Work, Energy and Power

Dr.Jinchu.I

Work

- In everyday life, any physical or mental activity may be regarded as 'work'.
- work is said to be done only when the applied force causes some displacement of a body in its direction.
- If a constant force is applied to a body in different directions, the work done depends on the displacement of the body in the direction of the force.
- Hence, Work in Physics is defined as the product of force and displacement in the direction of the force.
- If F is the applied force, S is the displacement in the direction of applied force, and work done W is given by

Work done = Force x Displacement in the direction of force

$$W = F \cdot S$$

Work is a scalar quantity. In the SI system, the unit of work is Nm or joule (J).

$1\ J = 1\ N \times 1\ m = 1\ kg\ m/s^2 \times 1m = 1\ kgm^2s^{-2}$

Types of Work

A) Positive work

- The work done on an object is said to be positive work when force and displacement are in the same direction.

Eg: Work done by the gravitational force on a freely falling.

B) Negative Work

- The work done is said to be negative work when force and displacement are in opposite directions.

Eg: When a body is thrown upwards, the work done by the gravitational force and displacement are opposite.

C) Zero Work

- The work done is said to be zero when force and displacement are perpendicular to each other or when either force or displacement is zero.

Eg: Work done by gravity when a person walks horizontally with some load on his head.

Energy

- The capacity (or ability) of a body to do work is called energy. Energy and work are equivalent concepts. The SI unit of energy is also joule (J).

Types of Energy

- Energy can exist in many forms, but it can be broadly classified into two categories –

1. kinetic energy
2. potential energy

a) Kinetic Energy

- The energy possessed by a body due to its motion is called kinetic energy.
- A moving vehicle, Earth revolving around the sun, and molecules moving in space all have kinetic energy.
- The kinetic energy of a moving object is directly proportional to the mass of the object and the square of its velocity. If m is the mass of the body and v is its velocity, then kinetic energy is given by

$$K = \frac{1}{2} mv^2$$

b) **Potential Energy**

- The energy possessed by a body by its position or configuration is called potential energy.
  - Eg: if we carry a brick to the top of the building, we do some amount of work against the force of gravity. The amount of energy is stored in the brick, in the form of potential energy.
  - Eg: Consider a bow and arrow. Pull the string along with the arrow in the backward direction by applying force. In doing so you change the configuration (shape) of the bow. The energy is used up in changing the shape of the bow and it is stored in the bow in the form of potential energy.
  - Water stored in a tank, a stretched rubber chord, etc. have potential energy.
- The potential energy of a body depends on the type of force acting on the body.
- Consider a mass m held at a height h above ground level in the gravitational field of Earth. If g is the acceleration due to gravity on the surface of the Earth, the potential energy of the body is given by

$$V = mgh$$

Different Forms of Energy

- Two basic types of energy namely kinetic energy and potential energy are sufficient to describe all forms of energy.
- But it is convenient to refer to a particular combination of kinetic energy and potential energy as its form. The major forms of energy include
  - mechanical energy
  - heat energy
  - light energy
  - sound energy
  - electrical energy
  - magnetic energy
  - chemical energy
  - nuclear energy.

a) Mechanical Energy

- Mechanical energy is the energy of a system due to its motion, position, or configuration. It is the sum of kinetic energy and potential energy of a system. A system can do work by utilizing its mechanical energy.
  - For example, machines use mechanical energy to do work.

b) Heat Energy

- An object possesses heat energy (thermal energy) due to the motion of molecules in it. The energy released when we burn wood, coal, oil, or gas is called heat energy.
- Steam possesses heat energy which is capable of doing work. If you cook food in a pressure cooker by placing it over a gas stove, the heat energy changes water into steam. The steam lifts the weight on the top of the lid and whistles. This lifting of weight suggests that heat is a form of energy that is capable of doing work.
- In 1765, James Watt, a young scientist, noted this phenomenon which led to the invention of the steam engine in which heat energy was used to do work.
- In thermal power stations, it is the heat energy of burning coal that is used to generate steam. The steam, in turn, runs the turbines of the generator and produces electric energy. All automobiles use heat energy by burning petrol, diesel, or CNG for doing work. The food which we consume burns slowly in our cells to produce heat energy.

c) Light energy

- Light energy is a form of electromagnetic radiation. When an excited electron in an atom or a molecule undergoes a transition from a higher energy level to a lower energy level, the difference in energy between the levels is sometimes emitted in the form of light. Light travels as waves and it is capable of travelling through vacuum.
- The plants absorb light energy and convert it into chemical energy (food) through a process called photosynthesis.

d) Sound energy

- Sound energy is produced when an object vibrates. A sound wave needs a medium to travel through such as air, water, wood, or metal. When sound waves fall on the ear membrane, they make it vibrate and we can hear the sound. When a supersonic plane breaks the sound barrier (speed of sound in air), the sound waves produced by it, shake the buildings. Similarly, the thunder of the cloud also shakes buildings. This shows that sound energy can also do work.

e) Electrical energy

- The energy produced by the movement of electrons is called electric energy. When electric energy passed through an electric motor, it sets its axle in a circular motion. This circular motion is utilized in running ceiling fans, juicers, grinders, etc. It is used for running electric moped, vehicles. It is used in factories for running heavy machines. It is also used in heating devices such as heaters, geysers, electric stoves, etc. It is also used in lighting bulbs.

f) Magnetic energy

- Magnetism is described by magnetic fields which are produced either by magnetic materials or by electric currents.
- Energy stored in a magnetic field is called magnetic energy.
- A magnet is capable of causing motion in magnetic substances.

  E.g: Iron cobalt, nickel are examples of magnetic substances.

