CALORIEMETRY

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Heat is the kinetic energy due to random motion of the molecules of a substance is called heat energy. Heat is a an invisible energy, that causes in us the sensation of hotness or coldness.

If a body absorbs heat the molecular motion of the body increases and if the body loses heat energy the molecular motion of the body decreases.

The average internal kinetic energy of the molecules of a substance is a measure of temperature of that substance.

If two bodies at different temperatures are kept in contact, heat flows from the hot body to the cold body i.e., heat flow from the body at high temperature to the body at the lower temperature.

Units of Heat

Similar to the other forms of the energy, The S.I unit of heat is joule. joule is represented as J.

Other than joule heat is commonly measure in calorie. calorie is represented as cal.

Calorie

The amount of heat energy required to raise the temperature of 1 g of water through 1 ^{0}C, is called one calorie.

In this definition of calorie, it has been assumed that the heat of energy required to raise temperature of 1 g of water through 1 ^{0}C at each initial temperature is the same, but this is not true due to non-uniform thermal expansion of water near 4 ^{0}C. Water shows uniform and smooth expansion only beyond 14 ^{0}C. So, the calorie is defined correctly as the following

The amount of heat energy required to raise the temperature of 1 g of water from 14.5 ^{0}C to 15.5 ^{0}C.

Kilo Calorie

The amount of heat energy required to raise the temperature of 1 kg of water from 14.5 ^{0}C to 15.5 ^{0}C, is called one kilo calorie.

1 calorie = 4.186 J

1 kilo-calorie = 1000 calorie = 4200 J Approximately.
Factors on Which Heat Energy in a Body Depends

The amount of heat energy (H) absorbed by a body is directly proportional to (i) the rise in temperature of the body (θ_R) and (ii) the mass of the body (m). Hence $H \propto m\theta_R = mc\theta_R$, where the constant of proportionality c is called the specific heat capacity, which depends on the nature of the substance. Thus

Heat absorbed by a body = mass of the body x specific heat capacity × rise in temperature.

$$H = mc\theta_R.$$

Similarly, if the temperature of a body falls by θ_F, heat is given out.
Heat given out by a body = mass of the body × specific heat capacity × fall in temperature.

$$H = mc\theta_F.$$

Specific Heat Capacity And Its Units

Specific heat capacity = Heat absorbed by the body/(mass of the body × rise in temperature)

$$c = H/(m\theta_R) .$$

Specific heat capacity is defined as the amount of heat energy required per unit mass of a substance to change (increase or decrease) its temperature by one unit. The SI unit for specific heat capacity is joule per kilogram per kelvin ($J\ kg^{-1}\ K^{-1}$). The SI unit of specific heat capacity is defined as the amount of heat energy required to raise the temperature of 1 kg of a substance through 1 K. Specific heat capacity for a given substance is a constant. It is different for different substances. For example, specific heat capacity of water is 4200 $J\ kg^{-1}\ K^{-1}$, which is very high, and that of copper is 400 $J\ kg^{-1}\ K^{-1}$.

Heat Capacity and Its Units

The amount of heat energy required to raise the temperature of a given mass of a substance by one unit is called its heat capacity. The SI unit of heat capacity is joule per kelvin ($J\ K^{-1}$). Heat capacity for a given substance is not a constant. It increases with the mass of the substance. It is different for different substances of the same mass as their specific heat capacities are different.

Heat capacity = Heat energy absorbed/ Change in temperature

⇒ Heat Capacity = Mass × Specific Heat Capacity

Measurement of Specific Heat Capacity of a Solid

Take two iron bodies, A and B, at two different temperatures and place them in a thermally insulated box and see that they are in contact with each other. We know that heat energy flows from hot body to cold body.

Since they are in thermally insulated box, no heat escapes to surroundings. Heat energy emitted by the hot body must completely be absorbed by the cold body. Even when more than two bodies are placed in a thermally insulated box, some bodies lose heat energy and some other bodies gain heat energy.

