UNIT 2: CONCEPT OF TEMPERATURE

(part 2)

The Zeroth Law

Consider two systems A and B separated from each other by an adiabatic wall but each system is in contact with a third system C separated through a diathermic wall. Consider the whole systems surrounded by an adiabatic wall (fig. 2.7). This is to ensure that no heat energy is lost to or gained from the surrounding. Experiments have shown that systems A and B will attain a thermal equilibrium with C. If however the adiabatic wall is replaced by a diathermic wall as shown in (fig. 2.8).

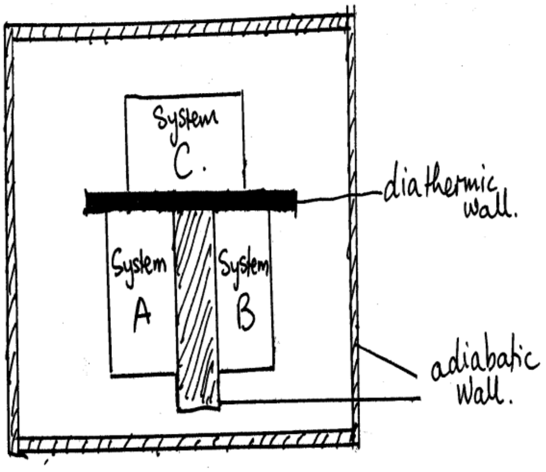

Fig. 2.7: A and B are each in Thermal Equilibrium with C

Instead of allowing both systems A and B to come to equilibrium with C at the same time, we can first have equilibrium between A and C and then equilibrium between B and C making sure that the state of C is the same in both cases, (fig. 2.7) then A and B are brought in contact through a diathermic wall, they will be found to be in thermal equilibrium (fig. 2.8). It means that no further changes occur in systems A and B

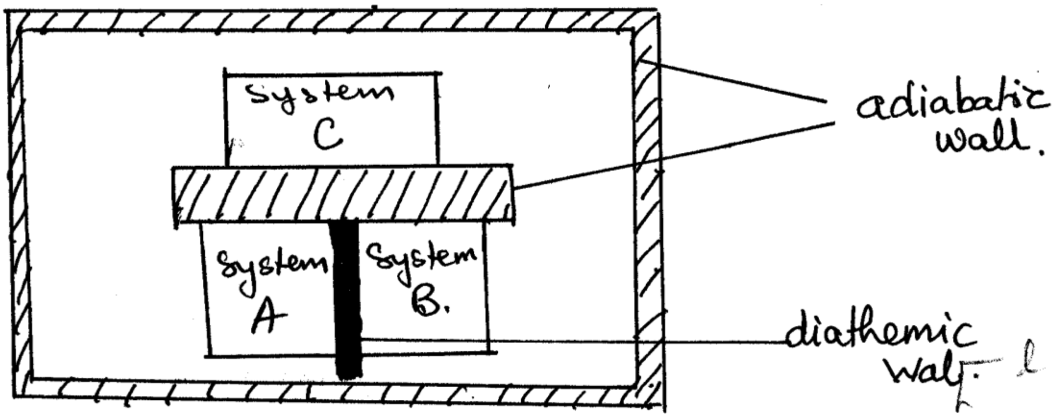

Fig. 2.8: A and B are in Thermal Equilibrium with Each Other.

That is systems A and B are already in equilibrium with each other. The above principle is called the zeroth law of thermodynamics. The zeroth law of thermodynamics states that:

“Two thermodynamics systems A and B are separately in thermal equilibrium with a third system C, then the systems A and B are in Thermal equilibrium with each other”.

It is called the zeroth law because the most important principles of thermodynamics have hitherto been identified as the first, second and third laws of thermodynamics.

2.3 Scale of Temperature:

To measure temperature, therefore, we need to select a physical property or parameter of a chosen substance which varies uniformly with temperature.

A parameter or property is a variable which is assigned a constant value during a discussion or event. that some of the examples of these parameters are:

(i) the volume of a liquid;

(ii) the volume of a gas at constant pressure;

(iii) the pressure of a gas at constant volume;

(iv) the electrical resistance of a conductor;

(v) the emf change of a thermocouple when there is a temperature difference between the junctions of a thermoelectric thermometer.

For the establishment of temperature scale, the following are required:

(a) specification of fixed points;

(b) specification of the method of interpolation.

Now we will discuss briefly about these concepts required for the establishment of temperature scale.

2.3.1 Specification of Fixed Points :

Fixed points are temperatures chosen which are fixed and reproducible. They are useful as reference temperatures. Changes in the parameters from the fixed points are assigned numbers called degrees on a calibrated scale. Two such fixed points are:

(i) The Lower fixed point (ice point): That is the temperature of equilibrium between ice, water and air saturated at standard pressure. This temperature is) 0ºC.

(ii) The Upper fixed point (steam point): That is the temperature of steam rising from pure water boiling under standard atmospheric pressure. That is, the temperature of one standard atmosphere. This temperature is 100ºC.

(iii) The fundamental interval: This is the difference between the upper fixed point and the Lower fixed point divided into equal parts.

2.3.2 Factors for Changes in Fixed Points

1. Changes in the atmospheric pressure cause variation in freezing and boiling points. Changes caused by pressure in freezing point can be ignored. That due to impurities cannot be ignored.

2. Freezing point depression and Boiling point elevation are caused by impurities of slats. Hence water used in determining these points is required to be pure.