  Magnetic energy is used in electromagnets, electric motors, electric generators, microphones, television tubes, telephones, etc. The cranes which lift heavy loads of iron or separate iron scrap from waste materials use electromagnets.

g) Chemical Energy

- Chemical energy is defined as the energy stored in the bonds between atoms or molecules in a compound. When this compound undergoes a chemical reaction, the chemical energy stored in the bonds will be released in the form of heat. The energy possessed by the fuels like coal, oil, gas, etc. is chemical energy. The chemical energy of diesel, petrol, or CNG is capable of moving vehicles. The food that we consume, possesses chemical energy which is utilized by our body to do work.

h) Nuclear energy

- The binding energy of nucleons (neutrons and protons) in the nucleus is called nuclear energy. The nucleus in an atom has an enormous amount of energy which holds the proton and neutrons together. When a heavy nucleus splits into light nuclei or two light nuclei combine to form one nucleus, it releases energy. Nuclear fission or fusion releases nuclear energy in the form of heat and light energy. In nuclear power stations, nuclear energy is used to generate electric energy. In the case of an atom bomb or hydrogen bomb, nuclear energy is used for destructive purposes

Solar Energy

- Solar energy is radiant light and heat from the Sun. Solar energy is created by nuclear fusion that takes place in the sun. The primary source of all kinds of energy on Earth is solar energy. Solar energy provides wind energy, tidal energy, and energy of sea waves. Solar energy causes the evaporation of water, which in turn leads to the water cycle. The phenomenon of photosynthesis is not possible without solar energy. It is necessary for life on Earth and can be harvested for human use in many ways. Solar cells absorb sunlight and convert solar energy into electrical energy. Solar cooker, Solar water heater, etc. utilizes heat energy present in the solar radiation.

Transformation of Energy

- Energy transformation is the process of converting one form of energy into another form.

There are various types of energy all around us and these energy sources can be converted from one form to another as explained below:

- Conversion of Potential energy into kinetic energy and vice versa
- Conversion of Light energy into heat energy.
- Conversion of Electrical energy into mechanical energy, light energy, heat energy, etc.
- Conversion of chemical energy into electrical energy.
- Conversion of mechanical energy into electrical energy, sound energy, etc.
- Conversion of Nuclear energy into light energy and heat energy.
- Conversion of Solar energy into heat energy, chemical energy, and electrical energy

Law Conservation of Energy

- *The Law of conservation of energy states that energy can neither be created nor be destroyed, but can be converted from one form to another. In other words, the total energy of an isolated system remains constant.*

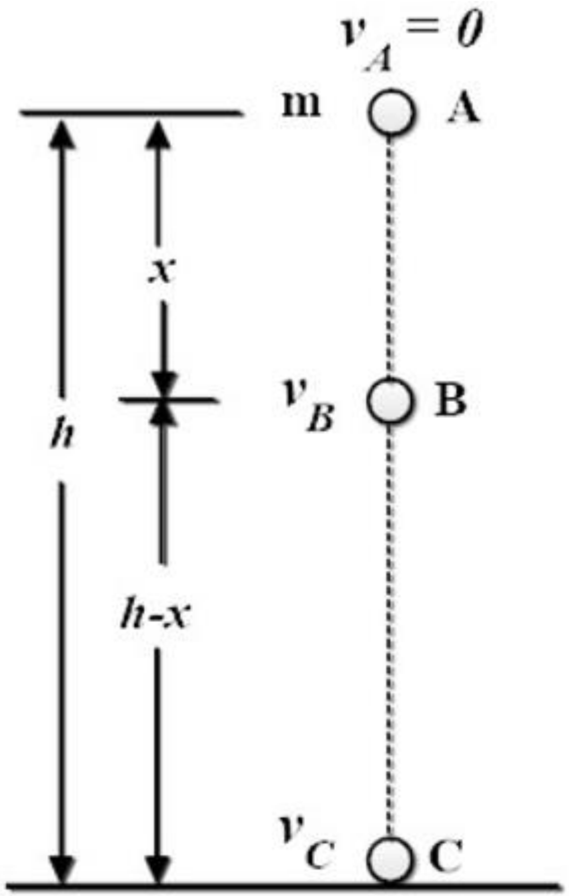
Proof

- Consider a body of mass ‘m’, initially placed at height ‘h’ above the ground level as shown in Figure.

Let the body is allowed to fall freely from its initial position A. In the case of a freely falling body, the total energy is the sum of its kinetic energy and potential energy.

As the body moves under gravity, its velocity increases and hence, kinetic energy increases.

But at the same time, the height of the body from the ground decreases, and hence, the potential energy decreases.



Total energy of a body freely falling from a height above the ground level

At Point A

Velocity at point A, $v_A = 0$

Kinetic energy at point A, $K_A = \frac{1}{2} m v_A{}^2 = 0$

The potential energy at point A, $V_A = mgh$

Total energy at point A, $E_A = K_A + V_A$

$E_A = 0 + mgh = mgh$ ------------ (1)

At Point B

Let B be a point at a distance x from point A. The velocity at point B, v_B can be calculated using the equation, $v^2 = u^2 + 2as$.

$$v = v_B; \quad u = v_A = 0; \quad a = g; \quad s = x;$$

$$v_B{}^2 = 2gx$$

Kinetic energy at point B, $K_B = \frac{1}{2} m v_B{}^2 = \frac{1}{2} m \times 2gx = mgx$

The potential energy at point A, $V_B = mg(h - x)$

Total energy at point A, $E_B = K_B + V_B$

$E_B = mgx + mg(h - x) = mgh$ ---------- (2)

At point C

Let C be a point on the ground. The velocity at point C, v_C can be calculated using the equation, $v^2 = u^2 + 2as$.

$$v = v_C\,; \quad u = v_A = 0; \quad a = g; \quad s = h;$$

$$v_C{}^2 = 2gh$$

Kinetic energy at point C, $K_C = \frac{1}{2}mv_C{}^2 = \frac{1}{2}m \times 2gh = mgh$

The potential energy at point A, $V_C = 0$

Total energy at point A, $E_C = K_C + V_C$

$$E_C = mgh + 0 = mgh \text{ ---------- } (3)$$

It is clear from equations (1), (2), and (3) that $E_A = E_B = E_C$. Hence total energy of the freely falling body remains constant at every point on its path.