Principle of Mixtures

If two or more bodies at different temperatures are brought into thermal contact, and if no heat is allowed to escape to the surroundings, then the total heat lost by hot bodies must be equal to the total heat gained by cold bodies". This is called "principle of calorimetry", Calorimetry "is the science of measuring heat.

Calorimeter

A colorimeter is a device that contains a cylindrical vessel which is used to measure the amount of heat gained or lost by a body when it is made up of a thin copper sheet as Copper is a good conductor of heat and has low specific heat capacity.

The amount of heat lost or gained by a body is given by the equation
$\Delta Q = ms\Delta T$
Where "m" is the mass of the body, "s" is the specific heat capacity of the body, and "ΔT" is the change in temperature of the body.

We use water in the calorimeter. So, we need to take a solid that is denser than water and insoluble in water.

Weigh the materials using a physical balance in the activity. First, the calorimeter with stirrer is weighed and let its mass be "m_1". Then find the mass of the solid, m_2.Enough water is poured into the calorimeter and then the mass of the "calorimeter, stirrer and water" is found to be "m_3".
Then mass of the water = $m_3 - m_1$

Note the temperature of the water, and let it be "t_1".

Now heat the solid in the steam chamber of Renault's apparatus till the thermometer in the apparatus shows a steady reading for few minutes, and let the temperature of the solid be "t_2". The wooden partition (Not shown in the figure) separating the steam chamber and the calorimeter provides thermal insulation to the calorimeter from the chamber so that there is no transfer of heat from the chamber to the calorimeter.

Now bring the calorimeter below the slider at the base of the steam chamber, slide open the base of the chamber and drop the solid into the water in the calorimeter and stir the mixture for some time and then note down the equilibrium temperature "t_3"

Let the specific heat capacity of the "copper" (for the calorimeter), "solid material", and "water" be "s_1, s_2, and s_3 "respectively.
Here, heat is lost by the hot "solid material" and gained by the cold "calorimeter" and "water".
Heat lost by the solid = $m_2s_2 (t_2 – t_3)$
Heat gained by the calorimeter = $m_1s_1 (t_3 – t_1)$
Heat gained by the water = $(m_3 – m_1) s_3 (t_3 – t_1)$

Applying the "principle of calorimetry"

Heat lost by hot body = Heat gained by the cold body
$m_2s_2 (t_2 – t_3) = m_1s_1 (t_3 – t_1) + (m_3 – m_1) s_3 (t_3 – t_1)$

$s_2 = [m_1s_1 (t_3 – t_1)+(m_3 – m_1)s_3(t_3 – t_1)]/m_2(t_2 – t_3)$

Advantages of High Specific Heat Capacity of Water
Due to the high specific heat capacity of water, it requires more heat energy to change its temperature, which gives it some advantages. Hence, water is used as a coolant in car radiators, in hot water packs

for fomentation, and for internal heating of buildings in cold countries. Wind cycles, land breezes and sea breezes are also caused due to the high specific heat capacity of water.

HEAT AND ITS UNIT

Heat is an invisible form of energy that causes the sensation of hotness or coldness. At the molecular level, the heat energy of a substance is equal to the total mechanical energy of all its molecules. Heat always flows from a body at higher temperature to a body at lower temperature. The SI unit for heat is the joule. The branch of physics that deals with the measurement of heat energy is called calorimetry.

Activities to Understand Heat Energy

Consider three vessels of equal capacities. Fill the three vessels with equal volumes of hot water, ice cold water and lukewarm water. Place your right hand in the vessel with ice cold water, and your left hand in the vessel with lukewarm water. You feel that your right hand is cooler than the left hand. Take out the right hand from the vessel with ice cold water and place it in the vessel with hot water, keeping the left hand in the vessel with lukewarm water only. Now, you feel that your right hand is hotter than the left hand. Thus, the terms ‘hot’ and ‘cold’ are relative. The lukewarm water contains more heat energy than the cold water. Similarly, the hot water contains more heat energy than the lukewarm water and the cold water.

