Energy

- Energy is a primitive property. We postulate that it is something that all matter has. It is further defined as capacity to do work.

Energy of a system

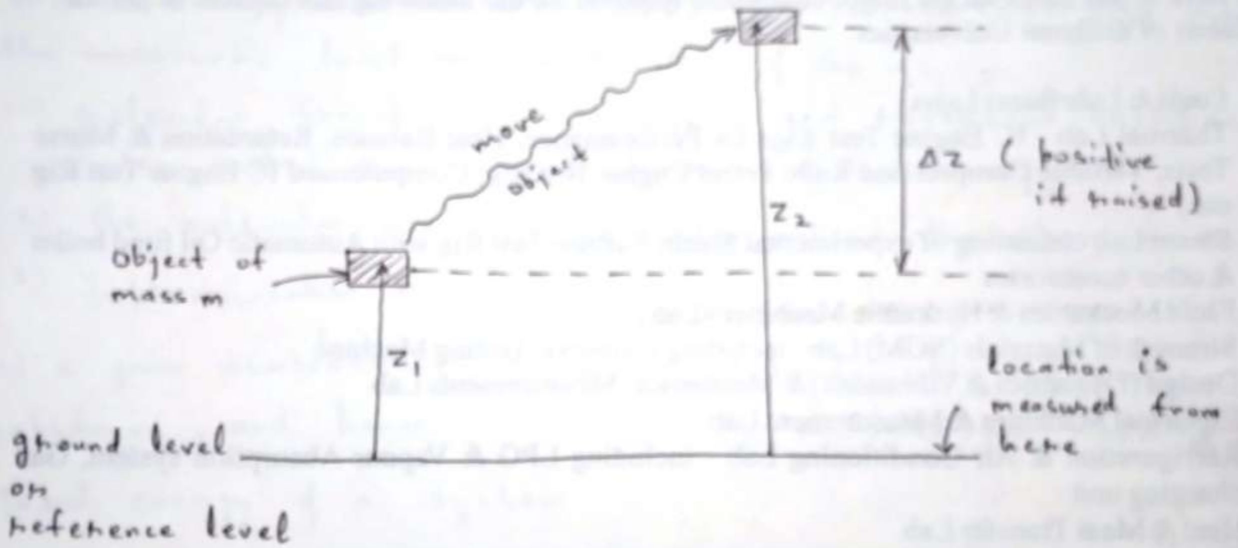
① energies that are expressed in terms of parameters measured w.r.t. a frame of reference outside the system, like mechanical energies (Potential energy, kinetic energy)

② energies that are functions of the molecular configuration of matter and microscopic modes of motion.
e.g. Internal energy

Potential energy :-

Any two masses, regardless of their size, exert an attraction on one another. If this force of attraction is multiplied by the distance of separation, the resultant energy is known as potential energy. That is, potential energy is the kind of energy that a body has because of its position in a potential field.

The kind of potential energy that is relevant to us is that associated with a mass above an arbitrary datum plane when the force of attraction is that due to the earth's gravitational field. So, when we speak of potential energy in thermodynamics, we mean gravitational potential energy.



In raising a mass m in vertical direction from elevation z_1 to z_2, the potential energy change is given as –

$$\Delta PE = mg\,(z_2 - z_1)\ J/kg$$

Kinetic energy :

It is the kind of energy that a body has because of its bulk motion and is defined in terms of the relative motion of two bodies.

As a matter of convenience, we assume that earth has zero velocity and measure velocities of bodies relative to the earth.

$$\Delta KE = \frac{1}{2} m \left(V_2^2 - V_1^2 \right) \quad J/Kg.$$

Internal Energy, U :

Internal energy includes all forms of energy in a system other than kinetic energy and potential energy. It represents energy modes on the microscopic level and is the sum of the –

(1) molecular translation, vibrational and rotational energies (also called the thermal portion of the energy),

(2) the molecular bond energy (also called the chemical energy)

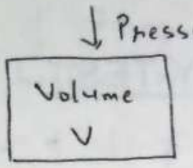
(3) Intermolecular potential energy

At a given temperature, the energy depends upon the nature of a substance, and hence, is known as an intrinsic form of energy.

Total energy of a system,

$$\boxed{E = PE + K.E. + U}$$

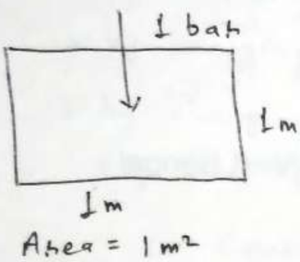
Enthalpy, H :



When you want to evaluate the energy of an object of volume V, it must be remembered that the object had to push the surroundings to make room for itself.

