Temperature

The accurate measurement of temperature is vital across a broad spectrum of human activities, including industrial processes (e.g. making steel), manufacturing (e.g. glass products), monitoring (e.g. food transport and storage), and in health and safety (e.g. sterilisation of instruments). In fact, in almost every sector, temperature is one of the key parameters to be measured.

History of thermometry

The means of accurately measuring temperatures has long fascinated people. One of the differences between temperature and other physical concepts, such as mass or length, is that it is subjective: different people will have different perceptions of what is hot and what is cold. To make objective measurements, we must use a thermometer in which some physical property of a substance changes with temperature in a reliable and reproducible way.

Thermoscopes, the ancestors of modern thermometers, have been around since about 200 BC. The first recognisable, modern thermometers were made in the 16th century by both the Italian Galileo Galilei and Santorio Santorio, a physician to the King of Poland. The latter produced a thermometer incorporating a scale, and his writings show that he understood the importance of the temperature measurement in the diagnosis of disease. The first sealed thermometer was made by the Grand Duke Ferdinand of Tuscany in 1641. This thermometer was more accurate than its predecessors since it wasn't dependent on atmospheric pressure. Later, the scientists Fahrenheit and Celsius both made glass thermometers containing mercury, and used reference points (the melting point of pure ice and the boiling point of water) to improve the accuracy.

Temperature scales

The two temperature scales commonly in use today date from the eighteenth century and are named after Gabriel Daniel Fahrenheit and the Swedish astronomy professor Anders Celsius. Fahrenheit designed his scale to have two reference points that could be set up in his workshop. He originally chose the melting point of pure ice and the temperature of a normal human body, which he took as being 32° and 96° respectively. These conveniently gave positive values for all the temperatures he encountered. Later he changed to using the boiling point of water (212°) as the upper fixed point of the scale.

Celsius also used the ice and steam points, but took them to be 0 °C and 100 °C respectively. Although the Celsius scale has taken precedence over the Fahrenheit scale, the latter is still familiar in weather reports in the United Kingdom: a summer's day temperature of 75 °F seems much more pleasant than one of 23 °C!

A third, fundamental, temperature scale was proposed in 1854 by the Scottish physicist William Thomson, Lord Kelvin. It is based on the idea of the absolute zero, the point of no discernible energy, which is independent of any particular material substance. The Kelvin scale is widely used by physicists and engineers to determine and apply fundamental laws of thermodynamics.


200 million °C
The Joint European Torus (JET) nuclear fusion project, Culham Oxfordshire