POWER

Dr.Jinchu.I

Power

Power is defined as the rate at which work is done.

power is the work done in unit time.

If W is the work done in a time t, the average power is given by

$$Power = \frac{work}{time}$$

$$P = \frac{W}{t}$$

But work done is defined as the product of force and displacement.

$$W = FS$$

$$\therefore \quad P = \frac{FS}{t}$$

- But the velocity of the body is given by

$$v = \frac{S}{t}$$

$$\therefore P = Fv$$

$$Power = Force \times velocity$$

Power can also be defined as the energy converted or transferred in unit time.

$$Power = \frac{energy}{time}$$

Power is a scalar quantity. The SI unit of power is joule/second or watt (W).

1 watt = 1 joule/second.

Other commonly used units are

1 kilowatt (kW) = 10^3 watt
1 megawatt (MW) = 10^6 watt
1 Horsepower (hp) = 746 watt

The energy consumption of electrical devices is expressed in kilowatt-hour (kWh).

Kilo watt-hour is not the unit of power, but it is a practical unit of electrical energy.

Problems

1. Calculate the work done in lifting a mass 5 Kg vertically through 8m.

Given m = 5 Kg, h = 8 m

W = force × vertical displacement = mgh = 5 × 9.8 × 8 = 392 J

2. A body of mass 5 kg initially at rest is subjected to a force of 20 N. What is the kinetic energy acquired by the body at the end of 10 s?

Given, m = 5 kg, F = 20 N, t = 10s, u = 0

$$F = ma$$

$$a = \frac{F}{m} = \frac{20}{5} = 4\ m/s^2$$

$$v = u + at = 0 + 4 \times 10 = 40\ m/s$$

$$K = \frac{1}{2} mv^2 = \frac{1}{2} \times 5 \times 40^2 = 4000\ \mathrm{J}$$

3. A work 900 J is done when a force of 30 N is applied to a body. Calculate the distance through which the body moves.

Work done (W) = 900 J

Force (F) = 30 N

$W = F.S$

Distance covered, S = W/F

=900/30

= 30 m

4. The momentum of a body of mass 10 kg is 30 SI units. Calculate its kinetic energy.

Momentum, p =mv = 30 kgm/s.

Mass m = 10 kg

Velocity = p/m = 3m/s

Kinetic energy K = ½ mv^2 = ½ x 10 x 3^2 = 45 J

The relation $E = p^2/2m$ can also be used to get the result.

5. An engine develops 10 kW of power. How much time will it take to lift a mass of 200 kg to a height of 40 m?

Force acting on a body of mass 200 kg, F = mg = 200 x 9.8 = 1960 N

Work done W = F.S = 1960 x 40 = 78400 J

Power = 10 kW = 10000 W.

Power = work/time

Time taken = work/power = 78400/10000 = 7.84 s

6. An electric motor raises 200 kg of water to a tank at a height 30 m above ground level in a time of 3 minutes. If the efficiency of the pump is 87 %,what is the power of the motor (designed by the company/ manufacturer)?

Output energy of the pump = mgh = 200 x 9.8x 30 = 58,800 J

Time = 3 min = 3 x 60 = 180 s

Output power of the pump = energy /time = 58800/180 = 326.67 W

Efficiency = output power /input power = 87% = 87/100 =0.87

Input power = output power /0.87 = 326.67/0.87 = 375.48 W

Power of the motor = 375.48 W

7. A cricket ball of mass 0.3 kg is thrown vertically up with a velocity of 14.7 m/s. Calculate the K.E and P.E of the ball after one second.

8. An elephant lifts a body of mass 1000 kg through a vertical height of 3 m in 10 s. What is power?

- Answers

7.

Mass of the ball $m = 0.3$ kg

Initial velocity $u = 14.7$ m/s

$a = g = 9.8\ m/s^2; t = 1$ s

The velocity after 1 s, $v = u + at = 14.7 - 9.8 \times 1 = 4.9$ m/s

K.E after 1 s is $K = \frac{1}{2} mv^2 = \frac{1}{2} \times 0.3 \times (4.9)^2 = 3.6$ J

