Evolution of the Thermometer

A thermometer is a device that gauges temperature by measuring a temperature-dependent property, such as the expansion of a liquid in a sealed tube. The Greco-Roman physician Galen (c. 129-c. 199) was among the first thinkers to envision a scale for measuring temperature, but development of a practical temperature-measuring device—the thermoscope—did not occur until the sixteenth century.

The great physicist Galileo Galilei (1564- 1642) may have invented the thermoscope; certainly he constructed one. Galileo's thermoscope consisted of a long glass tube planted in a container of liquid. Prior to inserting the tube into the liquid—which was usually colored water, though Galileo's thermoscope used wine—as much air as possible was removed from the tube.

This created a vacuum (an area devoid of matter, including air), and as a result of pressure differences between the liquid and the interior of the thermoscope tube, some of the liquid went into the tube. But the liquid was not the thermometric medium—that is, the substance whose temperature-dependent property changes were measured by the thermoscope. (Mercury, for instance, is the thermometric medium in many thermometers today; however, due to the toxic quality of mercury, an effort is underway to remove mercury thermometers from U.S. schools.) Instead, the air was the medium whose changes the thermoscope measured: when it was warm, the air expanded, pushing down on the liquid; and when the air cooled, it contracted, allowing the liquid to rise.

EARLY THERMOMETERS: THE SEARCH FOR A TEMPERATURE SCALE.

The first true thermometer, built by Ferdinand II, Grand Duke of Tuscany (1610- 1670) in 1641, used alcohol sealed in glass. The latter was marked with a temperature scale containing 50 units, but did not designate a value for zero. In 1664, English physicist Robert Hooke (1635-1703) created a thermometer with a scale divided into units equal to about 1/500 of the volume of the thermometric medium. For the zero point, Hooke chose the temperature at which water freezes, thus establishing a standard still used today in the Fahrenheit and Celsius scales. Olaus Roemer (1644-1710), a Danish astronomer, introduced another important standard.

Roemer's thermometer, built in 1702, was based not on one but two fixed points, which he designated as the temperature of snow or crushed ice on the one hand, and the boiling point of water on the other. As with Hooke's use of the freezing point, Roemer's idea of designating the freezing and boiling points of water as the two parameters for temperature measurements has remained in use ever since.

Temperature Scales

THE FAHRENHEIT SCALE.

Not only did he develop the Fahrenheit scale, oldest of the temperature scales still used in Western nations today, but in 1714, German physicist Daniel Fahrenheit (1686-1736) built the first thermometer to contain mercury as a thermometric medium. Alcohol has a low boiling point, whereas mercury remains fluid at a wide range of temperatures. In addition, it expands and con-tracts at a very constant rate, and tends not to stick to glass. Furthermore, its silvery color makes a mercury thermometer easy to read. Fahrenheit also conceived the idea of using “degrees” to measure temperature. It is no mistake that the same word refers to portions of a circle, or that exactly 180 degrees—half the number of degrees in a circle—separate the freezing and boiling points for water on Fahrenheit’s thermometer.

Ancient astronomers first divided a circle into 360 degrees, as a close approximation of the ratio between days and years, because 360 has a large quantity of divisors. So, too, does 180—a total of 16 whole-number divisors other than 1 and itself. Though today it might seem obvious that 0 should denote the freezing point of water, and 180 its boiling point, such an idea was far from obvious in the early eighteenth century. Fahrenheit considered a 0-to-180 scale, but also a 180- to-360 one, yet in the end he chose neither—or rather, he chose not to equate the freezing point of water with zero on his scale. For zero, he chose the coldest possible temperature he could create in his laboratory, using what he described as “a mixture of sal ammoniac or sea salt, ice, and water.” Salt lowers the melting point of ice (which is why it is used in the northern United States to melt snow and ice from the streets on cold winter days), and thus the mixture of salt and ice produced an extremely cold liquid water whose temperature he equated to zero. On the Fahrenheit scale, the ordinary freezing point of water is 32°, and the boiling point exactly 180° above it, at 212°. Just a few years after Fahrenheit introduced his scale, in 1730, a French naturalist and physicist named Rene Antoine Ferchault de Reaumur (1683-1757) presented a scale for which 0° represented the freezing point of water and 80° the boiling point. Although the Reaumur scale never caught on to the same extent as Fahrenheit's, it did include one valuable addition: the specification that temperature values be determined at standard sea-level atmospheric pressure.

