Temperature/Humidity

Content

Measurement Principles and Sensors for Temperature Measurement

Mechanical Thermometers

Mechanical temperature measurement processes are founded on the physical expansion of gaseous, liquid or solid matter under the influence of temperature. Where the functional dependence of the thermal expansion of a material is known and reproducible from physical calculations or empirical processes, this material characteristic can be employed in the measurement of temperature.

Bimetallic Thermometers

The temperature-sensitive sensor element is a bimetallic strip in the form of a spiral or coil spring. A bimetallic strip is a measuring element consisting of two materials with different thermal expansion coefficients. The material coefficients are selected in such a way as to give the largest possible difference in their coefficient of heat expansion. The angle of twist of a bimetallic spiral therefore changes dependent on temperature.

The relation between angle of twist and temperature can be described by the following formula:

$$\alpha = \frac{360°}{\pi} \frac{a \cdot l}{s} (t_2 - t_1)$$, where

a: specific thermal expansion

l: length of bimetallic strip

s: thickness of bimetallic strip

Gas Pressure Thermometers

In gas pressure spring thermometers the entire closed system is filled with an inert gas or gas mixture. The temperature-dependent change in gas pressure is transmitted to a display by means of a capillary lead and an elastic measurement spring.

Van der Waal's equation of state is used to calculate the relation between pressure and temperature.

Liquid-in-Glass Thermometers

The liquid-in-glass thermometer is a widely used type of expansion thermometer. The method of operation is based on the thermal expansion of liquids. The sensitivity of the thermometer can be influenced by variation of the volume of the thermometer vessel. The most common thermometer liquids are mercury, gallium and alcohol.

Electric Thermometers

Resistance Thermometers

Metal resistance thermometers change their electrical resistance dependent on temperature. The change in electrical resistance under temperature influence is caused by the conduction mechanism of the metals. The freely moving electrons in the atomic grid are the basis for the conductivity of metals. Their quantity and movement energy are temperature-dependent. When energy is supplied to the metal atoms by means of an increase in temperature, the metal atoms oscillate with correspondingly greater amplitude and frequency. An increasing resistance is set against the electron movement, this corresponds to the increase in electrical resistance. Since the electrical resistance rises in proportion to temperature the expression **positive temperature coefficient** is used.

The metal with the best characteristics is platinum and as a result the Pt resistance thermometer is the most important in measurement technology. Further metals that are used in temperature measurement are copper (Cu), nickel (Ni) and molybdenum (Mo).

The platinum resistance thermometer is described in detail in EN 60751. The so-called Pt100 resistance thermometer is the most commonly used. The thermometer has a nominal resistance of $R = 100\,\Omega$ at $t = 0$ °C and obeys the following equation:

In the range -200 to 0°C:

$$R(t) = R_0(1 + At + Bt^2 + C(t - 100°C)t^3)$$

in the range 0 to 850°C:

$$R(t) = R_0(1 + At + Bt^2)$$

where:

$R_0 = 100{,}00\,\Omega$

$A = 3{,}9083 \times 10^{-3}$ °C^{-1}

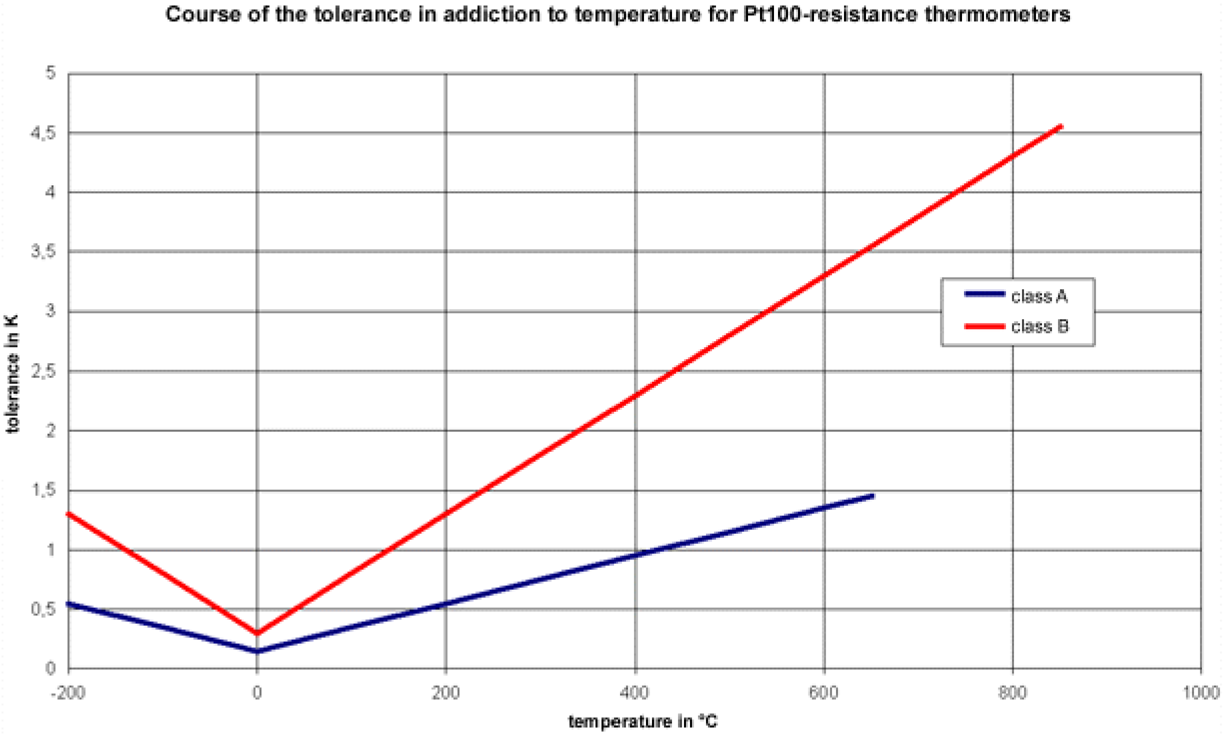
$B = -5{,}775 \times 10^{-7}$ °C^{-2}

$C = -4{,}183 \times 10^{-12}$ °C^{-4}

The Pt100 resistance thermometer is divided into two accuracy classes:

Class A: (0.15 + 0.002 | t |) °C

Class B: (0.30 + 0.005 | t |) °C



Thermocouples

The measurement principle of the thermocouple is based on the effect discovered by *Seebeck*, that a voltage arises at the ends of two wires of different materials, when the temperature at the junction point of the two materials is different to the temperature of the measuring instrument terminals.

According to latest knowledge this effect is based on a material-specific characteristic of electrically conductive materials. A displacement of electron density is apparent within a conductor (volume diffusion effect) if a thermal gradient exists over the conductor. The collection of electrons is denser in the lower temperature range.

If one uses a thermocouple from two suitable materials, for example NiCr and Ni, the contact potential of this pair of materials can be measured. The thermoelectric voltage range against platinum at 100°C measuring junction temperature and 0°C reference junction temperature is presented in the following table.

Material	**Voltage in mV**
Tellurium	50
Silicon	45
Silit	27
Antimonite	4,8
Nickel-Chromium (85Ni-10Cr)	2,55
Iron	1,9
Platinum-Rhenium	1,5
Molybdenum, Uranium	1,2
Brass	1,1
Iridium-Rhodium (40IR, 60Rh)	1,0
Tungsten, High-Grade Steel (V2A)	0,8
Copper	0,75
Silver, Gold, Zinc	0,7

