Thermometers

A thermometer is a device that measures temperature or temperature gradient, using a variety of different principles. The word thermometer is derived from two smaller word fragments: *thermo* from the Greek for heat and *meter* from Greek, meaning to measure. A thermometer has two important elements, the temperature sensor (e.g. the bulb on a mercury thermometer) in which some physical change occurs with temperature, plus some means of converting this physical change into a value (e.g. the scale on a mercury thermometer). Industrial thermometers commonly use electronic means to provide a digital display or input to a computer.

Types of Thermometers

The Liquid in Glass Thermometer.

The Liquid in Glass thermometer utilizes the variation in volume of a liquid in temperature. They use the fact that most fluids expand on heating. The fluid is contained in a sealed glass bulb, and its expansion is measured using a scale etched in the stem of the thermometer If we consider that the thermometer does not expand then as physical property it utilizes the variation of length of liquid with temperature. Liquid in Glass thermometers have been used in science, medicine, metrology and industry for almost 300 years.

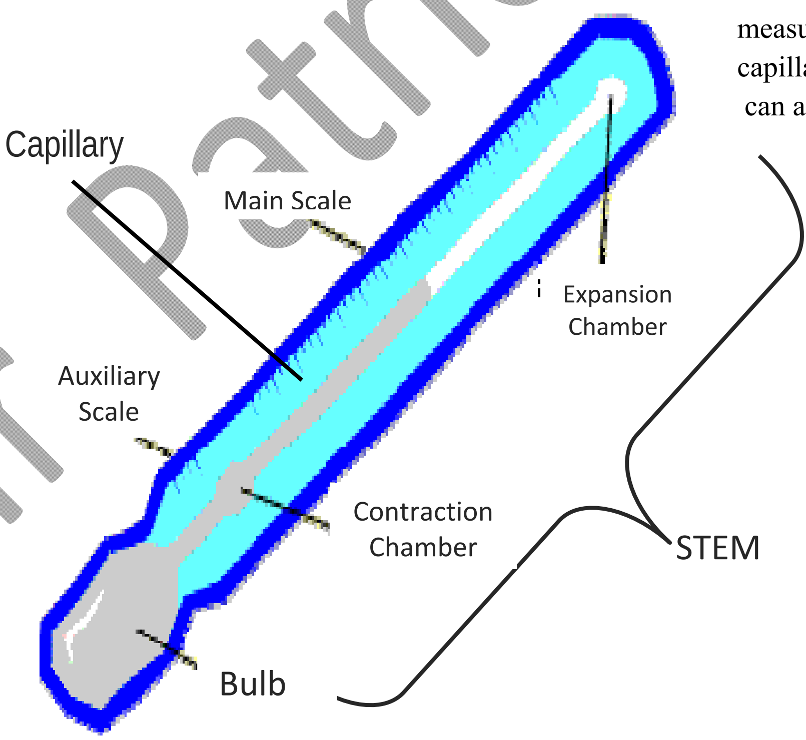
Liquids commonly used include Mercury and Alcohol.

Structure:

Two basic parts:

a. **The bulb:** Acting as a reservoir holding the liquid whose volume changes with temperature. The Bulb also acts as a sensor or gauge which is inserted in the body whose temperature is to be measured.

b. **The Stem:** containing the scale that is measuring the temperature and a capillary through which the liquid can accordingly expand and contract



General Properties

Advantages:

1. They are cheap to manufacture
2. Easy to carry and handle.

Disadvantages:

1. They tend to have high heat capacities. They are not sensitive enough, that is they cannot measure rapid temperature changes.

The mercury-in-glass thermometer:

Invented by German physicist Daniel Gabriel Fahrenheit, is a thermometer consisting of mercury in a glass tube. Calibrated marks on the tube allow the temperature to be read by the length of the mercury within the tube, which varies according to the temperature. To increase the sensitivity, there is usually a bulb of mercury at the end of the thermometer which contains most of the mercury; expansion and contraction of this volume of mercury is then amplified in the much narrower bore of the tube. The space above the mercury may be filled with nitrogen or it may be a vacuum.

Range: Covering a wide temperature range from -38 °C to 356 °C, although the introduction of a gas into the instrument can increase the range to 600 °C or beyond.

Advantages:

1. Mercury is a naturally opaque liquid (Silver). This means that it can be directly utilised in its pure form
2. Mercury does not wet glass. When it moves up and down in the capillary strong cohesive properties of mercury do not allow it to leave any traces on the inside of the capillary.
3. Mercury is a liquid metal. As a metal it has high conductive properties that allow it to be more sensitive than the alcohol in glass thermometer.