Vertical displacement of the ball after 1 second is

$h = ut - \frac{1}{2} gt^2 = 14.7 \times 1 - \frac{1}{2} 9.8 \times 1 = 9.8$ m

P.E after 1 s = $mgh = 0.3 \times 9.8 \times 9.8 = 28.81$ J

8. Work done = mgh= 1000 x 9.8 x 3 =29400 J

Power = work /time = 2940 W

Modes of heat transfer

Dr.Jinchu.I

Modes of heat transfer

Heat may be transferred from one point to another in three different ways

- Conduction
- Convection
- Radiation

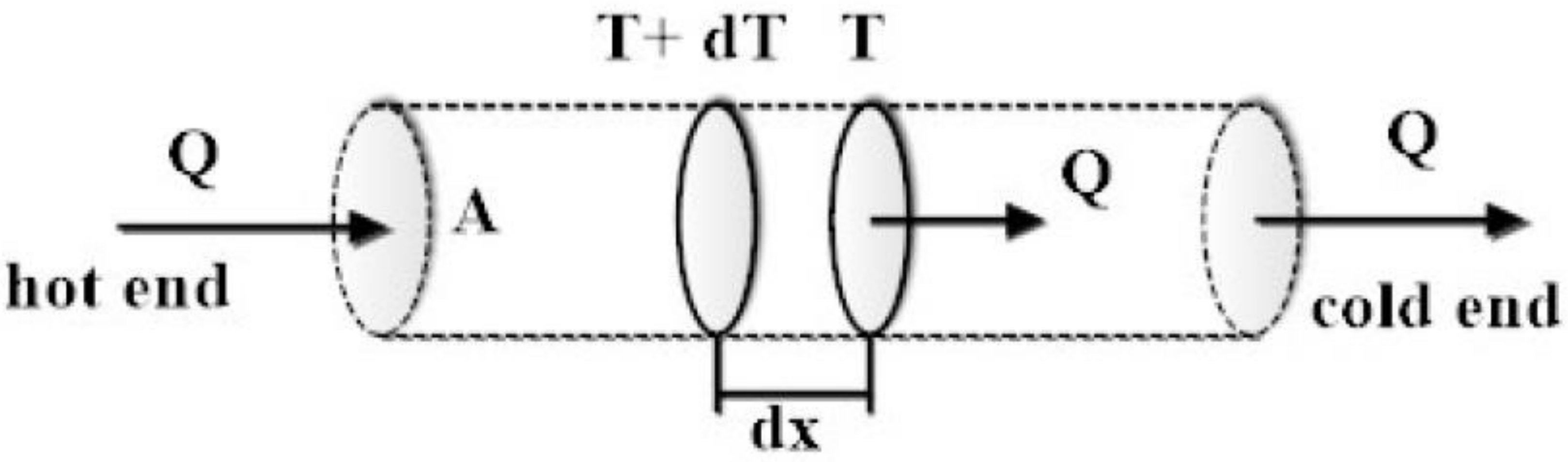
Conduction

- If one end of a metal rod is heated, the temperature of the other end gradually increases. Heat is transferred from one end of the rod to the other end. This transfer takes place due to molecular collisions and there is no movement of particles.

Transfer of heat from one place to another or one end (hot end) to the other end (cold end) of the substance, without the actual movement of particles, is called conduction.

- Conduction is the slowest mode of heat transfer.
- Conduction is most significant in solids and less in liquids and gases, due to the space between molecules.
- Substances that conduct heat are called good conductors and which do not conduct are called poor conductors or insulators.

- Metals are good conductors whereas gases and nonmetals are poor conductors.
- Aluminium, gold, copper, silver are examples of conductors.
- Silver is the best conductor of heat.
- Asbestos, rubber, glass paper, etc. are examples of insulators.
- The ability of a material to conduct heat is measured by a quantity called thermal conductivity of the material(λ_k).
- The SI unit of λ_k is $Js^{-1}m^{-1}K^{-1}$ or $Wm^{-1}K^{-1}$.
- Metals have a high value of thermal conductivity due to the presence of a large number of free electrons.



- Consider a metallic rod of the area of cross-section A. Suppose one end of the rod is heated and an amount of heat Q is conducted from the hot end to the cold end of the rod. Consider a small element of the rod of length dx and a temperature difference of dT exists between its ends. The quantity of heat flowing through the rod depends on its area of cross-section, temperature

gradient ($\frac{dT}{dx}$) and time (t) for which heat flows. It can be mathematically expressed as

$$Q \propto A\frac{dT}{dx}t$$

$$Q = \lambda_k A\frac{dT}{dx}t$$

Here the constant of proportionality λ_k is called the thermal conductivity of the material.

Practical applications of thermal conductivity

- Cooking utensils are made of metals and their handles are made of wood.

(This is because metals are good conductors of heat, while wood is a bad conductor of heat.)

- When we take a metal ice tray and a package of frozen food from the freezer of the refrigerator, the metal tray feels colder than the package.

(This is because metal is a good conductor of heat and it removes heat from our hands much faster.)

- Houses made of hollow brick walls are cooler than concrete walls.
- During winter birds swell their feathers.

(In doing so the air trapped between the feathers prevent the loss of heat from their body. This is because air is a poor conductor of heat.)

- Ice is packed in sawdust or gunny bags.

(This is because air trapped in them prevents loss of heat and so ice does not melt. Air is a poor conductor of heat.)

Convection

- Convection is the phenomenon in which heat is transferred from one place to another by the actual movement of the particles of a heated substance.
- The convection process is faster than conduction. Transfer of heat by convection mode takes place in liquids and gases.
- If we boil a kettle of water, the hot water molecules become less dense and move to the top surface. At the same time dense water molecules at the top move to the bottom. Thus, a convection current gets established and the entire water gets heated.
- The rate at which heat is transferred from the surface of the fluid is given by the relation

$$\frac{Q}{t} = hA\Delta T$$

where A is the surface area of fluid,
ΔT is the temperature difference between the fluid at the upper and lower surfaces
h is a constant called convection coefficient.
The value of h depends on the shape of the surface and whether the surface is horizontal or vertical.

- Convection is classified as natural convection and forced convection.
- Natural convection is a process in which fluid motion is generated due to differences in densities and temperature gradient.
- Forced convection is a convection process in which fluid motion is generated by an external source (like a pump, fan, suction device, etc.).
- The main mechanism of heat transfer inside a human body is forced convection.
- The heart serves as the pump and blood as the circulating fluid. The heat from our body is lost to the atmosphere through all three processes –conduction, convection, and radiation. But our blood circulation system transports just the required amount of heat to maintain a constant body temperature

Radiation

- Radiation is the fastest mode of heat transfer which does not require a material medium.
- All bodies radiate energy in the form of electromagnetic waves.
- The energy transferred in this mode is often called thermal radiation.
- The type of radiation associated with the transfer of heat energy from one location to another location is often known as infrared radiation. This is because the wavelength range of thermal radiation is from 800 nm to 400 μm, which belongs to the infrared region.
- In the radiation process, a hot body emits thermal radiation in all directions. Emitted radiation travels through space and falls on another body. The body absorbs thermal radiation and gets heated up.
- The heat from the sun reaches the earth by radiation.