Take a small ice cube in your hand. Your hand is at a higher temperature than the ice cube. Then the heat energy transfers from your hand to the ice cube. Since you are losing heat energy to the ice cube, you feel that the ice cube is cold. If you touch a vessel on a stove at a temperature higher than that of your body, then the heat energy transfers from the vessel to your body. Since you are gaining heat energy from the vessel, you feel that the vessel is hot. Thus, heat is an invisible form of energy, which causes the sensation of hotness or coldness.

Consider a certain amount of gas in a closed container. Heat the container at its bottom with the spirit lamp. As the substance gains heat energy, its molecules move randomly inside the container. According to the law of conservation of energy, energy can neither be created nor destroyed, but can be transformed from one form into another. That is, the heat energy supplied to the substance is transformed into the kinetic energy and potential energy of all its molecules. Thus, heat energy can be defined as the sum of the potential energy and kinetic energy of all the molecules of a substance.

If we supply some heat energy to a substance, the kinetic energy of its molecules increases. The temperature of a substance is directly proportional to the average kinetic energy of its molecules. Therefore, the temperature of a substance increases as the kinetic energy of its molecules increases. Conversely, if some heat energy is given out by a hot substance, the kinetic energy of its molecules decreases. As a result, the temperature of the substance also decreases. Thus, heat is the cause and temperature is the effect.

Now consider two bodies, A and B at different temperatures. That is A is at a higher temperature than B. If they are kept in contact with each other, heat energy will flow from the body A to the body B till their temperatures are equal. The common temperature that they attain is called equilibrium temperature. Thus, temperature is the physical quantity that determines the direction of flow of heat energy. The amount of heat energy lost by the hot body is equal to the amount of heat energy gained by the cold body. At equilibrium temperature, the rate of flow of heat energy from one body to the other and back is the same. As a result, the temperature of the bodies remains constant.

Heat always flows from a body at higher temperature to a body at lower temperature. The amount of heat energy transferred from one body to another is measured with different units in different systems. The branch of physics that deals with the measurement of heat energy is called calorimetry.

Units of Heat

Since heat is a form of energy, its SI unit is joule. In olden days, heat energy was measured in calories. Calorie is the CGS unit of heat energy.

One calorie is defined as the quantity of heat energy required to change the temperature of one gram of water by one degree Celsius. However, calorie is too small a unit to measure heat energy for practical purposes. Thus, kilocalorie is used to measure heat energy, which is the MKS unit of heat energy. One kilocalorie is defined as the quantity of heat energy required to change the temperature of one kilogram of water by one degree Celsius.

The different units of heat energy are related as follows.

1 calorie = 4.186 joule.

1 kilocalorie = 1000 calorie = 4186 Joule.