15 million °C
Temperature of centre of the Sun


6000 °C
Temperature of surface of the Sun


1200 °C to 1500 °C
Molten glass/steel


1064 °C
Melting point of gold


100 °C
Boiling water at one atmosphere of pressure


0 °C
Freezing point of pure water


-89.2 °C
All time coldest point on earth

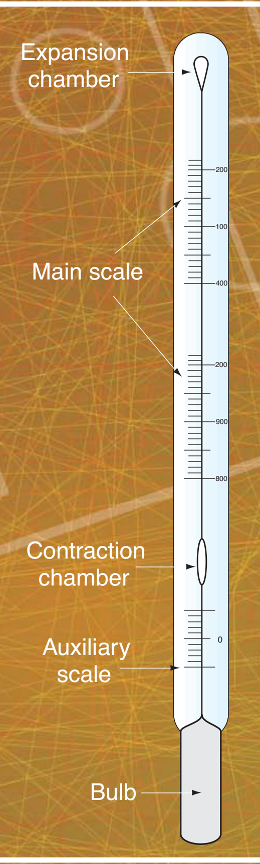

-196 °C
Cryogenic storage in liquid nitrogen


-270 °C
Cosmic background radiation

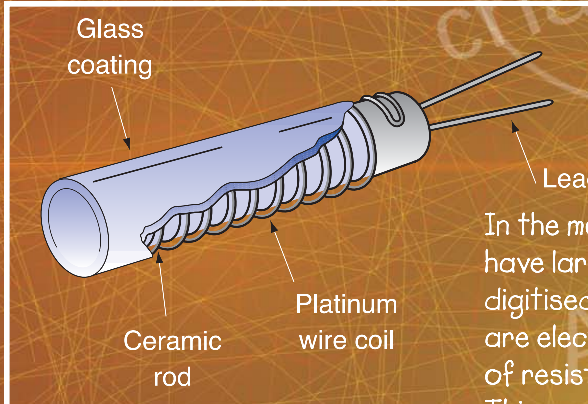
Types of thermometer

Liquid-in-glass

Liquid-in-glass, in particular mercury, thermometers have been used for almost 300 years in science, medicine, metrology and in industry. They rely on the expansion of a fluid with temperature. The fluid is contained in a sealed glass bulb and the temperature is read using a scale etched along the stem of the thermometer.



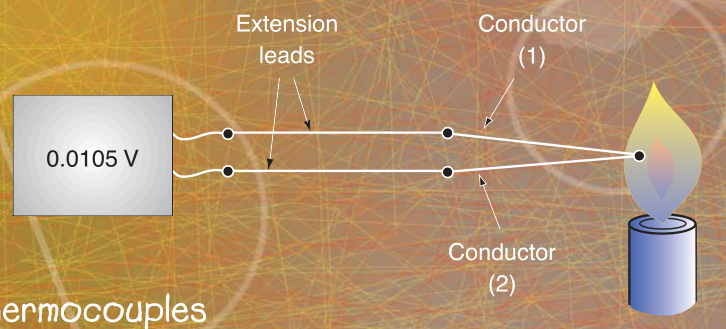
Platinum resistance



In the modern world, mercury and spirit-filled thermometers have largely given way to electrical devices, which can be digitised and automated. Platinum resistance thermometers are electrical thermometers which make use of the variation of resistance of high-purity platinum wire with temperature. This variation is predictable, enabling accurate measurements to be performed. They are sensitive and, with sophisticated equipment, measurements can routinely be made to better than a thousandth part of 1 °C.

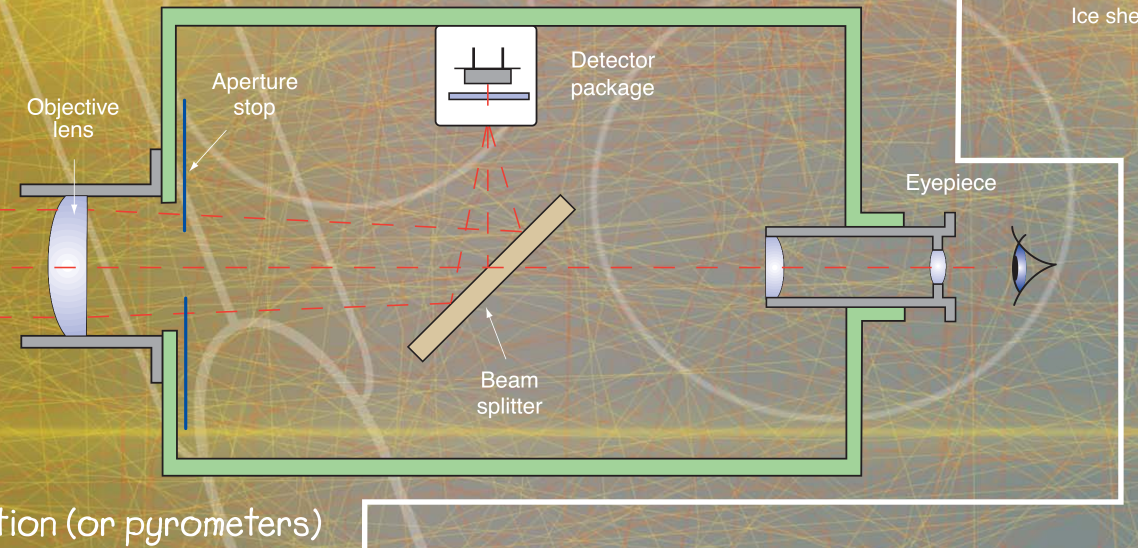
Thermocouples

Thermocouples are the most common sensors in industrial use. They have a long history, the original paper on thermoelectricity by Seebeck being published in 1822. They consist of two dissimilar metallic conductors joined at the point of measurement. When the conductors are heated a voltage is generated in the circuit and this can be used to determine the temperature.