The work required to push the surroundings –

$$W = \int_0^V P.\,dV = P.V$$



Atmospheric force on each sq. mt.

$\equiv$ Force exerted by 10 Tonnes mass

(This is not a small force to neglect.)

Thus, the total energy of a body is its internal energy plus the extra energy it is credited with by having a volume V at pressure P. This total energy is called the enthalpy H.

$$\boxed{H = U + PV}$$

U → Internal energy

PV → Pressure in system

The PV term represents a sort of potential energy.

Various forms of energy change of a system

1. Heat – the way of adding or removing energy from a system by contact with a hotter or cooler body.

2. Work – all ways of changing the energy of a system other than by adding or removing heat, including
   - * Push-pull work (Piston-cylinder)
   - * electric and magnetic work (electric motor)
   - * Chemical work (by reaction of gasoline with air in an automobile engine)
   - * elastic work (winding up a spring)

3. Changing the internal energy of an object or of a system –
   - * by changing the temperature of a system (heat or cool)
   - * by changing phase (solid → liquid, or liquid → gas)
   - * by changing the molecular arrangement (chemical reaction), e.g. $C + O_2 \longrightarrow CO_2$

     Combining carbon with oxygen to form carbon dioxide, as in the burning of charcoal
   - * by changing the atomic structure (nuclear fission) or breakup of large atoms to yield small fragment atoms

     $${}_{92}U^{235} + {}_{0}n^{1} \longrightarrow {}_{42}Mo^{100} + {}_{54}Xe^{134} + 2\,{}_{0}n^{1} + 4\,{}_{-1}\beta^{0}$$

     Uranium, neutron → Molybdenum, Xenon, electron
   - * by combining small atoms to form large atoms (fusion)

     $${}_{2}D^{1} + {}_{3}T^{1} \longrightarrow {}_{2}He^{4} + {}_{0}n^{1}$$

     Deuterium, Tritium → Helium, Neutron

4. Changing the potential energy of an object –
   - * by changing the location of the object in a force field, whether gravitational, electrical, or magnetic

     e.g. (i) in raising an object from the ground

     (ii) Pushing an electron towards a negatively charged plate

5. Changing the kinetic energy of an object –
   - * by changing its velocity (the faster the object moves, the greater is its kinetic energy)

Specific Heat (of Solids and liquids)

The specific heat of a substance is defined as the amount of heat required to raise the temperature of the unit mass of the substance through a unit degree (1°C or 1 K).

$$c = \frac{Q}{(m)(\Delta T)} \qquad \frac{J}{kg.K}$$

Where Q = the amount of heat transfer (J)
m = the mass of the substance (kg)
ΔT = rise in temperature (°C or K)

Specific heat depends upon the material of the body. It is therefore called the 'specific heat' of the material. For most substances, the specific heat increases with increase in temperature and assumes a constant value at high temperatures. The specific heat of water, however, decreases with increase in temperature from 0°C to about 40°C after which it increases with temperature.

Specific Heat of a Gas

The above definition of specific heat is sufficient for solids and liquids, but not for gases. On the basis of the above formula, the specific heat of a gas may be any thing from zero to infinity.

Example :

Suppose a mass m of a gas, instead of heating, is compressed so that its temperature rises by ΔT. Since no heat is given to gas ($Q=0$),

$$c = \frac{0}{m \cdot \Delta T} = 0$$

If the compressed gas be allowed to expand, its temperature will fall. But if during the expansion of the gas, heat Q is supplied so that its temperature does not fall ($\Delta T = 0$), then

$$c = \frac{Q}{m \times 0} = \infty$$

Hence, the specific heat of a gas depends upon the conditions of pressure and volume of the gas during its heating.

(a) Specific Heat at Constant Volume (C_v)

It is the amount of heat required to raise the temperature of 1 gm of the gas through 1°c (or 1K), when the volume is kept constant.

(b) Specific Heat at Constant Pressure (C_p)

It is the amount of heat required to raise the temperature of 1 gm of the gas through 1°c (or 1K), when the pressure is kept constant.

Heat Capacity (C)

The product of mass and specific heat (mc) is called the heat capacity of the substance. The capital letter C, C_v or C_p is used for heat capacity.

Latent heat

The latent heat is the amount of heat transfer required to cause a phase change in unit mass of a substance at a constant pressure and temperature.