SPECIFIC HEAT

Factors on Which Heat Energy in A Body Depends

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Heat Capacity and Its Units

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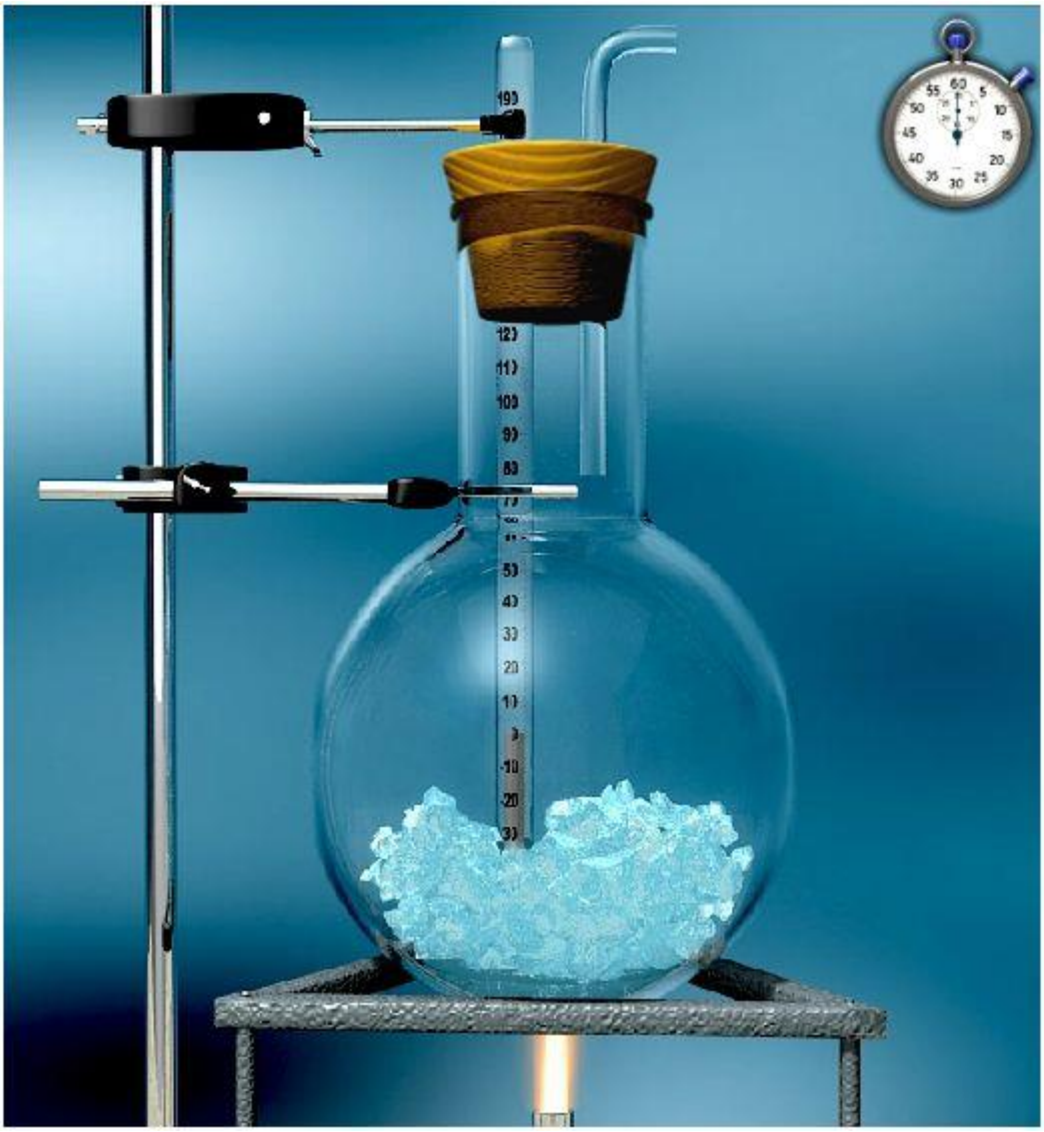
CHANGE OF STATE

