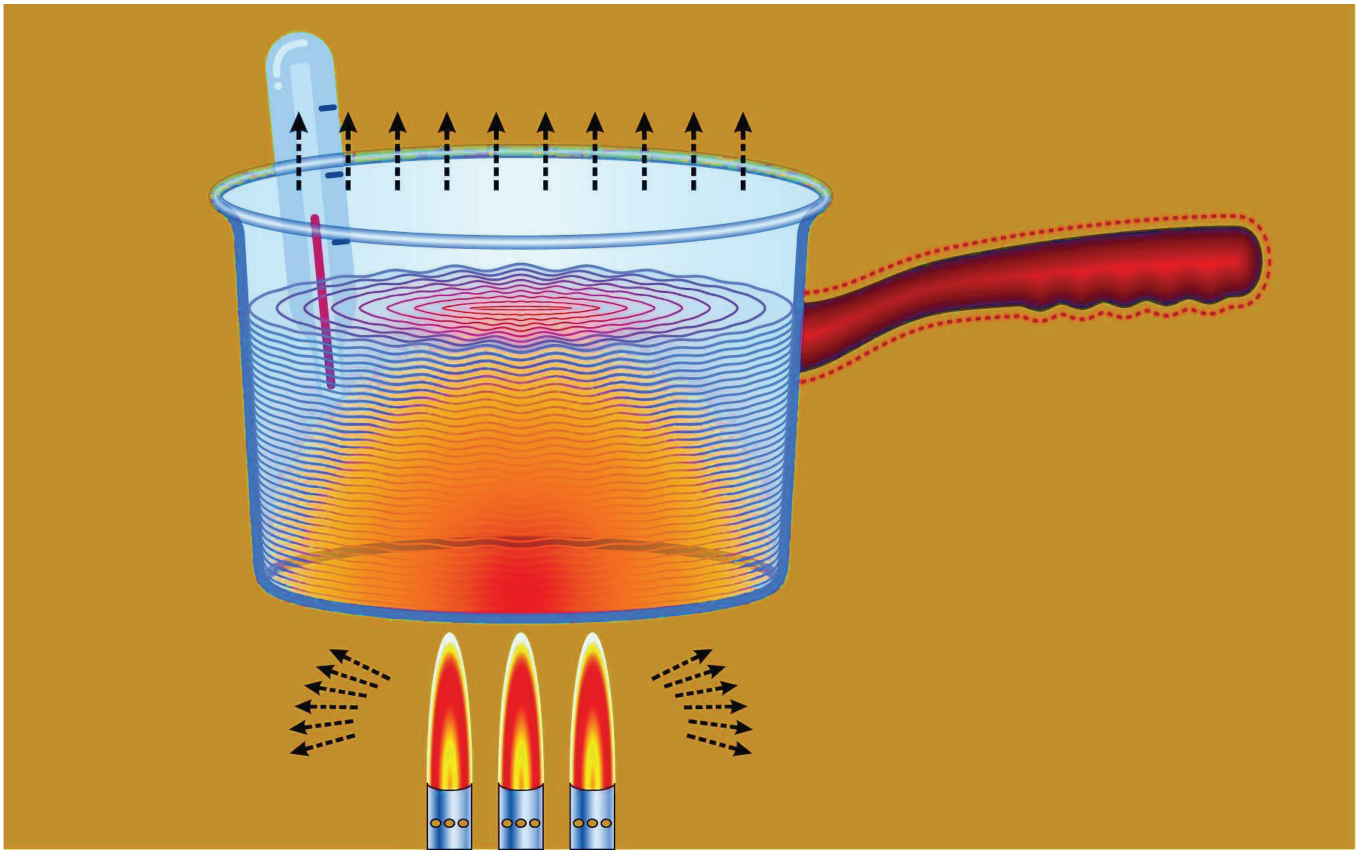
Thermal Properties of Matter



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THERMAL PROPERTIES OF MATTER

Heat and Temperature

Heat, temperature and thermal equilibrium

The energy transferred from a hot body to a cold body is called heat. Thus "heat is energy in transit".

Temperature is an index of hotness or coldness of a body and it determines the direction of heat flow.

Heat flows from a body at a higher temperature to a body at a lower temperature.

Two bodies are said to be in thermal equilibrium if no net transfer of heat takes place when they are placed in thermal contact. Then two bodies are at the same temperature.

Zeroth law of thermodynamics

Statement: If two bodies are in thermal equilibrium with a third body, then those two bodies are in thermal equilibrium with each other.

Thus, temperature is a thermal property which has the same value in all bodies which are in thermal equilibrium.

Thermometry

A device used to measure the temperature of a body is called a thermometer.

The linear variation of some physical property of a substance with change in temperature is the principle of a thermometer.

For example, following properties are used in different thermometer.

- The property of increase in volume of a gas (at constant pressure) or increase in pressure of a gas (at constant volume) with increase in temperature is used in gas thermometers.
- The property of expansion of liquids on heating is used in mercury thermometer.
- The property of increase in resistance with increase in temperature is used in resistance thermometers.

Depending upon the range of measurement of temperature, the following thermometers are also used:

1. Thermoelectric thermometers
2. Radiation thermometer (Pyrometers)
3. Bimetalic strip thermometers

Temperature scales

Different scales are employed to measure temperature. Each scale is characterized by its own set of lower fixed point and upper fixed points.

