



# Fundamentals of Temperature Measurement

An Online Continuing Education Course for Engineers

**Course Number: IC-2001**

**Credit: 2 Hours / 2 PDH / 2 CPD**

# Fundamentals of Temperature Measurement

This course covers the basic methods used to measure temperature in commercial, municipal and industrial applications. It is intended to be an introductory course and somewhat broad in discussing early-to-current methods of measurement. It will also discuss applications and conditions that can influence the accuracy and repeatability of various types of electronic temperature sensors; including thermocouples, thermistors, RTDs, and infrared technology.

## *Brief History of Temperature Measurement*

In the early 1600s an Italian physicist named Santorio Santorio developed a crude thermometer-like device which he referred to as a “thermoscope”. In some ways resembling the liquid-filled thermometer of today, it lacked any sort of calibrated scale; and the tube was open to the atmosphere, which adversely affected its accuracy due to variations in barometric pressure.

Also in the early 1600s, among his other scientific credits, Galileo Galilei reportedly invented another style of thermoscope, sometimes referred to as a “Galileo Thermometer”. This type of instrument, which is still available as more of a decorative item than a functioning thermoscope, operates on the principal of buoyancy. As the temperature of the clear fluid contained within its vertical glass cylinder increases, the fluid expands and its density decreases, causing small glass spheres that are each filled with a uniquely-colored fluid that has a slightly different specific density corresponding to a specific temperature, to sink within the cylinder as their density becomes greater than that of the clear fluid in which they are submerged. The temperature is read from a small engraved metal disc on each sphere. The current approximate temperature is indicated by the lowest floating glass sphere within the cylinder, such as the yellow liquid filled glass sphere appearing in the thermoscope shown in Figure No. 1 below.

Further development of temperature measurement, still using a fluid as the indicator and a calibrated scale to measure the fluids displacement in relation to temperature is credited to such scientists as Ole Christensen Rømer, who in 1701 reportedly made one of the first practical thermometers using red wine as the indicator; Daniel Gabriel Fahrenheit, who soon after developed a more accurate mercury-filled thermometer and thermometer scale; and Anders Celsius (also in the 1700s), who developed a metric scale of temperature measure. William Thompson (Lord Kelvin) and William Rankin were credited in the mid-1800s with having broadened the calibrated temperature measurement scale range to include “absolute zero”, thus making it more useful for research purposes.

As technology in the areas of physics, metallurgy and electronics have progressed since the 1800s, so has temperature measurement technology and measurement instrumentation in general.



*Figure No. 1 – Galileo Thermometer (Image Source: Wikipedia)*

Liquid filled temperature indicators were followed by the development of bimetallic and gas-filled instruments, which were later followed by electric and more recently solid state electronic devices. Please note that I said “followed by” and not “replaced by” the next generation of instrumentation. Virtually all of the mentioned technologies are still in use and still commercially available; and that is because each has inherent qualities that make it more suitable than another type for a particular application. For that reason there are many hundreds of variations of the various types and styles of temperature measurement instruments.

### *Measurement Scales*

There are several commonly used scales of temperature measurement that were created in the 16<sup>th</sup> and 17<sup>th</sup> centuries that are still in use today. They include Fahrenheit, Centigrade (also referred to as Celsius), Kelvin, and Rankin. Each is based on a different scale, and must be mathematically converted from one to another in order to determine the equivalent value in another scale. For the most part, outside of scientific applications, the United States uses the Fahrenheit scale, while most of Europe and other parts of the world have standardized on the centigrade scale. The Fahrenheit scale uses 32 degrees as the freezing point of water and 212 degrees as the boiling point of water. By comparison, the centigrade scale uses zero as the freezing point of water and 100 degrees as the boiling point of water. Therefore, in order to convert a temperature from Fahrenheit to centigrade, one would have to use the equation

$$\text{Degrees } C = (\text{Degrees } F - 32) \times 5/9$$

The centigrade scale conforms to the metric system, which is based upon units of ten.

