Unit 2. MEASUREMENT OF TEMPERATURE

2.1 Definition

Temperature (T) is defines as the degree of hotness or coldness of a body. Temperature is one of the seven SI base quantities and it is measure in Kelvin (K). Temperature of a body has no upper limit but it has lower limit (absolute zero or zero Kelvin)

Heat (Q) is a form of energy that is transferred from one part of a substance to another, or from one body to another by virtue of a difference in temperature (i.e. temperature gradient). The unit of heat is in Joules (J).

Sign of heat (Q)

Q is **positive** when there is a flow of **heat into** the system

Q is **negative** when there is a flow of **heat out** of the system

2.2 Zeroth Law of Thermodynamics

From the concept of heat and temperature discussed above in chapter 1, it is now clear that if two bodies are in thermal contact there will be heat exchange (provided they are not at the same temperature). This process of heat transfer will continued until the two bodies attained the same temperature. Then it is said that thermal equilibrium is reached. Supposed one of the two bodies is in thermal contact with third body, after some time thermal equilibrium will be reached between these two bodies. Using figure 2.1 as an illustration, suppose body B is in thermal contact with bodies A and C but bodies A and C are not in thermal contact. If B is in thermal equilibrium with each of A and C, then A and C are in thermal equilibrium.

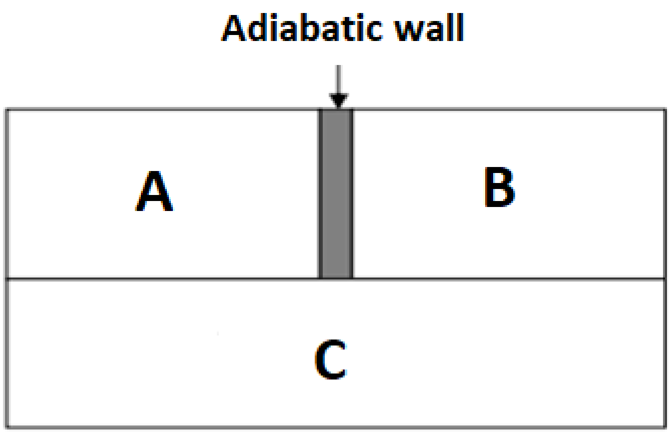

Fig.2.1 a body in thermal contact with two separated bodies

Zeroth Law of thermodynamics states that if bodies A and C are each in thermal equilibrium with a third body B, then they are in thermal equilibrium with each other.

2.3. Temperature Scales

Available temperature scales are; the Celsius scale (also known as the Centigrade scale), the Fahrenheit scale, the Kelvin scale, the Rankine scale, and the international thermodynamic temperature scale

2.3.1 Triple Point of Water

In setting up a temperature scale, there is need to pick some reproducible thermal phenomenon and, quite arbitrarily, assign a certain Kelvin temperature to its environment; that is, we select a standard fixed point and give it a standard fixed-point temperature. Triple point of water is the temperature at which solid ice, liquid water, and water vapor coexist in thermal equilibrium at the same temperature and pressure. By international convention, the triple point of water is 273.16 K and this value is a standard fixed-point temperature (T3) for the calibration of thermometers.

$$\mathbf{T3 = 273.16\ K \qquad 2.1}$$

Other fixed-point temperatures besides T3 are boiling point of water, and absolute zero temperature. The boiling point of water is 100 °C while the absolute zero temperature (0 K) is the all gases have zero volume.

2.3.2 Conversion between Temperature Scales

There is possibility of changing from one temperature scale to another. The conversion formulas are listed below.

Kelvin scale to Celsius Temperature Scale

The relation between Kelvin scale and Celsius scale is

$$\mathbf{Tc = (T - 273.15)\ ^\circ C \qquad 2.2}$$

where T_C is the temperature in degree centigrade, and T is the temperature in Kelvin. Kelvin Temperature scale. The relation between Celsius scale and Kelvin scale is

$$\mathbf{T = (T_C + 273.15)\ K \qquad 2.3}$$

where T_C is the temperature in degree centigrade, and T is the temperature in Kelvin.

Fahrenheit Temperature scale

The relation between Celsius scale and Fahrenheit scale is

$$T_F = 9/5\ Tc - 32 \qquad 2.4$$

where T_c is the temperature in degree centigrade, and T_F is the temperature in Fahrenheit.

2.4 Thermometers

Thermometers are instruments used to measure the temperature of a body or a system.

2.4.1 Thermometric Properties

It has been observed experimentally that the properties of many bodies or objects change with temperature. Examples of such properties are volume of liquid, length of metal rod, and electrical resistance of a wire. These properties of material can be used as the basis of an instrument to measure temperature and they are called Thermometric Properties.

2.4.2 Calibration

Generally, calibration is the process of comparing the output value an instrument is given with that of a standard instrument (i.e. the one that its output is known to be true or correct value). From this process, adjustment can then be made to the instrument to be calibrated to give a correct output. When this is done, the instrument is said to be calibrated.

