ESO201A : THERMODYNAMICS
2021-22 Ist semester
IIT Kanpur

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Lecture 2

Basic quantities in Thermodynamics:

Density and specific volume :

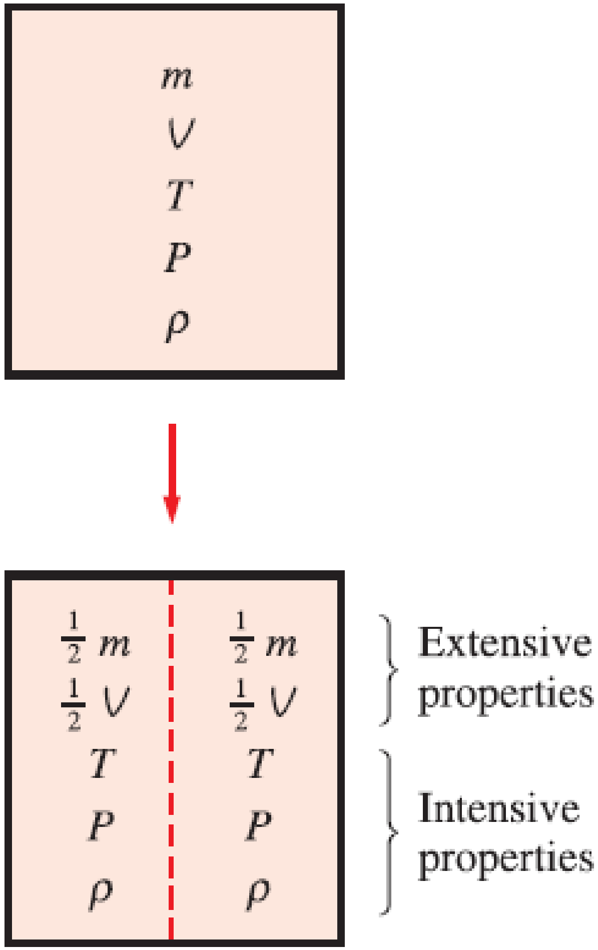
Density is defined as : $$\rho = \frac{m}{V} \quad (\mathrm{kg/m^3})$$

Here, m is mass and V is volume

Specific volume is defined as : $$v = \frac{V}{m} \quad (\mathrm{m^3/kg})$$

Besides these there are other important quantities like mole fractions, internal energy U etc. We will describe these in detail later.

Intensive and extensive properties:



T, P, ρ are <u>intensive properties</u>

m, V are <u>extensive properties</u>

Ref : Cengel and Boles , 8th Edition (2015)

Equilibrium state :

Equilibrium state or state of equilibrium is where **all** (macroscopic) driving forces are balanced and hence there is no observable change in the system.

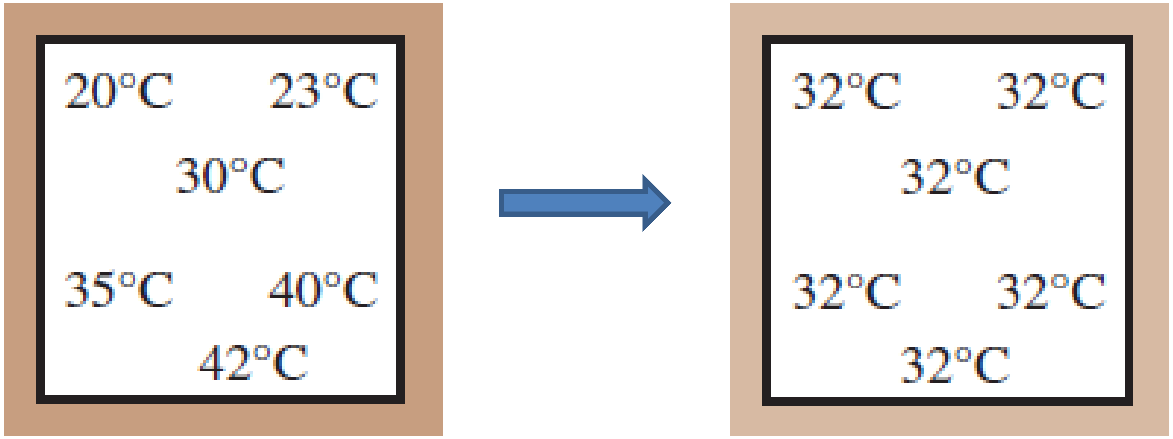
There are different types of equilibria depending upon the driving force:

Besides mechanical and thermal equilibrium, we also deal with chemical equilibrium in engineering applications.

