Lecture 3

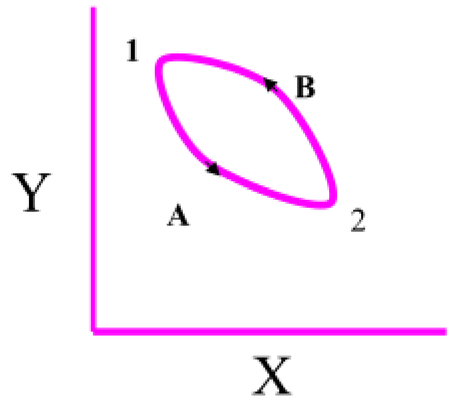
First Law of Thermodynamics

The first law of thermodynamics gives relationships among the various forms of energy and energy interactions. The first law is the conservation of energy principle and it can be stated as *energy can be neither created nor destroyed during a process; it can only change forms*.

First law applied to a closed system undergoing a cycle

When a closed system executes a complete cycle the sum of heat interactions is equal to the sum of work interactions.

or $\Sigma Q = \Sigma W$ or $\oint đQ = \oint đW$



The cycle given in the figure consists of two processes (A and B)

$Q_{A,1-2} + Q_{B,2-1} = W_{A,1-2} + W_{B,2-1}$

$Q_{A,1-2} = \int_1^2 đQ$ (integration along path A)

For the cycle, $\int_1^2 (đQ - đW)_A + \int_2^1 (đQ - đW)_B = 0$

$$\int_1^2 (đQ - đW)_A - \int_1^2 (đQ - đW)_B = 0$$

$\int_1^2 (đQ - đW)_A = \int_1^2 (đQ - đW)_B$ The quantity $\int (đQ - đW)$ is same for the path A and B connecting the states 1 and 2. It depends only on end states not the path. This implies that $\int (đQ - đW)$ is a state function or a **property**. This property is termed as **energy** E, of the system.

Alternatively

For the cycle $\oint đQ = \oint đW$

$\oint (đQ - đW) = 0$ This implies that the difference between the heat and work interactions during a process is a property of the system. If cyclic integral of any quantity is zero then that quantity is a state function, i.e. a property of the system.

First law applied to a closed system undergoing a process

First law for a process is just an energy balance equation

$Q\text{-}W = \Delta E$

In differential form $đQ - đW = dE$

the change in the total energy, E of a system during a process is the sum of the changes in its internal energy (U), kinetic energy, and potential energy and can be expressed as

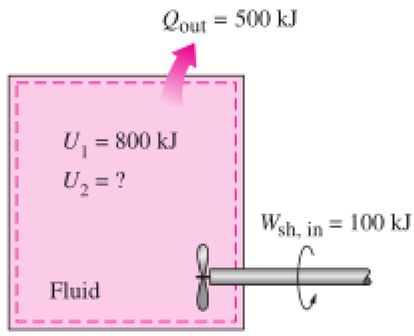
$\Delta E = \Delta KE + \Delta PE + \Delta U$

$\Delta U = m(u_2\text{-}u_1)$ $\Delta KE = ½\, m(\mathbf{V}_2^2\text{-}\mathbf{V}_1^2)$ and $\Delta PE = mg(z_2\text{-}z_1)$

Most systems encountered in practice are stationary, that is, they do not involve any changes in their velocity or elevation during a process. For stationary systems $\Delta KE = \Delta PE = 0$. Therefore $\Delta E = \Delta U$

Example 1

A rigid tank contains a hot fluid 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.



Solution: A fluid in a rigid tank loses heat while being stirred. The final internal energy of the fluid is to be determined.

Assumptions:

1 The tank is stationary and thus the kinetic and potential energy changes are zero, $\Delta KE = \Delta PE = 0$. Therefore $\Delta E = \Delta U$

2.Energy stored in the paddle wheel is negligible.

Analysis:

Take the contents of the tank as the system. This is **a closed system** since no mass crosses the boundary during the process. We observe that the volume of a rigid tank is constant, and thus there is **no moving boundary work**. Also, **heat is lost from the system** and **shaft work is done on the system**. Applying the energy balance on the system gives

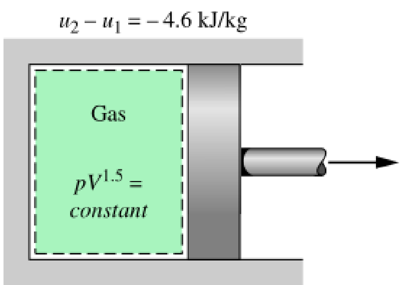
$Q\text{-}W=\Delta U$

$-500 - (-100) = U_2 - 800$

$U_2 = 400$ kJ

Example 2

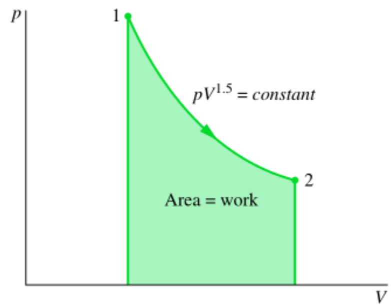
Four kilograms of a certain gas is contained within a piston–cylinder assembly. The gas undergoes a process for which the pressure–volume relationship is $pV^{1.5}$ = constant



The initial pressure is 3 bar, the initial volume is 0.1 m^3, and the final volume is 0.2 m^3. The change in specific internal energy of the gas in the process is $u_2 - u_1 = -4.6$ kJ/kg. There are no significant changes in kinetic or potential energy. Determine the net heat transfer for the process, in kJ

Solution: A gas within a piston–cylinder assembly undergoes an expansion process for which the pressure–volume relation and the change in specific internal energy are specified. **The net heat transfer for the process has to be determined.**

Assumptions:



1. The gas is a closed system.

2. The process is described by $pV^{1.5}$ =constant.

3. There is no change in the kinetic or potential energy of the system.

Applying the energy balance on the system gives

$Q\text{-}W{=}\Delta U$

$Q = m(u_2-u_1) + W$

$$W = \frac{p_2V_2 - p_1V_1}{1-n}$$

$$p_2 = p_1\left(\frac{V_1}{V_2}\right)^n$$

$$p_2 = 3 \text{ bar}\left(\frac{0.1}{0.2}\right)^{1.5} = 1.06 \text{ bar}$$

$$W = \frac{(1.06)(0.2)-(3)(0.1)}{1-1.5}\frac{10^5}{10^3} = 17.6 \text{ kJ}$$

$m(u_2-u_1) = 4\ (-4.6) = -18.4$ kJ

Q = -18.4 + 17.6 = -0.8 kJ

The minus sign for the value of Q means that a net amount of energy has been transferred from the system to its surroundings by heat transfer.