1.1 NATURE OF HEAT

Prior to the nineteenth century, scientists thought that the sense of hot and cold was related with the amount of heat a body contained. The theory was called the **caloric theory**. In the caloric theory, heat is considered to be a "weightless fluid" that flowed from a hot body to a cold body with the total quantity being conserved. This viewpoint of heat is no longer held since experiments have suggested better ways of looking at the phenomena involving heat as we will see below.

In 1798 **Count Rumford**, born as Benjamin Thompson in Massachusetts, USA, presented a paper to the Royal Society of Great Britain in which he described the results of a series of experiments conducted in Munich, Germany concerning heat associated with the boring of cannons. He had observed that in the drilling of canons, the cannons became blazingly hot and water poured to cool them also became very hot. After a series of careful measurements he found that the amount of heat released would be enough to completely melt the canon if it could be returned to the metal. Therefore, he concluded that more heat was being released in the drilling process than could have been originally contained in the metal. This observation contradicted the caloric theory. Rumford concluded that it was the mechanical process of boring that was responsible for heat production and not the supposedly heat present in the metal beforehand. In his own words,

"It appears to me extremely difficult, if not impossible, to form any distinct idea of anything capable of being excited and communicated in the manner that heat was excited and communicated in these experiments, except it be motion."

As a result, physicists consider heat as a form of energy in transit as opposed to an energy that a system contains. When a body at higher temperature comes in a direct contact with another body at lower temperature then the energy transferred from the body at higher temperature to the body at lower temperature is said to be heat.

Rumford also calculated the amount of heat produced in the boring of a cannon and related it to the mechanical energy put in for boring thereby finding the first reported value of the mechanical equivalent of heat. His value expressed in the unit of heat (calories) and the British unit of mechanical energy (Foot-pound) would be 3.15 foot-pound per calorie, which is approximately 1.5% higher than the presently accepted value. Count Rumford also invented many other useful devices, such as the kitchen range, the double boiler, the pressure-cooker and the drip coffee maker.

A clearer demonstration of the mechanical equivalence of heat was provided by James Joule in England in 1840's. To demonstrate the equivalence of mechanical energy and heat, Joule constructed a device where he could measure the mechanical energy and the thermal energy at the same time. In his device, paddle wheels attached to a shaft were placed in a set amount of water in a copper cylinder. The shaft rotated when the strings wrapped over it unwound when the two masses fell (Fig. 1.1). Joule expected that the rotating paddle wheels would force the water molecules to rub against one another and produce heat as a result of the friction between the paddle wheel and the liquid.

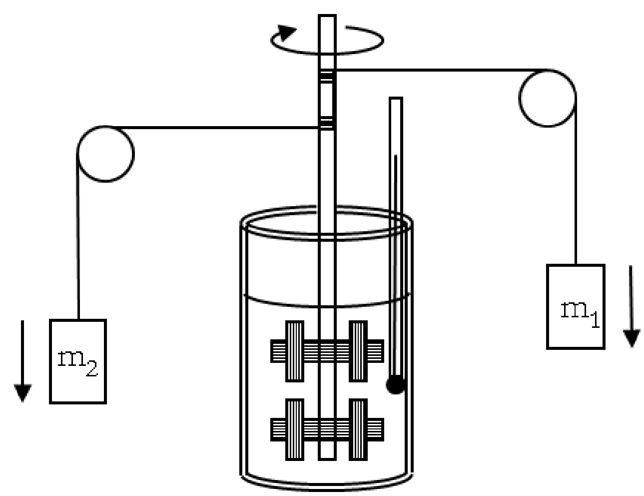

Figure 1.1: Joule's experiment. As the masses fall, the rotating paddle wheel forces the water molecules to rub against each other and produce heat.

The potential energy of the masses provided a measure of the mechanical energy and the change in temperature was measured to figure out the amount of thermal energy. In Joule's set-up, the change in temperature was expected to be very small, approximately 0.2 degrees Celsius. To measure such small differences in temperature Joule constructed his own thermometer, and conducted experiments in a wine cellar, which provided a stable temperature environment. He found that the loss in the mechanical energy was directly proportional to the rise in the temperature. He was also able to put forth a numerical value of the proportionality constant between the work and the thermal energy.

The unit of heat energy, 1 calorie (cal), is defined as the amount of heat needed to raise the temperature of 1 g of water by 1 degree Celsius from 14.5°C to 15.5°C at 1 atm of pressure, while the SI unit of the mechanical work is 1 Joule (J). The proportionality constant between the work and the thermal energy is presently known to be 4.1855 Joules per calorie.

$$\boxed{\text{1 calorie} = \text{4.1855 Joules. (mechanical equivalence)}}$$

In engineering practice in the United States and the Great Britain, heat is also expressed in a unit called the British Thermal Unit or BTU. One BTU is the amount of heat needed to raise the temperature of one pound of water by one degree Fahrenheit. It is equal to 252 calories.

$$\text{1 BTU} = \text{252 calories (units of heat)}$$

Note that nutrition professionals also use a unit of energy called Calorie, which is not the same as 1 calorie defined above, but instead 1000 calories. You might want to remember that 1 nutrition Calorie (written with capital letter C) equals 1000 calories (written with a small letter c).

$$\boxed{\text{1 Nutrition Calorie} = \text{1000 calories.}}$$

Theremal Contact

If two systems can participate in heat transfer, then we say that they are in thermal contact with one another and their contact is often called a **diathermal wall**. If two bodies are insulated from each other so that no heat can be exchanged between them, then the wall is called an **adiabatic wall**. In a **Dewar flask** a vacuum between the outer wall and the inner wall serves as an adiabatic wall (Fig. 1.2). Since energy from a hot body to a cold body can go through vacuum by the mechanism of radiation, in principle, no adiabatic wall can insulate 100%. However, as a practical matter, we can block the heat transfer to a desired degree in most situations of interest.

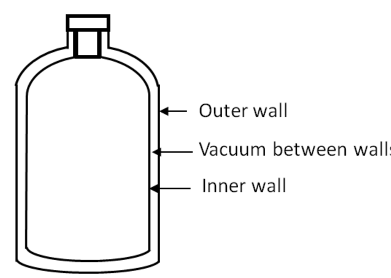

Figure 1.2: The Dewar flask. The vacuum between the outer and inner walls serves as an adiabatic wall and prevents the flow of heat.

Microscopic Picture

Microscopically, heat is related with the change in the translation, vibration and rotation of atoms and molecules in a substance. When we touch a hot cup, the vibrational energy of the molecules of the cup are transferred to the molecules of the skin by physical impulse thereby increasing their energy, which gives us the sensation of heat. This mechanism where the energy of a body is changed without moving its boundaries macroscopically is an example of heat transfer, and the amount of energy transferred in this way is called heat.