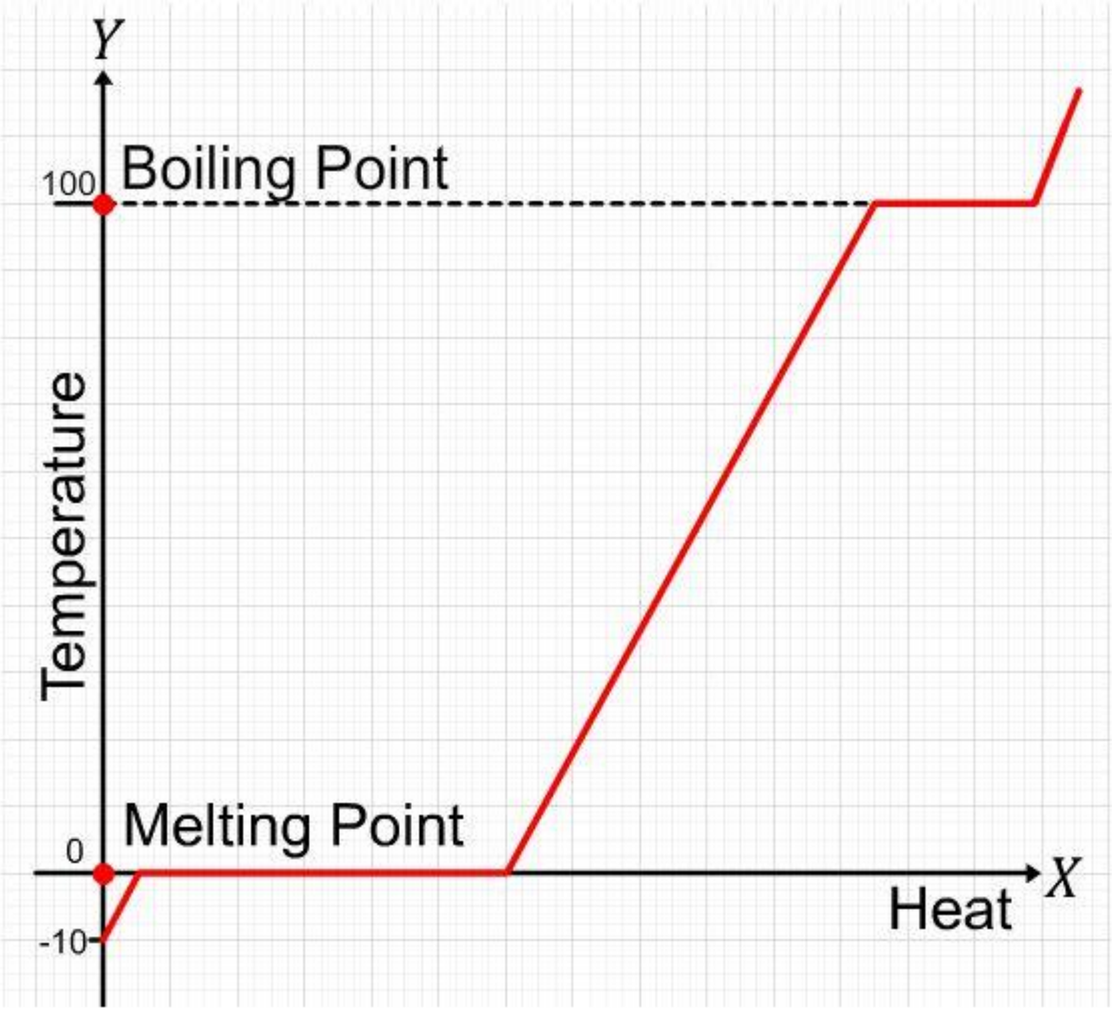
Normally matter exists in three states, solid, liquid and gas. A transition from one state to another is called change of state. The change of state from solid to liquid is called melting or fusion, and from liquid to solid it is called solidification or freezing. A change of state from liquid to gas is called boiling or vaporisation and from gas to liquid is called condensation.

Consider a round bottomed flask as shown with a thermometer and steam outlet fixed through the cork. Place some ice cubes, at $-10°C$ temperature, in the flask and start heating the flask on a flame. Let us observe the change in the temperature of the contents and plot a graph between temperature and time. Initially we observe rise in the temperature of the ice as it absorbs heat energy. This continues till the ice attains a temperature of 0°C. If we continue heating the flask, strangely, we don't observe any rise in the temperature of the ice cubes. But we can observe some of the ice cubes melting.



If we continue heating the water in the flask, again its temperature starts increasing and continues to rise up to 100°C. At this point, even if we continue supplying heat, the temperature of water remains constant and the heat supplied is used to change the state from liquid to gas. This indicates the change of state of ice to water, and during this process both solid ice and liquid water co-exist. No change in the temperature is observed till the entire ice in the flask melts to water. That means, on absorbing heat, ice at 0°C converts to water at 0°C.

The temperature at which solid and liquid states of a substance are in thermal equilibrium with each other is called the melting point. Thus, the melting point of ice is 0°C. In this case, the heat supplied is utilised in increasing the internal energy of the substance. The constant temperature at which the liquid and the vapour states of a substance co exit is called the boiling point.



The amount of heat absorbed by unit mass of a substance to convert it completely from one state to another state is called specific latent heat, usually denoted by L. The word 'latent' means 'hidden' derived from the Latin root word 'latentem' which means 'to lie hidden'. Specific latent heat is a characteristic of the substance. The heat required to convert one unit mass of a substance completely from liquid to gas is called specific latent heat of vaporisation, and is denoted by L_V. If Q is the heat required to convert a substance of mass m completely from one state to other, then $Q = mL$, where L is the specific latent heat of the substance for that particular change of state. The specific latent heat in the case of solid to liquid transition is called specific latent heat of fusion, denoted by L_f.