- The latent heat of fusion is the amount of heat transferred to melt unit mass of solid into liquid, or to freeze unit mass of liquid to solid.
- The latent heat of vaporization is the amount of heat required to vaporize unit mass of liquid into vapor, or condense unit mass of vapor into liquid.
- The latent heat of sublimation is the amount of heat required to convert unit mass of solid to vapor or vice verse.
- The latent heat of fusion is not much affected by pressure.
- The latent heat of vaporization is highly sensitive to pressure.

First law of Thermodynamics

"Energy cannot be created or destroyed. One can only change it from one form to another, or one can only add it to the system from the surroundings."

Energy does not just appear from nowhere. If a system or object gains energy, then this energy must have come from outside of it.

Example :

Heat a cup of cold water
(i.e. Increase its thermal energy)

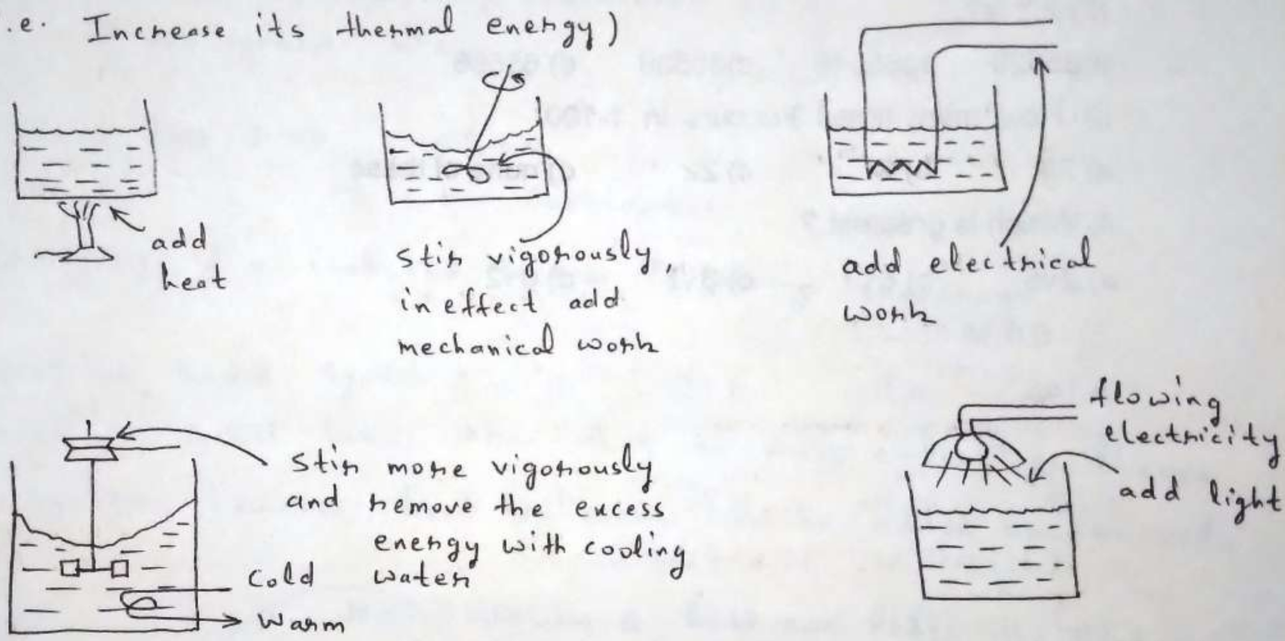


Fig: various combinations of heat and work can be used to heat a cup of cold water.