The method being employed in calibrating thermometers is to use the device to measure the easily reproducible temperatures like triple point of water and boiling point of water. If the thermometric property being used is recorded at these two temperatures, a linear graph can be plotted using these two set of variables. From this graph, a linear relationship can be obtained between temperature and the thermometric property.

In another way, one can measure the thermometric property, say X, when the thermometer is placed in contact with the system or body which temperature is to be measured. Then we have

$$T(X) = aX \qquad 2.5$$

where T_X is the temperature of the body to be measured, a is a constant, and X is the value of the thermometric property at T_X . Equation is also applies when the thermometer is placed in contact with easily reproducible temperature. The triple point of water is mostly used. Then we have

$$T3 = 273.16\ K = a\ X3 \qquad 2.5$$

so we obtain

$$\mathbf{a = 273.6K/X3} \qquad \mathbf{2.7}$$

Insert equation 2.7 into equation 2.6

$$\mathbf{T(X)= (2736K)\ X/X3} \qquad \mathbf{2.8}$$

Equation 2.8 is generally applicable to all thermometers

2.5 Types of Thermometers

Thermometer is named after the thermometric property used for the construction. For example, thermometric property of the mercury-in- glass thermometer is the length of mercury column, while in the constant-volume gas thermometer the thermometric property is the pressure of the gas. Examples of thermometer are thermocouple thermometer, resistance thermometer, liquid in gas thermometer (e.g. mercury in glass thermometer), and gas thermometer (e.g. constant volume gas thermometer) among others. Three types of thermometer are discussed below.

2.5.1 Thermocouple Thermometer

It has been observed that when two dissimilar metals are joined together to make two junctions, an electromotive force (emf) will flow in the circuit. This emf can be measured using a voltmeter and its value depends on the temperature difference between the junctions. The arrangement is called thermocouple and the observation is known as See beck effect. Thermocouple thermometer is based on the See beck effect.

Thermometric property: emf generated when two junctions made from two different metals are maintained at different temperature.

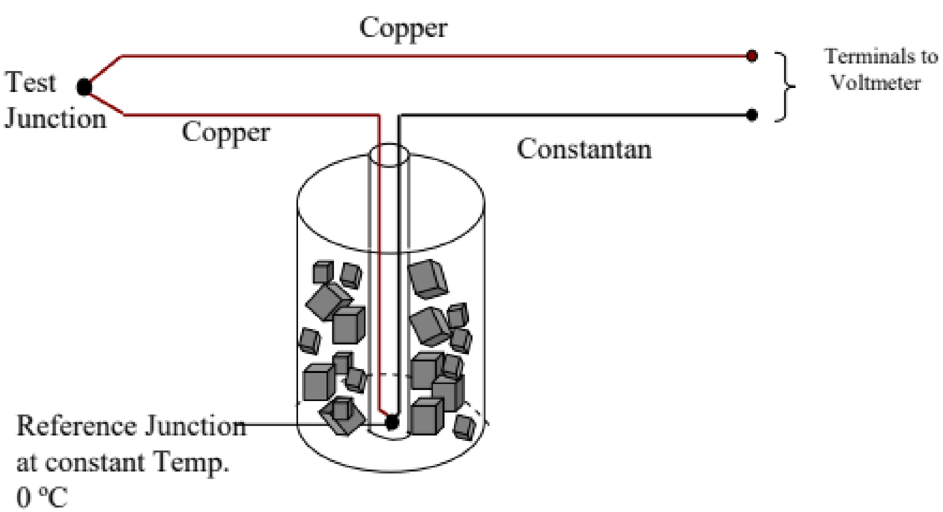

Fig. 2.2. Thermocouple Thermometer

The diagram for Figure 2.2 shows the arrangement for the copper- constantan thermocouple thermometer. The test junction is placed on the body or inside the system whose temperature is to be measured, while the reference junction is maintained at constant temperature at 0 ºC. The potentiometer is connected to the terminals to the voltmeter. The relationship between the emf and temperature is

$$\mathbf{emf = a + bT + cT^2 + dT^3} \quad \mathbf{2.9}$$

Where a, b, c, and d are constant and they are different for each thermocouple.

Using equation 2.8, we can write

$$T(emf) = (273.16\,K)\frac{emf}{emf_3} \qquad \mathbf{2.10}$$

The range of measurement of thermocouple thermometer depends on the choice of metals used. For example, a platinum-10 % rhodium/platinum thermocouple has temperature range of 0 to 1600 ºC. Thermocouple thermometer is used extensively in scientific laboratories.

2.5.2 Resistance Thermometer

Electrical conductivity of a metal depends on the movement of electrons through its crystal lattice. The electrical resistance of a conductor, due to thermal excitation, varies with temperature. This forms the basic principle of operation of resistance thermometer Resistance thermometer therefore, uses the variation in electrical conductivity of a conductor to indicate temperature. Figure shows a generalized form of a resistance thermometer. In the diagram, RT is the resistance element which could be any conductor (e.g. platinum). This is usually wound round a frame constructed so as to avoid excessive strains when the wire contracts upon cooling. S is the power supply and the purpose is to maintain a known constant current in the thermometer while measuring the potential difference with the aid of a bridge output (usually a sensitive potentiometer).

