With this issue Pentronic begins its training in temperature measurement. We will start lesson 1 with a historical review and then continue with thermodynamics, heat transfer and quality assurance with calibration. Only after that will we move on to temperature sensors – primarily thermocouples and Pt100s.

LESSON 1 THE NATURE AND HISTORY OF TEMPERATURE

TEMPERATURE – HEAT

Temperature does not exist. It is a theoretical model constructed so that humans can measure, compare and understand changes of kinetic energy among a body's smallest components such as atoms and molecules.

In contrast, heat does exist and is described as being the amount of kinetic energy inside a body. From this it follows that everything above absolute zero (-273.15°C) is heat. But this definition leads to peculiar effects. For example, an iceberg contains more heat than a cup of coffee, because the iceberg contains a greater amount of energy.

Anyone who puts a finger on the iceberg and the coffee respectively experiences the opposite. What we then feel is the heat, the kinetic energy, at a given point. Temperature is our tool for describing this experience in a comparable and reproducible way. The coffee feels hotter than the iceberg because it has a higher temperature.

THE PIONEERS

The thermometer was invented at the beginning of the 17th century by the Italians Galileo and Santorio at the Accademia del Cimento in Florence and by the Dutchman Drebbel. The first thermometer consisted of a spiral-shaped glass tube filled with alcohol. The tube was not closed and therefore the instrument also measured the air pressure at the same time. The academy in Florence also developed simple scales, which included the divisions of 40 and 80 degrees between the "fixed points" of the high summer temperature and the low winter temperature.

However, the thermometer had no real practical use until 1714, when the German physicist Daniel Gabriel Fahrenheit developed a temperature scale that made it possible to take comparative measurements. He is also considered to be the inventor of the mercury thermometer as it is today – that is, mercury inside a closed glass tube.

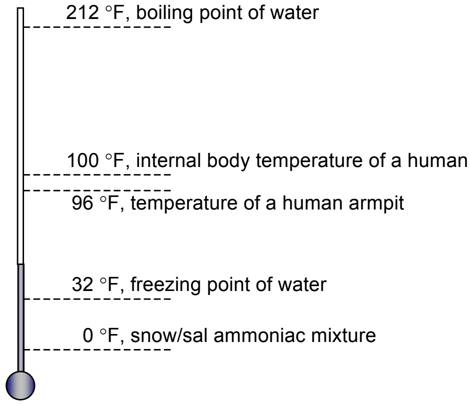
It is worth pointing out that the glass thermometers containing mercury that may still be in use are being used by special exemption. Mercury is a stable substance but it becomes dangerous out in the environment. Today we use other liquids such as coloured alcohol.

THE TEMPERATURE SCALES

FAHRENHEIT

Fahrenheit created a 100-degree scale in which zero degrees was the temperature of a mixture of sal ammoniac and snow – the coldest he could achieve in his laboratory in Danzig.

As the upper fixed point he used the internal body temperature of a healthy human being and gave it the value of 100°F. In degrees Celsius this scale corresponds approximately to the range of -18 to +37 degrees.



Fahrenheit's mercury-in-glass thermometer with the reference points that were apparently used.

Because it can be awkward to achieve the upper fixed point, he apparently introduced the more practical fixed points of +32°F and +96°F, which were respectively the freezing point of water and the temperature of a human being's armpit.

Fahrenheit's scale was later extended to the boiling point of water, which was assigned the temperature value of +212°F.

ANDERS CELSIUS

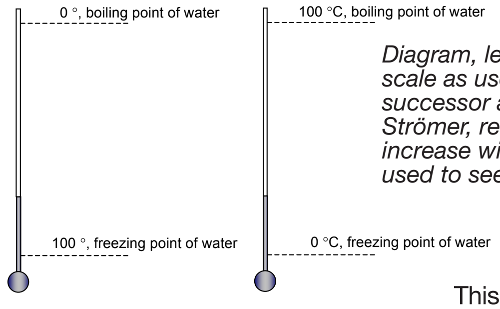
At the same time, people were considering having a scale with more natural divisions whereby 0 degrees was defined as the melting point of ice and 100 as the boiling point of water. We know that even before 1737 Linneaus was using this scale, which was later named after the Swedish astronomer Anders Celsius.

In 1742 Celsius launched the scale in reverse order, arguing that water should boil at 0 degrees and freeze at 100. Not until eight years later was the scale reversed by his successor as professor at Uppsala University, the mathematician Mårten

A finger feels how the heat energy (also called thermal energy) moves (see the arrow) in or out depending on whether the temperature of the object being touched is higher or lower than the finger's.

Anders Celsius.