If we know the rate of heat supplied by the source, we can convert the graph shown earlier to Temperature – Heat graph, and then it is usually called a heating curve. Some parts of the curve are parallel to X –axis and some are inclined. The temperature corresponding to parallel portions of the graph correspond to melting and boiling points. The inclined portions of the graph correspond to a particular state of the substance. The slopes of the inclined portions are not equal. That means, a substance will have different specific heat capacities in different states.

The melting point and the boiling point of a substance depends on pressure. If measured at standard atmospheric pressure, they are called normal melting point and normal boiling point. For example, the melting point of ice decreases with pressure. The phenomenon of refreezing is called regelation. Ice skating is possible because of regelation only. The phenomenon of changing directly from solid to gas or from gas to solid is called sublimation. Dry ice and iodine are some examples of substances that undergo sublimation.

INTERCONVERSION OF STATE OF MATTER

Normally matter exists in three states, solid, liquid and gas. A transition from one state to another is called change of state.

The change of state from solid to liquid is called melting or fusion, and from liquid to solid it is called solidification or freezing. Heat energy that is used up by a body to change its state or phase is called latent heat.

Latent Heat of Fusion is the amount of heat energy that is required to change unit mass of a solid into liquid at a standard atmospheric pressure.

A change of state from liquid to gas is called boiling or vaporisation and from gas to liquid is called condensation or liquification. Latent Heat of Vaporisation is the amount of heat required to change a unit mass of liquid to gas at standard atmospheric pressure.
Evaporation is the process of changing of a liquid into vapor at any temperature below its boiling point. Surface area, temperature and the wind are the factors that affect the rate of evaporation.

The process of changing of a solid directly into gas without changing into liquid on heating, and the process of changing of a gas directly into a solid without changing into liquid on cooling is called sublimation.

“Dry ice” and “Iodine” are some examples of such substances.

Applying pressure and reducing temperature can liquefy gases. The phenomenon of the change of matter from one state to another and back to original state, by altering the temperature is called inter conversion of states of matter.

Consider a round bottomed flask with a thermometer and steam outlet fixed through the cork. Place some ice cubes, at “- 10^0C” temperature, in the flask and start heating the flask on a flame. Observe the change in the temperature of the contents and plot a graph between “temperature” and “Time”.
Initially we observe rise in the temperature of the ice as it absorbs heat energy. This continues till the ice attains a temperature of “0 ^{0}C”.

If we continue heating the flask, strangely, we don’t observe any rise in the temperature of the ice cubes. But we can observe some of the ice cubes melting. If we continue heating the water in the flask, again its temperature starts increasing and continues to rise up to 100 ^{0}C.

At this point even if we continue supplying heat, the temperature of water remains constant and the heat supplied is used to change the state from liquid to gas.

This indicates the change of state of ice to water, and during this process both solid ice and liquid water co-exist.

No change in the temperature is observed till the entire ice in the flask melts to water. That means, on absorbing heat, ice at 0 ^{0}C converts to water at 0^o C.

The temperature at which solid and liquid states of a substance are in thermal equilibrium with each other is called the melting point.

Thus, the melting point of ice is 0^0 C. In this case, the heat supplied is utilised in increasing the internal energy of the substance.

The constant temperature at which the liquid and the vapour states of a substance co exit is called boiling point**.**

The amount of heat absorbed by unit mass of a substance to convert it completely from one state to another state is called specific latent heat, usually denoted by “L”. The word latent means hidden, derived from the Latin root word
latentem which means to lie hidden.
Specific latent heat is a characteristic of the substance.

The heat required to convert one unit mass of a substance completely from liquid to gas is called specific latent heat of vaporisation, and is denoted by “L_V”.

