MECHANICAL ENGINEERING SCIENCE (UE25ME141A/B)

Dr. Mantesh B Khot

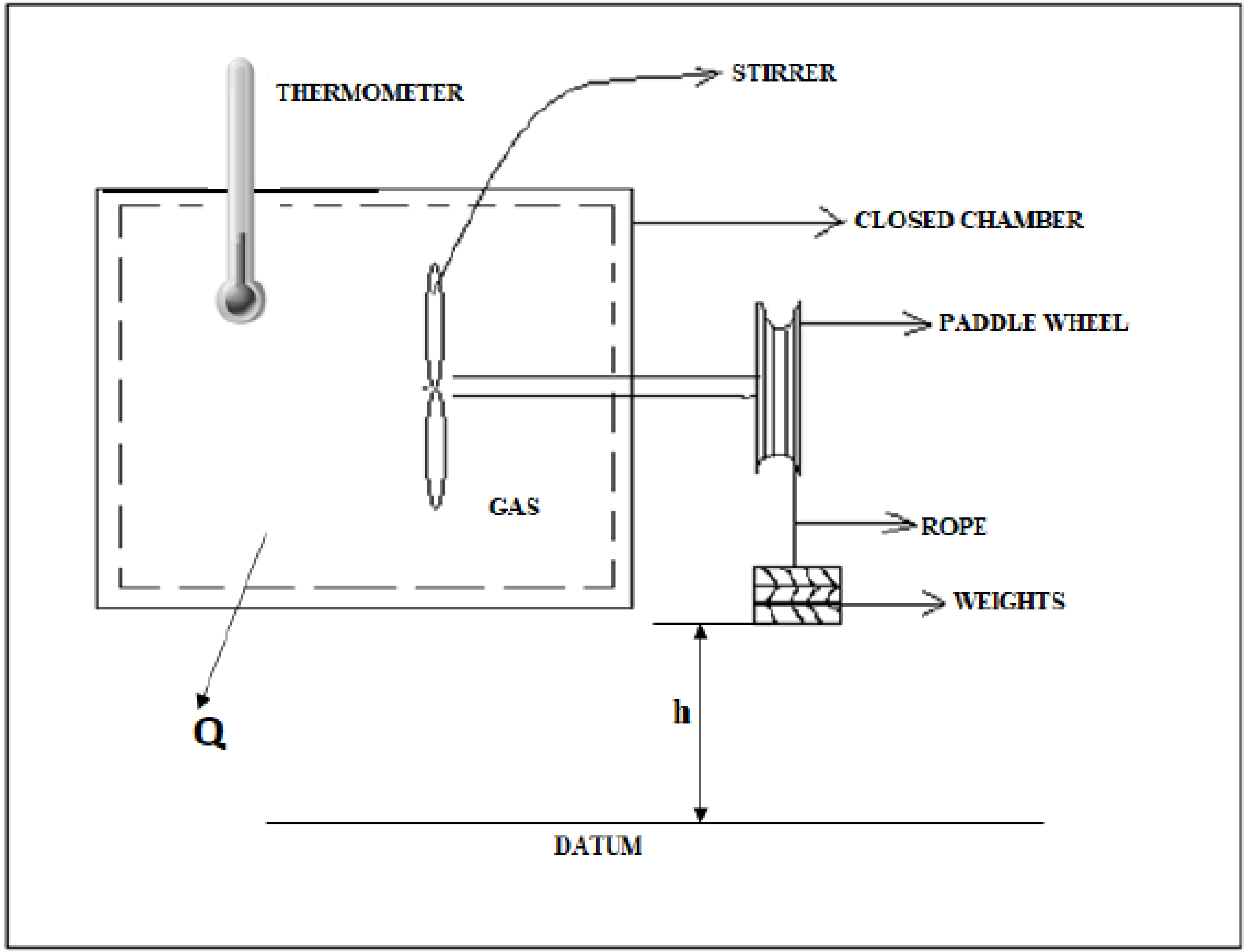
Department of Mechanical Engineering

In 1845, Joule published a paper entitled "**The Mechanical Equivalent of Heat**", in which he specified a numerical value for the amount of mechanical work required to produce a unit of heat.

In particular Joule had experimented on the amount of mechanical work generated by friction needed to raise the temperature of a pound of water by one degree Fahrenheit and found a consistent value of 778.24 foot pound force (4.1550 $J.cal^{-1}$ later corrected to 4.1868 $J.cal^{-1}$)

Joule contended that motion and heat were mutually interchangeable and that, in every case, a given amount of work would generate the same amount of heat.

