ESO201A

Lecture#14

(Class Lecture)

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By

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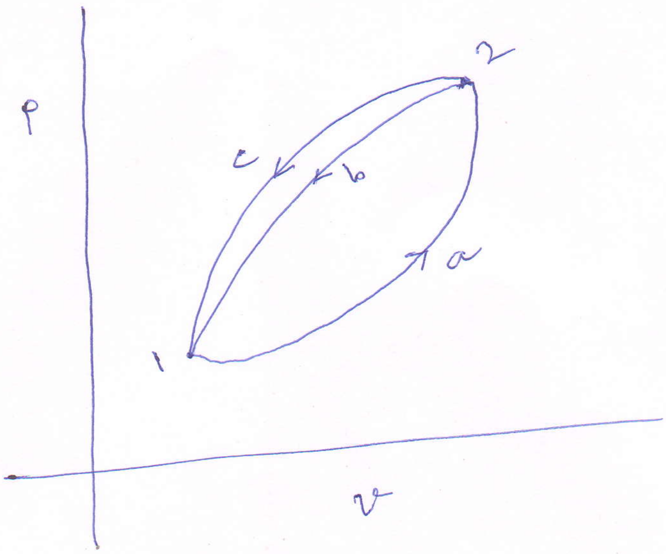
Consequences of First Law of Thermodynamics

(a) Heat is a Path Function



$$\int_{1a2} \delta Q + \int_{2b1} \delta Q - \int_{1a2} \delta W - \int_{2b1} \delta W = 0 \quad (1)$$

$$\int_{1a2} \delta Q + \int_{2c1} \delta Q - \int_{1a2} \delta W - \int_{2c1} \delta W = 0 \quad (2)$$

Subtracting eq. (2) from eq. (1),

$$\int_{2b1} \delta Q - \int_{2c1} \delta Q - \left(\int_{2b1} \delta W - \int_{2c1} \delta W \right) = 0 \quad (3)$$

Since work depends on the path, we have

$$\int_{2b1} \delta W - \int_{2c1} \delta W \neq 0$$

Therefore,

$$\int_{2b1} \delta Q \neq \int_{2c1} \delta Q$$

Hence, heat is a path function and inexact differential.

(b) Energy is a Property of a System

Quite often, we are concerned with the changes in the state of a system when it undergoes a process, rather than when it passes through a cycle.

From the previous discussion (eq. (3)) we know

$$\int_{2b1} (\delta Q - \delta W) = \int_{2c1} (\delta Q - \delta W)$$

Eq. (3)

$$\int_{2b1} \delta Q - \int_{2c1} \delta Q - \left(\int_{2b1} \delta W - \int_{2c1} \delta W \right) = 0$$

This shows that while $\int \delta Q$ and $\int \delta W$ depend on the path followed by the system, the quantity $\int (\delta Q - \delta W)$ is the same for both the processes 2b1 and 2c1 connecting the states 2 and 1. Therefore, $\int (\delta Q - \delta W)$ does not depend on the path followed by the system, but depends on the initial and final states of the system. Hence, the quantity $(\delta Q - \delta W)$ is an exact differential. It can be concluded that it is the differential of a property of the system. This property is the energy of the system and is represented by E. The differential change in the energy of the ~~system~~ the system is given by

$$\delta Q - \delta W = dE$$

We already know that

$$E = KE + PE + U$$

and $dE = d(KE) + d(PE) + dU$

$$= \delta Q - \delta W$$

or $\delta Q - \delta W = d(KE) + d(PE) + dU$

or, $Q - W = \Delta E$ or $q - w = \Delta e$ or $\delta q - \delta w = de$

(c) Energy of an Isolated system is Conserved

A system which does not exchange energy with the surroundings in the form of either heat or work, is called an isolated system. During any ~~such~~ process in such a system, $\delta Q = 0$, $\delta W = 0$.

The first law of thermodynamics then reduces to

$$dE = 0$$

$$\text{or } E_2 = E_1$$

for a reversible or an irreversible process.

Therefore, the energy of an isolated system remains constant.

(d) In a stationary system, $\Delta KE = 0$, $\Delta PE = 0$ and the first law of thermodynamics reduces to

$$\delta Q - \delta W = dU$$

$$\delta q - \delta w = du$$

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

or

Various Expressions of First Law applicable to closed systems

For a cycle,

$$\oint \delta Q = \oint \delta W$$

or $$\sum_{cycle} \delta Q = \sum_{cycle} \delta W$$

For a process : General

$$\delta Q - \delta W = dE$$

$$Q - W = \Delta E$$

Per unit mass :

$$\delta q - \delta w = de$$

$$q - w = \Delta e$$

For a process : Stationary systems
($\Delta KE = 0$, $\Delta PE = 0$)

$$\delta Q - \delta W = dU$$

$$Q - W = \Delta U$$

Per unit mass :

