TEMPERATURE

A BRIEF HISTORY OF TEMPERATURE MEASUREMENT

Ancient people were physically aware of hot and cold and probably related temperature by the size of the fire needed, and how close to sit, to keep warm.

An Australian tribe, still primitive, uses dogs instead of blankets to keep warm, thus, they can relate temperature by the *dog*. A moderately cool night may require two dogs to keep warm, thus it is a *two-dog night*. An icy night would be a *six-dog night*.

Early people were, at first, fire tenders, maintaining fires originally started by natural causes. Later, they learned how to make fire and became fire makers. Eventually, they became fire managers as they learned to work with fire to gain the heat needed to boil water, cook meat, fire pottery (500°F or 257°C), work with copper, tin, bronze (an alloy of copper and tin) and iron, and to make glass. Although they had no quantitative measuring devices to determine how hot a fire was, they developed recipes for building different types of fires and probably used a physical indicator, such as some mineral or metal melting, to indicate the correct temperature for a particular process.

The ancient Greeks knew that air expanded when heated and applied the principle mechanically, but they developed no means of measuring temperature or amount of heat needed and devised no measuring instruments.

Figure 1. Galileo's air Thermometer

The Italian scientist Galileo (1564-1642) is one of the first recorded to attempt to measure temperature in 1592. His measuring device consisted of a bulb of air, which, when heated, forced liquid (water or spirits of wine [alcohol]) down a column immersed in an open container of the liquid (see Figure 1).   In about 1611, the thermometer was calibrated by Sanctorius Sanctorius, a colleague of Galileo, who noted the liquid level when the bulb was cooled with melting snow and again, when heated with a candle. The space on the column, between these two points was then divided into 110 equal parts.

Jean Rey (1582-1645), a French physician, invented the first liquid thermometer in 1632. His thermometer consisted of a flask with a long slender neck partially filled with water (see Figure 2). As the temperature changed, the liquid level would rise or fall in response.

Figure 2. Rey's liquid thermometer

Unfortunately, it was later realized that these early thermometers were affected by changes in atmospheric pressure.

Sealed, liquid in glass thermometers were first made in about 1644. Of the various liquids used, such as water, alcohol, and mercury, alcohol was preferred since is showed the greatest expansion in response to increases in temperature.
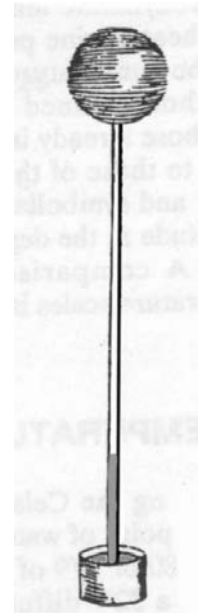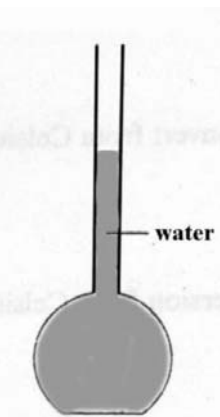
For the next century, most of the attention was given to attaining a reproducible temperature scale and over 35 scales were devised. Normally, the thermometer was calibrated at two temperatures, providing fixed marks, and dividing the interval between them. One such scale was a 12 degree scale devised by Sir Issac Newton (1642-1727) where melting ice was assigned as zero degrees and body temperature as 12 degrees. One of the better scales was that of Ole Romer (1644-1710), a Danish astronomer, who used an ice-salt mixture, which he assigned as zero (degrees), and boiling water which he assigned as 60 (degrees). This made the freezing point of water 8 (degrees) on his scale and body temperature was 22½ (degrees).

