

- Recap: Lecture 5: 16<sup>th</sup> January 2014, 0930-1025 hrs.
  - Joule's experiment
  - Work
    - Types of work
    - Displacement work
    - Displacement work for different processes
  - First law of thermodynamics
    - Energy balance
    - Energy change of a system
    - Energy transfer mechanisms

# Heat

- Thermodynamic definition of heat:
- When a system whose surroundings are at a different temperature and on which work may be done undergoes a process.
- The energy transferred by non-mechanical means, equals to the difference between the internal energy change and the work done is called heat.
- It took many years before it was understood that heat is energy
  - First really conclusive evidence that heat could not be substance was given by *Benjamin Thompson* from Massachusetts who later became *Count Rumford*
  - In 1798, *Rumford* observed the temperature rise in the brass chips produced during the boring of cannon and concluded that work on boring was responsible for the flow of heat.

# Heat

- One year later *Sir Humphry Devy* tried to prove the point by showing that two pieces of ice could melt if they are rubbed together
- His idea was to show that heat is a manifestation of energy but his experiment was highly inconclusive.
- *Seguin* (a French engineer) in 1839 and *Mayer* (German Physician) in 1842 tried unsuccessfully to prove the point.
- Experiments of *Joule* between 1840-1849 in a private laboratory were able to convince the world through a series of experiments
  - Showed the relation between heat and work once and for all and showed the equivalence between the two quantities
  - *Helmholtz* wrote a brilliant paper in 1847 on Joule's experiments and applied these ideas for physical chemistry and physiology.

# Concept of Heat

- Heat is internal energy in transit
  - Flowing from a part of the system to another
  - or from one system to another
  - By virtue of only a temperature difference

- Heat transfer can be  $Q = \int_{t_1}^{t_2} \dot{Q} dt$  time  $t_2 - t_1$  is known
- It is incorrect to say
  - Or work in the body
- The performance of work and flow of heat are methods whereby the internal energy of a system is changed
- It is impossible to separate or divide the internal energy into mechanical and thermal part.

## First law for a cycle

- For a closed system undergoing a cycle, the initial and final states are identical.
- Therefore,  $\Delta E_{system} = E_2 - E_1 = 0$
- The energy balance for a cycle simplifies to

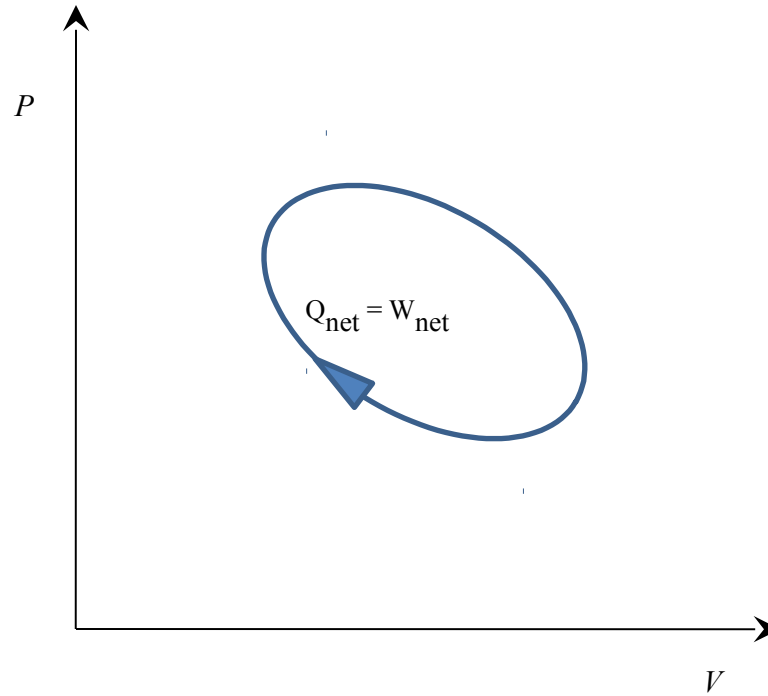
$$E_{in} - E_{out} = 0 \text{ or } E_{in} = E_{out}$$

## First law for a cycle

- A closed system does not involve any mass flow across its boundaries, the energy balance for a cycle can be expressed in terms of heat and work interactions as

$$W_{net,out} = Q_{net,in} \quad \text{or} \quad \dot{W}_{net,out} = \dot{Q}_{net,in}$$

## First law for a cycle



For a cycle,  $\Delta E = 0$ , thus  $Q_{\text{net}} = W_{\text{net}}$

## **First law for a system undergoing a change of state**

- In processes involving a change of state, heat and work interactions may be unknown.
- It is a usual practice to assume the direction of heat and work interactions.
- It is usually assumed that heat to be transferred into the system (heat input) in the amount of  $Q$  and work to be done by the system (work output) in the amount of  $W$ .