Basic properties of thermal radiations

a)They travel in straight lines with the speed of light ($3x10^8 m/s$)

b) A material medium is not necessary for propagation.

c) They do not heat the medium through which they are travelling.

d) They can be reflected and refracted just as light.

e) They also exhibit the phenomena like interference, diffraction, and polarization.

f) Thermal radiations have longer wavelengths than visible light.

Specific heat capacity of a substance

- The heat capacity of a body is the quantity of heat required to raise the temperature of the body by one kelvin.
- The amount of heat (Q)absorbed by a body depends on the mass of the body (m), change in temperature (ΔT), and nature of the material. Hence,

$$Q \propto m\Delta T$$

$$Q = Cm\Delta T$$

- where the constant C is called the specific heat capacity of the substance.
- The specific heat capacity of a substance is defined as the quantity of heat required to raise the temperature of the unit mass of a substance through one kelvin.

$$C = \frac{Q}{m\Delta T}$$

The SI unit of specific heat capacity is s $Jkg^{-1}K^{-1}$.

The specific heat capacity of water is about 4200 $Jkg^{-1}K^{-1}$.This means that it will take 4200 J of energy to raise the temperature of 1 kg of water by 1 degree kelvin or degree Celsius.

Applications

a) Substances having a small specific heat capacity can be quickly heated up to a higher temperature even though only a small amount of heat is supplied. Such materials are very useful in making cookware such as frying pans, pots, kettles, etc.

b) Sensitive thermometers also must be made from materials with small specific heat capacity so that they can detect and show a change in temperature quickly.

c) Substances that have a high specific heat capacity are suitable as a material for constructing kettle handlers, insulators, and oven covers because a high amount of heat will cause only a small change in temperature and the material won't get hot too fast.

d) Heat storage instruments are usually made of substances with a high specific heat capacity.

e) Water acts as an excellent cooling agent in engines due to its high specific heat capacity.

f) Water is also used in houses in cold climate countries because as it is heated up (boiled), it tends to retain heat and warm the house due to its high specific heat capacity.

HEAT

Dr.Jinchu.I

Heat

- The energy transferred from one body to another without any mechanical work involved is called heat.

When a hot body is kept in contact with a cold body, the cold body warms up and the hot body cools down. Energy is transferred from the hot body to the cold body when they are placed in contact.

- If no transfer of heat takes place between two bodies in contact, then they are said to be in thermal equilibrium
- The internal energy of a body is the sum of kinetic energy and potential

energy of constituent atoms or molecules.

A cold body absorbs energy to become hot.

A hot body has more internal energy than the identical cold body.

Heat is an invisible energy that causes the sensation of hotness or coldness

- In the CGS system, the unit of heat is calorie. The SI unit of heat is Joule. One calorie is equal to 4.2 J.

Temperature

- The temperature of a substance is the degree of hotness or coldness on some chosen scale.

- The effects of heat energy are:

a) Heat energy brings about change in temperature

b) Heat energy brings about change in dimension.

c) Heat energy brings about change in the state.

Temperature scales

- A temperature scale is a way to indicate or measure temperature relative to a starting point and a unit of measurement.
- The temperature scale chosen must be precise, consistent, and accurate. All temperature scales make use of some physical property that changes with temperature.
- The major temperature scales used are the

  Celsius, Fahrenheit, and Kelvin scales.
- Most temperature scales have two fixed points: lower fixed point and upper fixed point.

a) Celsius Scale

- Celsius or centigrade scale is a temperature scale based on the freezing point of water and the boiling point of water.
- The temperature corresponding to the freezing point of water is taken as the lower fixed point and it is taken as 0 ^{0}C.
- The boiling point of water is taken as upper fixed pint and is given a value of 100 ^{0}C.
- The interval between these two temperatures is divided into 100 equal parts and one division is called one degree Celsius (1^{0}C).

b)Fahrenheit scale

- In the Fahrenheit scale, the freezing point of water is taken as 32 ^{0}F, and the boiling point