THE CELSIUS SCALE

With its 32° freezing point and its 212° boiling point, the Fahrenheit system lacks the neat orderliness of a decimal or base-10 scale. Thus when France adopted the metric system in 1799, it chose as its temperature scale not the Fahrenheit but the Celsius scale. The latter was created in 1742 by Swedish astronomer Anders Celsius (1701-1744). Like Fahrenheit, Celsius chose the freezing and boiling points of water as his two reference points, but he determined to set them 100, rather than 180, degrees apart. The Celsius scale is sometimes called the centigrade scale, because it is divided into 100 degrees, cent being a Latin root meaning "hundred." Interestingly, Celsius planned to equate 0° with the boiling point, and 100° with the freezing point; only in 1750 did fellow Swedish physicist Martin Strömer change the orientation of the Celsius scale.

In accordance with the innovation offered by Reaumur, Celsius's scale was based not simply on the boiling and freezing points of water, but specifically on those points at normal sea-level atmospheric pressure.

In SI, a scientific system of measurement that incorporates units from the metric system along with additional standards used only by scientists, the Celsius scale has been redefined in terms of the triple point of water. (Triple point is the temperature and pressure at which a substance is at once a solid, liquid, and vapor.) According to the SI definition, the triple point of water—which occurs at a pressure considerably below normal atmospheric pressure is exactly 0.01°C.

THE KELVIN SCALE.

French physicist and chemist J. A. C. Charles (1746-1823), who is credited with the gas law that bears his name (see below), discovered that at 0°C, the volume of gas at constant pressure drops by 1/273 for every Celsius degree drop in temperature.

This suggested that the gas would simply disappear if cooled to -273°C, which of course made no sense. The man who solved the quandary raised by Charles's discovery was William Thompson, Lord Kelvin (1824-1907), who, in 1848, put forward the suggestion that it was the motion of molecules, and not volume, that would become zero at –273°C. He went on to establish what came to be known as the Kelvin scale. Sometimes known as the absolute temperature scale, the Kelvin scale is based not on the freezing point of water, but on absolute zero—the temperature at which molecular motion comes to a virtual stop. This is –273.15°C (–459.67°F), which, in the Kelvin scale, is designated as 0K. (Kelvin measures do not use the term or symbol for "degree.")

Though scientists normally use metric units, they prefer the Kelvin scale to Celsius because the absolute temperature scale is directly related to average molecular translational energy, based on the relative motion of molecules. Thus if the Kelvin temperature of an object is doubled, this means its average molecular translational energy has doubled as well. The same cannot be said if the temperature were doubled from, say, 10°C to 20°C, or from 40°C to 80°F, since neither the Celsius nor the Fahrenheit scale is based on absolute zero.

CONVERSIONS BETWEEN SCALES.

The Kelvin scale is closely related to the Celsius scale, in that a difference of one degree measures the same amount of temperature in both. Therefore, Celsius temperatures can be converted to Kelvins by adding 273.15. Conversion between Celsius and Fahrenheit figures, on the other hand, is a bit trickier.

To convert a temperature from Celsius to Fahrenheit, multiply by 9/5 and add 32. It is important to perform the steps in that order, because reversing them will produce a wrong figure. Thus, 100°C multiplied by 9/5 or 1.8 equals 180, which, when added to 32 equals 212°F. Obviously, this is correct, since 100°C and 212°F each represent the boiling point of water.

But if one adds 32 to 100°, then multiplies it by 9/5, the result is 237.6°F—an incorrect answer. For converting Fahrenheit temperatures to Celsius, there are also two steps involving multiplication and subtraction, but the order is reversed. Here, the subtraction step is performed before the multiplication step: thus 32 is subtracted from the Fahrenheit temperature, then the result is multiplied by 5/9. Beginning with 212°F, when 32 is subtracted, this equals 180.