## First law for a system undergoing a change of state

- The energy balance would be:

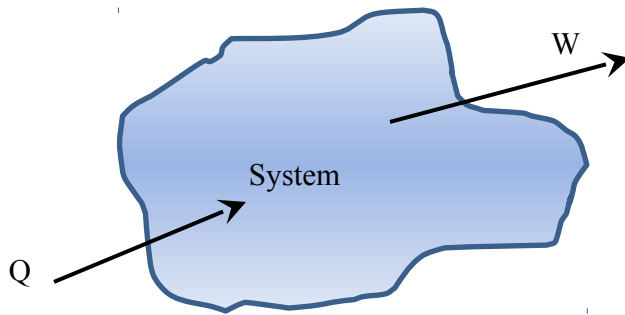
$$Q_{net,in} - W_{net,out} = \Delta E_{system} \quad \text{or} \quad Q - W = \Delta E$$

where,  $Q = Q_{net,in} = Q_{in} - Q_{out}$  is the net heat input  
and  $W = W_{net,out} = W_{out} - W_{in}$  is the net work output.

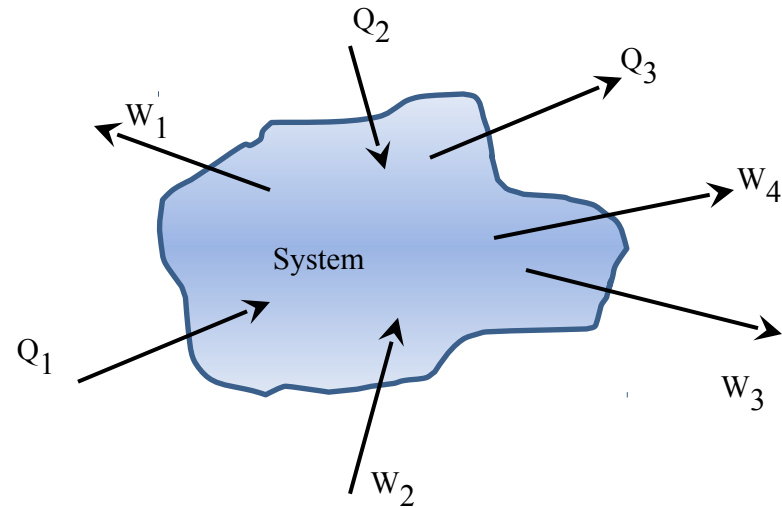
- Obtaining a negative quantity for  $Q$  or  $W$  simply means that the assumed direction for that quantity is wrong and should be reversed.

## First law for a system undergoing a change of state

Surroundings



$$Q - W = \Delta E$$



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

## First law for closed systems

General :  $Q - W = \Delta E$

Stationary systems :  $Q - W = \Delta U$

Per unit mass :  $q - w = \Delta e$

Differenti al form :  $\delta q - \delta w = de$

## First law: isolated system

- An isolated system has no interaction between the system and its surroundings
- For an isolated system,  $dQ=0$  and  $dW=0$
- The first law gives

$$dE=0$$

$$\text{or, } E=\text{constant}$$

- The energy of an isolated system is thus, always a constant.