Radiation (or pyrometers)

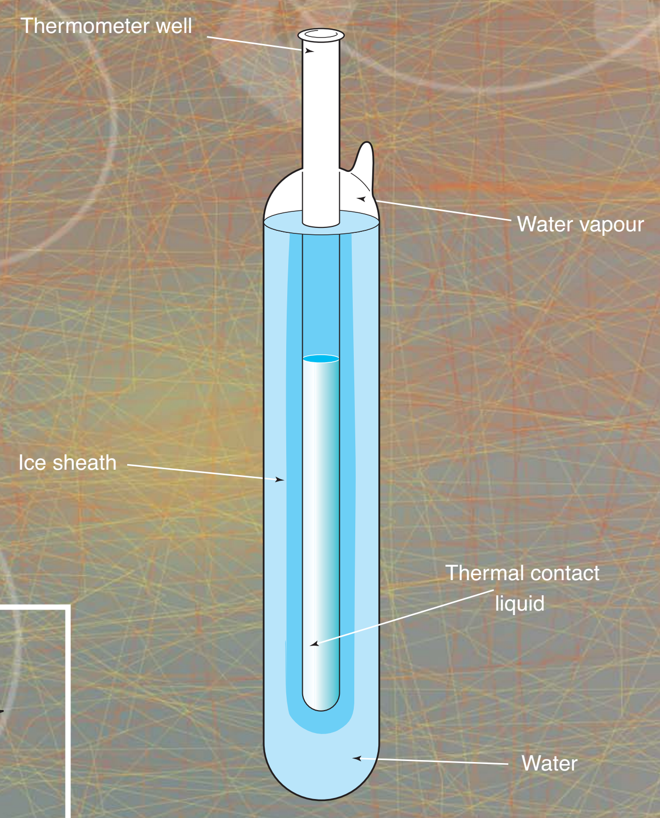
Radiation thermometers, or pyrometers, make use of the fact that all objects emit thermal radiation, as seen when looking at the bars of an electric fire or a light bulb. The amount of radiation emitted can be measured and related to temperature using the Planck law of radiation. Temperatures can be measured remotely using this technique, with the sensor situated some distance away from the object. Hence it is useful for objects that are very hot, moving or in hazardous environments.



The International Temperature Scale of 1990 (the ITS-90)

Since 1954 the unit of (thermodynamic) temperature has been defined as the kelvin, and is the fraction 1/273.16 of the thermodynamic temperature of the triple point of water. This is the unique temperature and pressure at which the three phases of water (solid, liquid and vapour) co-exist in equilibrium. It is fractionally higher than the melting point, being 0.01 °C or 273.16 K. From this single point it is possible to generate a thermodynamic temperature scale using gas thermometers and radiation thermometers which accurately obey known laws.

Such experiments are not easy and are rarely done, but good values have been established for a series of fixed points: freezing points of pure metals at high temperatures and triple points of gases at low temperatures. These are incorporated into the International Temperature Scale so that standard platinum resistance thermometers and radiation thermometers can be calibrated with excellent reproducibility. The National Physical Laboratory maintains the temperature scale (currently the International Temperature Scale of 1990, the ITS-90) in the UK, and compares this with the ITS-90 maintained in other national laboratories. In this way temperature standards around the world can be accurately equivalent, and all manner of thermometers can be reliably calibrated for everyday use.



Triple point of water cell - definition of the kelvin

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