6. HEAT

Internal Energy

Matter is composed of continually moving molecules. The total kinetic and potential energy of these molecules is termed the 'internal energy' of a substance. The greater the internal energy of a substances, the hotter it is.

When we strike an iron nail with a hammer, the nail becomes warm. The hammer's blow causes the molecules in the nail to move faster and therefore increase internal energy.

Water at the bottom of a waterfall is slightly warmer than that at the top. The potential energy possessed by water at the top of the fail is transformed into kinetic energy as the water descends. Part of this kinetic energy is transformed into internal energy at the bottom and the temperature rises.

The lower part of the barrel of a bicycle pump becomes quite warm when a tyre is being inflated because the work done in compressing the air is converted into internal energy.

When a ball moving on a surface slows down and then stops, its initial kinetic energy is transformed into the internal energy of the ball, the surface and the air.

Temperature and Heat The temperature of a body is the quantity that tells how hot or cold it is with respect to some standard body. Heat is the internal energy transferred from one body to another due to temperature difference. Thus heat is the name given to energy only in the process of transfer. After heat has been transferred to a body it becomes the internal energy of the body. Heat always flows from substance at a higher temperature into a substances at a lower temperature, but not necessarily from a substance with more internal energy into a substances with less internal energy. For example, if on dippings a very hot spoon in a bucketful of warm water, heat will flow from the spoon to the water, even thought there is more internal energy in the warm water than in the spoon. It is clear from this example that temperature and heat are different things and should not be confused.

If one places two identical containers, one containing double the quantity of water than in the other, on the same hot plate, one finds that the temperature of the smaller quantity of water rises faster even though equal quantities of heat are being supplied to each container.

Measurement of Temperature Temperature is measured by a **thermometer**. There are several types of thermometer but the most common is the mercury in glass type which measures temperature by means of the expansion and contraction of mercury.

To fix a scale for a thermometer, the number 0 (zero) is assigned to the temperature of pure melting ice and the number 100 to the temperature of steam from water boiling under the standard atmosphere pressure of 760 mm of mercury. The space between is divided into 100 equal parts, called degrees. This is called the Celsius scale and the temperature on this scale are called **degrees Celsius** (ºC)

On the Fahrenheit scale of temperature the number 32 corresponds to 0ºC and the number 212 to 100ºC. To convert temperature from the Fahrenheit to the Celsius scale, the following relation is used.

$$T\text{-}c/5=(T_F-32)/9$$

Where t_C is the temperature on the Celsius scale corresponding to t_F on the Fahrenheit scale.

Using the formula, one can easily see that at – 40 degrees both Celsius and Fahrenheit scales will show identical readings.

Absolute Zero and Kelvin Scale In principle, there is no upper limit to temperature but there is a definite lower limit, the 'absolute zero'. This limiting temperature is 273.16º below zero' on the Celsius scale of temperature. On the Kelvin scale absolute zero is 0 K (it is not written as 0º K). On Kelvin scale 0ºC corresponds to 273.16 K and 100ºC to 373.16 K Degrees on the Kelvin scale are calibrated with the same-sized division as on the Celsius scale. Thus, a 10ºC rise of temperature is equal to a 10 K rise of temperature.

There is an absolute thermodynamic temperature scale. The most recent official temperature scale is the international Temperature Scale of 1990. It extends from 0.65 K (–272.5ºC) to approximately 1358K (1085ºC) .

Types of the Thermometers There are different kinds of thermometers. Some of them are considered here.

Liquid-in-glass Thermometer This thermometer consists of a liquid-filled glass bulb and a connecting partially filled capillary tube. When the temperature of the thermometer increases, the differential expansion between the glass and the liquid causes the liquid to rise in the capillary. A variety of liquids, such as mercury, alcohol, toluene and pentane, and a number of different glasses are used in thermometer construction, so that various designs cover diverse ranges between about-300ºF and + 1200ºF (-184ºC and + 649ºC).

The advantages and disadvantages of mercury and alcohol are as follow:

Mercury Advantage

Doesn't wet sides of tube thread easy to see.