When a system has achieved chemical equilibrium, there is no further change in composition of the system.

Equilibrium state :

All systems reach an equilibrium state after sufficient time



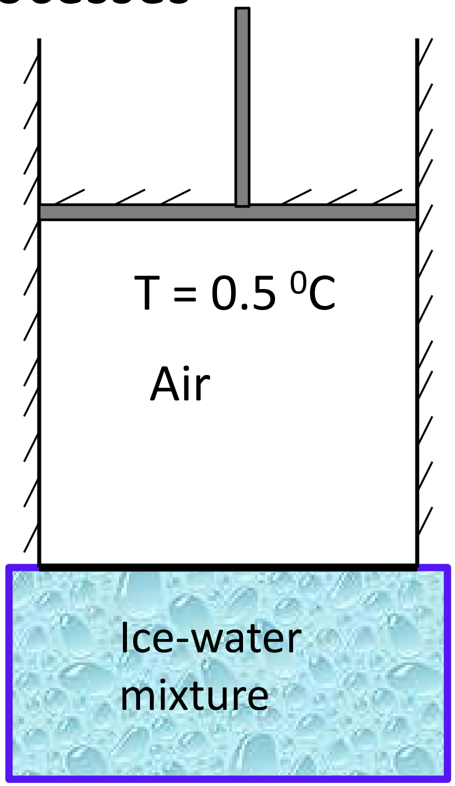
Initial (non-equilibrium) state

Final (equilibrium) state

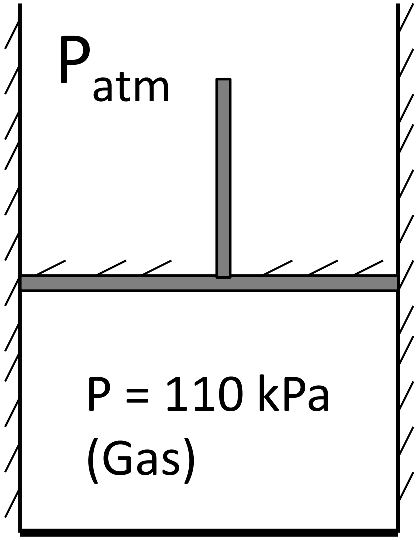
Ref : Cengel and Boles , 8th Edition (2015)

'Internal' Equilibrium state :

This is based on separation of time scales of different processes



Gas is in thermal equilibrium internally



$P > P_{atm}$

Gas is in mechanical equilibrium internally

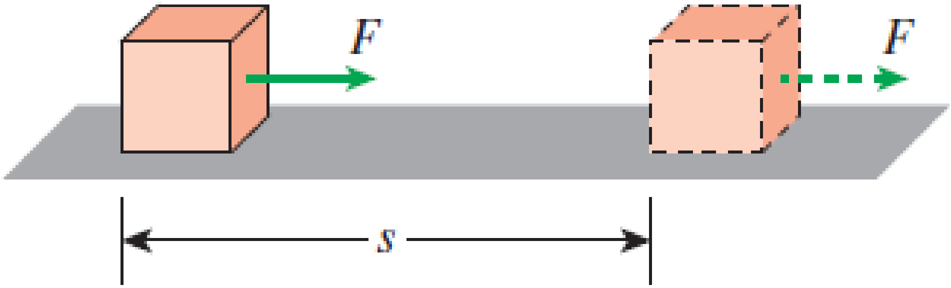
Energy transfer by work :

Mechanical work = (Force)(Displacement)

$$W = \int_1^2 \vec{F}.d\vec{s}$$

If the force F is constant (as in the picture below) and displacment is in the direction of the force,

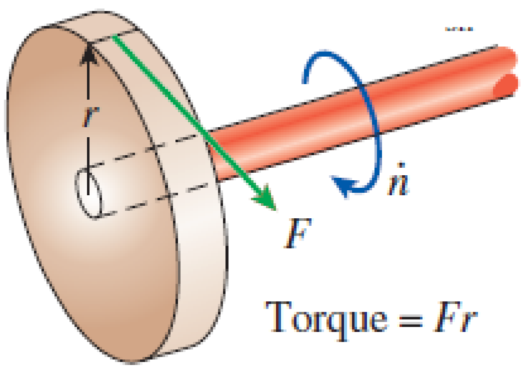
$$W = Fs$$



Ref : Cengel and Boles , 8th Edition (2015)