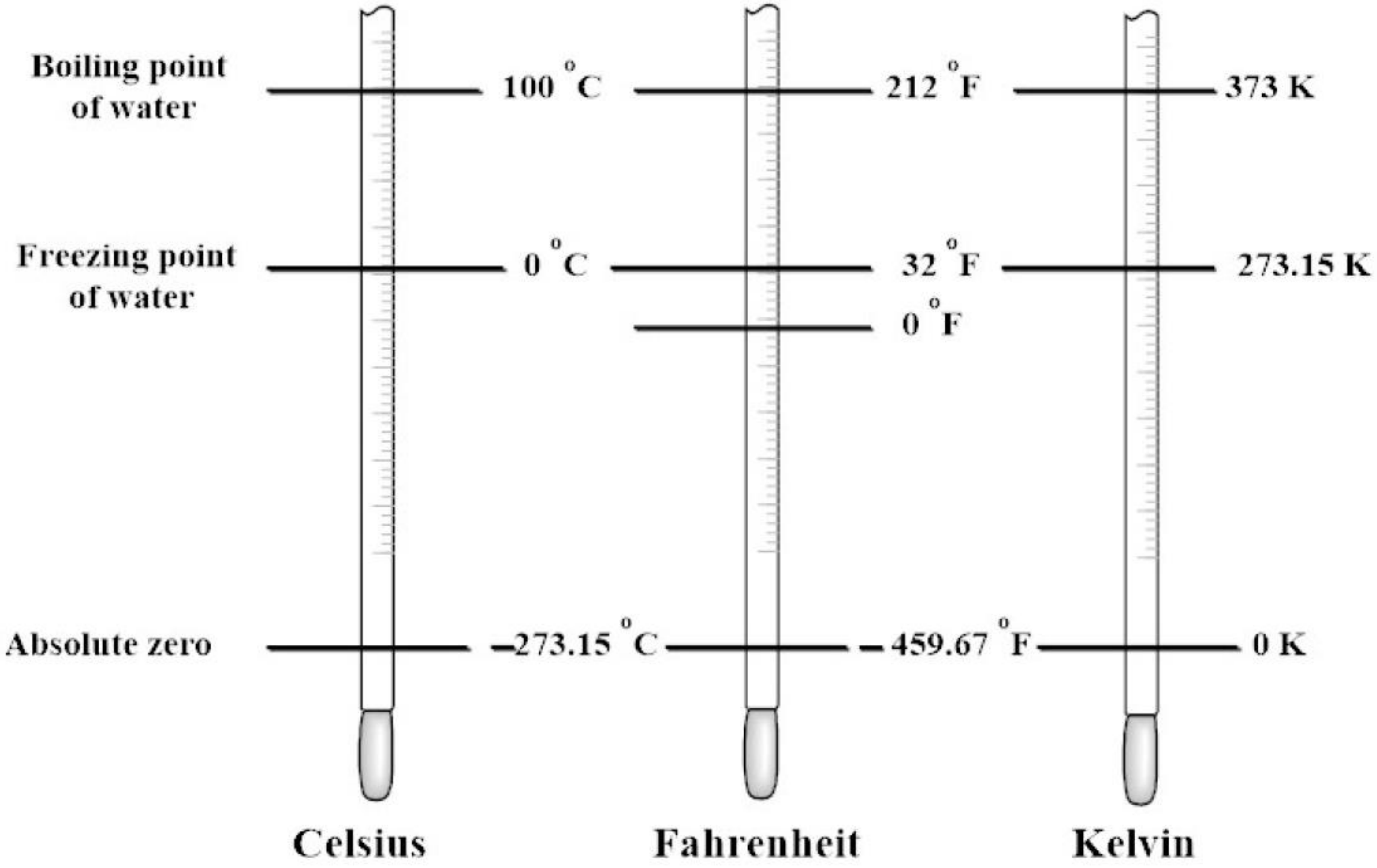
of water is 212 ^{0}F.

The interval is divided into 180 equal parts. Each division is called one degree Fahrenheit (1^{0}F).

c) Kelvin scale

- Kelvin scale is a temperature scale based on absolute zero of temperature.
- Absolute zero, or 0K, is the lowest possible temperature for any substance and it corresponds to a temperature of -273.15° on the Celsius scale.
- In the Kelvin scale, the freezing point of water is taken as 273K and the boiling point of water is 373 K.
- Magnitude of a degree in the Kelvin scale and Celsius scale are equal. Kelvin is the SI unit of temperature.

Comparison of Celsius scale, Fahrenheit scale and Kelvin scale



Conversion between temperature scales

- The relation connecting Celsius, Fahrenheit, and Kelvin scales is given by the following formula where C stands for temperature in Celsius, F stands for temperature in Fahrenheit and K stands for temperature in Kelvin scale.

$$\frac{C-0}{100} = \frac{F-32}{180} = \frac{K-273}{100}$$

$$\frac{C}{5} = \frac{F-32}{9} = \frac{K-273}{5}$$

The equation to convert between Celsius and Kelvin temperature scales is given by

$$K = C + 273$$

The equation to convert between Celsius and Fahrenheit temperature scales is given by

$$F = 1.8\,C + 32$$

Thermometers and its classifications

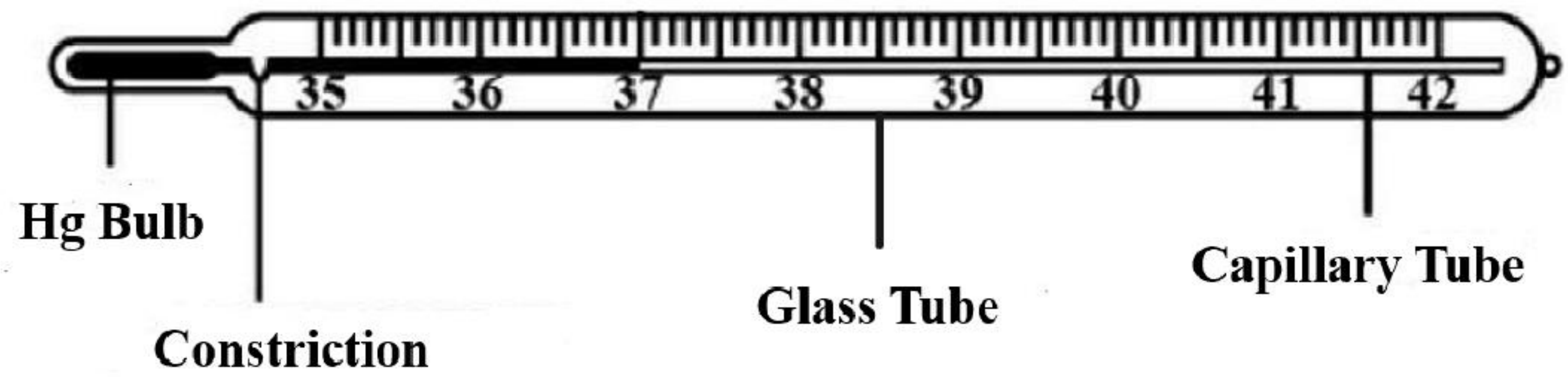
- A thermometer is a device used to measure temperature. The science of measuring temperature is known as thermometry.
- According to its measurement principles, thermometers are classified into different categories as listed below:

1. The liquid in the glass thermometer (Mercury thermometer, alcohol thermometer, etc.)
2. Constant volume gas thermometer
3. Constant pressure gas thermometer
4. Resistance thermometer
5. Thermoelectric thermometer or Thermocouple
6. Pyrometers
7. Silicon diode thermometer
8. Bimetallic thermometer

Mercury Thermometer

- It is the common thermometer used in laboratories principle of thermal expansion of liquids. The thermometer consists of a very fine glass tube having a very small bore (capillary tube) thin glass bulb at one end as shown in the figure.
- The bulb is filled with mercury. The other end of the capillary tube is sealed. The capillary tube is protected by a thick glass tube called on the stem.
- These markings are called graduations or degrees. As the glass bulb and the liquid are heated, the volume of both glass tube and mercury increase with temperature. The mercury expands more than glass. Hence, the liquid level rises with the increase in temperature and falls when the temperature is lowered. The practical range of mercury thermometers is -30^{0}C to 250^{0}C.

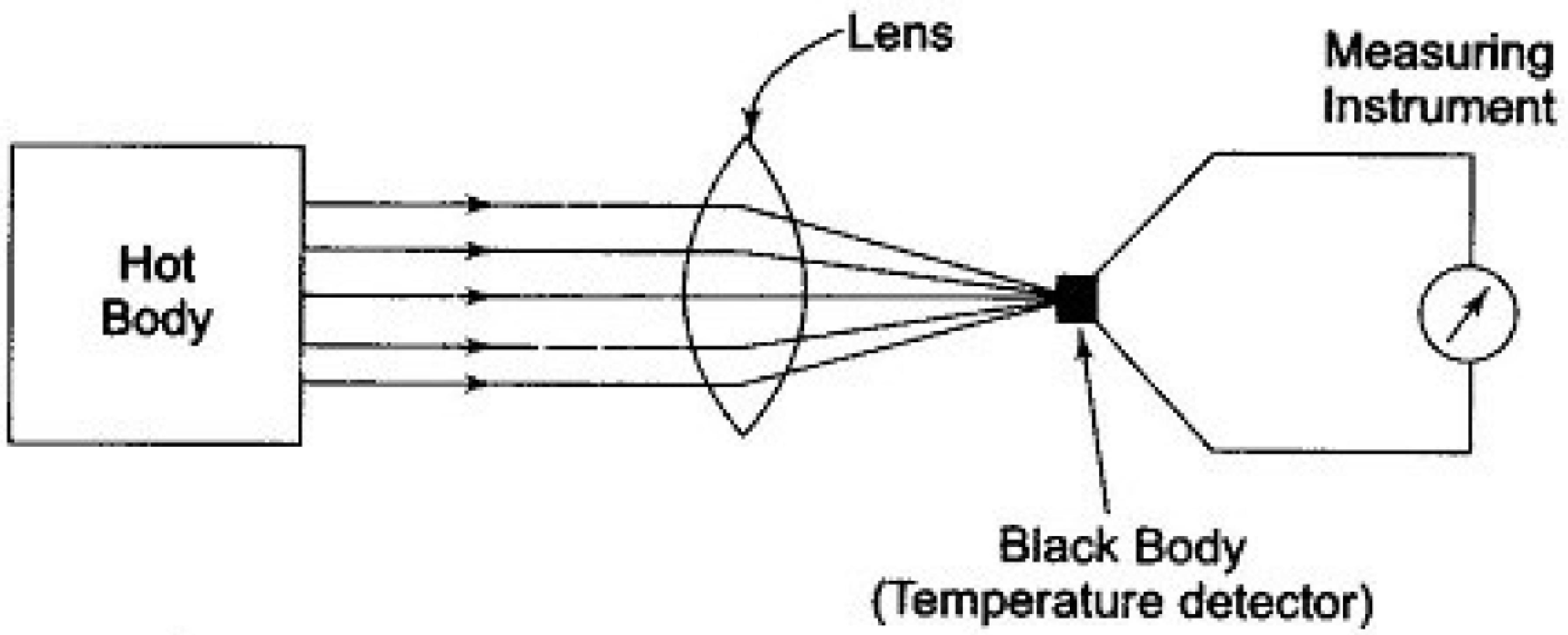
Schematic diagram of Mercury Thermometer



Pyrometers

- The name pyrometer is given to those thermometers which are used for measuring temperatures above 500^0C. The familiar pyrometers are total radiation pyrometers and optical pyrometers.
- A pyrometer, also known as an non-contact thermometer is used to detect the temperature of an which depends on the radiation (infrared or visible) emitted from the object.
- Pyrometers act as photo detectors because of the property of absorbing energy and measuring EM wave intensity at any wavelength.
- A pyrometer is useful for measuring moving, extremely hot or hard to reach objects.
- The basic principle of the pyrometer is that it measures the object's temperature by sensing the heat radiation emitted from the object without making contact with the object. It records the temperature level depending upon the intensity of radiation emitted. The pyrometer has two basic components like optical systems and detectors that are used to measure the surface temperature of the object.

Schematic diagram of a pyrometer



Infrared pyrometers are made up of pyroelectric materials like polyvinylidene fluoride (PVDF),

triglycine sulfate (TGS), and lithium tantalate ($LiTaO_3$).

- This radiation can be directed to a thermocouple to convert into electrical signals.

The advantages of pyrometer are

a) It can measure the temperature of the object without any contact with the object. This is called non-contact measurement.

b) It has a fast response time.

c) Good stability while measuring the temperature of the object.

d) It can measure the temperature of different types of objects at variable distances.