First Law of Thermodynamics – Joule's Experiment



First Law of Thermodynamics – Joule's Experiment

Energy imparted to paddle wheel and converted to work done on gas by stirrer = W = $m_w gh$

where m_w is the mass of the weights and h is the height of fall.

The temperature of the gas rises due to the conversion of work to heat by friction. Let this be ΔT.

We have Q = $mc\Delta T$, where m is the mass of the gas and c the specific heat.

It is observed that W α Q for every different height of fall.

On removing this amount of heat the system is restored to its initial state, thus completing a cycle.

This was the Joule's experiment.

Statement of First Law of Thermodynamics for Cyclic Process

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'When a system undergoes a cyclic process, the algebraic sum (or cyclic integral), of heat transfers is proportional to, the algebraic sum (or cyclic integral), of work transfers.'

Or we say

$$\sum_{cycle} W \; \alpha \sum_{cycle} Q$$

$$\Sigma_{cycle} W \; = J \, \Sigma_{cycle} Q,$$

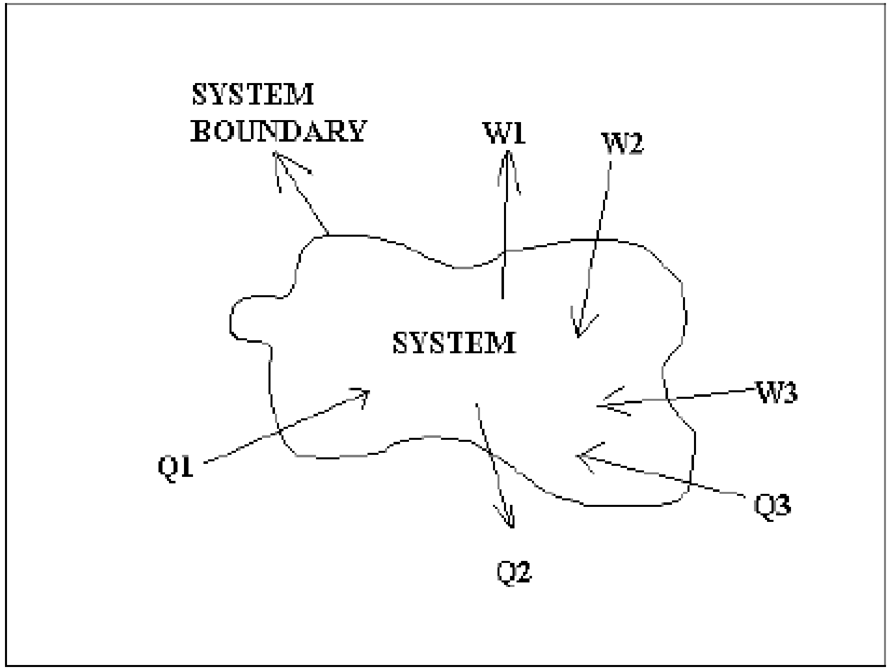
where J is the proportionality constant called the Joule's constant.

In the language of calculus

$$\oint \partial W = J \oint \partial Q$$

J = 418.68 kJ/kCal OR
J = 427 kgf-m/ kCal

Statement of First Law of Thermodynamics for Cyclic Process



Consider the system shown.

Let it experience the heat and work transfers indicated while undergoing a cyclic process.