Energy transfer by work :

Mechanical work :

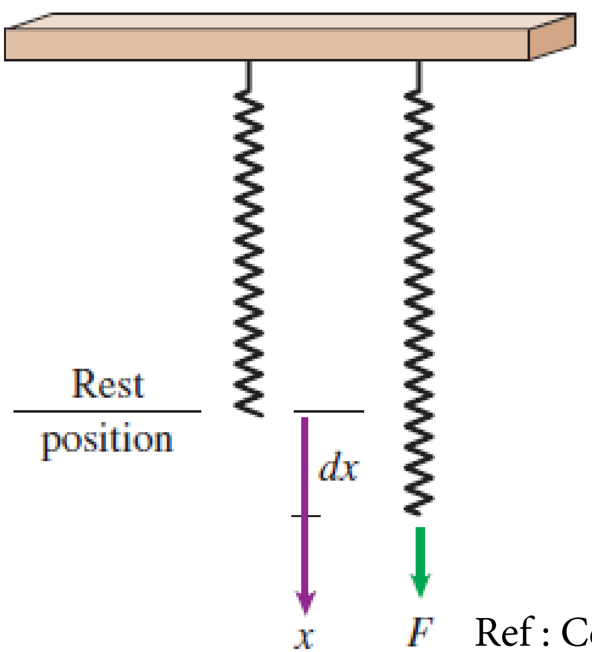


$$W(\text{for a single rotation}) = F(2\pi r)$$

Shaft work

$$\dot{W} = F(2\pi r)\dot{n}$$

$$\dot{W} = 2\pi T\dot{n}$$



Spring work

$$W = \int_1^2 \vec{F}.d\vec{x}$$

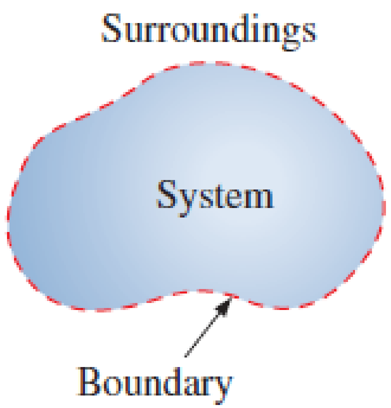
For a linear spring, F = k x

$$W = \frac{1}{2}k(x_2^2 - x_1^2)$$

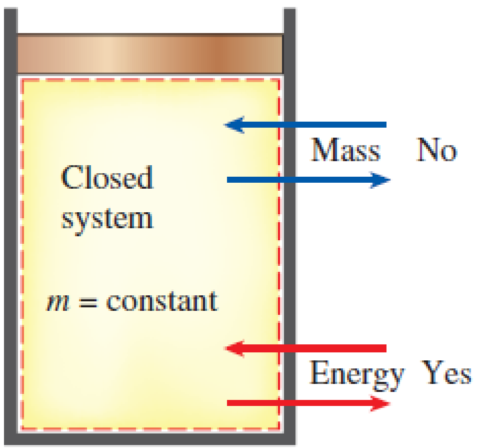
Ref : Cengel and Boles , 8th Edition (2015)

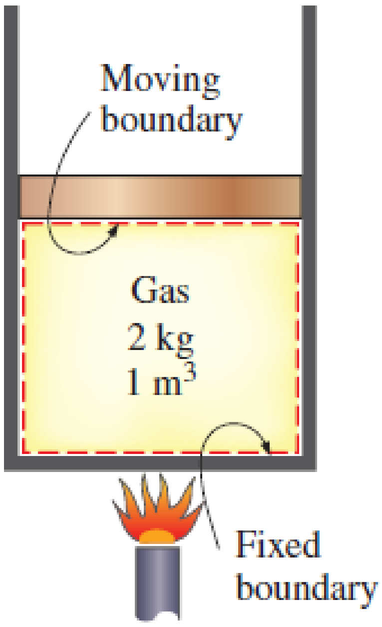
Systems :

Thermodynamic analysis : we define a system and its surroundings by means of a boundary



