Module

2

Lecture
2

Asansol Engineering College
Department of Mechanical Engineering

Thermodynamics

Temperature and Zeroth Law of Thermodynamics

Dr. Ramesh P Sah
Department of Mechanical Engineering

FIRST LAW OF THERMODYNAMICS

- The first law of thermodynamics is known as the principle of *conservation of energy*.
- It provides a basis for the study of the relationship among the various forms of energy and energy transformation.
- Based on the experimental observations, the first law of thermodynamics states that energy can neither be created nor destroyed, it can only change forms.
- In other words, during an interaction between a system and its surroundings, the amount of energy gained by the system is exactly equal to the amount of energy lost by the surroundings.

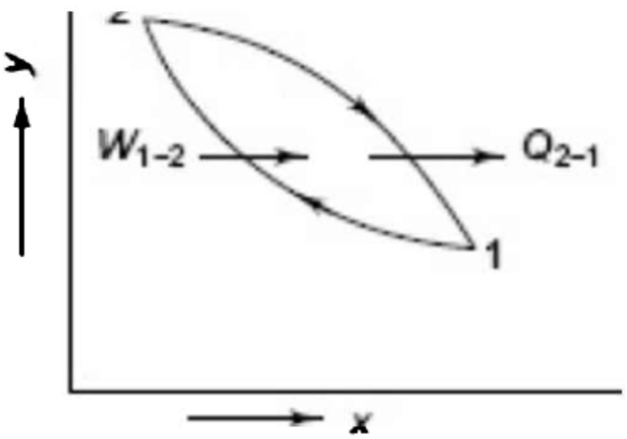
First law of thermodynamics for a closed system undergoing a cycle

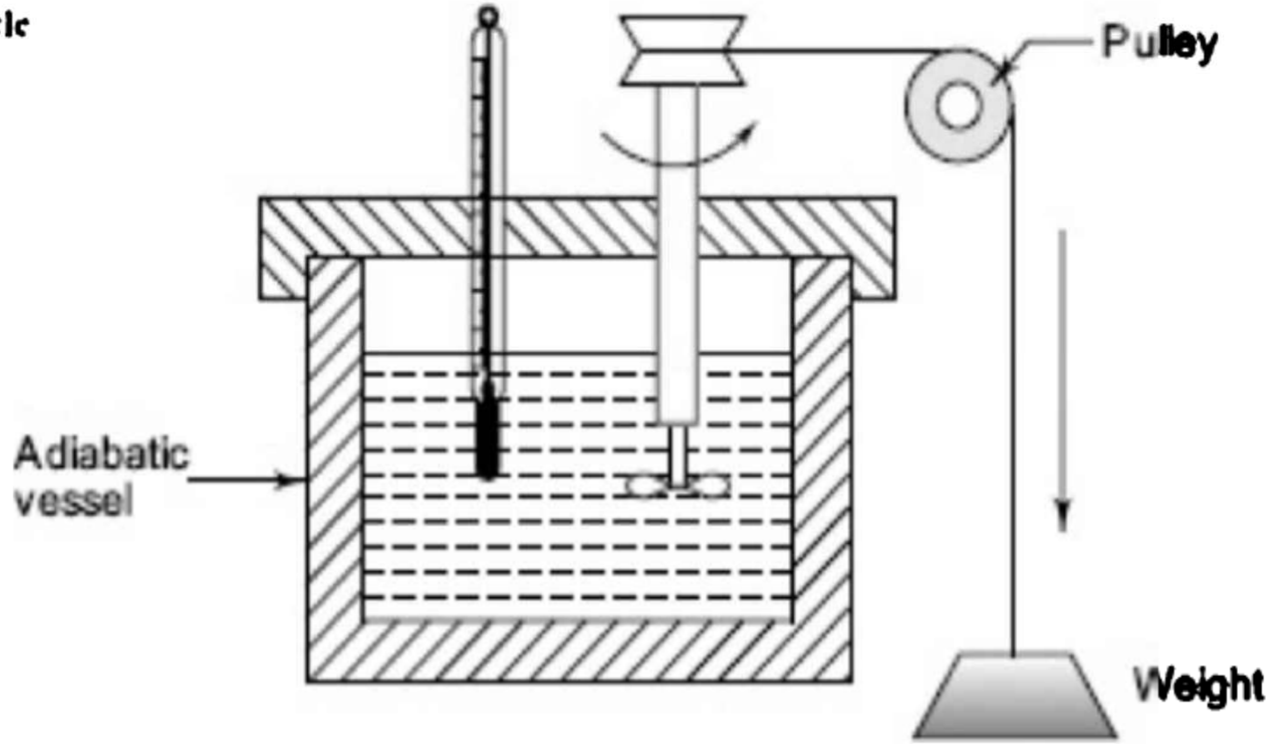
- If a system executes a cycle transferring heat and work through its boundary, the net work transfer is equivalent to the net heat transfer.