Disadvantages:

1. Mercury poses a potential toxic hazard if the glass container is ruptured.

The alcohol-in-glass thermometer:

As a liquid it utilises ethyl alcohol, toluene and technical pentane, which can be used down to -200 °C.

Range c. -200 °C to 80°C, though range tends to be highly dependent on the type of alcohol used.

Advantages:

1. It can measure very low temperatures.

Disadvantages:

1. Alcohol is transparent therefore it requires a dye to make it visible. Dyes tend to add impurities that may not have the same temperature range as the alcohol making reading difficult especially at the limits of each liquid.

2. Alcohol wets glass.

General Equation for Temperature calculation using a liquid in glass thermometer:

$$\Theta = \left[\frac{L_{\Theta} - L_0}{L_{100} - L_0} \right] \times 100$$

The resistance thermometer

Makes use of the change of resistance in a metal wire with temperature. As electrons move through a metal, they are impeded by the thermal vibrations of the atoms in the crystal lattice. The higher the temperature the greater the impediment to flow thus the higher the resistance. This effect is very marked in pure metals, and for a well-behaved material enables measurements of temperature to be made to better than 0.001 °C.
Usually platinum wire is used in the construction of the thermometer, since it is a noble metal which is un-reactive over a wide range of temperatures. But copper, nickel and rhodium alloy may also be used in various temperature ranges. Usually a coil of the pure wire is wound onto an alumina former or placed in the bores of an alumina tube, and this assembly is mounted in a steel tube.

Resistance thermometers are slowly replacing thermocouples in many lower temperature industrial applications (below 600°C). Resistance thermometers come in a number of construction forms and offer greater stability, accuracy and repeatability. The resistance tends to be almost linear with temperature. A small power source is required.

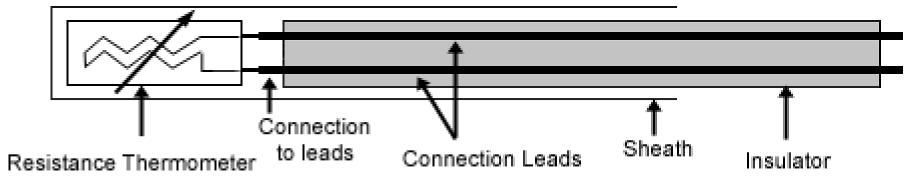
No special extension cables or cold junction compensations are required. The resistance of a conductor is related to its temperature. Platinum is usually used due to its stability with temperature. The Platinum detecting wire needs to be kept free of contamination to remain stable. A Platinum wire or film is created and supported on a former in such a way that it gets minimal differential expansion or other strains from its former, yet is reasonably resistant to vibration.

Resistance thermometers require a small current to be passed through in order to determine the resistance. This can cause self heating and manufacturers limits should always be followed along with heat path considerations in design. Care should also be taken to avoid any strains on the resistance thermometer in its application.

Resistance thermometers elements are available in a number of forms. The most common are:

Wire Wound in a ceramic insulator - High temperatures to 850 °C
Wires encapsulated in glass - Resists the highest vibration and offers most protection to the Pt
Thin film with Pt film on a ceramic substrate - Inexpensive mass production

Practical Construction



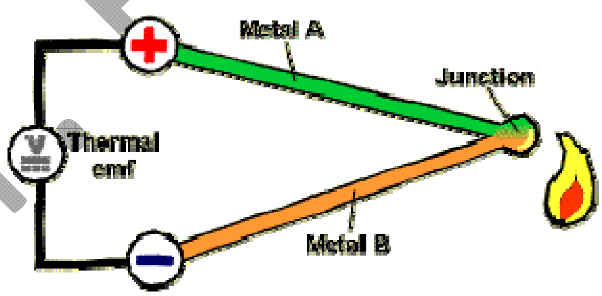
Advantages

1. Depending on the metal being used resistance thermometers are able to cover extensive temperature ranges. Maximum values are generally related to the melting points of the metal used.
2. Variation of resistance with temperature is stable over an extensive temperature range.
3. Very accurate

Disadvantages

1. Compared to liquid in glass thermometers, they tend to be expensive.
2. Require other equipment to measure temperature.
3. They exhibit high heat capacities thus they are not sensitive to temperature change meaning that they cannot be used to measure rapid temperature changes.

$$\Theta = \frac{R_{\Theta} - R_0}{R_{100} - R_0} \times 100$$



Thermocouples

As a Thermometric property thermocouples utilise the variation of EMF generated at a bi-metallic junction with temperature.