<u>Closed system or Control mass</u>



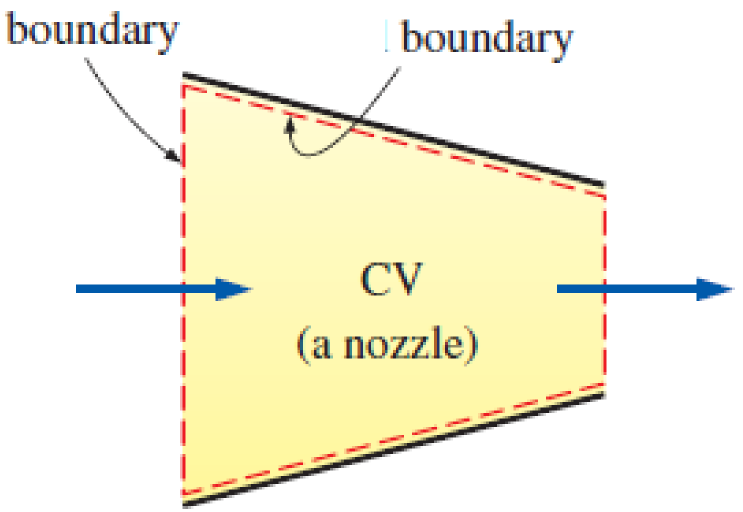


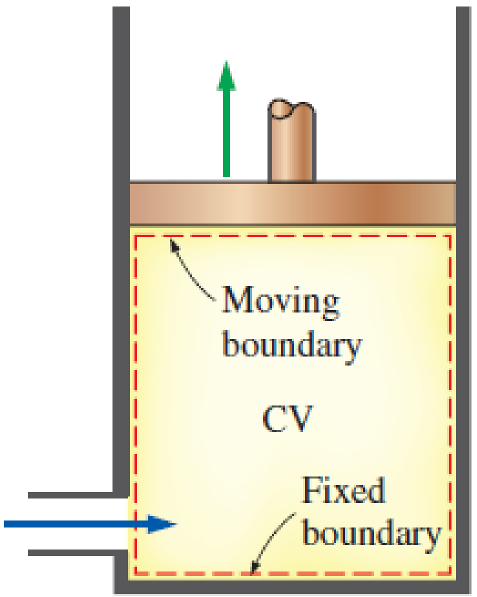
Ref : Cengel and Boles , 8th Edition (2015)

Systems :

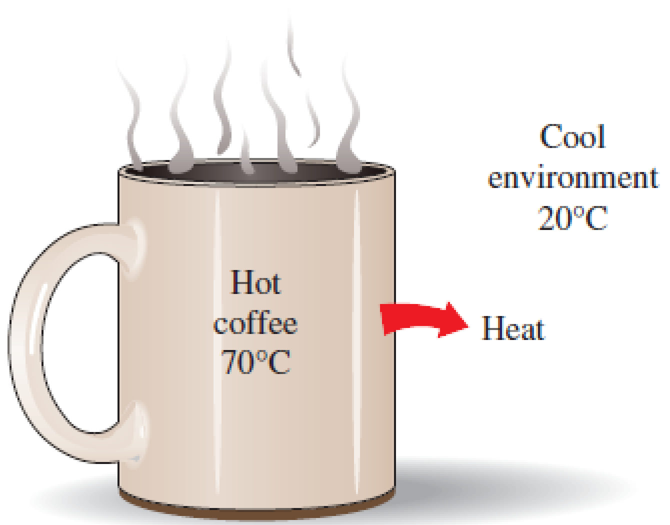
Ref : Cengel and Boles , 8th Edition (2015)

Open system or a control volume:





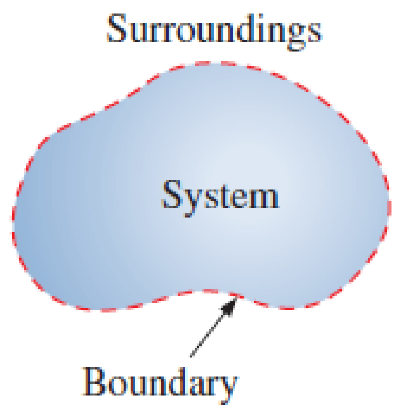
Examples :



Systems :

