Energy

Energy can exist in numerous forms such as thermal, mechanical, kinetic, potential, electric, magnetic, chemical, and nuclear. In thermodynamics, energy is classified into two groups:

Energy

The **microscopic** forms of energy are those related to the molecular structure and molecular activity of a system. The sum of all the microscopic forms of energy is called the **internal energy (U)** of a system.

The **macroscopic** energy of a system is related to motion and the influence of some external effects such as gravity. This usually includes **kinetic (KE)** and **potential (PE)** energies

Internal Energy (U): Related to the Kinetic energy of the Molecules (الجزيئات), for example molecules transitional, vibrational and rotational motion.

Kinetic Energy (KE): The energy that a system possesses as a result of its motion.

$$KE = \frac{1}{2}\, m\, V^2$$

Potential Energy (PE): The energy that a system possesses as a result of its elevation

$$PE = mgz$$

The **total energy (E)** of the system is equal to the summation of both microscopic and macroscopic form of energies.

$$E = U + \mathrm{KE} + \mathrm{PE} = U + \frac{1}{2}\, m\, V^2 + mgz$$

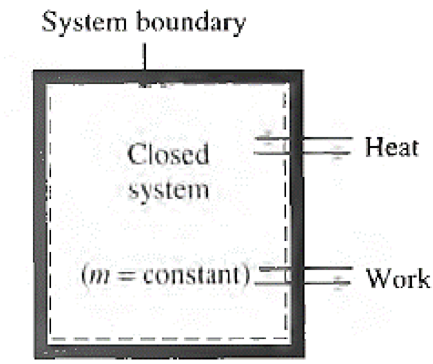
Close systems remain **stationary** during a process and thus experience no change in their kinetic and potential energies. The change in total energy is equal to the change in its internal energy.

$$\Delta \boldsymbol{E} = \Delta \boldsymbol{U}$$

Energy Transfer by Heat (Q)

Energy can cross the boundary of a **closed system** as **heat** and **work** only.

Heat (Q) is defined as the form of energy that is transferred between two systems or a system and its surroundings by the mean of **temperature difference**.



Heat (Q) has a unit of **(KJ),** sometimes heat is given per unit mass of the system (q)

$$q = \frac{Q}{m} \ (KJ/Kg)$$

Also, it is desirable to know the ***rate of heat transfer*** $\dot{Q}$ (the amount of heat transferred per unit time)

$\dot{Q} = Q\ /\Delta t\ (KJ/s)$, where Δt time interval during which the process takes place.

Ex$_1$) A 30 KJ of heat is added to a system having a mass of 2 kg, the entire process took 5s to complete. Calculate the heat added per unit mass and the rate of heat transfer.

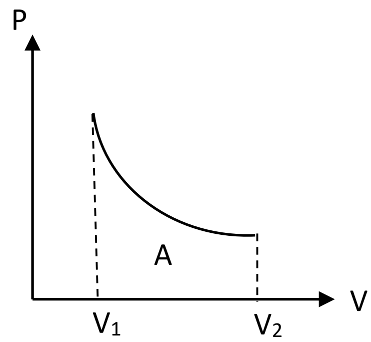
Energy Transfer by Work (W)

*Work is the energy transfer associated with a **force** acting through a **distance**.* Generally, energy interaction that is not caused by a temperature difference between a system and its surroundings is work.

Examples: rising piston, a rotating shaft, electric wire (Heater) crossing the system boundaries.

Work (W) has a unit of **(KJ)** and it can be calculated from:

$$\boldsymbol{W = \int_{V_1}^{V_2} P\, dV}$$



Which is the **area under the curve** (A)

Sometimes work is given per unit mass of the system (w)

$$w = \frac{W}{m} \ (KJ/Kg)$$

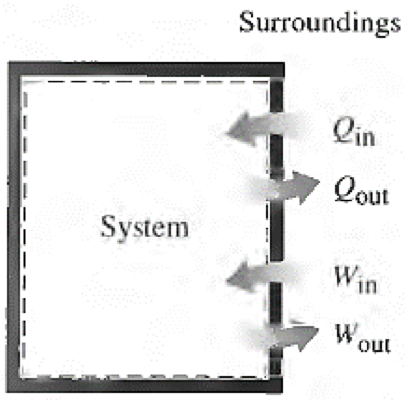
Also, the work done *per unit time* is called power (P)

$P = W\ /\Delta t\ (Watt\ 'w')$

Ex$_1$) A 100 KJ of work is done by a system having a mass of 5 kg, the entire process took 10s to complete. Calculate the power and work added per unit mass.

Ex$_2$) Calculate the work done by a piston expanded from 0.2 m^3 to 0.3 m^3 at a constant pressure of 300 Kpa.

Heat and work are ***directional quantities,*** thus we need to specify both the ***magnitude*** and ***direction.***



The generally sign convention for heat and work is as follows:

- heat transfer to a system and work done by a system are positive.
- heat transfer from a system and work done on a system are negative***.***

First Law of Thermodynamics

The first law of thermodynamics, also known as the conservation of energy law, states that energy can be neither created nor destroyed during a process; it can only change from one form to another.

For **closed system**, 1st law of thermodynamics can be written as:

The change of the internal energy (ΔU) of a system is equal to the heat added to the system (Q) minus the work done by the system (W). i.e.

$$\boxed{\Delta U = Q - W}$$

Ex₃) A rigid tank contains a hot fluid that is cooled by a paddle wheel. Initially, the internal energy of the fluid is 800 kJ. During the cooling process, the fluid loses 500 kJ of heat, and the paddle wheel does 100 kJ of work on the fluid. Determine the final internal energy of the fluid.

