- Recap: Lecture 5: 16th 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 diference 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 Messachusetts who later became *Count Rumsford*
  - In 1798, *Rumsford* 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

$$Q = \int_{t_1}^{t_2} \dot{Q} dt$$

  - Heat transfer can be determined only when time t2 – t1 is known
  - It is incorrect to say that heat is in the body
    - 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, $\Delta Esystem = E2 - E1 = 0$
- The energy balance for a cycle simplifies to

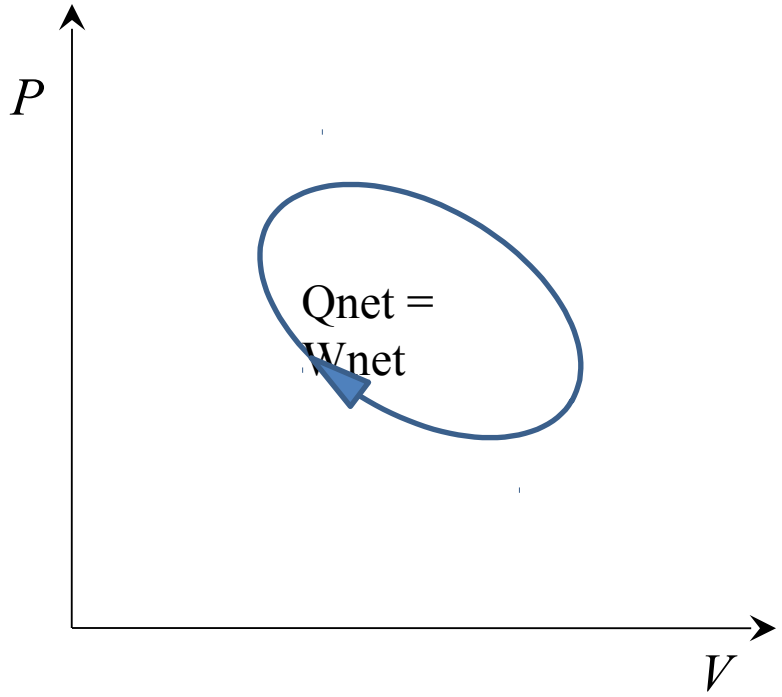
$$Ein - Eout = 0 \text{ or } Ein = Eout$$

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 Qnet = Wnet

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:

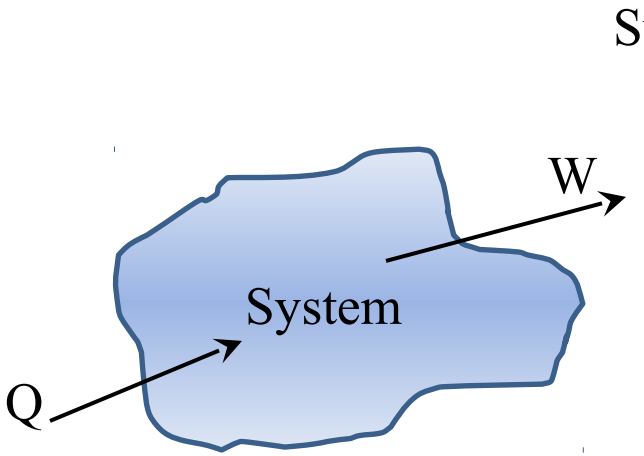
$$Q_{net,in} - W_{net,out} = \Delta E_{system} \quad or \quad Q - W = \Delta E$$

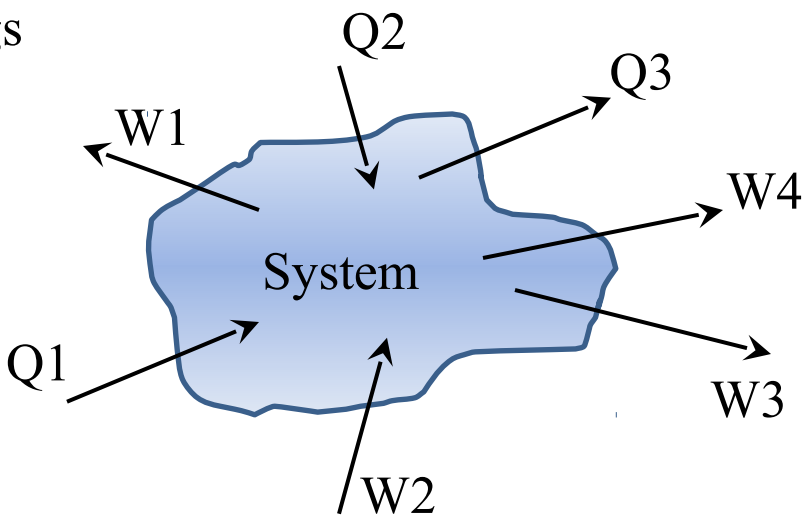
where, $Q = Q_{net,in} = Q_{in} - Q_{out}$ is the net heat input