Manganese (86Cu, 12Mn, 2Ni)	0,68
Rhodium	0,65
Iridium-Rhodium (40Ir, 66Rh)	0,64
Platinum-Rhodium (10%)	0,64
Ididium	0,63
Phosphorus-Bronze	0,52
Tantalum, Caesium	0,5
Lead, Iridium-Rhodium	0,45
Aluminium, Magnesium, Zinc	0,4
Graphite	0,2
Platinum, Mercury	**0,0**
Thorium	-0,1
Sodium	-0,21
Palladium	-0,3
Potassium	-0,94
German Silver (Cu, Ni, Zn)	-1,0
Nickel	-1,55
Cobalt	-1,6
Constantan (55Cu, 45Ni)	-3,5
Bismuth, perpendicular to axis	-5,2
Bismuth, parallel to axis	-7,7

Thermocouples and compensating conductors are defined by colour codes. Unfortunately, these codes are often country-specific. The colour coding of the most common thermocouple types can be found at the following Internet addresses:

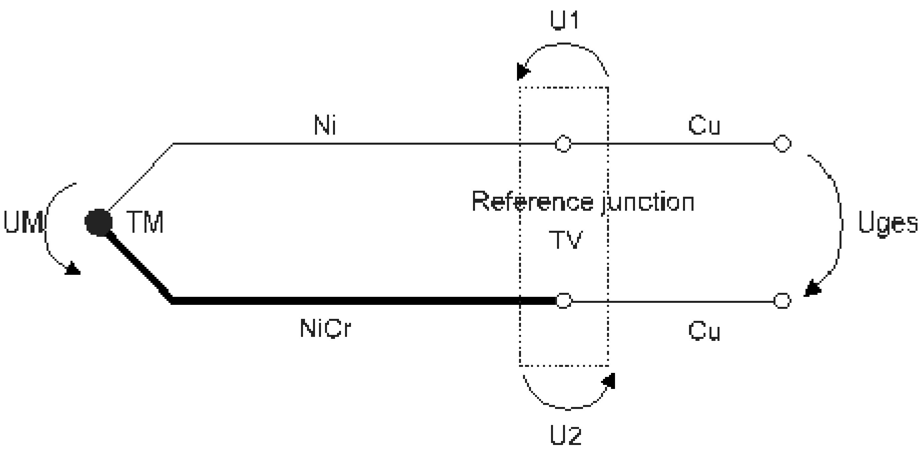
http://world.omega.com/germany/techref/thcpref1.html

http://world.omega.com/germany/techref/thcpref2.html

http://world.omega.com/germany/techref/thcpref3.html

Reference Junction Compensation for Thermocouples:

In thermocouples two wires of different materials are joined at the point of measurement. When these so-called thermoconductors are joined with copper conductors this transition point is known as the reference junction. The contact potential measured at the reference junction is directly proportional to the temperature difference between measurement point and reference junction. A Type K thermocouple is presented in the example below.



Total voltage U_{ges} is calculated as follows:

$$U_{ges} = U_1 + U_M + U_2$$

$$U_{ges} = U_{Cu-NiCr}\big|_{T_V} + U_{NiCr-Ni}\big|_{T_M} + U_{Ni-Cu}\big|_{T_V}$$

$$U_{ges} = U_{Cu}\big|_{T_V} - U_{NiCr}\big|_{T_V} + U_{NiCr-Ni}\big|_{T_M} + U_{Ni}\big|_{T_V} - U_{Cu}\big|_{T_V}$$

$$U_{ges} = U_{NiCr-Ni}\big|_{T_M} - U_{NiCr-Ni}\big|_{T_V}$$

The contact potential proportional to temperature is obtained by deducting the contact potential arising at the reference junction. For reasons of simplicity the reference junction temperature is usually set to zero, since all thermocouples then have a contact potential of 0mV and thereby the voltage at the measurement point is equal to the total voltage.

Semiconductor Sensors

Resistance thermometers based on semiconductors use the temperature-dependent change of the electrical resistance of semiconductive, mostly ceramic materials for temperature measurement.

To this category belong:

Cold conductors (PTC)

Hot conductors (NTC)

Silicon sensing resistors

A *cold conductor (PTC-Resistor)* is a temperature-dependent semiconductor resistor, whose resistance value rises in step form on reaching a certain reference temperature. In the manufacturers' data the corresponding resistance value, the transition temperature and the maximum operating voltage are given for a specific reference temperature. Cold conductors are manufactured from implanted polycrystalline ceramic on the basis of barium nitrate.