Applications of Pyrometer

1) To measure the temperature of moving objects or constant objects from a greater distance.
2) In metallurgy industries
3) In smelting industries
4) Hot air balloons to measure the heat at the top of the balloon.
5) Steam boilers to measure steam temperature
6) To measure the temperature of liquid metals and highly heated materials.
7) To measure furnace temperature

FRICTION

Dr.Jinchu.I

Friction

- The property by which an opposing force is generated between two surfaces in contact with bodies in relative motion is called friction.

Causes of Friction

- Friction is a force resisting motion of an object when in contact with another. This resistive force is caused by the surface roughness of the contact area of the materials, molecular attraction or adhesion between materials, and deformations in the materials.
- When two bodies come into contact, due to the irregularities of the surfaces, the area of contact is less than the actual area of the surfaces. This causes very high pressure at the point of contact. The high pressure causes deformation of the surface of the material and eventually increases the resistance to motion.

Types of Friction

1. Static Friction

The frictional force comes into play when one body tends to move over the surface of another, but the actual motion that has yet not started is called static friction.

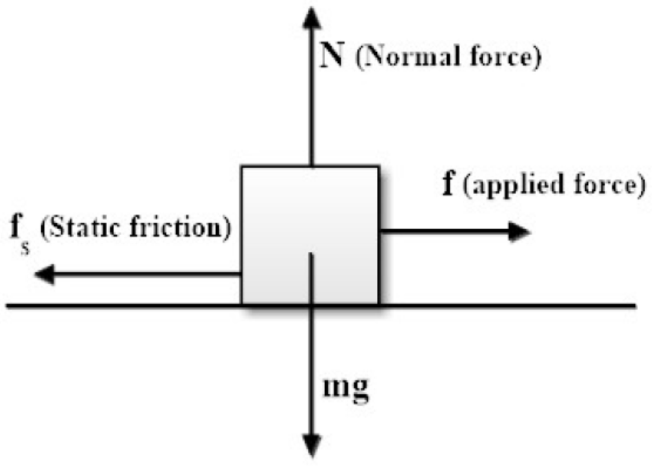
The frictional force cannot go beyond a maximum value. When the applied force exceeds this value, the body starts moving over the surface.

The maximum value of static friction before the body starts moving over a surface is called limiting friction.

The limiting friction, f_{max} is directly proportional to

the normal force between the t $f_{max} \propto N$

$$f_{max} = \mu_s N$$



Friction opposes the relative motion between the sliding body and the surface

- The constant of proportionality μ_s is called the coefficient of static friction

and its value depends on the material and nature of the two surfaces in contact.

The static friction f_s is always less than or equal to

the limiting friction f_{max}.

$$f_s \le f_{max} = \mu_s N$$

- **Kinetic or dynamic friction:** It is the opposing force that comes into play when one body is moving over the surface of another body. The magnitude of kinetic friction, f_k is directly proportional to the normal force acting between the two bodies.

$$f_k \propto N$$

$$f_{max} = \mu_k N$$

- The constant of proportionality μ_k is called the coefficient of kinetic friction and its value also depends on the material and nature of the two surfaces in contact.
- If the surfaces are smooth μ_k will be small and if surfaces are rough μ_k will be large.

Kinetic friction is classified into two types – sliding friction and rolling friction.

a) Sliding friction: The frictional force that comes into play when one body is actually sliding over the surface of the other body is called sliding friction.

b) Rolling friction: The frictional force that plays when one body is actually rolling over the surface of the other body is called rolling friction. Rolling friction is less than sliding friction.

Laws of friction

1. The Force of friction depends on the nature of surfaces in contact.
2. Friction is independent of the area of contact as long as the normal force is the same.
3. The maximum force of static friction is directly proportional to the normal force acting between the two bodies in contact.
4. Kinetic friction is directly proportional to the normal force acting between the two bodies in relative motion.
5. The direction of kinetic friction on a body is opposite to the velocity of the body.
6. The magnitude of kinetic friction is independent of the velocity of motion of the body.
7. The coefficient of kinetic friction is always less than the coefficient of static friction for the same pair of surfaces.

Advantages of friction

1. It is the friction between the ground and the feet that help us to walk
2. It helps us to hold things.
3. The friction between tyres and the road helps us to stop the vehicle when the brake is applied.
4. Nails and screws join two surfaces due to the force of friction.
5. Without friction, it is impossible to climb a tree or fix a nail on the wall.

Disadvantages of friction

1. Friction slows down the motion of moving objects.
2. Friction produces unnecessary heat leading to the wastage of energy.
3. It decreases the efficiency of the machines.
4. It causes wear and tear for the moving parts of the machines.
5. Friction sometimes creates fire accidents like forest fires

Methods to reduce friction

a) Lubrication

When the gap between two surfaces is filled with oil or grease, irregularities become filled with this and the friction reduces. This process is called lubrication and the substance used for this are called lubricants. The lubricants are selected based on the nature of the machines.

- A modern lubricant is a mixture of mineral oil, vegetable oil, and colloidal thin oil. For light machinery, oils are used while for heavy machines grease is used. For light machinery like watches, sewing machines, etc., thin oil is used. In very heavy machinery, solid lubricants like graphite are used.

b) Polishing of rough surfaces

A hard substance is used to grind and remove the irregularity on the soft surface.

Examples including polishing of wooden surfaces, tiles, marbles, etc. Sandpaper is also used for polishing to a fine level. Harsh chemical treatments are sometimes done to reduce irregularities on surfaces. When the surface becomes smooth, the contact pressure decreases, and hence friction reduces.

c) Use of ball bearings in moving parts

It is our common experience that it is easier to role a body than to slide it along the ground. This is the principle in which ball bearings work. Hard steel balls place between the moving parts like coaxial cylinders. The balls rotate as the cylinders turn relative to each other. This considerably reduces friction