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





$$Q - W = \Delta E$$

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

First law for closed systems

$$\text{General}: \quad Q - W = \Delta E$$

$$\text{Stationary systems}: Q - W = \Delta U$$

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

$$\text{Differential form}: \delta q - \delta w = de$$

First law: isolated system

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

$$dE=0$$

$$or, \quad E=constant$$

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

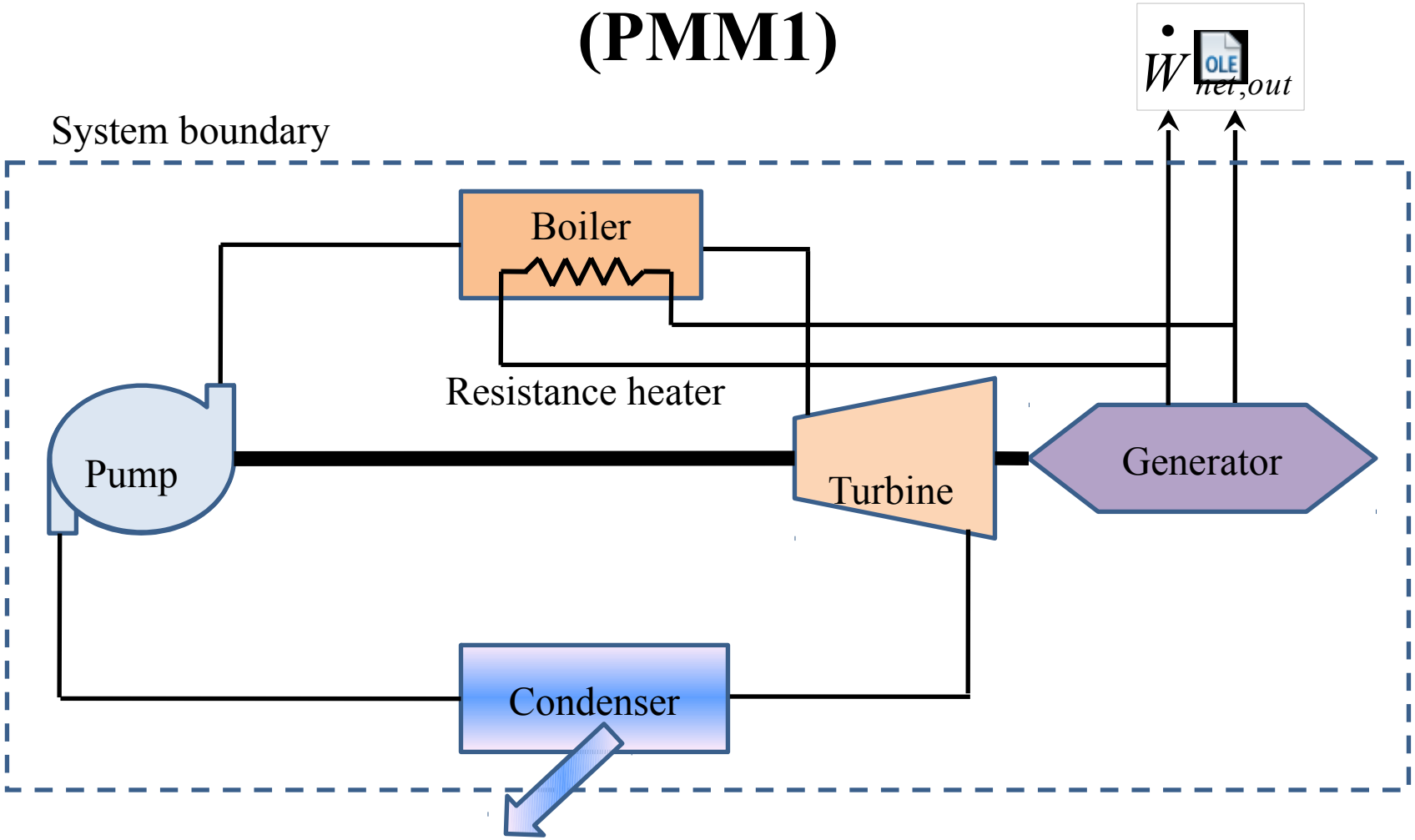
First law : some observations

- 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 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.