Specific Heat

Specific heat: is defined as the energy required to raise the temperature of a unit mass of a substance by **one degree**. In thermodynamics, we are interested in two kinds of specific heats: specific heat at constant volume **Cv** and specific heat at constant pressure **Cp**.

Specific heat at constant volume (Cv): The energy required to raise the temperature of the unit mass o f a substance by one degree when the volume is maintained constant.

Specific heat at constant pressure (Cp): The energy required to raise the temperature of the unit mass of a substance by one degree when the pressure is maintained constant.

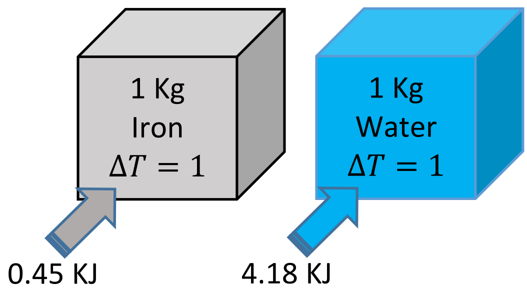
Note: The specific heat at constant pressure ***Cp*** is always greater than Cv because at constant pressure the system is allowed to expand and the energy for this expansion work must also be supplied to the system.

Cp = Cv + R

Heat Capacity (Stored Heat)

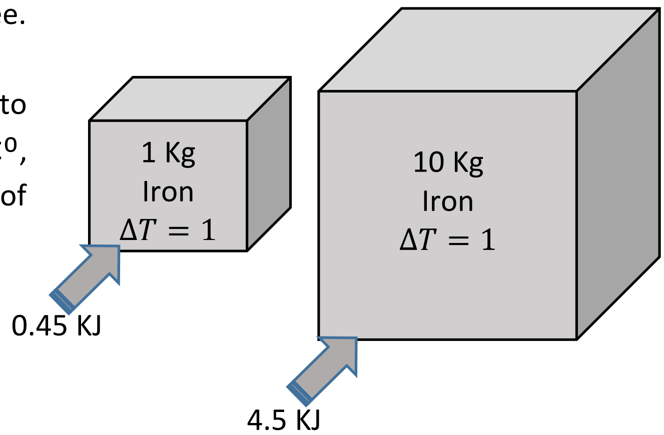
- It takes different amounts of energy to raise the temperature of **identical masses** of **different substances** by one degree. This is basically due to the fact that those masses have different specific heat values.

For example, we need about 0.45 kJ of energy to raise the temperature of 1 kg of iron by 1 C^0, whereas it takes 4.18 kJ ($9xQ_{iron}$) to raise the temperature of 1 kg of water by 1 C^0.



- Also, it takes different amounts of energy to raise the temperature of **different sized masses** of the **same substances** by one degree.

For example, we need about 0.45 kJ of energy to raise the temperature of 1 kg of iron by 1 C^0, whereas it takes 4.5 kJ to raise the temperature of 10 kg of iron by 1 C^0.



Therefore, the amount of **heat** that can be stored in an object is proportional to the **mass** and **specific heat** of that object.

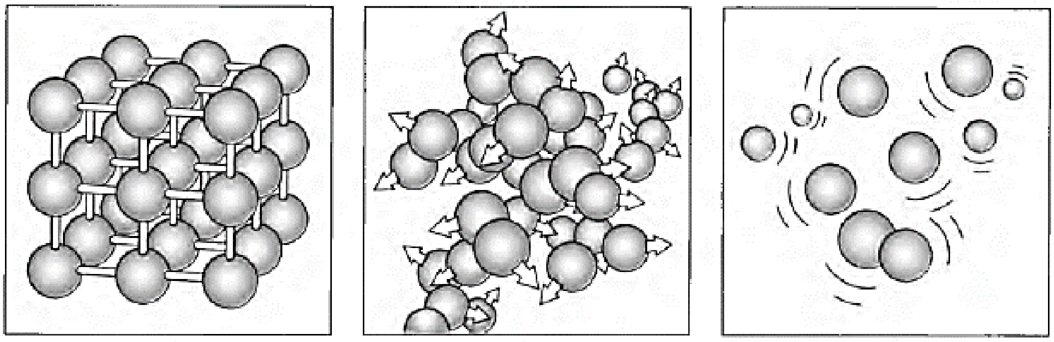
$$Q = m\,C\,\Delta T$$

Ex$_4$) A 50,000 J of heat is added to bucket of water (2kg) initially at 20 ^{0}C. What will be the final Temperature of the water?

Change of Phase and Heat Latent

Substances exist in three different phases: Solid, Liquid and Gas.

- The molecules in a solid phase are arranged in a **three-dimensional pattern** and they are connected through Intermolecular bonds (a).
- The molecules are **no longer connected** in a liquid phase and they are free to rotate and translate (b).
- In the gas phase, the molecules are far apart from each other, and a molecular order is not existed (c).



(a) (b) (c)

The amount of energy absorbed or released during a phase-change process (melt a solid or vaporize a liquid) is called the **latent heat**.

The **latent heat of fusion** (lh_f) of water is 333 kJ/kg and the **latent heat of vaporization** (lh_v) is 2256 kJ/kg. Therefore:

$$Q = m \,.\, lh$$

Ex$_5$) How much heat will require to raise a cube of ice (150 g) initially at (-20) up to 0 ^oC and then melt it to water and finally raise to 50 ^oC. Take $C_{ice} = ½\, C_{water}$

H.W) A 10 g of steam initially at 100 ^{o}C is mixed with 50 g of ice at -10 ^{o}C. What will be the final temperature of the mixture?