Fig. 16.1.

16.1. OVERVIEW

With this unit we begin the study of *thermodynamics*, a new and profoundly different way of studying physical phenomena. Much of the physics studied in previous units involved motions that we could see, while many of the changes we will encounter in thermodynamics will not be visible without the help of indirect measuring instruments such as thermometers and manometers. We will use some of the concepts from mechanics, such as work and kinetic energy, in our discussion of thermodynamics, but we will introduce some new terms as well. Although you have already encountered some of the terms used in the science of thermodynamics, such as *heat transfer* and *temperature*, we will eventually define them more precisely. Other new terms such as *entropy*, *adiabatic process*, and *isothermal process* that will be introduced in the next few units are less familiar.

Temperature is one of the most familiar and fundamental thermodynamic quantities and it is the major focus of study in this first unit on thermodynamics. In general, the measurement of temperature depends on some characteristic of material in a thermometer changing as it is warmed or cooled. Thus, the length of a metal rod, the height of a column of mercury, or the volume of a gas under pressure can serve as means of measuring temperature. When we study electrical phenomena, you will also discover that the electrical current carried by certain materials can change with temperature. Thus, it is possible to use electronic devices to measure temperature. In the early sections of this unit you will use both the familiar glass bulb thermometer and an electronic temperature sensor interfaced to a computer data acquisition system to measure temperature.

In later activities you will take a much more careful look at the concept of temperature. In particular you will observe how the temperature of a substance or system is affected when it interacts with an environment or another substance at a different temperature. Whenever the temperature of something changes, we say glibly that it has undergone a *thermal interaction*. When the temperature of a system remains constant, we refer to it as being in *thermal equilibrium*. Since we cannot see what really goes on when something changes temperature, we have to develop some new concepts to try to explain what is happening. One of these new concepts is that of *thermal energy transfer* (also commonly known as heat transfer).

In the last sections you will combine ideas about temperature change, thermal energy transfer, and internal energy to develop the First Law of Thermodynamics. An understanding of this law is essential to the practical application of thermodynamics to heat engines and other phenomena of vital economic importance. It is also another piece of the energy conservation puzzle that is crucial to our understanding of all physical phenomena.

16.3. TEMPERATURE SCALES

You are probably familiar with the Fahrenheit scale from weather forecasts and you may have worked with the Celsius scale in other science courses. These are just two of the many temperature scales set up by early investigators of heat and thermodynamics. Most of these scales were set up by taking two "fixed points" of reliable, easily reproducible temperatures. The investigator then had to decide how many "degrees" lay between these two temperatures.

The Fahrenheit scale was developed by a German physicist, Gabriel Fahrenheit in 1724. The zero point (0°F) of his scale was supposed to be the lowest temperature attainable with a mixture of ice and salt, while the upper point was human body temperature that he called 96°F. On his original scale the freezing point of water exposed to air at sea level turned out to be about 32°F (the ice point) and the boiling point of water exposed to air at sea level turned out to be about 212°F (the steam point).

In 1742 a Swedish investigator named Celsius devised another scale that he referred to as the centigrade scale. On this scale the freezing point of water exposed to air at sea level was fixed at 0°C and the boiling point of water exposed to air at sea level was fixed at 100°C. Today we use a modification of the original scale that is based on a degree that is the same "size" as the centigrade scale, but is fixed so that the *triple point* of water is 0.01°C. The triple point is defined as the temperature and pressure at which solid ice, water, and vapor can coexist.

Physicists have discovered that there is a natural limit to how cold any object can get. This coldest possible temperature, now called absolute zero, is the zero point of another temperature scale, the Kelvin scale. Since it is based on a "true" zero point, this is a very important temperature scale for thermodynamics. This scale has the same "size" degree as the Celsius scale, and on this scale the triple point of water is 273.16 K (exactly). Conversion between the Celsius scale and the Kelvin scale is very simple since one merely needs to add 273.15 to the temperature in degrees C to get the Kelvin temperature. In other words,

$$T_K = \left(1\frac{\mathrm{K}}{^\circ\mathrm{C}}\right)T_C + 273.15\,\mathrm{K}$$

Conversely,

$$T_C = \left(1\frac{^\circ\mathrm{C}}{\mathrm{K}}\right)T_K - 273.15\,^\circ\mathrm{C}$$

16.3.1. Activity: Defining a Temperature Scale Operationally

a. Define a temperature scale of your own or use one of the standard scales. To do this you should pick *two* objects whose temperatures you suspect are different and seem convenient to measure, assign different values, known as *fixed points,* to the temperatures of these two objects, and then decide how many "degrees" should lie between these assigned values. Use a strip of masking tape on the thermometer to mark your scale. Describe how you set up your scale.

1. The slope m tells us how many Celsius degrees there are for each Fahrenheit degree. You can find out what m is by comparing T(steam) – T(ice) (or other fixed point temperatures) in both scales.

   m = _______ °C/°F

2. The constant b can be solved for by noting that when the Celsius scale is 0°C (the ice point) the Fahrenheit scale is 32°F.

   b = _______ °C

3. The final relation is:

b. Using the same procedure, write down an equation that converts a temperature expressed on the scale you developed in Activity 16.3.1 to the Celsius scale.

c. Express the temperature of this room on the *Kelvin* scale.

16.4. SENSING TEMPERATURE ELECTRONICALLY

Next you will explore temperature measurement with an electronic temperature sensor that can be attached directly to a computer data acquisition system. This system has several advantages over the use of the glass bulb thermometers. The sensors usually respond more quickly to changes in temperature. You can produce a graph of temperature vs. time for one or two sensors at a time automatically. And, as usual, the data you collect can be displayed in tabular form and analyzed. Or you can transfer your data to other programs for further analysis and display. The purpose of this activity is to become familiar with electronic temperature measurement, some limitations of electronic sensing, and features of the data acquisition software you'll need to use in future activities.

16.4.2. Activity: Time Delays

a. When someone pops a thermometer that is at room temperature in your mouth to see if you have a fever, can your temperature be determined immediately? Why not?


Fig. 16.3.

b. Suppose you want to measure room temperature with a thermometer that has been in ice water. Which do you predict would cause more time delay—measuring room temperature water or room temperature air? Explain the reason for your prediction.

c. Use the graphing feature of your temperature software to verify your prediction *quantitatively*. To do this, record how the temperature of an electronic temperature sensor changes over time when it is transferred from ice water to room air and then to room temperature water. Then determine the time it takes for the sensor to reach room temperature in each case.

Ice water to room air: Δt (sec) =

Ice water to room temp water: Δt (sec) =

d. On the basis of these measurements what should you watch out for in making temperature measurements?

e. The temperature difference between room temperature and ice water is about 20°C. What do you think will happen to the measured time delays if the temperature of the sensor is only a degree or two below room temperature? **Hint:** Your temperature vs. time graphs contain the answer.