Hot conductors are also commonly known as *Thermistors* or *NTC-Resistors*. The resistance of hot conductors dependent on temperature is almost exponential. Hot conductors consist of polycrystalline mixed oxide ceramic. Manufacturers provide information in the form of characteristic curves. The following formula applies approximately to the characteristic curve:

$$R_T = R_{T_0} \cdot e^{B\left(\frac{1}{T}-\frac{1}{T_0}\right)}$$

, where

T : Temperature in K

T_0 : Reference Temperature in K

R_T : Resistance at Temperature T

R_{T_0} : Resistance at Temperature T_0

B : Constant dependent on form and material in K

Silicon Measurement Resistors (spreading resistance sensor) have a positive temperature coefficient. The graph is characterised by a small non-linearity, which can be compensated by simple switching.

Radiation Pyrometer

As well as heat exchange through conduction and convection, solids also exchange heat with their surrounding environment through radiation. The heat radiation of a measurement object is optically filtered and concentrated on a radiation detector. The electrical reaction consists of a change in resistance, voltage or current of the radiation detector, directly induced, or induced indirectly by an increase in temperature, dependent on the principle applied. The electrical change is amplified, measured and processed (see also VDI 3511, Page 4).

Other Temperature Measurement Processes

The following is a list of other temperature measurement processes (more detailed observations are not made here):

- Optical measurement process (determination of the intensity or wavelength of the electromagnetic radiation of a solid)
- Temperature measurement colours (physical effects of materials whose colour changes dependent on temperature)
- Liquid crystal (for indication of surface temperatures and optical presentation of temperature fields)
- Quartz crystal temperature sensors (the resonance frequency changes dependent on temperature)
- Acoustic measurement process (temperature-dependent speed of propagation of sound)
- Noise thermometers (temperature dependence of mean electron speed → Brown movement)
- Capacitive temperature sensors (temperature dependence of dielectricity constants)
- Inductive temperature sensors (temperature dependence of the magnetic moment)