<u>Isolated system</u> : No mass or energy can can cross the boundary

For example, System + Surroundings = Isolated system



Sometimes useful for analysis based on 2nd law of thermodynamics

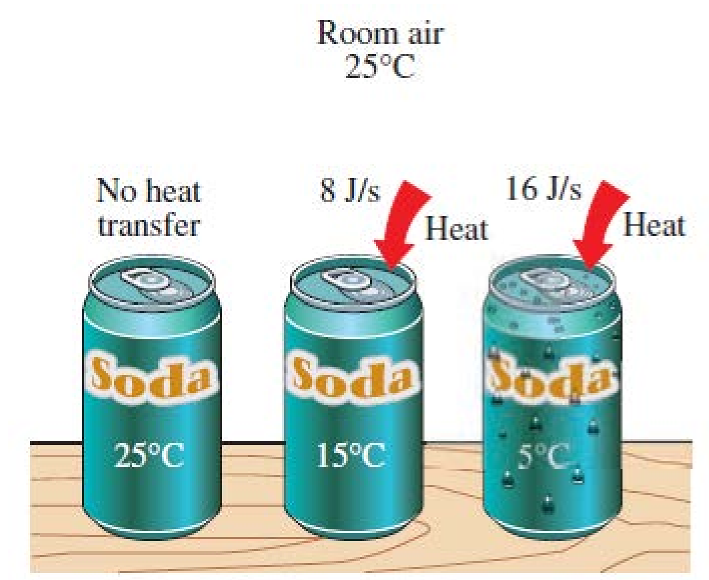
Ref : Cengel and Boles , 8th Edition (2015)

Energy transfer by Heat :

Heat is that part of the energy transfer which is not work

Systems at different temperatures exchange heat by three modes : (i) conduction (ii) convection and (iii) radiation

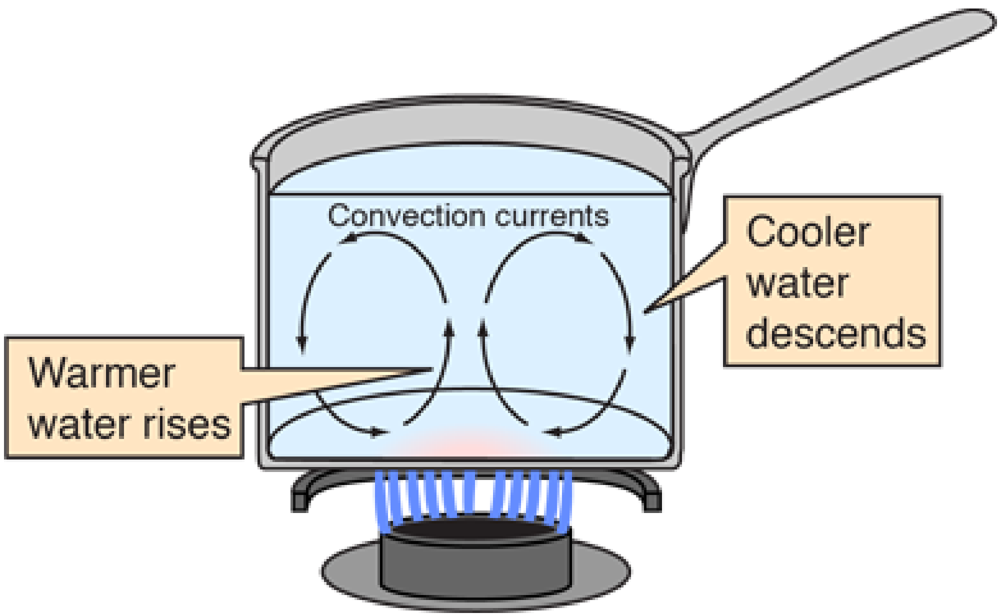
Conduction :



Ref : Cengel and Boles , 8th Edition (2015)

Energy transfer by Heat :

