

Take C_p=1 kJ/kg K

Solution:

Thank you for listening