THERMAL PROPERTIES OF MATTER

TEMPERATURE AND HEAT

Temperature is a relative measure, or indication of hotness or coldness. A hot utensil is said to have a high temperature, and ice cube to have a low temperature. An object that has a higher temperature than another object is said to be hotter. Heat transfer takes place between the system and the surrounding medium, until the body and the surrounding medium are at the same temperature.

Heat is the form of energy transferred between two (or more) systems or a system and its surroundings by virtue of temperature difference. The SI unit of heat energy transferred is expressed in joule (J) while SI unit of temperature is kelvin (K), and °C is a commonly used unit of temperature

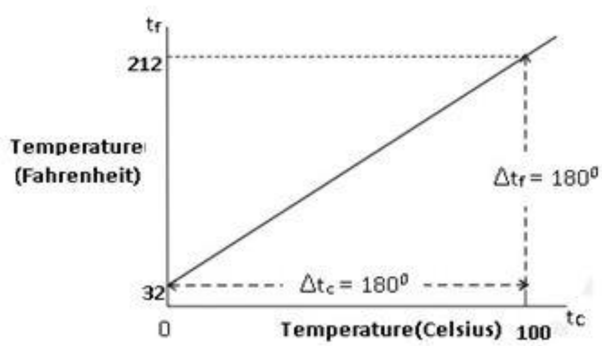
MEASUREMENT OF TEMPERATURE

Temperature is measured with the help of thermometer. Mercury and Alcohol are commonly used liquids in the liquid-in-glass thermometers.

To construct a thermometer two fixed points are to be chosen as a reference points. These fixed points are known as freezing (ice point) and boiling point (steam point). The water freezes and boils at these two points under standard pressure.

- The ice and steam point in Fahrenheit Temperature scale are 32°F and 212 °F resp. It has 180 equal intervals between two reference points.
- On Celsius Scale values are 0°C and 100°C for ice and steam point resp. It has 100 equal intervals between two reference points.

Graphically the relation between the temperature in Celsius and in Fahrenheit is given by the following graph:-



- The three main temperature scales are **Celsius, Fahrenheit, and Kelvin**. Temperatures can be converted from one scale to another using temperature conversion equations.

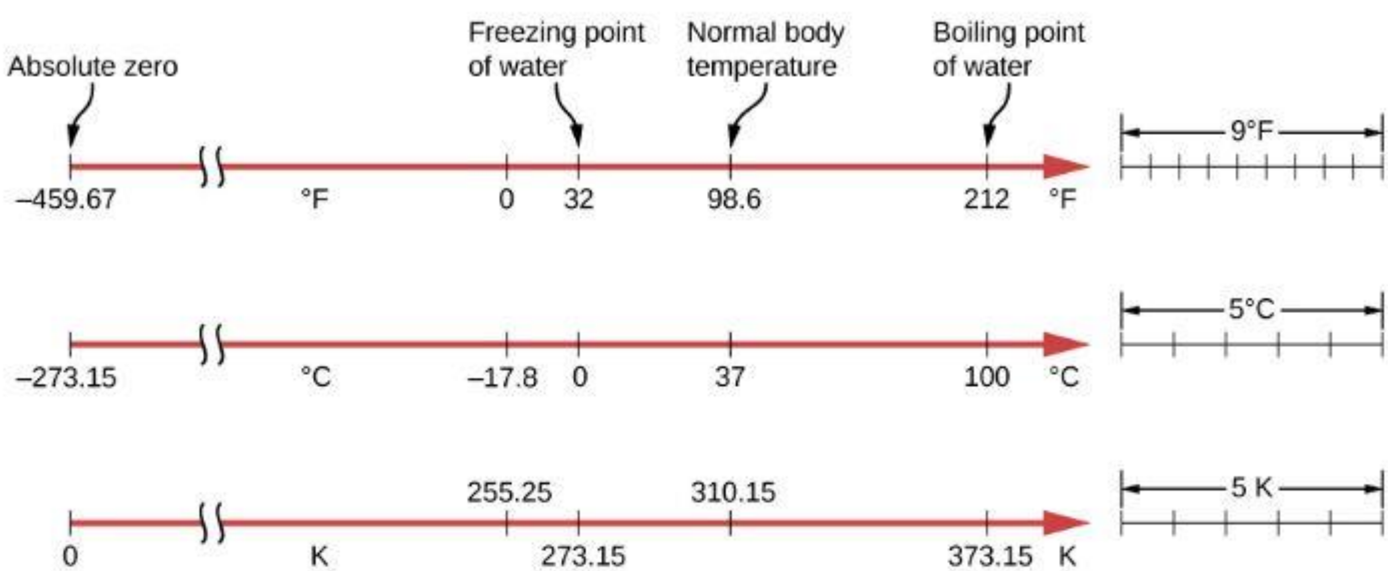
The ice and steam point in Fahrenheit Temperature scale are 32°F and 212 °F respectively. It has 180 equal intervals between two reference points. On Celsius Scale values are 0°C and 100°C for ice and steam point resp. It has 100 equal intervals between two reference points.

