Thermodynamics I
Chapter 3
Energy, Heat and Work

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Energy, Heat and Work (Motivation)

A system changes due to interaction with its surroundings.

Energy interaction is a major factor.

This chapter studies the nature of energy and its various forms and transfers so that we are able to follow its interaction with a system.

ENERGY & THE 1st LAW OF THERMO.

1st Law : concerning **quantity of energy**

Energy is **conserved**
(Amount of energy is constant, but can change forms)
(e.g. potential, kinetic, electrical, chemical, etc.)

$$E = Total\ system\ energy[J,$$

$$e = \frac{E}{m}\left[\frac{kJ}{kg}\right](specific\ energ$$

Energy

- Macroscopic – system energy which value depends on a *reference point* (Kinetic Energy (KE), Potential Energy (PE)
- Microscopic – energy due to *molecular interactions & activity* (independent of any reference point) (Internal Energy, U)

Total System Energy

$$E = KE + PE + U \quad [\text{kJ}]$$

$$e = ke + pe + u \quad [\text{kJ/kg}]$$

Kinetic Energy (KE)

$$KE = \frac{m\vec{V}^2}{2} \qquad \Delta KE = \frac{m}{2}\left[\vec{V}_2^2 - \vec{V}_1^2\right]$$

$$ke = \frac{KE}{m} = \frac{\vec{V}^2}{2} \qquad \Delta ke = \frac{\Delta KE}{m} = \frac{(\vec{V}_2^2 - \vec{V}_1^2)}{2}$$

Potential Energy (PE)

$$PE = mgz \qquad \Delta PE = mg(z_2 - z_1)$$

$$pe = \frac{PE}{m} = gz \qquad \Delta pe = \frac{\Delta PE}{m} = g(z_2 - z_1)$$

Internal Energy, U

- Molecular movement (vibration, collision, etc) *sensible energy* (molecular activity temperature)
- Bond Energy between molecules (phase change) *latent energy* (constant temperature)
- Bond Energy between atoms in a molecule *chemical energy*
- Bond Energy between protons & neutrons in the nucleus *nuclear energy*

Modes of Energy Transfer

Energy Interaction between System and Surrounding

Energy can cross the boundary (transferred) of a closed system by **2 methods**;

HEAT & WORK

HEAT, Q [J, kJ]

Heat - Energy that is *being transferred* due to a temperature difference

- Heat is a mode of energy transfer
- Heat is not a property
- Energy is related to states (property)
- Heat is related to processes (not a property, depends on the path)

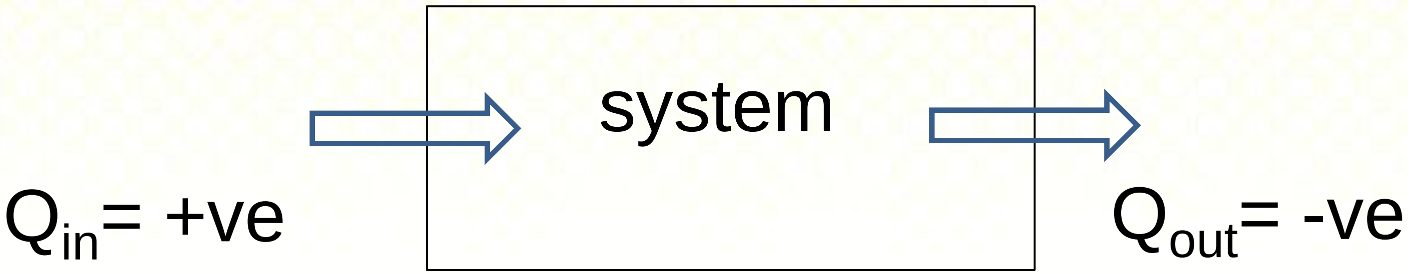
$$q = \frac{Q}{m}$$

$$\dot{Q} = \frac{Q}{t} \left[\frac{kJ}{s} = kW \right]$$ = rate of heat transfer

$$\int_1^2 \delta Q = Q_{12}$$

Amount of heat transferred during a process (depends on the path)

Heat (ctd.)



Adiabatic Process ($Q = 0$)

- insulated
- $T_{system} = T_{surrounding}$

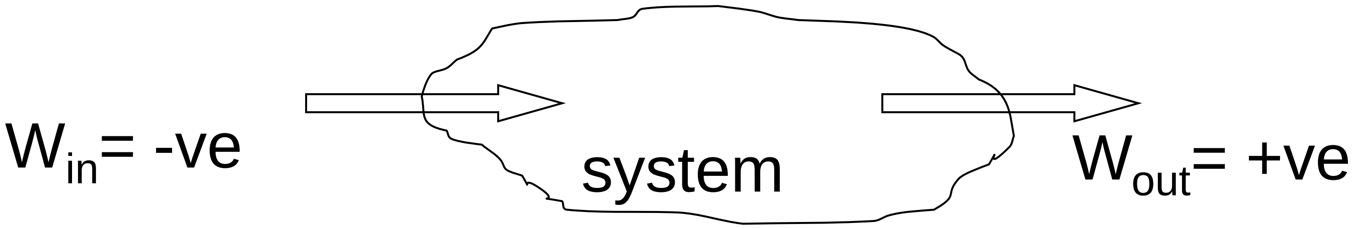
Adiabatic ≠ Isothermal!

