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## CHAPTER ELEVEN

# THERMAL PROPERTIES OF MATTER

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### 11.1 INTRODUCTION

We all have common sense notions of heat and temperature. Temperature is a measure of 'hotness' of a body. A kettle with boiling water is hotter than a box containing ice. In physics, we need to define the notion of heat, temperature, etc., more carefully. In this chapter, you will learn what heat is and how it is measured, and study the various processes by which heat flows from one body to another. Along the way, you will find out why blacksmiths heat the iron ring before fitting on the rim of a wooden wheel of a horse cart and why the wind at the beach often reverses direction after the sun goes down. You will also learn what happens when water boils or freezes, and its temperature does not change during these processes even though a great deal of heat is flowing into or out of it.

### 11.2 TEMPERATURE AND HEAT

We can begin studying thermal properties of matter with definitions of 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. Note that hot and cold are relative terms, like tall and short. We can perceive temperature by touch. However, this temperature sense is somewhat unreliable and its range is too limited to be useful for scientific purposes.

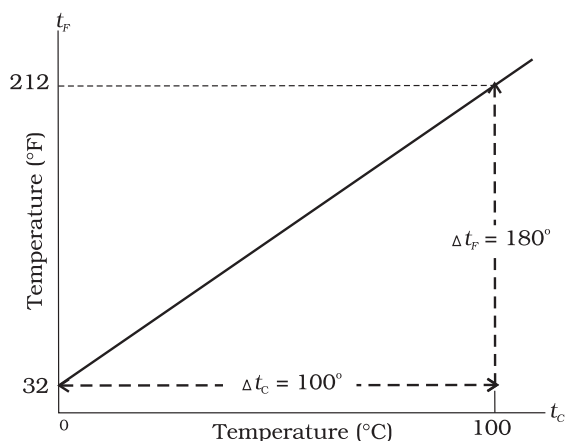
We know from experience that a glass of ice-cold water left on a table on a hot summer day eventually warms up whereas a cup of hot tea on the same table cools down. It means that when the temperature of body, ice-cold water or hot tea in this case, and its surrounding medium are different, heat transfer takes place between the system and the surrounding medium, until the body and the surrounding medium are at the same temperature. We also know that in the case of glass tumbler of ice-cold water, heat flows from the environment to

the glass tumbler, whereas in the case of hot tea, it flows from the cup of hot tea to the environment. So, we can say that **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 degree Celsius ( $^{\circ}\text{C}$ ) is a commonly used unit of temperature. When an object is heated, many changes may take place. Its temperature may rise, it may expand or change state. We will study the effect of heat on different bodies in later sections.

### 11.3 MEASUREMENT OF TEMPERATURE

A measure of temperature is obtained using a thermometer. Many physical properties of materials change sufficiently with temperature. Some such properties are used as the basis for constructing thermometers. The commonly used property is variation of the volume of a liquid with temperature. For example, in common liquid-in-glass thermometers, mercury, alcohol etc., are used whose volume varies linearly with temperature over a wide range.

Thermometers are calibrated so that a numerical value may be assigned to a given temperature in an appropriate scale. For the definition of any standard scale, two fixed reference points are needed. Since all substances change dimensions with temperature, an absolute reference for expansion is not available. However, the necessary fixed points may be correlated to the physical phenomena that always occur at the same temperature. The ice point and the steam point of water are two convenient fixed points and are known as the freezing and boiling points, respectively. These two points are the temperatures at which pure water freezes and boils under standard pressure. The two familiar temperature scales are the Fahrenheit temperature scale and the Celsius temperature scale. The ice and steam point have values  $32^{\circ}\text{F}$  and  $212^{\circ}\text{F}$ , respectively, on the Fahrenheit scale and  $0^{\circ}\text{C}$  and  $100^{\circ}\text{C}$  on the Celsius scale. On the Fahrenheit scale, there are 180 equal intervals between two reference points, and on the Celsius scale, there are 100.



**Fig. 11.1** A plot of Fahrenheit temperature ( $t_F$ ) versus Celsius temperature ( $t_C$ ).

A relationship for converting between the two scales may be obtained from a graph of Fahrenheit temperature ( $t_F$ ) versus Celsius temperature ( $t_C$ ) in a straight line (Fig. 11.1), whose equation is

$$\frac{t_F - 32}{180} = \frac{t_C}{100} \quad (11.1)$$

### 11.4 IDEAL-GAS EQUATION AND ABSOLUTE TEMPERATURE

Liquid-in-glass thermometers show different readings for temperatures other than the fixed points because of differing expansion properties. A thermometer that uses a gas, however, gives the same readings regardless of which gas is used. Experiments show that all gases at low densities exhibit same expansion behaviour. The variables that describe the behaviour of a given quantity (mass) of gas are pressure, volume, and temperature ( $P$ ,  $V$ , and  $T$ ) (where  $T = t + 273.15$ ;  $t$  is the temperature in  $^{\circ}\text{C}$ ). When temperature is held constant, the pressure and volume of a quantity of gas are related as  $PV = \text{constant}$ . This relationship is known as Boyle's law, after Robert Boyle (1627–1691), the English Chemist who discovered it. When the pressure is held constant, the volume of a quantity of the gas is related to the temperature as  $V/T = \text{constant}$ . This relationship is known as Charles' law, after French scientist Jacques Charles (1747–1823). Low-density gases obey these laws, which may be combined into a single