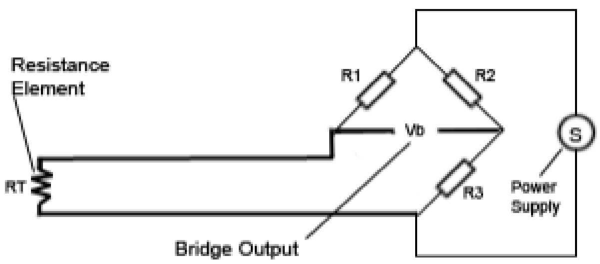

Fig.2.3. Resistance Thermometer

The relationship between the temperature and the electrical resistance is usually non-linear and described by a higher order polynomial:

$$\mathbf{R(T) == R_0\ (1 + AT + BT^2 + CT^3 + ...) \qquad 2.11}$$

Where T is the Celsius temperature, Ro is the nominal resistance at a specified temperature, and A, B, C are constants. The number of higher order terms considered is a function of the required accuracy of measurement. The constants (i.e. A, B and C etc.) depend on the conductor material used and basically define the temperature-resistance relationship. The value R_0 is referred to as nominal value or nominal resistance and is the resistance at 0°C. Material most commonly used for resistance thermometers are Platinum, Copper and Nickel. However, Platinum is the most dominant material internationally.

The calibration of this instrument requires the measurement of R (T) at various known temperatures and from these the constants in equation 2.11 can be obtained. However, equation 2.8 can be used to obtained

$$\mathbf{T\ (R) = (273.16\ K)\ R / R3 \qquad 2.12}$$

Where T (R) is the temperature of the body or system to be measured, R is the resistance at that temperature, and R3 is the resistance at triple point of water?

The range of measurement of resistance thermometer depends on the choice of conductor used. Platinum resistance has a very accurate measurement within -253 to 1200 ºC.

2.5.3 Constant-Volume Gas Thermometer

Constant-Volume gas thermometer is normally referred to as the standard thermometer and is mostly used to calibrate other thermometers. The working principle is based on the pressure of a gas in a fixed volume. Figure 2.4 shows an example of a constant-volume gas thermometer. It consists of a gas-filled bulb connected by a tube to a mercury manometer. By raising and lowering reservoir R, the mercury level on the left can always be brought to the zero of the scale to keep the gas volume constant (Note that variation in the gas volume can affect temperature measurement).

The basic equation is

$$\mathbf{P = P_0 - \rho.g.h \qquad 2.13}$$

where $\mathbf{P_0}$ is the atmospheric pressure, $\boldsymbol{\rho}$ is the density of the mercury in the manometer, g is the acceleration due to gravity, and **h** is the measured difference between the mercury level in the two arms of the tube.

The difference in height h between the two arms of the manometer can be measured when the gas filled bulb is surrounded by the system which temperature is to be measured, and when it is surrounded with water at triple point. Using equation 2.8, the relationship between temperature and the pressure of the gas is

$$\mathbf{T(P) = (273.16K).(P/P3)} \qquad \mathbf{2.14}$$

Where T (P) is the temperature of the system which temperature is to be measured, P is the pressure of the gas at that temperature, and P3 is the pressure at triple point.

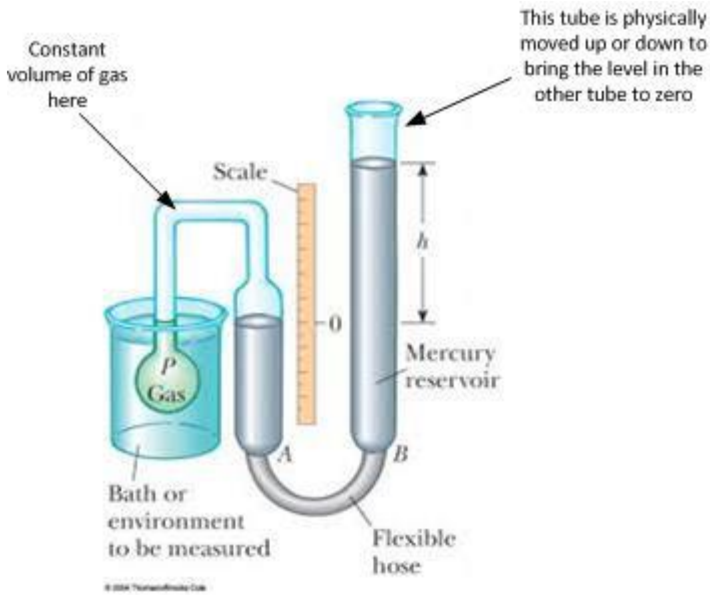

Fig. 2.4: Schematic of Constant-Volume Gas Thermometer (after Halliday et al., 2001)