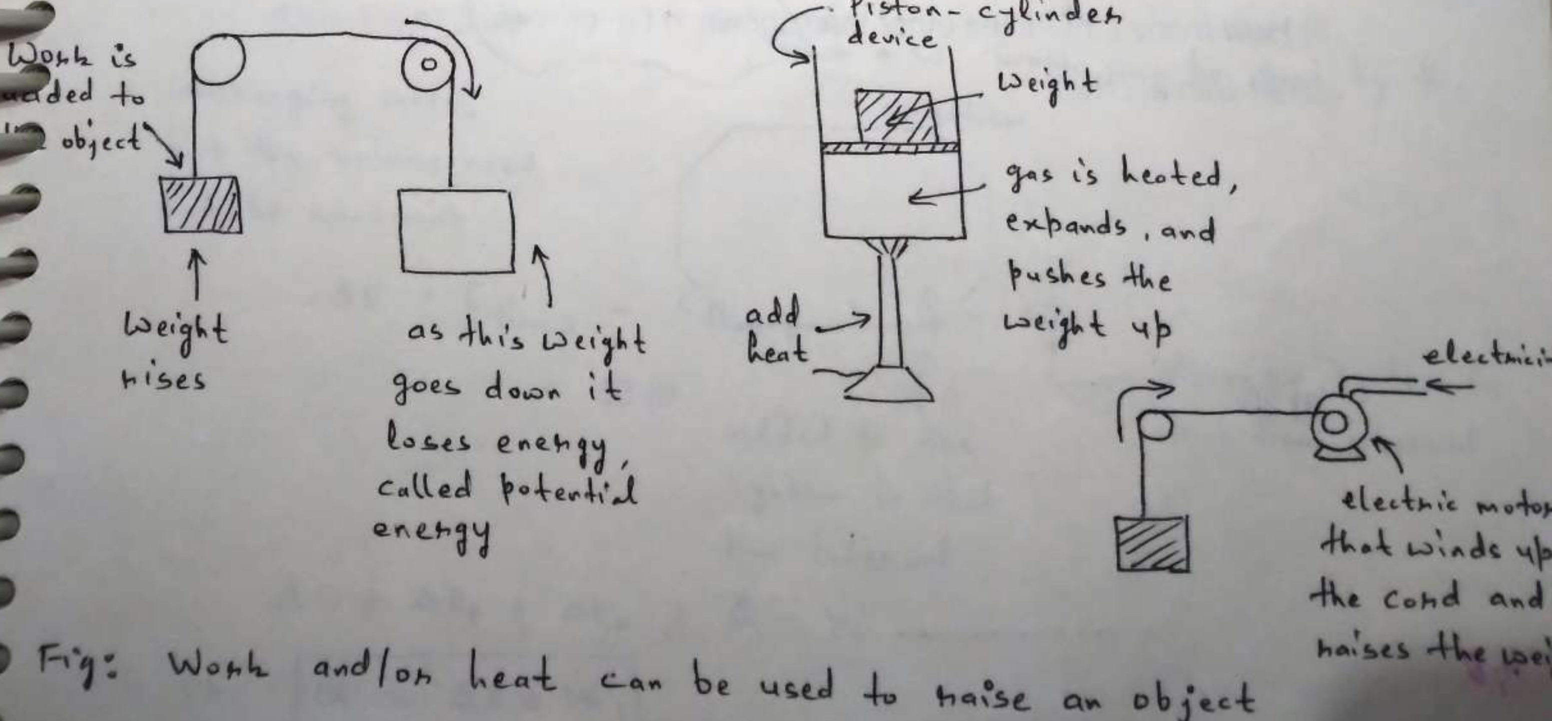
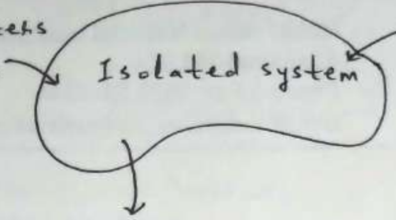


Fig: Work and/or heat can be used to raise an object

Various forms of the first law

1. Isolated system :-

No heat enters from outside, $Q = 0$



Kinetic, potential, and internal energy can interchange within the system, but not with the surroundings.

no work is done by the system, hence no expansion or contraction of the system, $W = 0$

The first law gives, $\Delta E = 0$

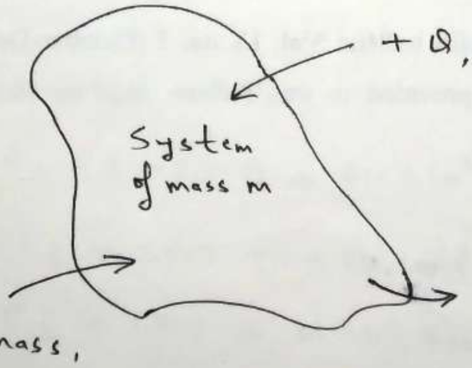
or $E = \text{Constant}$

The energy of an isolated system is always constant.

2. Closed or Batch System :-

"Closed" or "Batch" terms mean that no mass enters or leaves the system; however, heat or work can be added or removed.

$+Q$, heat can enter the system



$+W$, work can be done by the system

unchanging mass, but the volume need not be constant

$$\Delta E = E_{time\,2} - E_{time\,1} = Q - W$$

Q: added to the system in that time interval

W: done by system in that time interval

$$\Delta U + \Delta E_p + \Delta E_K = Q - W$$

or, $$\boxed{Q = \Delta E + W}$$