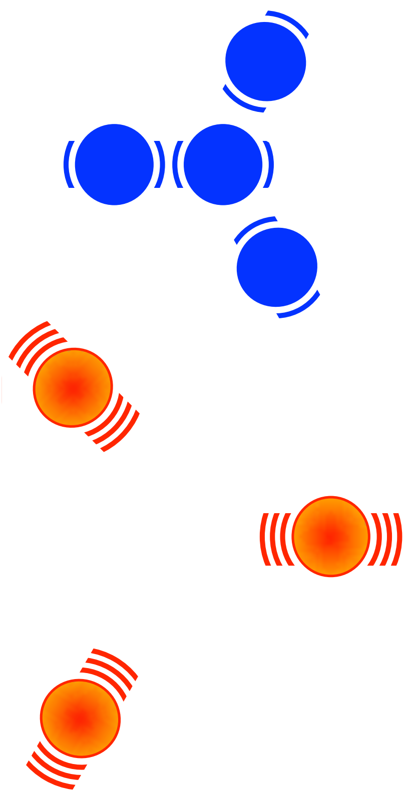
In the first lesson we did a historical review. Now we will work through the basic theory necessary for being able to measure temperature at all – thermodynamics and heat transfer.

LESSON 2 THERMODYNAMICS AND HEAT TRANSFER

A TEMPERATURE MODEL – THE KINETIC THEORY

The smallest constituent parts of a hot body have greater movement than those of a cold body. The average value of the kinetic vibrational energy of atoms and molecules in a body is a measurement of its temperature.



This figure indicates that hot materials have greater kinetic energy (energy from motion) in their smallest constituent parts whereas colder materials have a lower kinetic energy level. Higher energy levels also usually require more space.

THERMODYNAMICS

To understand temperature measurement you must have a basic knowledge of thermodynamics and heat transfer.

The zeroth law of thermodynamics:

If two bodies are in thermal equilibrium with a third body, then the first two bodies must also be in thermal equilibrium with each other. In other words, if the bodies have the same temperature, no heat is transferred. We understand this intuitively but it is not stated in any of the other laws so it was added afterwards and put first. All temperature measurement and calibration are based on this axiom.

The first law:

Energy can neither be created nor destroyed but only converted between different energy forms.

The second law:

This can be formulated in various ways but the most suitable formulation for measurement techniques is that heat never moves by itself from a cold body to a hot one.

HEAT TRANSFER

There are three different mechanisms of heat transfer and they can occur simultaneously or separately: heat conduction, convection and radiation. Knowledge about these various distribution methods is important for understanding what is happening in a measurement situation. This understanding makes it possible to prevent measurement error by arranging the installation so that the sensor does not disrupt the measurement process by e.g. creating new transport routes for the heat flow.

Conduction

In accordance with the temperature model shown above, in which atoms (or molecules) are vibrating, we can understand that an atom with a high level of vibration will soon influence its neighbour to also vibrate. This vibration or heat spreads because the vibrational energy is transferred from atom to atom. This is called thermal conduction. See the figure and table below.

Medium	Conductivity
Solid materials	**W / (m K)**
- Ag, Cu	420, 380
- Al (the element)	220
- Stainless steel	15
- Glass 0.93	
- Wood, pine	0.1 – 0.4
- Glass wool	0.035
Liquids	
- Water 20 – 100 °C	0.60 – 0.68
Gases	
- Air 20 – 100 – 300 °C	0.025 – 0.032 – 0.045

Heat transfer by conduction. Vibrational energy is transferred from atom to atom. In general, metals are the best conductors. Gases are the worst.

Metals are generally excellent thermal conductors. In liquids and gases the molecules maintain a greater distance from each other, so the vibrations cannot be spread so easily. A vacuum does not contain any molecules so it cannot conduct any heat.

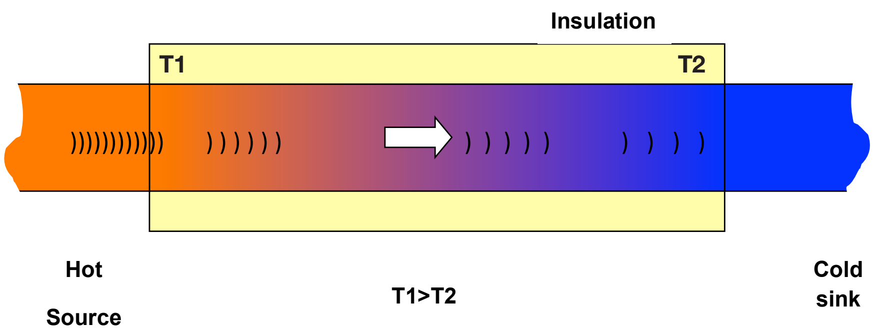
Convection

Convection is motion within a fluid (= liquid or gas)

Natural convection involves movements generated by density differences due to temperature differences. A hot fluid is “lighter” than a cold one and “rises”.

Forced convection is achieved by using mixers, pumps and fans. The temperature of the fluid can thereby become more even throughout its volume.