100 Celsius degrees span the same range as 180 Fahrenheit degrees. Thus, a temperature difference of one degree on the Celsius scale is 1.8 times as large as a difference of one degree on the Fahrenheit scale. $\boldsymbol{T_F = \frac{9}{5} T_C}$

An **ABSOLUTE TEMPERATURE** scale is one whose zero point is absolute zero. That is the lowest possible temperature, where the average kinetic energy of molecules is zero (or the minimum allowed by quantum mechanics)

The **Kelvin scale** is the absolute temperature scale that is commonly used in science. The SI temperature unit is the *kelvin*, which is abbreviated K (not accompanied by a degree sign). Thus **0 K is absolute zero**. The freezing and boiling points of water are 273.15 K and 373.15 K, respectively. Therefore, temperature differences are the same in units of kelvins and degrees Celsius, or $T_C = T_K$

- ❖ Relationships between the Fahrenheit, Celsius, and Kelvin temperature scales.



TEMPERATURE CONVERSIONS

$$\frac{temperature\ on\ one\ scale - lower\ fixed\ point}{upper\ fixed\ point - lower\ fixed\ point} = \frac{temperature\ on\ other\ scale - lower\ fixed\ point}{upper\ fixed\ point - lower\ fixed\ point}$$

$$\frac{T_C - 0}{100 - 0} = \frac{T_F - 32}{212 - 32} = \frac{T_K - 273.15}{373.15 - 273.15}$$

$$\frac{T_C}{100} = \frac{T_F - 32}{180} = \frac{T_K - 273.15}{100}$$

Celsius to Fahrenheit	$T_F = \frac{9}{5} T_C + 32$
Fahrenheit to Celsius	$T_C = \frac{5}{9}(T_F - 32)$
Celsius to Kelvin	$T_K = T_C + 273.15$
Kelvin to Celsius	$T_C = T_K - 273.15$
Fahrenheit to Kelvin	$T_K = \frac{5}{9}(T_F - 32) + 273.15$
Kelvin to Fahrenheit	$T_F = \frac{9}{5}(T_K - 273.15) + 32$

THERMAL EXPANSION

Most substances expand on heating and contract on cooling. A change in the temperature of a body causes change in its dimensions. **The increase in the dimensions of a body due to the increase in its temperature is called thermal expansion**

1) **LINEAR EXPANSION**:

The expansion in length is called linear expansion.

If the substance is in the form of a long rod, then for small change in temperature, ΔT, the fractional change in length, $\frac{\Delta l}{l}$, is directly proportional to ΔT.

$$\frac{\Delta l}{l} \propto \Delta T$$

OR

$$\frac{\Delta \boldsymbol{l}}{\boldsymbol{l}} = \boldsymbol{\alpha} \Delta \boldsymbol{T}$$

Where $\boldsymbol{\alpha}$ is known as **the coefficient of linear expansion** and is characteristic of the material of the rod. Normally, metals expand more and have relatively high values of α.

From $\frac{\Delta l}{l} = \alpha \Delta T$ we have $\alpha = \frac{\Delta l}{l\,\Delta T}$

i.e., coefficient of linear expansion = $\frac{increase\ in\ length}{original\ length \times rise\ in\ temperature}$

✓ NOTE

If $l = 1\ unit$ and $\Delta T = 1°\mathrm{C}$ then $\alpha = \Delta l = increase\ in\ length$

i.e., coefficient of linear expansion of substance is numerically equal to increase in length of rod per unit original length of that substance when its temperature is raised by 1℃.