Measurement Principles and Sensors for Humidity Measurement

Concepts

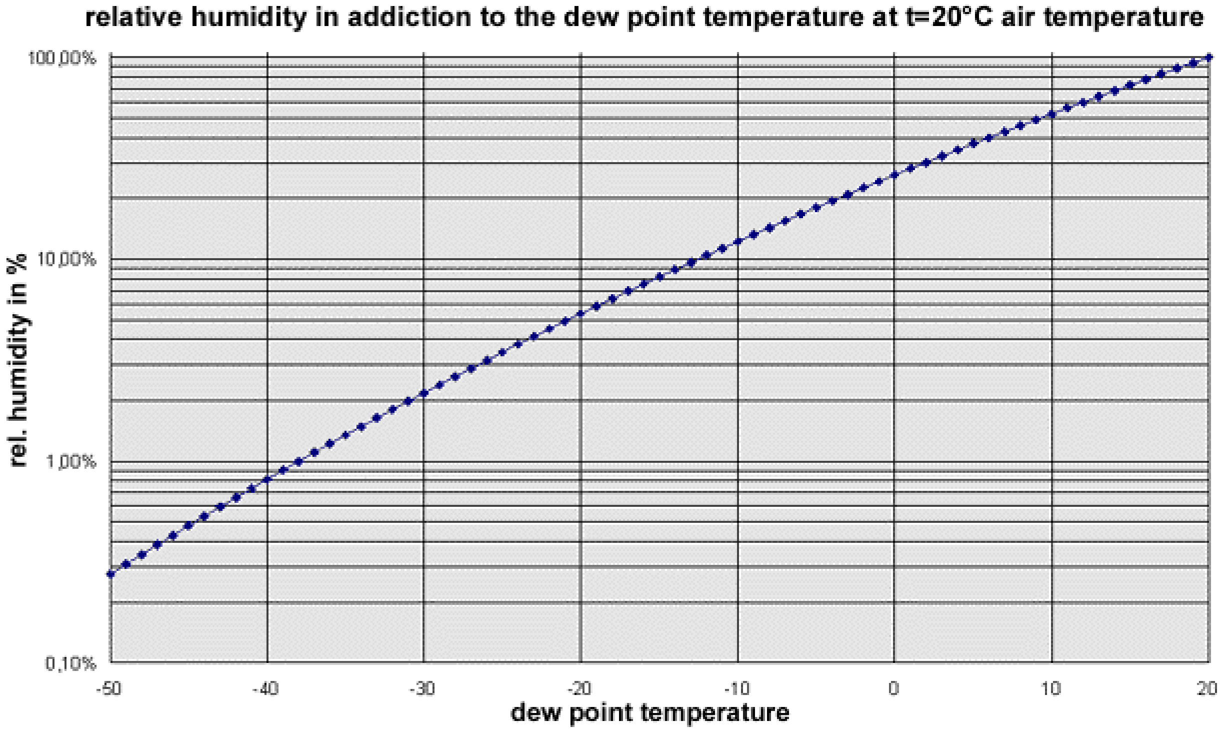
Relative Humidity

Unit: %

By relative humidity φ we refer to the ratio of water vapour actually present in the air to the maximum possible mass of water vapour in the air. Relative humidity is usually expressed as a percentage.

The formula applies: $$\varphi = \frac{f_{abs}}{f_{max}} \times 100\%$$

Note: Since maximum humidity is dependent on temperature, relative humidity changes with temperature, even when absolute humidity remains constant.