Heat transfer from a fluid to a solid body is facilitated by increasing the flow of the fluid. Similarly, it is easier to transfer heat with a liquid than with a gas. This is because the liquid contains atoms or molecules that transfer its vibrational energy



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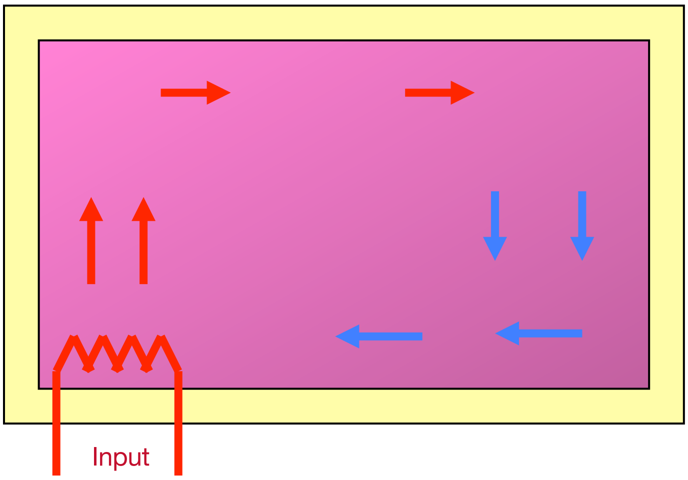


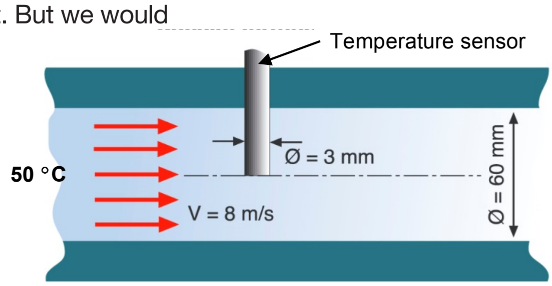
This figure shows an example of convection in an electrically heated hot water storage tank. The heat exchanger or immersion heater heats the water, whose molecules become more spread out due to their increased vibrational energy. Their density is thereby decreased and the hot fluid rises. When the fluid cools due to heat loss or heat extraction to a heat exchanger, the molecules become packed more tightly due to their reduced vibrational energy and they sink.

more densely. No convection is possible in a vacuum because it does not contain any molecules.

Water transfers heat better than air

In the figure below, a fluid is flowing in a pipe. At a right angle to the flow direction, a sensor probe with a Ø 3 mm has been inserted to reach the centre of the pipe. The flow has a velocity of 8 m/s and a temperature of 50 °C. In heat transfer theory we speak about the heat transfer coefficient, h (alpha), which is given in $W/(m^2K)$, that is, the amount of heat transferred per square metre and degree C of temperature difference. The heat transfer coefficient varies with the type of fluid and its velocity. In this particular example the calculations give a coefficient for water of 47,000 $W/(m^2K)$ whereas air cannot transfer more than 160 $W/(m^2K)$. Thus in this example water transfers almost 300 times more heat than air.

In life we have learned that we can spend a long time in a sauna that is 70-80 °C hot. But we would never voluntarily think of putting our finger into a saucepan containing water of the same temperature!



Radiation

Radiation is an electromagnetic wave movement (in the infrared range) that does not require a medium for transporting heat. A vacuum is therefore no obstacle to radiant heat, as solar radiation proves.

The net radiation between two bodies travels from the hot to the cold body. All bodies with a temperature above absolute zero (0 Kelvin = -273.15°C) radiate thermal energy.

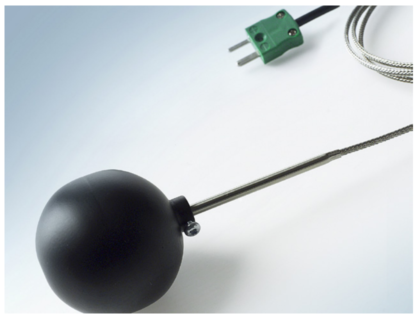
The sunbathing image here illustrates the sun's radiant heat. A cloud blocks some of the radiant heat, as most of us know from experience. Heat is transferred via convection between the person's body and the air (e.g. via the ocean breeze). Heat is conducted between the body and the sand. The direction is from the higher temperature to the lower one.

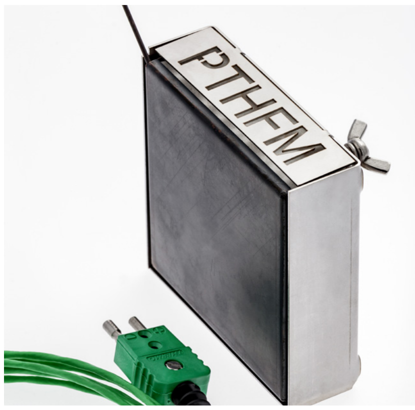
Thermal radiation is an often-ignored source of error in temperature measurement.

Examples:

- Reflectors for pyrometers
- The effect on a sensor when the surrounding surfaces differ in temperature from the fluid.
- In the case of combustion, the thermal radiation is significant.

A product that measures the air temperature and takes into account the effect of radiation is the black globe thermometer. A product that mostly measures thermal radiation is the Plate Thermometer Heat Flux Meter (PTHFM).





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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