Figure 3. Ole Romer

Romer's scale is important in that it influenced Daniel Gabriel Fahrenheit (1686-1736), a Dutch instrument maker of German descent. Fahrenheit, had gained famed for his high quality mercury thermometers (see Figure 4) and the agreement between them when calibrated using his temperature scale. Preferring finer scale divisions than those used by Romer, Fahrenheit used zero for the ice-salt mixture, 32 for the freezing point of water, and 96 for body temperature. Fahrenheit discovered that body temperature varied over the course of a day and searched for a better fixed point for his upper temperature. He finally determined the boiling point of water to be 212 degrees on his scale. Body temperature was later adjusted to approximately 98 degrees. The modern Fahrenheit scale uses the boiling point and freezing point of water as its two fixed points.
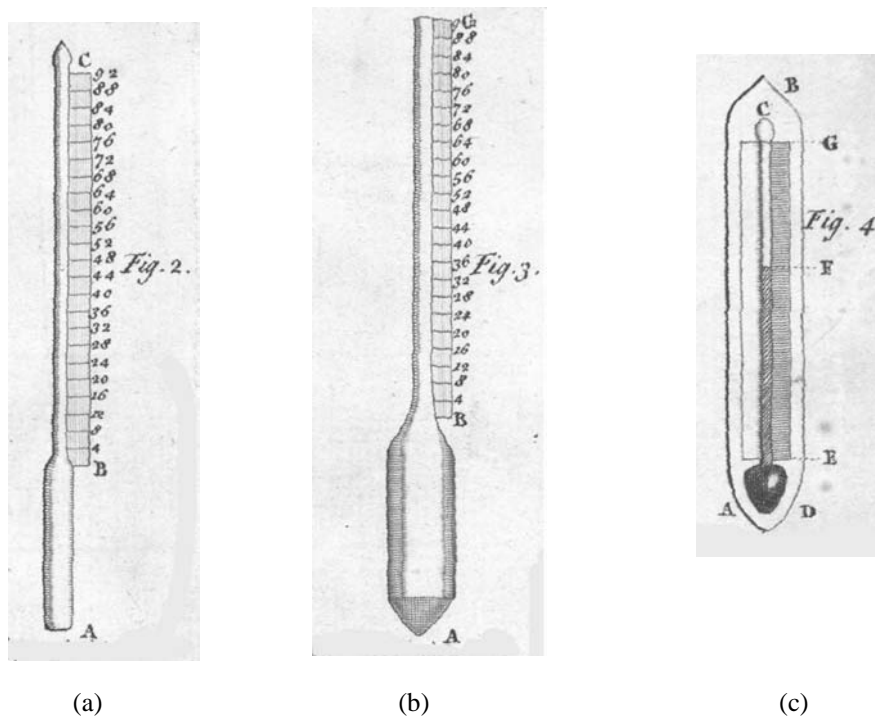

(a)	(b)	(c)

Figure 4. (a) Fahrenheit's first or spirit (alcohol) thermometer. (b) Fahrenheit's second or mercury thermometer. (c) Fahrenheit's third or animal thermometer, also a sealed mercury thermometer. From, Shaw, Peter, *A New Method of Chemistry*, translated from Dr. Boerhaave's Elementa Chemiae, Third Edition, 1753.

The Celsius scale is attributed to the Swedish astronomer Anders Celsius (1701-1744). In 1742, Celsius set up his thermometer scale by assigning 0° to the boiling point of water at a specific barometric pressure, and 100° to the temperature of melting snow. Shortly, thereafter the inverted form of Celsius' scale (*i.e.*, 0° for the freezing point and 100° for the boiling point of water) came into use in Sweden and France known as the Centigrade scale. In 1948, it was officially named the Celsius scale.

The Absolute temperature scale was based on calculations from the gas law of Jacques Charles' and Joseph Gay-Lussac which showed that the volume of a gas decreases by 1/273.15 its volume at 0°C and one atmosphere pressure for each one

Figure 5. Anders Celsius

degree drop in temperature. This law gave rise to the temperature, *absolute zero*, which was defined to be the temperature at which an ideal gas would have no volume and which was determined to be -273.15°C.