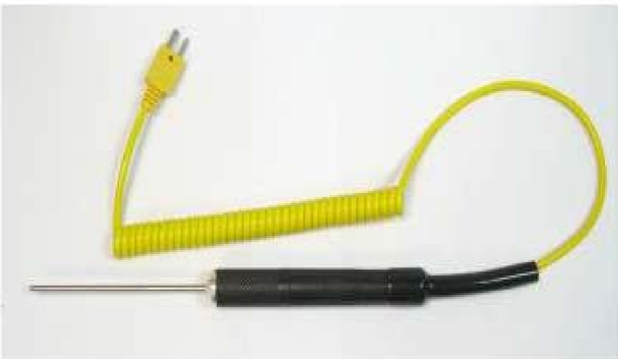
In 1821, the German-Estonian physicist Thomas Johann Seebeck discovered that when any conductor (such as a metal) is subjected to a thermal gradient, it will generate a voltage. This is now known as the thermoelectric effect or Seebeck effect.

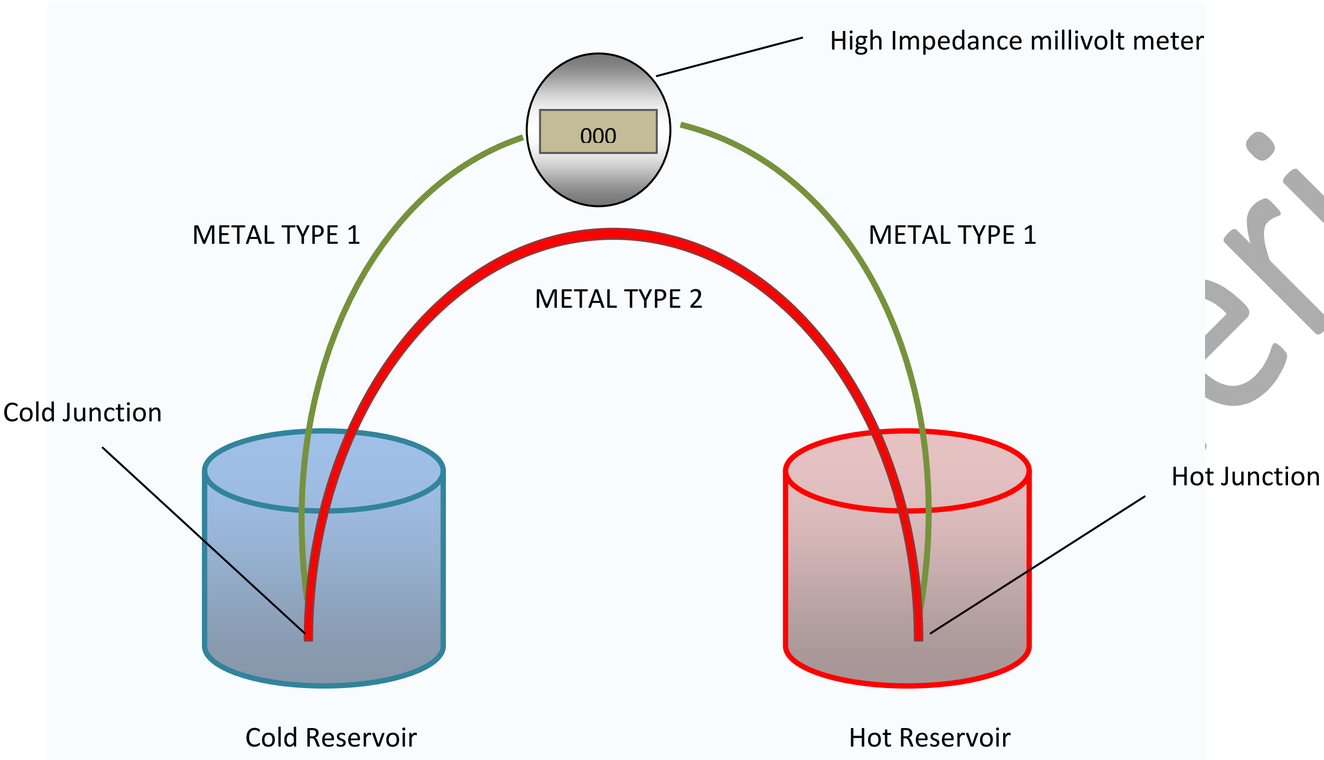
The Seebeck effect: when a conductor is placed in a temperature gradient, electrons diffuse along the gradient and an emf, or thermovoltage, is generated. The magnitude of the emf depends on the material and also on its physical condition. To measure the generated thermal emf (or Seebeck emf), the circuit must be completed using a second different conductor. This is joined to the first conductor at the point of measurement and passes through the same temperature gradient, forming a thermocouple. The thermocouple emf is then the difference between the emfs generated in the two conductors.