Strömer. As an interesting aside, it is worth mentioning that as early as 1743, Professor Christin in Lyon had built the first mercury thermometer with the Celsius scale “the right way round”.



Diagram, left: The 100-degree temperature scale as used by Anders Celsius. Right: His successor as professor at Uppsala, Mårten Strömer, reversed the scale so that its values increase with the energy level just as we are used to seeing it today.

RÉAUMUR

During the same period, the Frenchman Réaumur developed his own scale. He also began with the freezing and boiling points of water but he divided his scale into 80°R, because his favourite mixture of water and alcohol expanded itself from 1,000 till 1,080 units of volume between the fixed points.

HEAT WAS A SUBSTANCE

Only near the end of the 18th century did researchers begin to understand the nature of heat. Until then, heat was believed to consist of a particular substance called “caloric”.

It was the American-born Briton Count Rumford who tracked down the explanation by demonstrating that a specific amount of ice weighed the same when it was melted. The caloric theory could thereby be dismissed. He also succeeded in getting water to boil by boring a blunt drill into a piece of metal. Rumford was convinced that the movement of the drill was transformed into heat vibrations in the metal’s atoms.

THE IDEAL GAS LAW

At the beginning of the 19th century the ideal gas law was developed from Boyle’s law by several well-known researchers, including the Frenchmen Charles and Gay-Lussac and the Italian Avogadro. The law states:

$p V = R T$ where

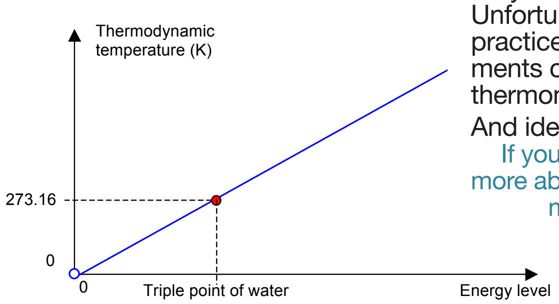
p = the gas pressure
V = the enclosed volume (in moles)
R = the universal gas constant
T = the absolute temperature of the gas

This law is the starting point of Avogadro’s temperature scale, which begins at absolute zero. Today absolute zero is defined as -273.15°C. The problem with the gas thermometer is that it assumes that so-called “ideal gas” exists.

THERMODYNAMIC SCALE

At the same time, other research was also being done into the field of energy. The Frenchman Carnot, the German Mayer and the Briton Joule were some of those who made major contributions to explaining the connection between different forms of energy. Joule’s experiments included determining the amount of mechanical effort required to raise the temperature of 1 gram of water by 1°C.

The research resulted in the laws of thermodynamics. In about 1850 the Briton Kelvin defined temperature in accordance with these laws. Today we still do not know what temperature really is. Instead, we use the theories of thermodynamics because they agree sufficiently well with experimental tests.



The thermodynamic scale is defined by two points: the triple point of water (solid circle) and absolute zero (empty circle), which cannot be achieved.

Temperature is a measurement of what is regarded as the “animation” or movements of the smallest components of matter such as atoms and molecules. From experience we know that increasing thermal (heat) energy leads to higher temperatures, and as a rule requires that matter expands in volume. (Compare with the ideal gas law!) It is therefore not unreasonable to assume that the lowest temperature is to be found where the so-called animation or movement has stopped. This occurs at absolute zero, 0 K.

To maintain agreement with the already accepted Celsius scale, it was decided that 1°C = 1 K = 1/273.16 of the thermodynamic temperature at the triple point of water.

We can say that thermodynamic temperature scale is defined by one fixed point and one fictive zero point – absolute zero. The fixed point is the triple point of water, which is a state of equilibrium between water’s three phases of solid, liquid and gas. In this condition, water assumes a highly stable and difficult-to-disrupt state of equilibrium, which has been assigned the theoretical temperature value of precisely 0.01°C. Note that in practical experiments such precision cannot be achieved. However, it is relatively simple to achieve the triple point of water with a measurement uncertainty of less than ±0.001°C.

Absolute zero cannot be fully achieved. Empirically, it has been established at -273.15°C. At Helsinki University of Technology researchers study low temperatures and in their experiments have apparently come down to nK (nanokelvin = 10-9) away from absolute zero.

The Kelvin scale is scientifically and mathematically correct. Unfortunately it is not useable in practice because the measurements can only be taken with gas thermometers containing ideal gas. And ideal gas does not exist.

If you would like to discover even more about temperature measurement, Pentronic offers courses in “Traceable temperature measurement” in Västervik or at your own premises if required. For more information visit www.pentronic.se

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