Unit: $(℃)^{-1}$ (per degree Celsius)

2) **AREA EXPANSION / (SUPERFICIAL EXPANSION)**:

The expansion in area is called area expansion.

If a thin metal plate is heated, then for small change in temperature, ΔT, the fractional change in area, $\frac{\Delta A}{A}$, is directly proportional to ΔT.

$$\frac{\Delta A}{A} \propto \Delta T$$

OR

$$\boldsymbol{\frac{\Delta A}{A} = \beta \Delta T}$$

Where $\boldsymbol{\beta}$ is known as **the coefficient of superficial expansion**

From $\frac{\Delta A}{A} = \beta \Delta T$ we have $\beta = \frac{\Delta A}{A\,\Delta T}$

i.e., coefficient of superficial expansion = $\frac{increase\ in\ area}{original\ area\ \times rise\ in\ temperature}$

✓ NOTE

If $A = 1\ unit$ and $\Delta T = 1℃$ then $\beta = \Delta A$ = $increase\ in\ area$

i.e., coefficient of superficial expansion of substance is numerically equal to increase in area of a substance per unit original area of that substance when its temperature is raised by 1℃.

Unit: $(℃)^{-1}$ (per degree Celsius)

3) **VOLUME EXPAMSION**:

The expansion in volume is called volume expansion

When a rectangular solid block is heated, then for small change in temperature, ΔT, the fractional change in volume, $\frac{\Delta V}{V}$ is directly proportional to ΔT

$$\frac{\Delta V}{V} \propto \Delta T$$

OR

$$\frac{\Delta V}{V} = \gamma \Delta T$$

Where γ is known as the **coefficient of volume expansion**

From $\frac{\Delta V}{V} = \gamma \Delta T$ we have $\gamma = \frac{\Delta V}{V\,\Delta T}$

i.e., coefficient of volume expansion = $\frac{increase\ in\ volume}{original\ volume \times rise\ in\ temperature}$

✓ NOTE

If $V = 1\,unit$ and $\Delta T = 1°C$ then $\gamma = \Delta V = increase\ in\ volume$

i.e., coefficient of volume expansion of substance is numerically equal to increase in volume of a substance per unit original volume of that substance when its temperature is raised by 1°C.

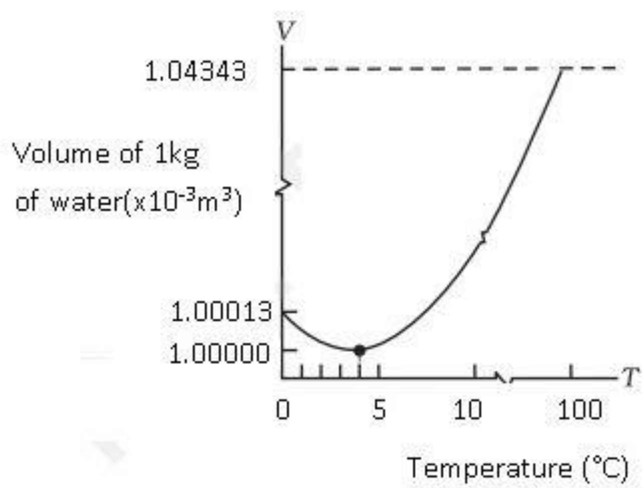
Unit: $(°C)^{-1}$ (per degree Celsius)

✓ NOTE

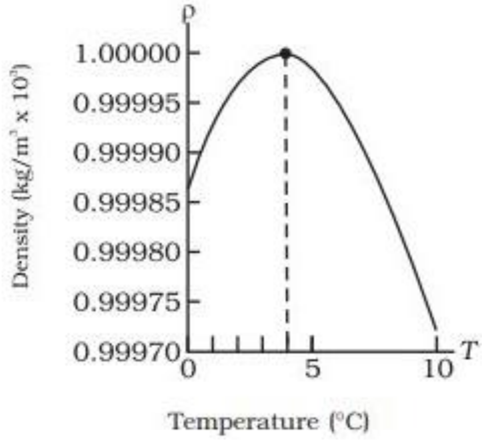
The coefficient of volume expansion characteristic of the substance but is not strictly a constant. It depends in general on temperature. It is seen that γ becomes constant only at a high temperature.