Conducts heat well:

Thermometer responds quickly to temperatures changes

Disadvantages

Freezes at-39ºC: thermometers not suitable for low Arctic temperatures. Poisonous: thermometer hazardous if broken. Expensive.

Alcohol Advantage

Freezes at -115ºC:

Thermometer suitable for low Arctic temperatures.

Expansion greater than mercury: wider tube can be used

Disadvantages

Has to be coloured to be seen easily.Clings to sides of tube. Thread has tendency to break.

The Clinical Thermometer is a special liquid-in-glass thermometer. This thermometer is a specially designed to measure human body temperature. It measures over a very limited range of 35-43ºC. 'Normal' body temperature is 37ºC (98.4ºF). The thermometer contains mercury and the tube has a constriction/(a narrowing) next to the bulb. This stops the mercury thread running back into the bulb, so the temperature reading can be taken after the thermometer has been removed from the patient's mouth. The thermometer has to be shaken to get the mercury back past the constriction.

Thermometers for Industry Many industrial processes depend on the accurate measurement and control of temperature. Liquid-in-glass thermometers aren't really suitable for industrial work. Firstly, their temperature range is often too limited. Secondly, it is usually more convenient for the operator to read the temperature on a meter or digital display placed some distance away from the source of heat. Thirdly, electrical methods of measuring temperature give readings which can be recorded automatically or fed directly to a computer controlling the heating process.

Resistance thermometers are based on the principle that it becomes more and more difficult to pass an electric current through a piece of metal as its temperature rises. These thermometers usually contain a length of this platinum wire connected to a power supply. The higher the temperature, the less the current passing through the wire and the further down the meter scale the needle moves. Resistance thermometers can be used to measure temperatures from about—200ºC to 1200ºC.

Thermistor thermometers work along similar lines. A thermistor is a small device which offers less and less resistance to a flow of electricity as its temperature rises.

Thermocouple thermometer In this two different types of metal wire are joined together at two junctions. A temperature difference between the junctions actually makes the metals produce a small electric current which moves the meter needle across the scale. Thermocouple thermometers are often used to measure oven and furnace temperatures. They can operate over a temperature range from about—200ºC to 1600ºC.

Bimetal thermometer A bimetal thermometer contains a bimetal strip (two thin strips of different metals are bonded together to form a bimetal strip) in the form of a long spiral. The centre of spiral is attached to a pointer; the other end is fixed. When the temperature rises, the bimetal strip coils itself into an even tighter spiral and the pointer moves across the scale. This thermometer is not as accurate as some other types of thermometers but they are robust and easy to read.

Pyrometers These instruments were developed to measure high temperatures using emitted radiation. These instruments are not to be in contact with the hot body. They can measure temperature howsoever high and the lower practical limit for radiation pyrometers is about 900K.

Thermal Expansion

Solids liquids and gases generally expand on heating and contract when cooled. All solids expand on heating and if there is not sufficient space for expansion, large forces may set up within solids resulting in their bending or cracking.

Gaps have to be left in railway tracks to make allowance for expansion, otherwise the rails will buckle. Allowance is made for the expansion of long steel bridges. One end of such bridge is fixed while the other rests on rollers. Telephone wires sag more in summer than in winter due to expansion.

Thermal expansion of solids has many useful applications too. Iron and steel are tightly fitted on cartwheels by first heating them and then slipping them onto the wheel. On cooling, these tyres contract and have a firm grip on the wheels.

Thermal expansion is made use of in riveting metal plates together. A rivet is heated and pushed through the holes of plates to be riveted till its head holds tightly against one plate. The other end of the rivet is hammered to form a head. On cooling, the rivet contracts and pulls the plates tightly together.

Expansivity If we heat a 1-m long iron and through 1ºC (or 1 K), its length increase by 0.0000012 m. We say that the linear expansivity of iron is 0.0000012º/C. Linear expansivities of some solids in per degree Celsius are as follows:

Substance	Linear Expansivity (/ºC)
Brass	0.000019
Invar	0.000001
Glass (ordinary)	0.000009
Glass (pyrex)	0.000003

Since metals expand much more than glass, metal caps of glass bottles and jars can be loosened by heating them under hot water.