If “Q” is the heat required to convert a substance of mass “m” completely from one state to other, then

Q = mL, where “L” is the specific latent heat of the substance for that particular change of state.
The specific latent heat in the case of solid to liquid transition is called specific latent heat of fusion, denoted by Lf.

If we know the rate of heat supplied by the source, we can convert the graph shown earlier to “temperature – Heat “graph, and then it is usually called a “heating curve”.
Some parts of the curve are parallel to X –axis and some are inclined.
The temperature corresponding to parallel portions of the graph correspond to “melting” and “boiling” points.
The inclined portions of the graph correspond to a particular state of the substance. The slopes of the inclined portions are not equal.

That means, a substance will have different specific heat capacities in different states.

The melting point and boiling point of a substance depends on pressure. If measured at standard atmospheric pressure, they are called normal melting point and normal boiling point.

Example
The melting point of ice decreases with pressure. The phenomenon of refreezing is called “regelation”. Ice skating is possible because of “regelation” only.

LATENT HEAT OF FUSION AND VAPOURISATION

Heat energy is absorbed by a solid during melting and an equal amount of heat energy is liberated by the liquid during freezing , without showing any change in temperature (i.e., fall or rise in temperature) .

Similarly, the heat energy is absorbed by a liquid during vaporisation and an equal amount of heat energy is liberated by the vapour during condensation, without showing any change in temperature (i.e., fall or rise in temperature).

As the heat energy is not externally manifested by any fall or rise in the temperature, it is considered to be hidden in the substance and is considered to be hidden in the substance and is called the latent heat.

Specific latent heat , L = (Heat energy exchanged for the change of phase) / (Mass)

$\Rightarrow L = Q/m$

⇒ The amount of heat energy liberated or absorbed for the change of phased can be expressed as the following

$Q = \text{Mass} \times \text{Specific latent heat}$

The latent heat is used up in developing the potential energy of the molecules of the substance and in doing work against external pressure if there is an increase in volume. There is no change in average kinetic energy of molecules, Hence the temperature remains unchanged (i.e., constant temperature).

The heat energy required to change the state or phase of a substance is known as the latent heat of that substance.

The heat energy required to convert a unit mass of a substance from solid to liquid state without any change in temperature is called the specific latent heat of fusion of that substance.

Unit of Specific Latent Heat

The S.I unit of specific latent heat is Joule per kilogram, i.e., J kg^{-1}.

- 1 kilo - cal kg^{-1} = 1 cal g^{-1}
- 1 cal g^{-1} = 4.2 J g^{-1}
- 1 cal g^{-1} = 4.2×10^{3} J Kg^{-1}

When a solid changes into a liquid without change in temperature the average kinetic energy of the of the molecules does not change, but the potential energy increases as the distance between the molecules on an average increases.

The specific latent heat of fusion of ice is 336000 joules per kilogram, which, in the CGS system, is 80 calories per gram.

It means that one kilogram of ice absorbs 336000 joules of heat energy to convert into water at 0° C. It also means that one kilogram of water will liberate 336000 joules of heat energy to convert into ice at 0°C.

Snow on mountains does not melt all at once because ice has a high specific latent heat of fusion. Ice changes into water slowly as it gets heat energy from the sun.

The latent heat of fusion of ice not been so high, all the snow would have melted very quickly even with a small amount of heat energy and would have caused floods.

In cold countries, water does not freeze all at once in ponds and lakes, the reason being that the specific latent heat of fusion of ice is high. Hence, a large amount of heat needs to be withdrawn for water in lakes and ponds to freeze.

Drinks get cooled very quickly by adding cubes of ice at 0℃ than ice cold water at 0℃. One gram of ice at 0℃ takes 336 joules of heat energy from the drink to melt into water at 0℃. Thus, the drink loses an additional 336 joules of heat energy for every gram of ice at 0℃, which is much more than for one gram of ice-cold water at 0°C. Ice-cold Water added to Drink Ice Cubes added Drink.

The heat energy required for melting a frozen lake is absorbed from the surrounding atmosphere. Hence, the surroundings become very cold when the ice in a frozen lake starts melting. Surrounding temperature decreases.