(T can change by other methods; energy can enter system by *work*)

<u>WORK</u>, W [J, kJ]

<u>Work</u> -–Energy that is *crossing the boundary* <u>other than heat</u> (electrical, stirrer, shaft, moving piston, etc.)

-Not a property (related to *process*)
-Mode of energy *transfer*



$$w = \frac{W}{m}\left[\frac{kJ}{kg}\right]$$

$$\dot{W}[kW] = \frac{W}{t}\left[\frac{kJ}{s}\right]$$ = rate of work = power

$$\int_1^2 \delta W = W_{12}$$ ← Depends on path

Types of Work

- Work
  - Electrical $$W_{el} = \int_1^2 VIdt$$
  - Mechanical $$W = \int_1^2 F \cdot ds$$
    - Boundary $$W_b = \int_1^2 p \cdot dV$$
    - Gravitational $$W_g = mg(z_2 - z_1)$$
    - Acceleration $$W = \frac{1}{2} m(\vec{V}_2^2 - \vec{V}_1^2)$$
    - Shaft $$W = 2\pi n \tau$$
    - Spring $$W = \frac{1}{2} k(x_2^2 - x_1^2)$$

Boundary Work for Polytropic Processes

Boundary Work

$$W_B = \int_{V_1}^{V_2} PdV$$

Area under P-v graph

General Polytropic Work

$$W = \frac{P_2V_2 - P_1V_1}{1-n} \qquad (n \neq 1)$$

Const. Pressure Work (n=0)

$$W = p(V_2 - V_1)$$

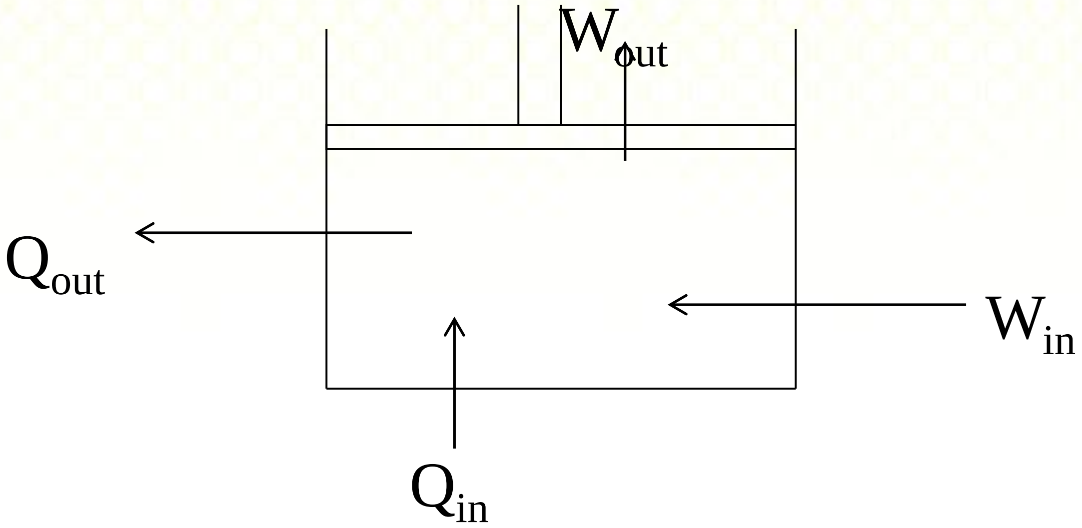
Isothermal Work (n=1) *ideal gas*

$$W = mRTln\left(\frac{V_2}{V_1}\right) = mRTln\left(\frac{P_1}{P_2}\right)$$

Const. Volume Work (dv=0)

$$W_{b-constvol} = 0$$

1st Law Closed System



$$\Delta E = \sum Q - \sum W$$

Net change of system energy (ΔE)

Net total energy transfer in the form of heat and work ($\sum Q - \sum W$)

- Recall that System Energy consists of:

$$E_{system} = U + KE + PE$$

or

$$\Delta E_{system} = \Delta U + \Delta KE + \Delta PE$$

thus;

$$Q - W = \Delta E_{system} = \Delta U + \Delta KE + \Delta PE$$

Or can be called as the

1st Law/Energy Balance of a Closed System;

$$\underbrace{Q - W}_{\text{Net transfer of energy}} = \underbrace{\Delta U + \Delta KE + \Delta PE}_{\text{Energy storage in different modes}}$$

Net *transfer* of energy

Energy *storage* in different modes

1st Law for Closed System in different forms;

$$Q - W = \Delta U + \Delta KE + \Delta PE \qquad [kJ]$$

per unit mass;

$$q - w = \Delta u + \Delta ke + \Delta pe \qquad [kJ/kg]$$

Rate form;

$$\dot{Q} - \dot{W} = \frac{dU}{dt} + \frac{d(KE)}{dt} + \frac{d(PE)}{dt} \qquad [kW]$$

Cyclic Process $\Delta E = 0$

$$Q - W = 0$$

$$Q_{cycle} = W_{cycle}$$

$$\oint \sum Q = \oint \sum W$$

summary;

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

- ΔPE: $mg(z_2 - z_1)$
- ΔKE: $\dfrac{m(V_2^2 - V_1^2)}{2}$
- ΔU:
  - $m(u_2 - u_1)$ water (Table)
  - $mC_v(T_2 - T_1)$ ideal gas
- W:
  - Electrical $W_{el} = \int_1^2 VIdt$
  - Mechanical $W = \int_1^2 F \cdot ds$
    - Boundary $W_b = \int_1^2 p \cdot dV$
    - etc…