In 1848, William Thomson (later Lord Kelvin) (1824-1927) proposed a thermodynamic temperature scaled based on the efficiency of an ideal heat engine proposed in 1824 by Sadi Carnot. Kelvin showed that the temperatures defined through his calculations were identical with those defined by the gas laws. To keep his scale compatible with those already in use, he set the size of the temperature degrees equal to those of the Celsius scale. Thus, the -kelvin (named in his honor and symbolized by K, without the degree sign) has the same magnitude as the degree Celsius.

A comparison of the Fahrenheit, Celsius and Kelvin temperature scales is shown in Figure 7.

Figure 6. Lord Kelvin

	Fahrenheit °F	Celsius °C	Kelvin K
Boiling point of water	212°	100°	373.15
Body temperature	98.6°	36.6°	309.8
Freezing point of water	32.0°	0.0°	273.15
Ice-salt bath	0.0°	-17.6°	255.6
Absolute zero	-459.7°	-273.15°	0.0

Figure 7. Comparison of the Fahrenheit, Celsius, and Kelvin temperature scales.

TEMPERATURE CONVERSIONS

Modern chemistry works in the Celsius andd Kelvin scales. Conversion from Celsius to Kelvin requires simple addition since the degrees are the same size. The formula is:

$$K = °C + 273$$

Example:

The boiling point of ethylene glycol, a substance used as antifreeze in automobiles, is 198°C. Express this temperature in K.

Solution:

This problem involves a conversion from °C to K. Use the equation:

$$K = °C + 273$$

Substitute 198 for °C:

$$K = 198 + 273$$

$$= 471 K$$

Remember that there is no degree sign used with Kelvin temperatures.

Generally, there is little need to convert between Fahrenheit and Celsius, however, examples of these conversions are included for information purposes only.

Comparing the Celsius and the Fahrenheit temperature scales there is a difference of 180 F° between the freezing point of water and its boiling point as compared with 100 C°. The average size of a Fahrenheit degree is 100/180 or 5/9 of a Celsius degree. To convert from Fahrenheit to, we also have to take into account that there is a 32° difference in starting temperature. Thus the formula for the temperature conversion from Fahrenheit to Celsius is:

$$°C = \frac{5}{9} \times (°F - 32)$$

Tthe formula for the temperature conversion from Celsius to Fahrenheit is:

$$°F = (\frac{9}{5} \times °C) + 32)$$

Examples:

Room temperature is usually about 70°F. Express the temperature in °C.

Solution:

This problem involves a conversion from °F to °C. Use the equation:

$$\degree C = \frac{5}{9} \times (\degree F - 32)$$

Substitute the Fahrenheit temperature for °F:

$$\degree C = \frac{5}{9} \times (70 - 32)$$

Subtract the 32:

$$\degree C = \frac{5}{9} \times (38)$$

Multiply by 5 and divide by 9:

$$\degree C = 21.1 \degree C$$

Pure aspirin melts at 135°C. Express this temperature in °F

Solution:

This problem involves a conversion from °C to °F. Use the equation:

$$\degree F = (\frac{9}{5} \times \degree C) + 32$$

Substitute the Celsius temperature for °C:

$$\degree F = (\frac{9}{5} \times 135) + 32$$

In this example, the 5 divides evenly into the 135:

$$\degree F = (9 \text{ x } 27) + 32$$

$$= (243) + 32$$

$$= 275\degree F$$

Problems: Temperature Conversion

1. Dry ice, carbon dioxide, sublimes (*i.e.*, goes from a solid to a gas without melting) at -78.5°C. Express this temperature in K.

2. Room temperature is usually considered to be 20°C. Express this temperature in K.

3. Liquid nitrogen boils at -195°C. Express this temperature in K.

(Optional)   Some conversions between Fahrenheit and Celsius

4. A recipe calls for baking a cake at 400°F. Express this temperature in °C.

5. The temperature on a cold winter day is 20°F. Express this temperature in °C.

6. The boiling point of ethyl alcohol is 78.5°C. Express this temperature in °F.

7. A cooling bath composed of dry ice (solid carbon dioxide) and acetone is used to maintain a temperature of -80°C. Express this temperature in °F.

8. The temperature of the surface of the sun is about 6,300°C. Express this temperature in °F.