Mathematically,

$$(\Sigma W)_{cycle} = J(\Sigma Q)_{cycle}$$

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





First law of thermodynamics for a closed system undergoing change of state

- For a closed system or a fixed mass, the first law may be expressed as follows:
- Net energy transferred to (or from) the system as heat and work=Net increase (or decrease) in the total energy of the system

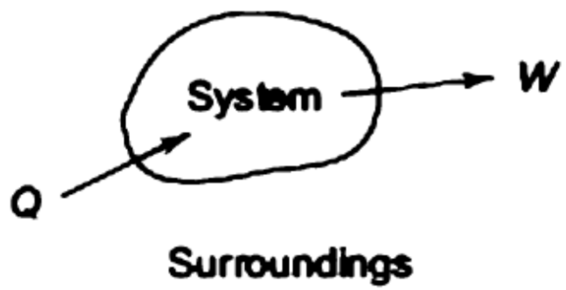
$$
\begin{aligned}
Q - W &= \Delta E \\
&= \Delta U + \Delta KE + \Delta PE + \ldots
\end{aligned}
$$

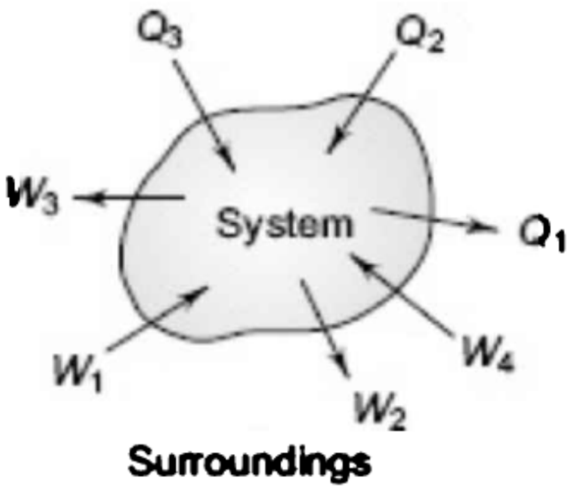
Neglecting the effects of magnetic and electric fields and surface tension, the above equation reduces to

$$Q - W = \Delta U + \Delta KE + \Delta PE$$

For a stationary closed system (the extrinsic effects on a closed system, such as the effects of motion and gravity, are neglected)

$$Q - W = \Delta U$$





$$(Q_2 + Q_3 - Q_1) = \Delta E + (W_2 + W_3 - W_1 - W_4)$$

- The above equation can be written in differential form as

$$\delta Q - \delta W = \mathrm{d}U$$

And per unit mass basis, the above equations can be written

$$q - w = u$$

$$\delta q - \delta w = \mathrm{d}u$$

- *Internal energy* is defined as the sum of all the microscopic forms of energy of a system.
- It is the energy associated with the molecular structure, and the molecular activity of the constituent particles of the system.

First Law of Thermodynamics for a Non-flow, Non-cyclic Process

- The net algebraic sum of heat and work during a process is equal to the change in internal energy during the same process.

  Mathematically,

$$\delta Q - \delta W = \mathrm{d}U$$

  Since for a quasi-equilibrium process, dW = PdV

$$\delta Q - P\mathrm{d}V = \mathrm{d}U$$

Energy-A property of the system

Consider a system which changes its state from state 1 to state 2 by following path A, and returns from state 2 to state 1 following path B as shown in Fig. 2. So the system undergoes a cycle.

By First law for path A,

$$Q_A = \Delta E_A + W_A$$

And for path B

$$Q_B = \Delta E_B + W_B$$

The processes A and B together constitute a cycle, for which

$$(\Sigma W)_{cycle} = (\Sigma Q)_{cycle}$$
$$W_A + W_B = Q_A + Q_B$$
$$Q_A - W_A = W_B - Q_B$$