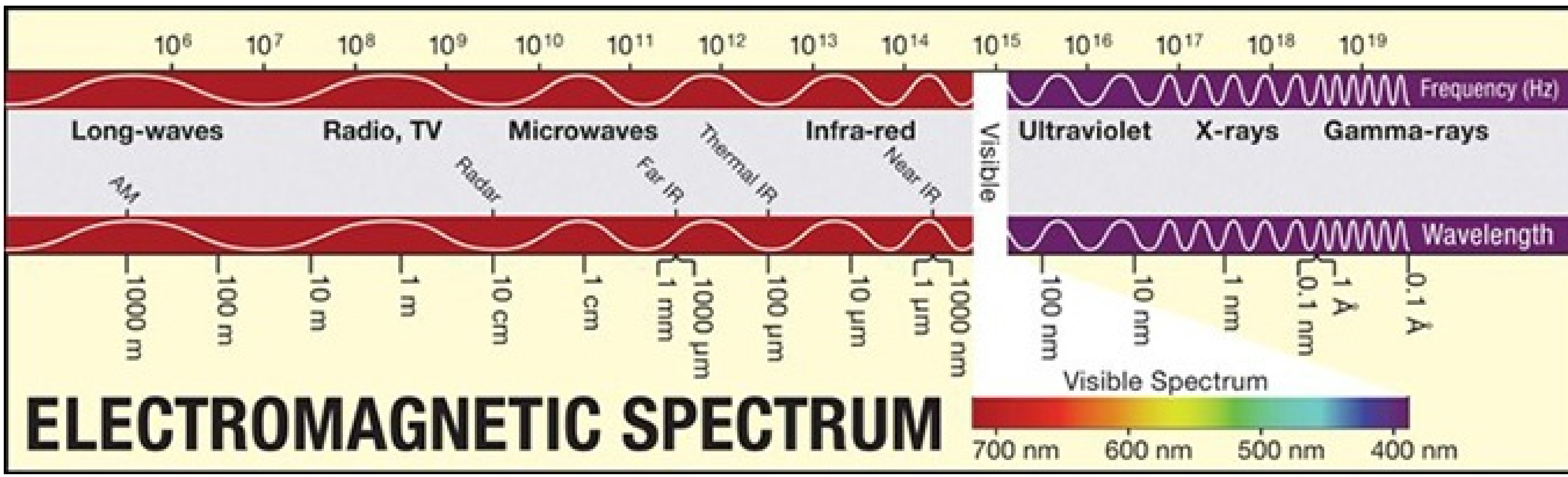
Convection : is the heat transfer due to bulk movement of fluid between regions with different temperatures



Ref : Cengel and Boles , 8th Edition (2015)

Energy transfer by Heat :

Radiation : is the heat transfer due to electromagnetic waves generated by thermal motion of particles in matter . Thermal radiation has a wavelength in the range of 0.1 to 100 µm (Infrared, visible and UV)

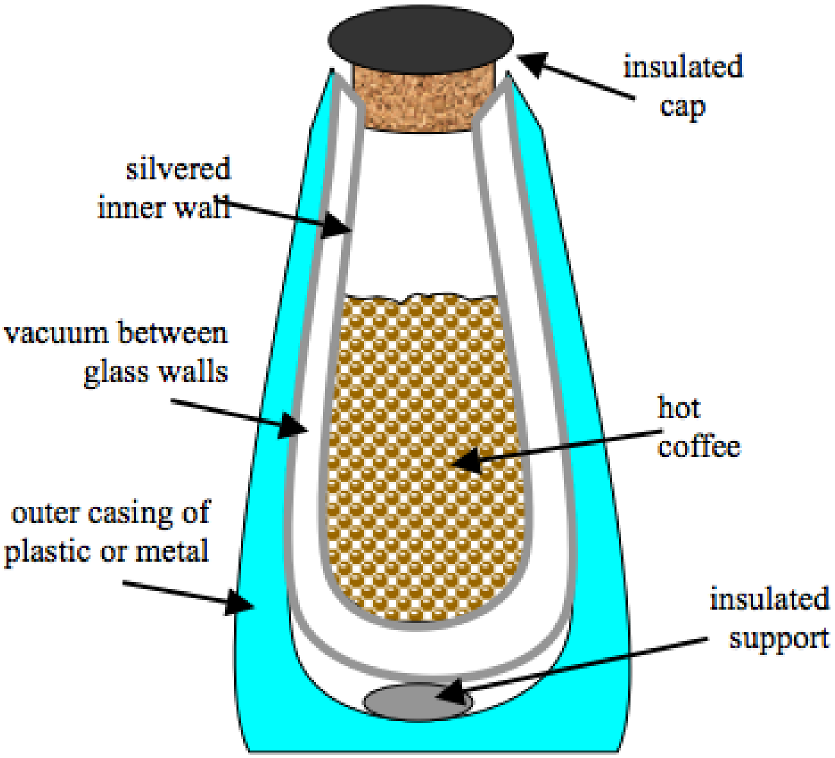


Infrared thermometer

Adiabatic process :