By law of conservation of energy

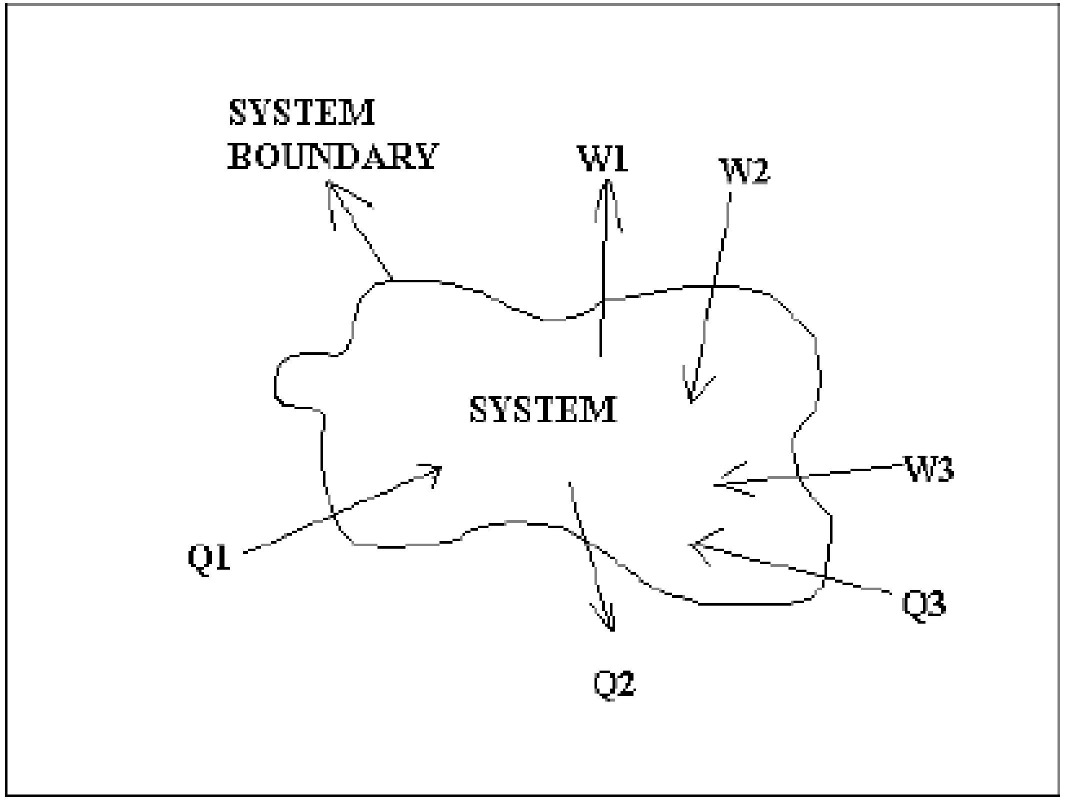
Total energy entering the system = Total energy leaving the system

$$Q_1+Q_3+W_2+W_3=Q_2+W_1$$

Putting the Qs on side and Ws on the other side we have

$$W_1-W_2-W_3 = Q_1-Q_2+Q_3$$

Statement of First Law of Thermodynamics for Cyclic Process



Or we say

$$\sum_{\text{cycle}} W = \sum_{\text{cycle}} Q$$

This is itself the statement of the First Law of Thermodynamics for a closed system undergoing a cyclic process

First Law of Thermodynamics for a closed system undergoing process

It can be shown that the quantity $(\partial Q - \partial W)$
is a property of the system and we call this property ENERGY with symbol E

OR $(\boldsymbol{\partial} \mathbf{Q} - \boldsymbol{\partial} \mathbf{W}) = \mathbf{dE}$

$$\left.\begin{aligned} \partial Q - \partial W &= dE \\ \partial Q &= dE + \partial W \end{aligned}\right\} \quad \textbf{(4)}$$

Equations (4) are the differential forms of the first law for a closed system undergoing an infinitesimal change of state.

Between end states 1 and 2 we can integrate and write

$$\int_1^2 \partial Q = \int_1^2 dE + \int_1^2 \partial W$$

First Law of Thermodynamics for a closed system undergoing process

$$\left.\begin{aligned} &\mathbf{Q_{1-2} = (E_2 - E_1) + W_{1-2}} \\ &\text{OR in general } \mathbf{Q = \Delta E + W} \\ &\textbf{OR } \mathbf{Q - W = \Delta E} \end{aligned}\right\} \quad (5)$$

Equations (5) represent the first law of thermodynamics for a closed system undergoing a finite change of state.

Process Type	Internal Energy Change ΔU	First Law Form
Cyclic process	0	$Q = W$
Non-cyclic process	Not zero	$\Delta U = Q - W$

Energy or Stored Energy of a System

Internal Energy: The Internal Energy (U) of a system is the total energy content of the system.

- It is the sum of the kinetic, potential, chemical, electrical, and all other forms of energy possessed by the atoms and molecules of the system.
- The Internal Energy (U) is path independent and depends only on temperature for an ideal gas.
- Internal energy may be stored in the system in following forms:

_ Kinetic energy of molecules

_ Molecular vibrations and rotations

_ Chemical bonds that can be released during chemical reaction

_ Potential energy of the constituents of the system

Energy or Stored Energy of a System

Internal energy is an extensive property while specific internal energy (energy per unit mass) is an intensive property.

Symbol for Internal Energy is ‘U’, with units J, kJ.. etc.

Symbol for specific internal energy is ‘u’ , with units J/kg, kJ/kg.. etc

THANK YOU

Dr. Mantesh B Khot
Department of Mechanical Engineering
mahanteshbk@pes.edu
+91 87 2202 4584