ANOMALOUS BEHAVIOUR OF WATER

Water shows some exceptional behaviour that is when it is heated at 0°C, it contracts instead of expanding and it happens till it reaches 4 °C. **The volume of a given amount of water is minimum at 4 °C therefore its density is maximum**.



After 4 °C water starts expanding. Above 4 °C, the volume increases, and therefore the density decreases. This means water has maximum density at 4 °C.



The information we get from the above graph means that the density increases as its temperature rises from 0°C to 4 °C and density decreases after 4°C.

Advantages of Anomalous behaviour of Water

Because of this property, water in lakes and ponds freeze only at the top layer and at the bottom it does not, but if the water freezes at the bottom also then animal and plant life would not be possible.

CALORIMETRY

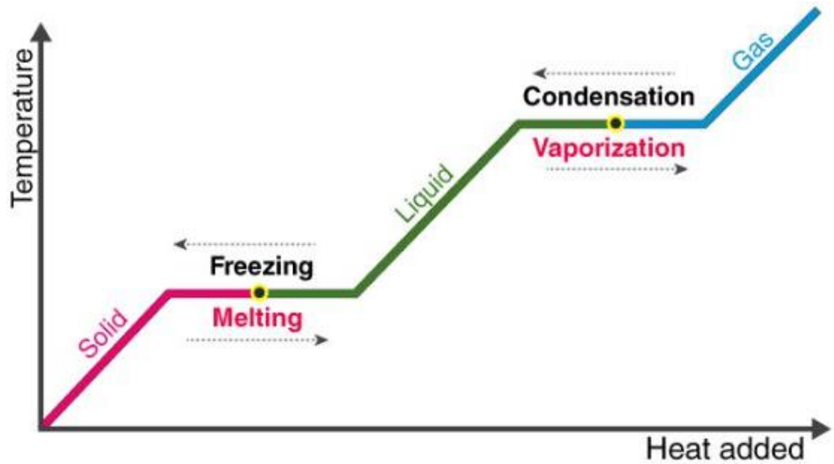
Calorimetry means **measurement of heat**. When a body at higher temperature is brought in contact with another body at lower temperature, the heat lost by the hot body is equal to the heat gained by the colder body, provided no heat is allowed to escape to the surroundings.

A device in which heat measurement can be made is called a **calorimeter**. It consists a metallic vessel and stirrer of the same material like copper or Aluminium. The vessel is kept inside a wooden jacket which contains heat insulating materials like glass wool etc. The outer jacket acts as a heat shield and reduces the heat loss from the inner vessel. There is an opening in the outer jacket through which a mercury thermometer can be inserted into the calorimeter

CHANGE OF STATE

Matter normally exists in three states: solid, liquid, and gas. A transition from one of these states to another is called a change of state. Two common changes of states are solid to liquid and liquid to gas (and vice versa). These changes can occur when the exchange of heat takes place between the substance and its surroundings.

The change of state from solid to liquid is called melting and from liquid to solid is called freezing. It is observed that the temperature remains constant until the entire amount of the solid substance melts. That is, both the solid and liquid states of the substance coexist in thermal equilibrium during the change of states from solid to liquid. The temperature at which the solid and the liquid states of the substance in thermal equilibrium with each other is called its **melting point**. It is characteristic of the substance. It also depends on pressure. The melting point of a substance at standard atomspheric pressure is called its normal melting point.



The change of state from liquid to vapour (or gas) is called **vaporization** and from vapour to liquid is called condensation. It is observed that the temperature remains constant until the entire amount of the liquid is converted into vapour. That is, both the liquid and vapour states of the substance coexist in thermal equilibrium, during the change of state from liquid to vapour. The temperature at which the liquid and the vapour states of the substance coexist is called its **boiling point**. The boiling point of a substance at standard atmospheric pressure is called its normal boiling point.

✓ NOTE

The three phases of water (ice, liquid water, and water vapor) can coexist at a single pressure and temperature known as the **TRIPLE POINT**.