13-1 Temperature Scales

In the next chapter, we'll come to a fundamental understanding of what temperature is. Let's begin our investigation of thermal physics, however, by discussing various temperature scales and how to measure temperature.

Temperature is something that has an important impact on our daily lives. In the United States, temperatures in a weather forecast are generally specified in Fahrenheit. In most of the rest of the world, however, such temperatures are given in Celsius. It is useful to know how to convert a temperature from one unit to another. The picture of the thermometer in Figure 13.1 helps us to understand the conversion process to go from Fahrenheit to Celsius, or vice versa, as well as the conversion between Celsius and Kelvin. Note that a temperature of –40°F is the same as a temperature of –40°C. Starting there, every change by 5°C is equivalent to a change of 9°F. This is where the factor of 9/5, or 5/9, in the conversion equations comes from.

$$T_C = \left(\frac{5°\text{C}}{9°\text{F}}\right)\left(T_F - 32°\text{F}\right).$$ (Equation 13.1: **Converting from Fahrenheit to Celsius**)

$$T_F = 32°\text{F} + \left(\frac{9°\text{F}}{5°\text{C}}\right)T_C .$$ (Equation 13.2: **Converting from Celsius to Fahrenheit**)

The Celsius scale is convenient for measuring everyday temperatures. The scale is based on the properties of water, with 0°C corresponding to the freezing point of water, and 100°C corresponding to its boiling point (at standard atmospheric pressure, at least). In scientific work temperatures are usually measured in Celsius, or in Kelvin. The Kelvin scale is an absolute temperature scale, because its zero corresponds to absolute zero. Because an increase by 1°C corresponds to an increase of 1K, it is easy to convert between the two scales.

$$T_C = T_K - 273.16° .$$ (Equation 13.3: **Converting from Kelvin to Celsius**)

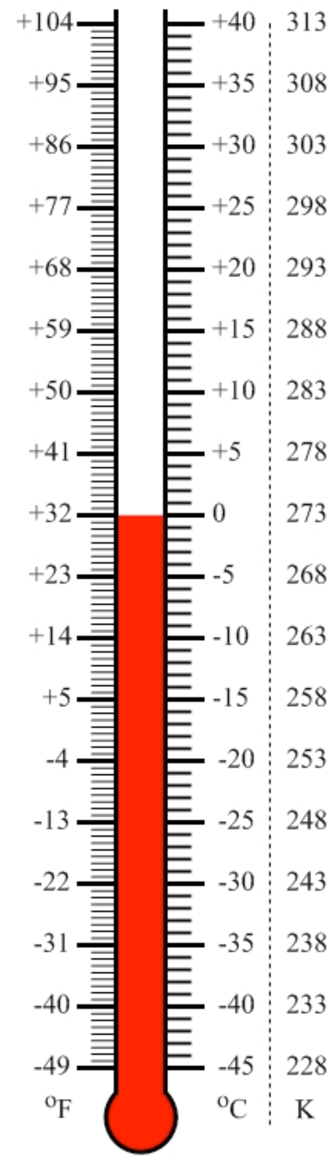

Figure 13.1: A thermometer that is immersed in a cup of ice water (not shown). The thermometer is calibrated in Fahrenheit (°F), Celsius (°C), and Kelvin (K).

In this three-chapter sequence on thermal physics, we will use several equations that involve either the temperature T or the change in temperature ΔT. When an equation involves T the temperature is an absolute temperature – use a temperature in Kelvin. When an equation has ΔT , we can use Celsius or Kelvin, because the change in temperature is the same on the two scales.

Measuring Temperature

There are many devices that can be used to measure temperature, such as the glass thermometer illustrated in Figure 13.1. These used to be filled with mercury but, with mercury now known to have negative health and environmental effects, such thermometers are now usually filled with alcohol. Almost any property of a material that changes with temperature can be exploited to make a temperature-measuring device. Examples include:

- A thermocouple – Two different kinds of metal are bonded together at two junctions. A temperature difference between the two junctions gives rise to a voltage (we'll explore that concept later in the book) that corresponds to that temperature difference.
- A gas-law thermometer – The pressure of a gas in a bulb of fixed volume can be directly converted to temperature via the ideal gas law (see Chapter 14).
- A thermopile – The higher its temperature, the more energy an object gives off. A thermopile picks up such radiated energy, which can be converted to temperature.

How does an alcohol-filled thermometer measure temperature? The thermometer, initially at room temperature (about 20°C), is placed in some hot water. To measure the water temperature, several things happen, which we will explore in the next three chapters:

- Energy is transferred from the water to the thermometer, raising the temperature of the thermometer (and lowering the temperature of the water by a small amount). This transferred energy is known as **heat**. Energy is always spontaneously transferred from the higher-temperature object to the lower-temperature object. Energy can only be transferred in the reverse direction with the aid of something else, such as a heat pump.

- The energy is transferred through the glass wall of the thermometer into the alcohol, through a process known as **thermal conduction**.

- The transfer of energy continues until **thermal equilibrium** is reached (when the thermometer reaches the same temperature as the water).

- As the temperature of the alcohol increases, the alcohol expands, causing the level of alcohol to rise in the thermometer. We exploit this expansion to measure temperature.

We will explore this last process, known as **thermal expansion**, in the next section.

Related End-of-Chapter Exercises: 18 and 20

A note about "heat" and "temperature"

We will discuss the ideas of heat and temperature in more detail in this chapter and in Chapters 14 and 15, but it is not too early to begin distinguishing between these two concepts. The word heat, as a noun, is reserved for a transfer of energy because of a temperature difference. Thus, it is incorrect to say that a hot object contains heat. A hot object has a high temperature, and thus has more **internal energy** (energy associated with the motion of the object's atoms and molecules) when it is warmer than when it is cooler. Temperature, as we will see, is a direct measure of this internal energy.

To add to the confusion, we also use "heat" as a verb, such as "I put the kettle on the stove to heat water so I could make tea." However, note that the meaning of heat as a transfer of energy is preserved here. In this situation, the water's internal energy, and therefore its temperature, increases because of heat (energy transferred to it) from, for instance, a high-temperature element on the stove.

Essential Question 13.1: Consider an alcohol thermometer of the kind drawn in Figure 13.1. Increasing the temperature causes both the alcohol and the glass shell of the thermometer to expand. Predict whether you think the cavity inside the glass (the volume occupied by the alcohol, and the space above the alcohol) increases or decreases because of the expansion of the glass. How does this affect the level of the alcohol? Is the level higher or lower because of the glass expansion than would be achieved by the expansion of the alcohol alone?