Scale	Lower fixed point	Upper fixed point
Celsius (centigrade)	0 °C	100 °C
Fahrenheit	32 °C	212 °C
Kelvin	273.15 K	373.15 K

If the temperature of a body on Celsius, Fahrenheit and Kelvin scale is recorded as C, F and K respectively, then,

$$\frac{C-0}{100}=\frac{F-32}{180}=\frac{K-273}{100}=\frac{\theta-\theta_0}{N}$$

where θ, θ_0 and N represent corresponding temperature, lower fixed point and number of divisions on some new scale.

In general, the temperature corresponding to any length l of the mercury column can be obtained using the formula

$$t=\frac{l-l_0}{l_{100}-l_0}\times 100$$

where l_0 and l_{100} denote the lengths of the mercury column at 0 °C and 100 °C respectively.

The triple point of water

By international agreement, the triple point of water is selected as the standard fixed-point temperature for the calibration of thermometers.

Triple point is a state in which ice, water and water vapour can stay together in equilibrium.

Triple point of water has been assigned a value of 273.16 K.

> In constant volume gas thermometers, the temperature of the gas when pressure is p is obtained by using the equation $T = \frac{p}{p_{tr}} \times 273.16$
> where p_{tr} is the pressure at triple point of water.

Illustrations

1. At what temperature, does the following pair of scales give the same reading? Celsius and Fahrenheit.

(A) – 60 (B) – 30 (C) – 50 (D) – 40

Ans (D)

Let the required reading be θ.

Then

$$\frac{°C - 0}{100} = \frac{°F - 32}{180} \Rightarrow \frac{\theta - 0}{100} = \frac{\theta - 32}{180} \Rightarrow -40$$

$\therefore -40°C = -40°F$

2. In a scientific book that describes a temperature called Y, boiling and freezing point of water are referred as 65 °Y and – 15 °Y respectively. To what temperature on Fahrenheit scale would a temperature –95°Y correspond?

(A) – 148 °F (B) – 158 °F (C) – 128 °F (D) – 138 °F

Ans (A)

$$\frac{°F - 32}{212 - 32} = \frac{°Y - (-15)}{65 - (-15)}$$

Putting – 95 °Y in place of °Y in the equation and solving for °F gives the answer – 148 °F

3. Why does a doctor taking your body temperature wait for the thermometer reading to stop changing before recording it?

Ans

It takes a while before the thermometer is in equilibrium with your body. At that stage, the thermometer reading corresponds to your body temperature.

4. Does a thermometer read the temperature of its body or that of some other object?

Ans

It reads its own temperature; however when it is in thermal equilibrium with the surrounding, we also get the temperature of the surroundings.

5. The fundamental interval (that is the number of divisions between the lower fixed point and the upper fixed point) on the two scales X and Y are 50 and 150, respectively. The ice point on both the scales is at 0°. If the temperature on the X-scale is 15°, the temperature on the Y-scale is

(A) 30° (B) 45° (C) 60° (D) 75°

Ans (B)

$\frac{x - 0}{50} = \frac{y - 0}{150}$ If x = 15°, then y = 45°

6. Express a temperature of 20 °C on Fahrenheit scale.

Solution

C = 20 °C

F = ?

We know that, $\frac{C-0}{100}=\frac{F-32}{180}=\frac{K-273}{100}$

Using, $\frac{C-0}{100}=\frac{F-32}{180}$

$\frac{20}{100}=\frac{F-32}{180}\ \Rightarrow F=68\ °F$

7. Express a temperature difference of 45 F° on Kelvin scale.

Solution

Given is a temperature difference of 45 F° i.e., ΔF = 45 F°

ΔK = ?

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

i.e., $\frac{\Delta C}{100}=\frac{\Delta F}{180}=\frac{\Delta K}{100}$

$\therefore \Delta K=\frac{100}{180}\ \Delta F\ =\frac{100}{180}\ 45\ \Rightarrow \Delta K=25\ K$

Thermal Expansion

Thermal Expansion of Solids

If the temperature of a body increases, in general, its size also increases. This expansion property is used to define a temperature scale. We can also study the thermal expansion of a body as a function of temperature.

Linear expansion

Consider a rod of length l_0 at some initial temperature t_0. When temperature is changed by Δt, the length increases by Δ*l*. The increase in length Δ*l* is given by

$\Delta l=\alpha l_0\Delta t$

where α is called 'coefficient of linear expansion' and has unit $°C^{-1}$.

If *l* is the length of the rod at some temperature 't' then

$l=l_0\,(1+\alpha\Delta t)$

where $\Delta t=(t-t_0)$ is change in temperature.

α is treated to be constant for a given material in a given temperature range.

Applications

1. A metal scale shows correct readings only at the temperature at which the calibration is done. When temperature is increased, scale expands and it reads lesser value. When temperature is decreased, scale contracts and it reads higher value.

If t_0 is the temperature at which scale is calibrated, then the percentage error if this scale is used at some temperature 't' is given by % error = $\alpha\Delta t\times 100$ where $\Delta t=t-t_0$

True reading and scale reading are related through,

True reading = Scale reading $(1+\alpha\Delta t)$

2. If a pendulum clock consists of an iron rod connected to a small, heavy bob, it shows different times at different temperatures as the length of the rod changes with temperature. If it shows correct time T_0 at some temperature t_0, then time shown by it at some temperature 't' is given by