A thick glass tumbler is liable to crack when hot water is poured into it because glass is a poor conductor of heat. When hot water is poured, the interior expands but the exterior remains unaffected and the tumbler cracks. A pyrex tumbler does not crack because pyrex has low expansivity.

Bimetal Strip A brass bar and an invar bar riveted together to form a bimetal strip. When temperature rises, brass expands more than invar and the strip bends with brass on the convex side. When temperature falls, the strip regains its original shape. Thus a bimetal strip can act like a switch. Bimetal strips are used in thermostats which are used for regulating temperature of electrically-heated rooms, Ovens, toasters, etc. Refrigerators are also equipped with special thermostats.

Anomalous Expansion of Water Water shows unusual expansion. If we take a cube of ice at -5ºC and heat it, it expands till ice starts melting. During melting its temperature remains 0ºC but its volume decrease. If heat is continuously supplied to water at 0ºC, it further contracts up to 4ºC and then it starts expanding. Thus water has its minimum volume and maximum density at 4ºC.

Expansion of Gases – The Gas Laws: The expansion of a gas isn't as simple as the expansion of a liquid or solid. There are more factors to consider because a gas is so much more compressible. Studying the behaviour of a gas is complicated by the fact that you have to consider its pressure as well as its volume and temperature. The pressure, volume and temperature of any fixed mass of gas are all related, so a change in one of these factors always produces a change in at least one of the other two. Sometimes, all three factors may change at once. This happens, for example, when air rises in a thundercloud or gases expand in the cylinders of a car engine.

To find the laws linking pressure, volume and temperature experimentally, each factor is kept constant in turn while the relation between the other two factors is investigated.

The Pressure law and the Kinetic theory : According to the kinetic theory, gas molecules are constantly bombarding the sides of any container they happen to be in. There is an outward force on the container whenever a molecule strikes it and bounces off. Many billions of molecules hit the container every second and this produces a steady outward pressure.

If the temperature rises, the molecules move faster. They strike the container with greater force, and the pressure increases as a result. A fall in temperature produces the opposite effect. The molecules move more slowly and the pressure drops.

If the pressure continued to drop as shown in the graph a gas would exert no pressure at all at absolute zero. It was this feature of a pressure-temperature graph that first suggested to experimenters that there might be an absolute zero of temperature at -273°C. In practice, all gases turn liquid before absolute zero is reached. Oxygen for example liquefies at about 90K.

Charle's Law. This law states that: The volume of a fixed mass of gas is directly proportional to its absolute temperature provided the pressure of the gas is kept constant.

The pressure is inversely proportional to volume.

Boyle's law and the kinetic theory. The kinetic theory explains Boyle's law as follows, If the volume of a gas is reduced to half is value, each cubic metre of a container will hold twice as many molecules as before. Every second, there will therefore be twice as many impacts with each square metre of the container sides. The pressure is doubled as a result.

The Combined Gas Equation. The result of the three laws just described can be expressed in the form of a single equation.

For a fixed mass of gas, $\frac{pV}{T}$= constant

This is sometimes known as the combined gas equation. The gas laws can all be obtained from his equation:

If V is constant , p/T is constant (the pressure law)

If p is constant , V/T is constant (Charle's law)

If T is constant ,pV is constant (Boyle's law)

A gas which obeys the gas laws exactly is known as an ideal gas. In reality, no gases are ideal though most can be regarded as such at low or medium pressures and medium temperature. If a gas is near its liquefying temperature, attractions between its molecules begin to influence its behaviour and it no longer acts like an ideal gas. If a gas is highly compressed, the size of molecules restricts the space available for movement this to affects the way the gas behaves.

Change of State. An important effect of heat is change of state. This means that as a body is heated, it passes from one another of the three states or phases, in which matter can exist – solid, liquid, and gas.