3. Daily floatation of barometric reading call for the correction of the boiling point. In the neighbourhood of standard atmospheric pressure, the boiling point rises by 0.37°C when the height of mercury barometer increases by 1.0 cm. Therefore true boiling point is given as on the Celsius scales as:

$$6^{o}C = 100^{o}C + 0.37\ (B - 76)^{o}C \ldots\ldots\ldots\ldots\ldots\ (2.1)$$

Where B is any atmospheric pressure in cm of mercury.

2.3.3 The Temperature Scales:

The systems of temperature scales are:

(i) The Celsius scales whose ice point is 0°C and the steam point is at 100oC. Each part represents 1°C.

(ii) The Fahrenheit scale whose ice point is 32°F while the steam point if 212oF. The fundamental interval is 180 divisions. Each division represents 10°F.

(iii) The absolute scale of temperature, the thermodynamics scale.

2.4.1 Definition of Temperature on Celsius Scale:

If X represents the property of the thermometric substance, which serves as temperature indicator, by adopting the Celsius scale. Let Xo be the values of X of the thermometric substance when surrounds by the melting ice for a long time. Let X_{100} be the value of X when the substance has reached an equilibrium with steam at standard pressure (1 atmosphere).

Hence, the fundamental interval is defined as the change of X between the ice and steam points = $X_{100} – X_o$.

Consequently, <u>the size of the Celsius degree, which results from our choice of property X, is defined at that range of temperature which causes a change in property which is Z.</u>

Hence $Z = \frac{X_{100} - X_o}{100}$ **……………………………………..…...…….(2.2)**

If X_t is the value of X of the substance in the neighbourhood of another body whose temperature is to be determined then, the number of degrees by which the Celsius temperature tc of the thermometric substance exceeds the temperature of melting ice 0°C is equal to the number of items the quantity Z is contained in ($X_t – X_o$).

$$(tc – 0^oC) \times Z = (X_t - X_0)^oC \quad \text{……………………...…..……. (2.3)}$$

But from Eq. 2.2, you know that

$$Z = \frac{X_{100} - X_o}{100}$$

Substituting Eq. (2.2) in Eq. (2.3), we get

$$(tc - 0) \times \frac{X_{100} - X_o}{100} = (X_t - X_o)^oC$$

$$tc = \frac{(X_t - X_0)}{(X_{100} – X_o)} \times 100\ ^o C \quad \text{………………..…………….. (2.4)}$$

2.4.2 Definition of Temperature on Fahrenheit Scale:

In the case of the Fahrenheit scale, one can also state that

$$(t_F - 32) Z = (X_t - X_{32})\ ^oF \quad \text{…………………………..……. (2.5)}$$

Where, $Z = \frac{(X_{212} – X_{32})}{(212 – 32)}\ ^oF$

$$Z = \frac{X_{212} - X_{32}}{180}\ ^oF \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2.6)$$

Substituting Eq. (2.5) in Eq. (2.6), we get the expression

$$\therefore \quad t_F - 32 = \left(\frac{X_t - X_{32}}{X_{212} - X_{32}}\right) X 180^\circ F$$

$$\therefore \quad t_F = \left(\left(\frac{X_t - X_{32}}{X_{212} - X_{32}}\right) X 180 + 32\right)^\circ F \quad \ldots\ldots\ldots (2.7)$$

Hence $X_{212} = X_{100}$ and $X_{32} = X_o$

Now inserting these parameters in Eq. (2.7), we get

$$\therefore \quad t_F = \left(\left(\frac{X_t - X_0}{X_{100} - X_0}\right) X 180 + 32\right)^0 F \quad \ldots\ldots (2.8)$$

Also from Eq. (2.4), we get

$$\frac{t_c}{100} = \frac{X_t - X_0}{X_{100} - X_0} \quad \ldots\ldots\ldots (2.9)$$

Therefore, a relation between tF and tc can be obtained as

$$t_F = \left(\frac{tc}{100} X 180 + 32\right)^\circ F$$

$$\therefore \quad t_F = \left(\frac{9}{5} t_c + 32\right)^\circ F \quad \ldots\ldots\ldots (2.10)$$

The Eq. (2.10) enables us to convert a temperature measurement from one scale to the other.

SELF-ASSESSMENT EXERCISE 1

Covert 50ºF to Celsius scale.

Now, let us discuss the examples of X property for different thermometers with Celsius scale.

(a) Platinum thermometer

X is in terms of resistance (R), thus

$$t = \frac{R_t - R_o}{R_{100} - R_0} X100^o C \quad \text{...........(2.11)}$$

(b) Mercury thermometer

X is in terms of length of mercury L.

$$t = \frac{L_t - L_o}{L_{100} - L_0} X100^o C \quad \text{...........(2.12)}$$

(c) Constant Volume thermometer

$$t = \frac{P_t - P_o}{P_{100} - P_0} X100^o C \quad \text{...........(2.13)}$$

(d) Constant Pressure thermometer

X is in terms of the volume of the gas at constant pressure

$$t = \frac{V_t - V_o}{V_{100} - V_0} X100^o C \quad \text{...........(2.14)}$$

SELF-ASSESSMENT EXERCISE 2

A platinum resistance thermometer has a resistance of 10.40 ohms at 0ºC and 14.35 ohms at 100ºC. Assuming that the resistance changes uniformly with temperature, what is

(a) The temperature when the resistance is 11.19 ohms?
(b) The resistance of the thermometer when the temperature is 45oC?