Kelvin and Rankin scales are primarily used in scientific research and reporting, where temperature conditions outside of the normal day to day environment are investigated and

explored. It is not necessary that we know each day how close the outdoor or indoor temperature, for example, are to absolute zero. Absolute zero is considered to be minus 273.15 centigrade, or zero degrees Kelvin - the theoretical temperature at which molecular movement, which is the fundamental source of heat energy, ceases. In other words, there is a total absence of heat at absolute zero. On a Kelvin scale the freezing point of water is 273.15 and the boiling point of water is 373.15 degrees.

Converting a temperature from Fahrenheit to the Kelvin or to Rankin equivalent requires using the formulas

$$\text{Degrees } K = (\text{Degrees } F + 459.67) \times 5/9$$

$$\text{Degrees } R = \text{Degrees } F + 460$$

We will not go further in depth in our discussion of the various temperature scales, as they are easily converted from one to another and the rest of this course topic will use either Fahrenheit or centigrade as the reference scale.

### *Early Methodology*

As already mentioned, the earliest methods of temperature measurement were mechanical in nature and used a fluid, such as colored water, oils or alcohol, as the indicator; and then applied a linear scale of change in the fluid's density in relation to its temperature. For centuries, what became a standard of temperature measurement was the glass tube filled with liquid mercury and later largely replaced by one containing red alcohol, as shown in Figure 2 below.



*Figure No. 2 – Standard Glass Thermometer*

Another, non-fluid method of measuring temperature that was developed much later uses a helically-wound bimetallic strip to operate a dial type indicator, such as that shown in Figure No. 3. A bimetallic strip consists of two thin layers of different metals that have

different coefficients of expansion, such as brass and steel that have been bonded together. With a given change in temperature, the two bonded metals expand at different rates, causing the strip to distort (bow) in the direction of the metal with the lesser coefficient of expansion. By arranging the bimetallic strip in a helical pattern, the differences in the expansion rates of the bonded metals cause the helix to partially coil or uncoil as their temperature changes. That movement, when mechanically attached to the dial of an indicator, causes the dial to move somewhat proportionally in response to a change in sensed temperature.



*Figure No. 3 – Dial Thermometer*

Older style, non-digital, wall-mounted room thermostats that control central residential and commercial heating and air conditioning systems have an integral thermometer mounted in the thermostat cover. By carefully removing the cover and examining the back of it, you can typically see the helical bimetallic element of the thermometer. U.S. patents are held on the helical bimetallic strip designs that are currently on the market.

Yet another mechanically-actuated type of temperature measurement device used the principal of the expansion of gases (vapor) according to the ideal gas law. This type of device is often referred to as a “filled system” thermometer. As temperature increases (and vice-versa) the liquid or vapor will expand and increase the pressure within a metallic bulb (hollow probe) and attached capillary tube to move a connected diaphragm or bellows at the indicator on the other end of the capillary. Movement of that diaphragm or bellows is then mechanically converted into a calibrated dial movement using a cantilever system. An example of a remote bulb thermometer is shown in Figure No. 4.



*Figure No. 4 – Remote Bulb Thermometer*

The advent of the remote bulb thermometer made it possible to monitor temperature without being very close to the point of measurement. When the accessibility of the

measurement location is difficult under normal circumstances, such as reading the temperature of water flowing through a pipe that is fifty feet in the air, having a remote bulb that allows the indicator dial to be down at eye level is very desirable. An added advantage of this type of expanding fluid device is that it operates without electrical current. Therefore, it cannot produce an electrical spark during normal operation, making it intrinsically safe for use in hazardous areas where a flammable or explosive vapor may be present and ignited by the occurrence of a spark.

Development of light emitting diodes (LEDs), liquid crystal displays (LCDs), and large scale integration of electronics to a size comparable to a grain of salt have brought about changes in the technology of temperature measurement in recent years.

Parameters such as accuracy, resolution, and response time are important in the selection of a digital thermometer. Figure 1 shows a digital thermometer with a resolution of 0.1°C.

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Digital value.

As mentioned previously, digital thermometers are most desirable because of their durability and reliability.

### Electronics

Many applications require the use of electric and/or remote control of temperature measurement devices. For electric and/or electronic control, such as a thermocouple, thermistor, or a resistance temperature detector (RTD). So what are these devices, how do they differ from one another, and when and where do you use one type rather than another?