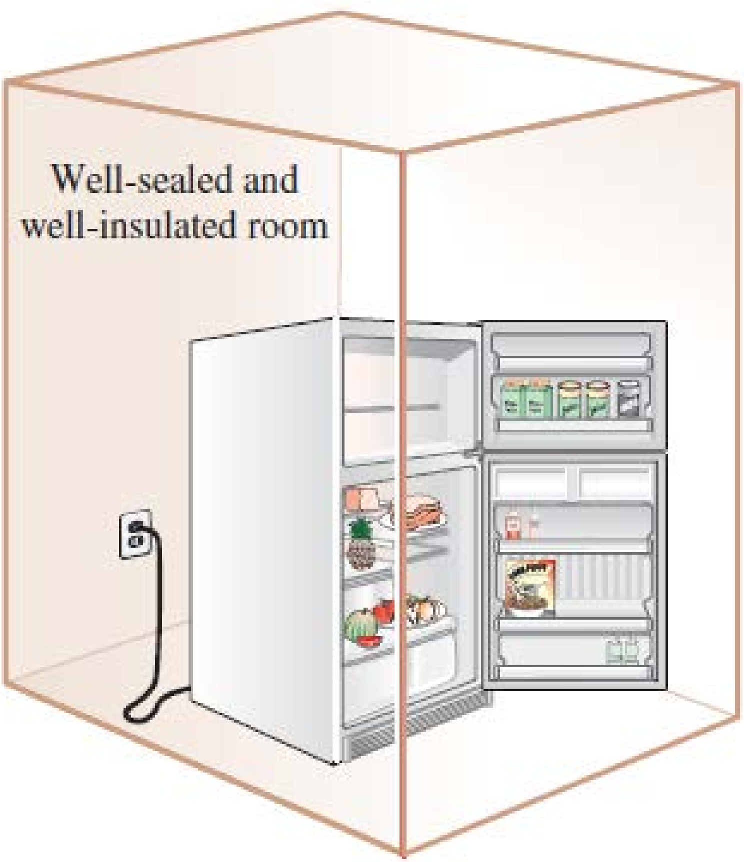
In this process, energy transfer is only due to work.

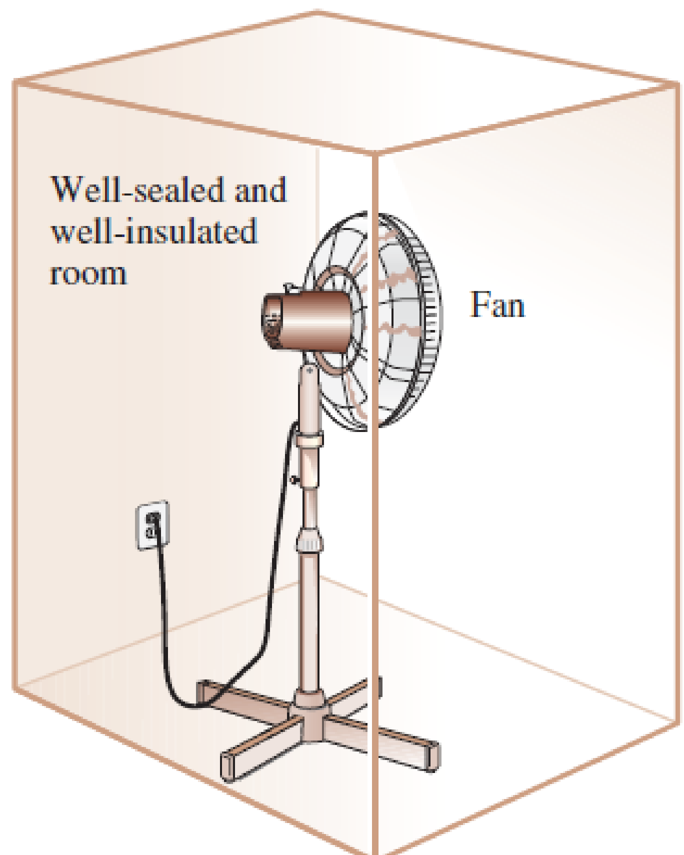
System is enclosed in a container with ‘adiabatic’ walls



Adiabatic process :

If surface tension effects and force field effects are not important, then the energy of the system can only be changed by Compression, expansion or by causing internal motion.





Ref : Cengel and Boles , 8th Edition (2015)

Adiabatic process :

Careful work measurements (in adiabatic processes) were performed by Joule in years 1843-1848

These experiments led to the concept of internal energy (U) and the formulation of first law of thermodynamics.