What happens when a body passes from the solid to the liquid phase? The molecules of a solid are closely packed together and exert considerable attractive force upon one another. That is why the original shape of the solid is maintained. Now, as heat is applied to the solid, the vibratory energy of the molecules is increased, and the individual molecules break loose from the bonds that formerly held them. What was formerly a solid has now become a liquid.

The cooling effect of ice is a consequence of the change of state from solid to liquid. The heat required for the melting of ice is absorbed from the surrounding objects, thus lowering their temperature. When ice cubes are added to a beverage, the cubes gradually melt as they absorb heat from the liquid. This causes the liquid to become cooler.

The temperature at which a solid changes to a liquid is called the melting point of the solid. The name freezing point is applied to the temperature at which a liquid solidifies. For a given crystalline material, these two temperatures are the same. They are not identical in the case of certain substances, such as fats and glasses. Glass is not a true solid, but a supercooled liquid.

The melting points of different materials vary widely. Mercury, for example, melts at –38.87º Celsius; iron, at1535ºC, tungsten at3370ºC. The low melting point of some alloys such as Wood's metal, makes them valuable in fire-control systems. The sprinkler valves in such systems are held shut by plugs of the alloy. If the temperature in the room rises above 70º Celsius, the plug melts, causing the sprinklers to go into action. Wood's metal is often used in making trick spoons. A spoon of this sort will melt when it is used to stir a hot liquid.

The amount of heat required to melt a unit mass of a substance when it reaches the melting point is called the heat of fusion. This varies with different substances. Ice, for example, absorbs 79.71 calories for each gram of ice melted. Aluminum absorbs 94 calories; copper, 49 calories; lead only 5.47. The heat energy absorbed at this stage does not show itself in a rise in temperature. Hence the heat of fusion is sometimes referred to as latent (hidden) heat.

If the temperature of a liquid is lowered, it will become a solid. Here, too, the kinetic molecular theory furnishes an adequate explanation of what takes place. As the temperature of the liquid drops, the molecules of which it consists possess less energy. They move more sluggishly and they undergo, to a greater extent than before, the attraction of adjacent molecules. Finally, they are so strongly attracted by these molecules that they acquire fixed positions.

An increase in pressure can result in a lowering of the melting point for some solids. It happens to those solids. It happens to those solids whose volume decrease on melting e.g. water. If we have a block of ice with a wire carrying weights around it, the wire passes slowly through the ice block, leaving it completely solid. The pressure under the wire is sufficient to lower the melting point; the ice melts and the wire sinks through the melted water which then re-freezes.

Evaporation. When a liquid is heated, a different sort of change takes place. At any specific temperature, a given liquid contains molecules possessing different amounts of energy. Some of the molecules will be energetic enough to pass through the boundary surface of the liquid, but the attraction of the surface molecules will draw the escaping molecules back again. Certain molecules, possessing even more energy, will pass to the outer air and will travel beyond the attractive influence of the molecules at the surface. The escaping molecules will constitute a gas, or vapour. The process of passing from the liquid to the gaseous state is called evaporation.

Evaporation goes on at all temperatures. It continues until the liquid disappears or until the space above the liquid becomes saturated. This condition occurs when as many molecules leave the liquid as return to it from the space above, thus bringing about a condition of equilibrium.

Since evaporation consists of the loss of high-energy molecules from the liquid, it is obvious that the average energy of the remaining molecules will decrease and the temperature will drop. This effect of evaporation has been known since ancient times and is still utilised in various tropical countries in order to cool drinking water.

Water evaporating from the skin helps maintain body temperature. When the weather is warm we perspire. As the perspiration evaporates, the skin is cooled. Evaporation is slowed up in damp weather, since the concentration of water vapour in the air approaches the saturation point. That is why we feel cooler on dry days than on damp days, even though the temperature may be the same.