Absolute Humidity

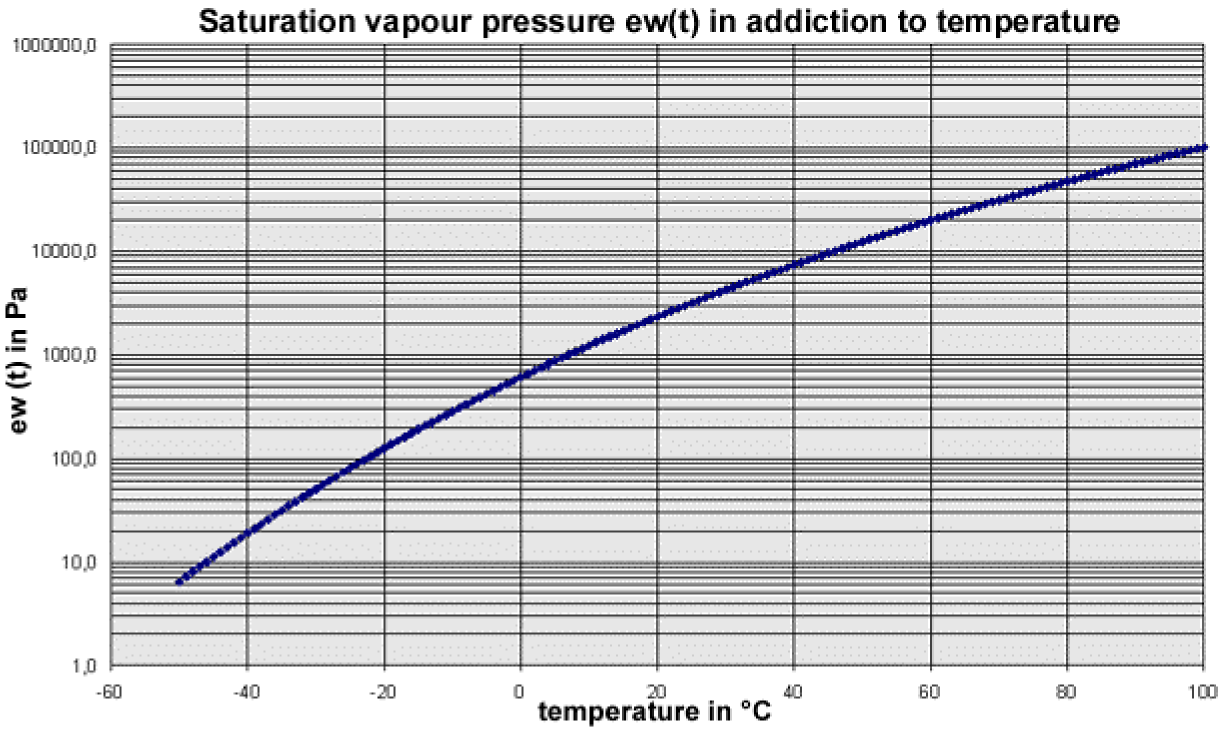
Unit: **g/m3**

By absolute humidity fabs we refer to the volume of water vapour actually present in a specific quantity of air. Absolute humidity is the ratio of the weight of the water contained in the air and the volume of this moist air.

Water Vapour Partial Pressure, Saturation Vapour Pressure

Unit: hPa

By saturation vapour pressure eS(t) we refer to the maximum possible pressure of the water vapour at a certain temperature. The saturation vapour pressure of water dependent on temperature is presented in the chart below. The water vapour partial pressure e(t) varies between 0 (dry air) and 30hPa. The saturation vapour pressure determines the upper limit.



Saturation humidity, maximum humidity, saturation quantity

Unit: g/m³

By maximum humidity fmax we refer to the maximum possible water vapour quantity in one cubic meter of air at a certain temperature. The moisture absorption capacity of air increases with increasing temperature. If maximum humidity is exceeded, the excess water vapour condenses in the form of condensate (droplet formation).

Dewpoint

Unit: °C, °F, K

By dewpoint temperature ttp we refer to the temperature at which the cooling of moist air leads to condensate formulation. This means that when moist air is cooled down to dewpoint the relative humidity rises to 100%.

Frost Point

Unit: °C, °F, K

In some cases where dewpoint temperatures are below 0°C we refer to the frost point temperature. Other descriptions are also dewpoint temperature above ice or freezing point.

Specific Enthalpy (heat content)

Unit: kJ/kg

By specific enthalpy Espez we refer to the quantity of heat necessary to raise the temperature of a gas (or gas mixture) from one temperature to another at constant pressure.

Or:

By specific enthalpy we refer to the quantity of heat that is available in the air mass relative to a certain air condition. The enthalpy of unsaturated air is the sum of the enthalpy to vaporise the water content present, plus the enthalpy to heat the water vapour mixture to the corresponding temperature.

Mixing Ratio

Unit: g/kg

By mixing ratio m we refer to the ratio of water vapour mass to the mass of dry air.

Wet Bulb Temperature

Unit: °C, °F, K

By wet bulb temperature tF in psychrometric measurement we refer to the temperature output or indicated by a thermometer wrapped in a moist sock. Due to the latent heat of evaporation, this temperature dependent on the relative humidity lies below the air temperature.

Sensors and Measurement Principles

Mechanical Humidity Measurement

The mechanical procedure is based on the expansion and contraction of various (mostly organic) measuring elements. Such measuring elements are, for example: hair, durometers, gut strings, etc. The measuring elements mostly used are hair elements or the so-called Durotherm, an artificial, humidity-sensitive measuring element. The change in length of the measuring element is transferred to the indicator by means of a mechanism.

Hair hygrometers require regular service and maintenance. To avoid drying-out and the associated drift, hair hygrometers must be regularly regenerated. To do this, the hair harp is wrapped in a cloth moistened with distilled water, or sprayed with distilled water, such that saturation occurs. After approximately one hour a measurement value of ca. 98%RH is obtained. A single point adjustment can be carried out on most units using an adjustment screw.

Psychrometric Humidity Measurement

Psychrometers function with two identical, very accurate thermometers, along which the air to be measured is led at a defined speed or over which the air circulates.