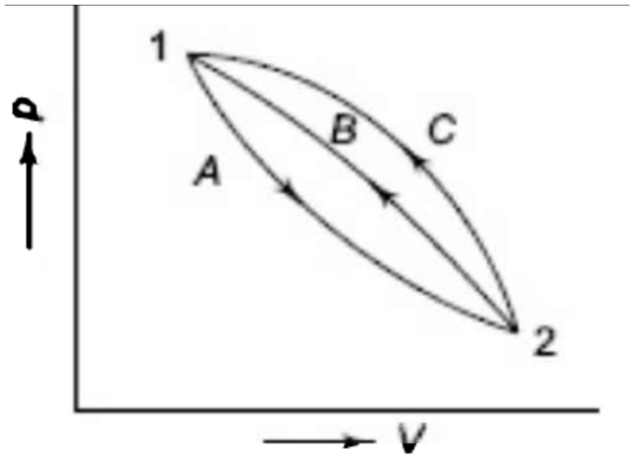


Fig. 2: Energy-A property of the system

• From above equations, $\Delta E_A = -\Delta E_B$

Similarly, for cycle 1-A-2-C-1,

$$\Delta E_A = -\Delta E_C$$

Then, we get

$$\Delta E_B = \Delta E_C$$

Therefore, it is seen that the change in energy between two states of a system is the same, whatever path the system may follow in undergoing that change of state. Hence it is a point function and a property of the system.

The energy E is extensive property. The specific energy e=E/M (J/kg) is an intensive property. The cyclic integral of any property is zero.

Solved Examples:

1. A system undergoes a cycle composed of four processes, 1–2, 2–3, 3–4 and 4–1. The rate of energy transfers are tabulated below:

Process	*Q(kW)*	*W(kW)*	$\Delta U(kW)$
1–2	400	150	*A*
2–3	200	*B*	300
3–4	–200	*C*	*D*
4–1	0	75	*E*

(i) Calculate the value of A, B, C, D and E

(ii) Determine the rate of work in kW.

Solution For process 1–2,

$$Q_{1-2} = \Delta U + W_{1-2}$$

$$400 = A + 150$$

$$A = 250 \text{ kW}$$

For process 2–3,

$$Q_{2-3} = \Delta U + W_{2-3}$$

$$200 = 300 + B$$

$$B = -100 \text{ kW}$$

For process 4–1,

$$Q_{4-1} = \Delta U + W_{4-1}$$

$$0 = E + 75$$

$$E = -75 \text{ kW}$$

Now,

$$\oint U = 0$$

$$A + 300 + D + E = 0$$

$$250 + 300 + D - 75 = 0$$

$$D = -475 \text{ kW}$$

For process 3–4, $\quad Q_{3-4} = \Delta U + W_{3-4}$

$$-200 = D + C$$

$$-200 = -475 + C$$

$$C = 275 \text{ kW}$$

Since $\quad \oint \delta Q = \oint \delta W$

Net cyclic work done $\quad = 400 + 200 - 200 + 0 = 400 \text{ kW}$

Negative sign indicates that heat is lost from the system.

2) A system undergoes a process 1-2 in which it absorbs 200 kJ energy as heat while it does 100 kJ work. Then it follows path 2-3 in which it rejects 50 kJ energy as heat when 80 kJ work is done on it. If it is required to restore the system to state 1 through an adiabatic path, calculate the work and heat transfer along the adiabatic path. Also calculate net heat transfer.

From the given data, we have

$$Q_{1-2} = 200 \text{ kJ}, \; W_{1-2} = 100 \text{ kJ},$$

$$Q_{2-3} = -50 \text{ kJ}, \; W_{2-3} = -80 \text{ kJ}$$

$$Q_{3-1} = 0$$

The processes 1-2,2-3 and 3-1 together constitute a cycle. Therefore, we have

$$\sum Q = \sum W$$

or, $$Q_{1-2} + Q_{2-3} + Q_{3-1} = W_{1-2} + W_{2-3} + W_{3-1}$$

or, $$200 - 50 + 0 = 100 - 80 + W_{3-1}$$

or, $$W_{3-1} = 130 \text{ kJ} \; W_{31} = 130 \text{ kJ}$$

Net heat transfer is $Q_{1-2} + Q_{2-3} + Q_{3-1} = 200 - 50 + 0 = 150$ kJ

References:

1. Sonntag, R. E, Borgnakke, C. and Van Wylen, G. J., 2003, 6th Edition, *Fundamentals of Thermodynamics*, John Wiley and Sons.

1. Jones, J. B. and Duggan, R. E., 1996, *Engineering Thermodynamics*, Prentice-Hall of India

3. Moran, M. J. and Shapiro, H. N., 1999, *Fundamentals of Engineering Thermodynamics*, John Wiley and Sons.

4. Nag, P.K, 1995, *Engineering Thermodynamics*, Tata McGraw-Hill Publishing Co. Ltd.

5. Y. A. Çengel and M. A. Boles, Thermodynamics: *An Engineering Approach*, McGraw-Hill

Thank You