The rate of evaporation of a liquid can be increased by the following methods:

- Increasing the temperature of the liquid; if the energy of the liquid is increased its molecules move more quickly and more molecules have enough energy to escape.
- Increasing the surface area of the liquid; this increases the chance of a molecule being at the surface.
- Placing the liquid in a draught; the air carries away the molecules that have left the liquid so that they cannot return.

Condensation. Condensation is a change from vapour to liquid. The temperature at which vapour condenses into liquid is dew point. Dew is the water droplets that condense from air onto a cooler surface.

Boiling. As the temperature of a liquid is increased, it will reach a point at which the liquid will begin to boil. Boiling may be considered as evaporation taking place throughout the body of the liquid rather than just at the surface. Bubbles of vapour are formed in the interior of the liquid. They rise and then break through the surface.

Boiling can be brought about more readily either by increasing the temperature or lowering the pressure. An increase in pressure will raise the boiling point. On the other hand, when the pressure is lessened, the boiling point is lowered. At high altitudes, the decrease in atmospheric pressure is such that certain cooking processes are slowed up. Such difficulties can be eliminated through the use of a pressure cooker. This is a closed vessel in which pressure is built up by the steam that forms as water in the vessel is heated.

The reduced boiling point at low pressure finds considerable practical application in the field of vacuum evaporation (evaporation under low pressure). This process is of primary importance in the sugar industry. Boiling off the water from the syrup at normal atmospheric pressure would char the sugar. However, the pressure is kept so low in vacuum evaporation that the water may be removed at comparatively low temperatures.

The amount of heat required to change a unit mass of liquid to its vapour state at its boiling point is called the heat of vaporization of the substance. Each material has its own heat of vaporization. For example, it takes nearly 540 calories to vaporize a gram of water at l00°Celsius. Only 204calories are required in the case of ethyl (grain) alcohol.

The quantity of heat required to completely change 1 kg of a solid to liquid at its melting point, without any change in temperature is known as the latent heat of melting. The latent heat of vaporization is defined as the quantity of heat required to convert 1 kg of water at 100°C into water vapour at the same temperature.

Sublimation. In going from the solid to the gaseous state, most substances pass through the intermediate liquid state. Certain substances, however, go directly from solid to vapour form—a process known as sublimation. Naphthalene moth balls, iodine crystals, and the insecticide paradichlorobenzene are good examples of this phenomenon. Solid carbon dioxide also sublimes under ordinary conditions. It is often called "dry ice" because it is used to keep objects cold. It is excellent for this purpose, since it does not wet the substances it refrigerate.

Greenhouse Effect

Glass is transparent to the light and short wavelength infrared radiation emitted by very hot objects. On the other hand, glass won't transmit the long wavelength infrared given out by cooler objects. The radiation is either reflected or absorbed. These properties of glass are used in a greenhouse to 'trap' heat on a sunny day.

Light and short wavelength infrared radiation from the Sun passes easily through the glass roof of a greenhouse and warms the air and other materials inside. These warmed materials also give off thermal radiation. The wavelengths are longer however, and much of the radiation is reflected back into the green house when it strikes the glass.

Solar Cooker

A simple solar cooker is a box made of insulating materials like wood, card-board etc. The box has a glass cover to retain heat inside by the greenhouse effect. The inside of the box is painted dull black to increase heat absorption. The cooking vessel is kept inside the box which is then kept in the sun. Generally this type of cooker is used only for warming food but can sometimes be used for cooking rice, pulses, etc.

Thermos Flask

A thermos flask is double walled with a vacuum between the walls. The two inner glass surfaces facing each other are silvered. It has a plastic or cork stopper. In a thermos flask heat transfer by conduction is almost nil through flask heat transfer by conduction is almost nil through the vacuum. The stopper, being a poor conductor, conducts very little heat. The vacuum also prevents heat loss by convection. Silvered surfaces of the walls prevent heat loss by radiation. Thus in a thermos flask, the transmission is minimized and, therefore its content remains at nearly the same temperature for a long time.