Multiplied by 5/9, the result is 100°C—the correct answer. One reason the conversion formulae use simple fractions instead of decimal fractions (what most people simply call "decimals") is that 5/9 is a repeating decimal fraction (0.55555....) Furthermore, the symmetry of 5/9 and 9/5 makes memorization easy. One way to remember the formula is that Fahrenheit is multiplied by a fraction— since 5/9 is a real fraction, whereas 9/5 is actually a mixed number, or a whole number plus a fraction.

Modern Thermometers

MERCURY THERMOMETERS.

For a thermometer, it is important that the glass tube be kept sealed; changes in atmospheric pressure contribute to inaccurate readings, because they influence the movement of the thermometric medium. It is also important to have a reliable thermometric medium, and, for this reason, water—so useful in many other contexts—was quickly discarded as an option. Water has a number of unusual properties: it does not expand uniformly with a rise in temperature, or contract uniformly with a lowered temperature. Rather, it reaches its maximum density at 39.2°F (4°C), and is less dense both above and below that temperature. Therefore alcohol, which responds in a much more uniform fashion to changes in temperature, soon took the place of water, and is still used in many thermometers today. But for the reasons mentioned earlier, mercury is generally considered preferable to alcohol as a thermometric medium.

In a typical mercury thermometer, mercury is placed in a long, narrow sealed tube called a capillary. The capillary is inscribed with figures for a calibrated scale, usually in such a way as to allow easy conversions between Fahrenheit and Celsius. A thermometer is calibrated by measuring the difference in height between mercury at the freezing point of water, and mercury at the boiling point of water. The interval between these two points is then divided into equal increments— 180, as we have seen, for the Fahrenheit scale, and 100 for the Celsius scale.

VOLUME GAS THERMOMETERS.

Whereas most liquids and solids expand at an irregular rate, gases tend to follow a fairly regular pattern of expansion in response to increases in temperature. The predictable behavior of gases in these situations has led to the development of the volume gas thermometer, a highly reliable instrument against which other thermometers including those containing mercury— are often calibrated. In a volume gas thermometer, an empty container is attached to a glass tube containing mercury. As gas is released into the empty container; this causes the column of mercury to move upward.

The difference between the earlier position of the mercury and its position after the introduction of the gas shows the difference between normal atmospheric pressure and the pressure of the gas in the container. It is then possible to use the changes in the volume of the gas as a measure of temperature.

ELECTRIC THERMOMETERS.

All matter displays a certain resistance to electric current, a resistance that changes with temperature; because of this, it is possible to obtain temperature measurements using an electric thermometer. A resistance thermometer is equipped with a fine wire wrapped around an insulator: when a change in temperature occurs, the resistance in the wire changes as well. This allows much quicker temperature readings than those offered by a thermometer containing a traditional thermometric medium. Resistance thermometers are highly reliable, but expensive, and primarily are used for very precise measurements. More practical for everyday use is a thermistor, which also uses the principle of electric resistance, but is much simpler and less expensive. Thermistors are used for providing measurements of the internal temperature of food, for instance, and for measuring human body temperature. Another electric temperature-measurement device is a thermocouple.When wires of two different materials are connected, this creates a small level of voltage that varies as a function of temperature.

A typical thermocouple uses two junctions: a reference junction, kept at some constant temperature, and a measurement junction. The measurement junction is applied to the item whose temperature is to be measured, and any temperature difference between it and the reference junction registers as a voltage change, measured with a meter connected to the system.

OTHER TYPES OF THERMOMETER.

A pyrometer also uses electromagnetic properties, but of a very different kind. Rather than responding to changes in current or voltage, the pyrometer is gauged to respond to visible and infrared radiation. As with the thermocouple, a pyrometer has both a reference element and a measurement element, which compares light readings between the reference filament and the object whose temperature is being measured. Still other thermometers, such as those in an oven that register the oven’s internal temperature, are based on the expansion of metals with heat. In fact, there are a wide variety of thermometers, each suited to a specific purpose. A pyrometer, for instance, is good for measuring the temperature of a object with which the thermometer itself is not in physical contact