$$\delta q - \delta w = du$$

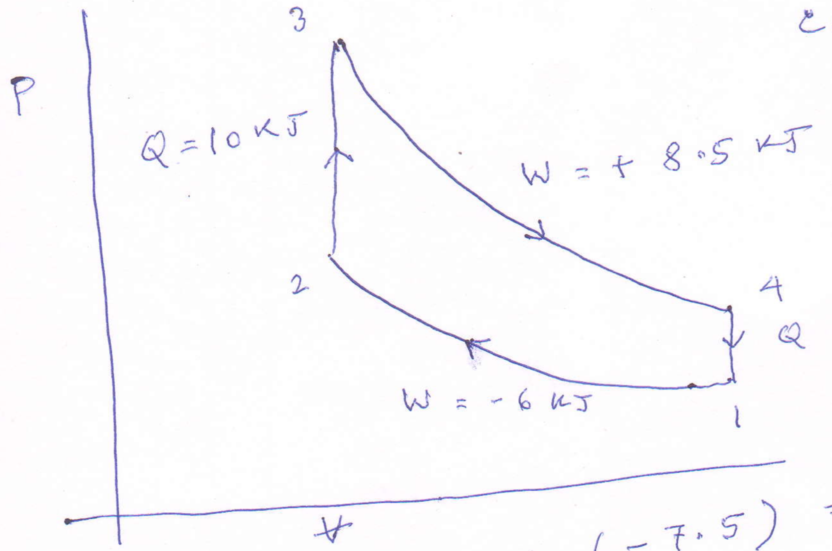
$$q - w = \Delta u$$

where $Q = Q_{net,in} = Q_{in} - Q_{out}$, $q = q_{net,in} = q_{in} - q_{out}$

$W = W_{net,out} = W_{out} - W_{in}$, $w = w_{net,out} = w_{out} - w_{in}$

Example Problem #1

Does this cycle satisfy the first law?



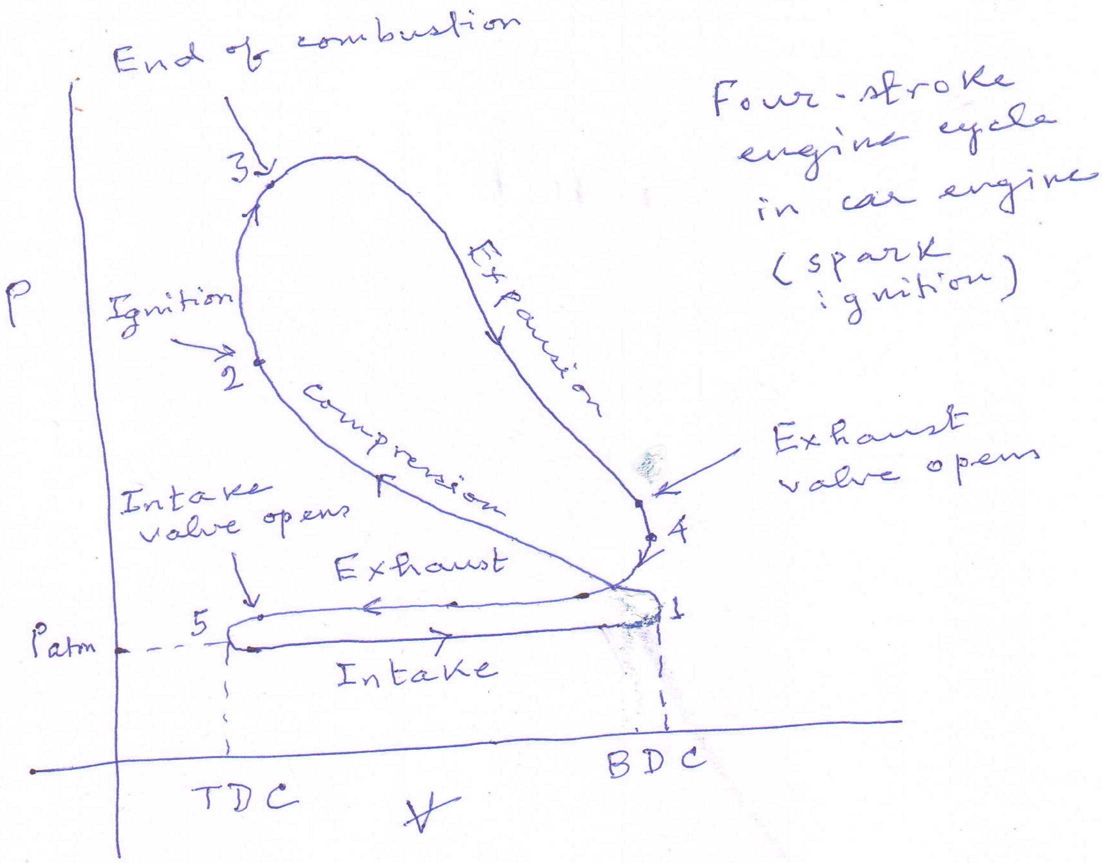
clockwise cycle
Otto cycle

$$\sum_{cycle} Q = 10 + (-7.5) = 2.5 \text{ KJ}$$

$$\sum_{cycle} W = 8.5 + (-6) = 2.5 \text{ KJ}$$

Since $\sum Q_{cycle} = \sum W_{cycle}$, the First Law is confirmed.

Actual



1 - 2 compression (1st stroke)

2 - 3 Ignition and combustion

3 - 4 Expansion (2nd stroke)

4 - 5 Exhaust (3rd stroke)

5 - 1 Suction (4th stroke)

TDC → Top dead centre (when the piston is at the closed end of the cylinder)

BDC → Bottom dead centre (when the piston is at the bottom end of the cylinder)

Example Problem #2

Suppose a gas expands and 10.7 KJ of work is done by the gas. During the process there is a heat transfer of 4.2 KJ to the gas. Find the change of energy.

Solution: Both Q and W are positive.

So, by applying the first law to the gas as the system we can write

$$Q - W = \Delta E$$

$$\Rightarrow 4.2 - (+10.7) = E_2 - E_1$$

$$\Rightarrow E_2 - E_1 = 4.2 - 10.7$$

$$= -6.5 \text{ KJ}$$