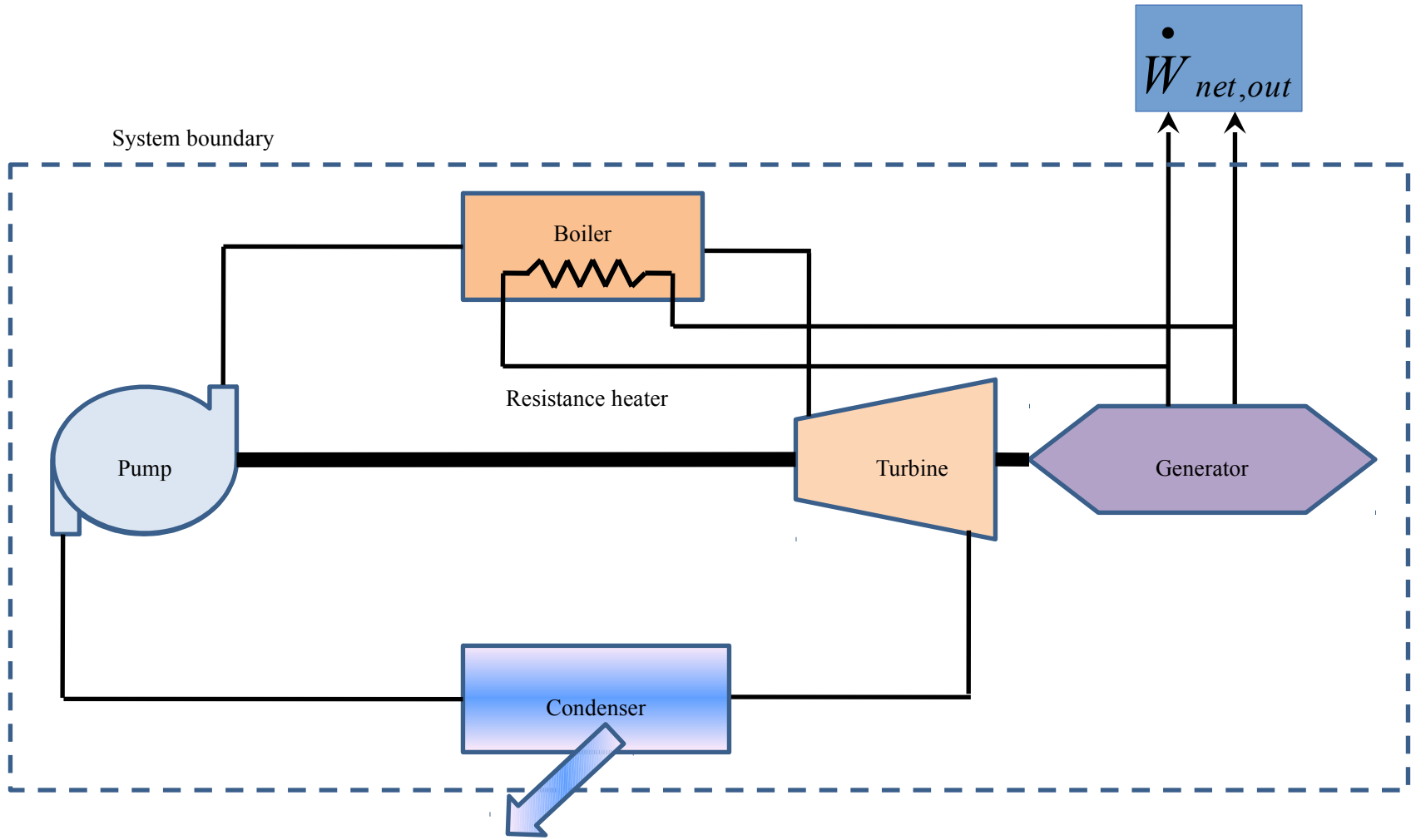
## **First law : some observations**

- The first law cannot be proven mathematically, but no process in nature is known to have violated the first law.
- First law of thermodynamics is a fundamental physical law in itself.
- From the first-law point of view, heat and work are not different at all.
- However heat and work are very different from the second law point of view.

## Perpetual Motion Machine of the First Kind (PMM1)

- Any device that violates first law is called a **perpetual-motion machine of the first kind (PMM1)**.
- Such a device will create energy!
- Numerous ideas have been proposed over the years, of various devices that generate energy in some way.
- These devices of course violate the first law and hence were never demonstrated.

# Perpetual Motion Machine of the First Kind (PMM1)



## Perpetual Motion Machine of the First Kind (PMM1)

- The device continuously produces energy at a rate of  $\dot{Q}_{out}$  without receiving any energy.

$$\dot{Q}_{out} + \dot{W}_{net,out}$$

- This is a clear violation of the first law.
- Converse of a PMM1: there can be no machine which would continuously consume work without some other form of energy appearing simultaneously.