Any attempt to measure this voltage necessarily involves connecting another conductor to the "hot" end. This additional conductor will then also experience the temperature gradient, and develop a voltage of its own which will oppose the original. Fortunately, the magnitude of the effect depends on the metal in use. Using a dissimilar metal to complete the circuit will have a different voltage generated, leaving a small difference voltage available for measurement, which increases with temperature. This difference can typically be between 1 and about 70 microvolts per degree Celsius for the modern range of available metal combinations. Certain combinations have become popular as industry standards, driven by cost, availability, convenience, melting point, chemical properties, stability, and output.

It is important to note that thermocouples measure the temperature difference between two points, not absolute temperature. In traditional applications, one of the junctions — the *cold junction* — was maintained at a known (reference) temperature, while the other end was attached to a probe.In practice, thermocouples have two junctions. One of the junctions is held at the temperature, t_1, to be measured, for example in a furnace. The second reference junction is held at temperature t_2 which is usually the melting point of pure ice. This can be done with real melting ice.

Typical Thermocouples





Unknown temperature is found according to the relation:

$$\Theta = \frac{E_{\Theta} - E_0}{E_{100} - E_0} \text{ X } 100$$

Many different thermocouple combinations have been used, but only 8 are standardised. These include 3 noble metal thermocouples using platinum and platinum-rhodium alloys, widely used for temperature measurement up to 1600 °C. The remaining 5 mainly use nickel-based alloys, which are cheaper and more suitable for industrial use up to about 1200 °C. Other refractory alloys can be used up to and beyond 2000 °C.

Advantages:

1. Cheap to manufacture.
2. The simplicity, ruggedness, low cost, small size and wide temperature range of thermocouples make them the most common type of temperature sensor in industrial use.
3. Low heat capacities making it capable of measuring rapid temperature changes.

Disadvantages:

1. Sensitivity reduces accuracy.

The Constant Volume Gas Thermometer

As a thermometric property it uses the variation of pressure of a gas with temperature.

Usually air is used as a gas. For better accuracy other gases like helium that tend to have very low melting points close to absolute zero are used.

Advantages:

1. It is very accurate. In fact its accuracy allows it to be utilised to calibrate other thermometers.

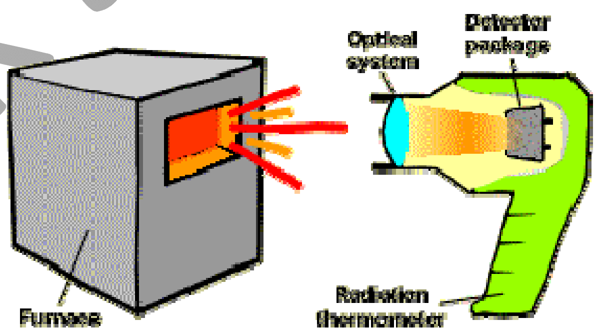
Disadvantages:

1. It is not easy to handle and read.
2. It tends to be highly sensitive to temperature change, and mechanical vibrations. In fact to give a reading it usually entails a lot of time.
3. Expensive to manufacture and keep.

$$\Theta = \frac{P_\Theta - P_0}{P_{100} - P_0} \times 100$$

Radiation thermometry/Pyrometry

Makes use of the fact that all objects emit radiation in the infrared and visible parts of the spectrum, the intensity of which varies strongly with temperature.



The radiation can be measured remotely, enabling measurements to be made of objects which are moving, very hot, in a hostile environment or rapidly changing in temperature, or in situations where contamination of a product must be avoided. The fundamental relationship governing thermally emitted radiation is the Planck law. This relates the intensity of the radiation from a perfect radiator (or blackbody) to the temperature and wavelength. Radiation thermometers gather and focus the thermal radiation onto a detector. Semiconductor detectors are usually used: the most common are Silicon, Lead Sulphide, Indium Antimonide or Indium Gallium Arsenide. The output can be easily digitised and continuously monitored. Radiation thermometry has long been used for measuring temperatures in industrial and manufacturing processes, and it is now being increasingly used to make measurements at more ordinary temperatures. However their apparent ease of use masks the equal ease with which they can be used incorrectly. Field-of-view effects, reflections, atmospheric absorption and unknown emissivity are all potential problems.