The first thermometer measures the ambient air, the second the so-called wet bulb temperature. For this purpose the measurement head of the thermometer is covered by a cotton wick and moistened with distilled water. Both thermometers are placed in an airflow or in moving air and are protected from radiant heat. Due to the latent heat of evaporation the temperature of the wet thermometer falls, and indeed the drier the air, the more so. After a short time (1 - 2 min) the temperature of the wet thermometer remains constant and the measurement values of the wet and dry thermometers can be read. With these two temperatures the relative humidity can be determined in accordance with the following formula :

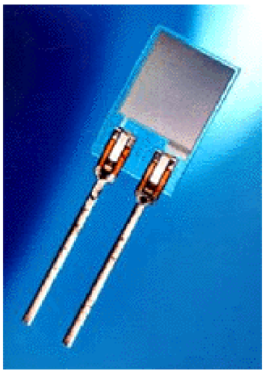
$$e(t) = e_S(t_F) - A \times p_{amb}(t_I - t_F)$$

where A is the so-called psychrometer constant. This depends on the air velocity and is presented in the table below.

Ventilation Speed	**0,0**	**1,0**	**1,5**	**2,3**	**3,4**	**4,4**	$\left[\frac{m}{s}\right]$
***A*: 10^6 in Degrees-1**	**1140**	**675**	**674**	**678**	**682**	**704**	

Electronic Humidity Measurement

Capacitive Procedure



The humidity-sensitive condenser consists of two flat electrodes, between which is located an electrically isolating, hygroscopic synthetic coating (dielectric). This dielectric can absorb the water present in the air. With increasing air humidity the capacity of the humidity-sensitive condenser also increases.

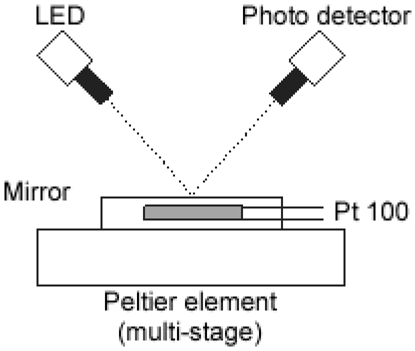
The following applies:

$$C_F = \varepsilon_0 \varepsilon_r \frac{A}{d},$$

where ε_r is the dielectrical constant of the humidity-sensitive condenser.

Dewpoint Mirror Hygrometer

The dewpoint mirror is a very precise measurement procedure for reading relative humidity, wherein the condensation of water vapour is evaluated as it falls below dewpoint. The temperature of a reflected surface (mirror) is cooled down to the point where it begins to be covered in condensation. The temperature measured at this moment by a Pt100 resistance thermometer corresponds to the dewpoint temperature, from which the relative humidity may be calculated by means of the saturation pressure with the aid of the measured air temperature. A Peltier element is installed for cooling, and the mirrored surface is evaluated using an optoelectronic procedure (see drawing).



In contrast to psychrometers the moisture content of the atmosphere is virtually unchanged by the measurement. Dewpoint mirror instruments may therefore also be installed in closed systems such as environmental cabinets.

The mirrors must be cleaned regularly with a suitable liquid, such as trichloroethylene for example.

Comparison of the different procedures

Procedure	Advantages	Disadvantages
Mechanical humidity measurement	• Simple operation • Inexpensive	• Long response times • High maintenance cost due to regular regeneration, changing of chart, etc. • Limited measuring range • Drift
Psychrometric humidity measurement	• High measurement accuracy • High long time stability • High reliability	• Assurance of constant sock wetness • Reading errors

Capacitive procedure	• High measurement accuracy • Simple operation • Maintenance-free • Short response times • Good price: performance ratio	• Temperature compensation of sensor necessary
Dewpoint mirror hygrometer	• Very high measurement accuracy • High reliability • High long-term stability • Short response times	• Expensive • Maintenance cost due to regular cleaning of mirror

Other humidity measurement procedures

The following is a list of other humidity measurement procedures (detailed observations are not made here):

- Resistive procedure (determination of the impedance of the alternating current resistance of an hygroscopic element)
- Lithium chloride dewpoint hygrometer (a measurement procedure based on the hygroscopic characteristic of lithium chloride)