THERMODYNAMIC PRINCIPLES AND ENTROPY

Laws of Thermodynamics Thermodynamic studies heat and mechanical motion as forms of energy and the conditions under which one may be converted into the other. The fruit of the science of thermodynamics was the development of many processes and devices that perform useful tasks through the conversion of heat into mechanical motion, or through the conversion of mechanical motion into heat. These include refrigeration systems, internal (such as gas turbine and diesel) and external (such as steam turbine) combustion engines, and rocket engines.

Two laws govern the transformation of energy from one form into another. These are known as the first and second laws of thermodynamics.

The first law of thermodynamics, also known as the law of the conservation of energy, states that energy can be neither created nor destroyed, only changed from one form to another. When a hydroelectric plant changes the energy of falling water into electricity, a specific amount of electricity will be created in a certain period of time. Similarly, when an electric motor changes this electricity into the mechanical motion is produced. According to the first law of thermodynamics, the falling water the electricity produced by the water, and the mechanical motion produced by the electricity all have the same amount of energy (ignoring energy lost due to imperfections in the systems). A fixed amount of falling water will never produce more than the equivalent amount of electricity, and this same amount of electricity will never produce more than the equivalent amount of mechanical motion.

In practice, this amount is not quite exact, for a certain amount of energy is converted through friction into heat . The total amount of energy produced, however, including heat energy due to friction, is always the same as the energy that entered into the system.

The first law, in short, says that, ideally, energy transformations are reversible.

Einstein's discovery in 1905 that energy can be created from matter does not affect the first law. It merely means that it must be extended to include the energy in matter (Physicists today regularly refer to subatomic particles not by how much mass they have, but by how much energy their mass represents.) The first law says that although energy may be converted into many forms, the amount of energy in the system is always the same.

The second law of thermodynamics, also known as the law of entropy, places a certain quantification on these energy transactions. Every time energy is converted from one form into another-form the energy of falling water into electricity, or electricity into mechanical motion, for instance-not all of it is completely converted into useful work. A certain percentage of it goes into the creation of heat energy which cannot be applied to do useful work.

This is not a contradiction of the first law. An equal amount of energy is always generated in energy transformations. All that the second law says is that a certain percentage of the energy, however small, must go to generating heat energy. Energy transformations, as it were, always "leak"; more specifically, they leak in the form of heat.

According to the second law, leaking energy as heat is a property of every reversible energy process. One of the pioneers of thermodynamics, the German physicist Rudolf Clausius, coined the word entropy for this property, from the Greek for "humiliation" or "lowering".

While the first law says that the total amount of energy in a system is always constant, the second law says that the percentage of energy in a system available for doing work is always decreasing.

Entropy A scientist thinks of disorder in terms of atoms and molecules. This disorder he calls entropy; i.e., it is the amount of disorder that occurs during a chemical or physical change, or the amount of disorder present in a system. The branch of science that deals with entropy and its changes is called thermodynamics.

In crystalline solids, atoms and molecules are always arranged in an orderly manner. Such an orderly arrangement is typical of matter in a solid state. The molecules do have some freedom of motion, but, because they are so close together and are held in place by very strong forces, their freedom of motion is quite limited. The molecules can rotate about the midpoint of their tiny "cage" within the crystal lattice, but they cannot migrate throughout the bulk of the material. There is, in other words, a great deal of order. Or, to put it another way, there is little entropy in this system.

In liquids and gases, distances between molecules are greater and the forces between them are weaker than in solids. The molecules can migrate throughout the bulk of the material. There is more disorder in liquids and especially in gases than there is in solids. Hence, there is more entropy in these states of matter.

Different substances have different amounts of entropy. Hard substances, such as diamonds, have less entropy than do platinum and lead.

Mechanical Equivalent of Heat The ratio between the energy lost in a mechanical process and the heat produced in the process is a constant, whatever be the nature of the substance or its volume. The ratio, 4185 joule/1Cal is known as the mechanical equivalent of heat and it is represented by J (1 cal= 4.2 joule.). All forms of energy, including heat, are now measured in joule. The heat Q required to raise the temperature of m kg of substance of specific heat C through T°C would be $Q=mCT$.