

Temperature measurements.

Exercise No 3

Theory

Definitions

Temperature is one of the most important thermodynamic parameters. It is a measurement of average kinetic energy of molecules in a substance. It is a macroscopic intensive parameter.

Units

There are two principal types of temperature scales:

- Absolute (thermodynamic temperature) – where the zero value (regardless of specific scale used) is the temperature at which all elements of a thermodynamic system have minimal possible energy
- Relative scales, where certain points (e.g. 0 and 100) are defined in reference to some physical phenomena.

There are four most popular temperature scales used in the world today:

- Celsius scale – one of the most popular (particularly in Europe) relative scales, first proposed by Swedish astronomer Anders Celsius. Originally defined in such a way that 0°C (read: degrees Celsius) matched water freezing point and 100°C – water boiling point, both at a pressure of a standard atmosphere. Today the actual scientific definition is different, relating the scale to the absolute zero and triple point of Vienna standard mean ocean water, but for practical purposes the original definition may be used.
- Kelvin scale – an absolute scale named after William Thomson, 1st Baron Kelvin. This scale has a zero at absolute zero and a unit size is such that interval of 1 kelvin (1 K) is equal to interval of 1°C . Temperature of 0°C is equal to 273.15 K, therefore temperature expressed in kelvins can be easily converted to degrees Celsius by subtracting 273.15. Kelvin is one of the seven base units of the International System of Units (SI).
- Fahrenheit scale, proposed by Dutch-German-Polish physicist Daniel Fahrenheit. Its definition is based on freezing point of certain brine mixture (0°F) and ice melting temperature (32°F). A popular legend says however that original scale was based on the coldest winter observed in Gdańsk (then Danzig) in 1708/1709 ($0^{\circ}\text{F} = -17.8^{\circ}\text{C}$) and a body temperature (as it turns out with a slight fever – $100^{\circ}\text{F} = 37.8^{\circ}\text{C}$) – this anecdote certainly helps to remember key points of that scale! It is still officially used in the USA.
- Rankine scale – an absolute scale based on intervals identical to those of Fahrenheit scale (so the relation between Rankine and Fahrenheit scale is similar to that between Celsius and Kelvin scales). Still sometimes used in the USA.

Temperature measurements

By its nature the temperature may only be measured indirectly – by measuring some other properties or parameters, which have known temperature dependency. Temperature measurement instruments can be divided according to different criteria:

- According to measurement method:
 - Contacting – where the measurement device comes into direct contact with body or fluid whose temperature is measured
 - Non-contacting, where temperature is measured according to properties of thermal radiation emitted by the object's surface.
- According to the design and working principle:
 - Glass thermometers, based on thermal expansion of liquids (usually mercury or some alcohol)
 - Bi-metal mechanical thermometers – utilising different thermal expansion of two metal elements bound together
 - Thermocouples (explained below)
 - Thermistors – based on special resistors whose electric resistance varies with temperature
 - Resistance temperature detectors – using dependence between conductor's temperature and resistance
 - Pyrometers – utilising thermal radiation emitted by the object's surface

Glass thermometer is one of the simplest, cheapest and most popular type. It is a quite accurate device, however it has a range of limitations:

- Temperature range limited by boiling and freezing point of utilised liquid
- High inertia (long measurement time)
- Lack of possibility to feed results directly into any data acquisition system.

One of the most popular types of thermometers in the industry is the thermocouple. It is a device which consists of two different conductors (in most cases metal alloys) joined together at both ends. If a temperature difference between the junctions occurs, it produces a voltage between them. A diagram of a simple thermocouple is presented in a figure below.

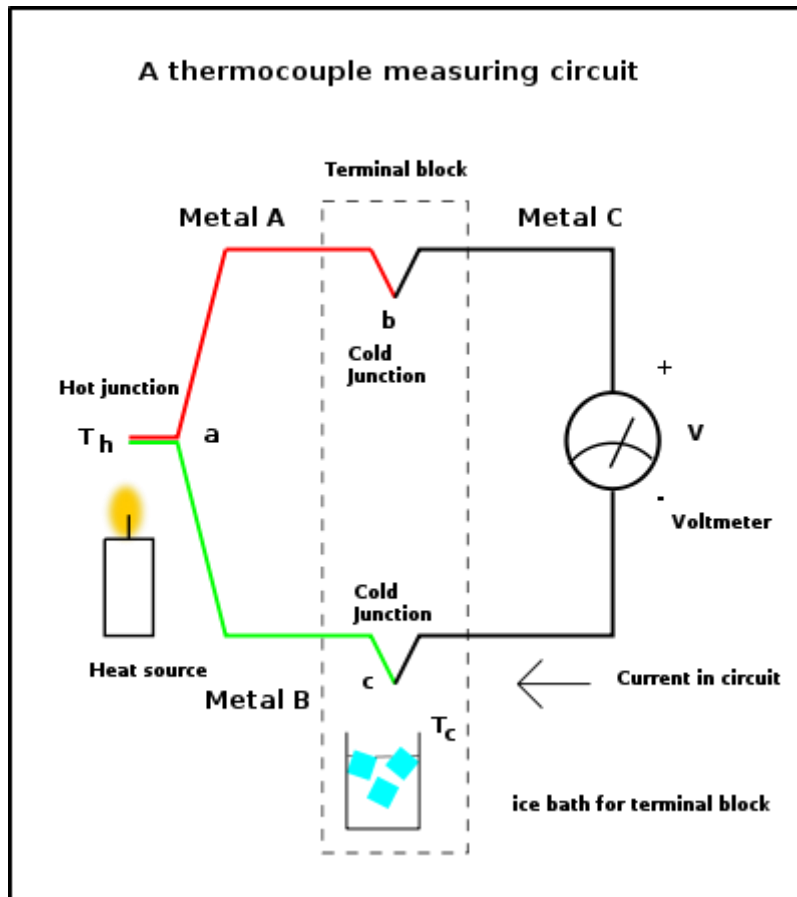


Figure 1. Diagram of a simple thermocouple measurement circuit (source: Wikipedia).

Voltage value is linearly dependant on that temperature difference and thus can be used to determine the temperature difference. This means that the simplest thermocouple can only be used to measure temperature, if the temperature of one junction (so-called cold junction – as opposed to the hot junction which is used as an actual measuring probe) is known. This is of course impractical and therefore a concept to compensate the cold junction was developed. Compensation is carried out by using some other measurement device, e.g. thermistor or diode – to determine cold junction temperature.

Exercise instructions

1. Familiarise yourself with different types of thermometers available at the laboratory. Identify thermocouples connected to a PC unit.
2. Calibrate the thermocouple connected to a voltmeter. Using various heat sources and ambient air, as well as other available thermometers, calibrate the thermocouple – produce a characteristic curve showing dependence between the temperature difference (note the temperature of the cold junction held in a thermos flask) and produced voltage.
3. Investigate inertia of various types of thermometers. Use a thermostat available at the laboratory to produce hot water. Then check and record time it takes for each type of thermometer to reach a stationary state after being transferred from ambient air to the hot water, and then back to the ambient air. Record indicated values every 60 seconds.

Do not turn any equipment on unless clearly instructed to do so by your instructor!

Report

Your report should contain at least:

- Chart presenting dependence between temperature difference and voltage for the investigated thermocouples
- Chart presenting inertia of investigated thermometers – their $T(t)$ characteristic curves.

More detailed information on the contents of your report will be specified by your instructor during the classes. Pay attention!