
The Basics in Temperature Measurement

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This is the first in a series of papers about the basics of measurement. The subject, temperature, is basic by itself, because it is so widely measured. In industry, laboratories and hospitals, many other measurements cannot be made or conclusions drawn without the measurement of temperature. In this paper the main focus is on thermometers that make contact with the item to be measured: contact thermometry. Radiation thermometry, the other thermometry subfield shall not be discussed extensively but left for discussion later in this series. Here we discuss the major contact thermometers (thermocouples and platinum resistance thermometers) and some phenomena that need attention when using contact thermometers. We start and finish the paper with a discussion of temperature and temperature scales.

1. Introduction

Like any subfield in measurement, thermometrists (those who measure temperature) wish to stand out from the crowd by indicating the difficulty and/or particularity of their working area. Thermometrists will then refer to temperature being an *intensive* quantity.

Unlike many other measurements, temperature standards or temperature reference points cannot be added or divided to arrive at other values of the quantity (see Figure 1). When two batteries are put in series, the resulting voltage will be the sum of the two battery voltages; a weighing balance will be in equilibrium when two reference masses on the one side have equal mass to a single mass on the other side. When water is added into a glass that was already half-filled with water at the same temperature, the temperature will not change.

Temperature is a statistical quantity of the “ensemble” that consists of all water molecules added together. Adding more water only adds molecules to combine their statistical average, being the same, unchanged temperature. This is what makes temperature an *intensive* quantity: a quantity that does not depend on

the size (or the amount or extent) of the system. Thermodynamically it is defined (Figure 2) that two systems (A and B) have equal temperatures if both of them have thermal contact with a third system (C) that they do not exchange heat with[1]. Calibrating thermometers is nothing else than to find this thermal equilibrium. If thermal equilibrium cannot be reached, then this adds to the uncertainty of the calibration, more often than not as a dominant contribution.

For calibrations, one needs an appropriate system (a comparator) to compare measurement standards. For comparing voltage references one uses voltmeters with micro- or even nano-volt capability. For mass standards the comparators are balances called universal, analytical or just mass comparators dependent on range and uncertainty of the desired comparison.

Comparing temperature references with differing temperatures is not

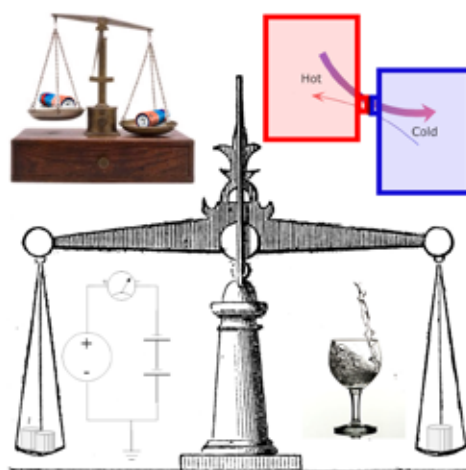


Figure 1. Mass and voltage are measured by comparison. Temperature can also be compared using an appropriate comparator, but unlike mass and voltage, temperature cannot be increased or decreased by addition or subtraction of quantity.



Figure 2. Zeroth law of thermodynamics: thermometers A and B do not exchange heat with system C, then A and B are in thermal equilibrium. If two systems are in thermal equilibrium, their temperatures are defined as equal, so A and B have the same temperature.

straightforward. A simple heat meter can only be used to see if the two systems have the same temperature (the net heat exchange is zero). When the heat exchange is not zero, the heat relates to the temperature difference through the heat capacities of both systems if there is no change of state involved (e.g. from solid to liquid).

The comparators that are required for temperature are then complex, so-called *absolute* thermometer systems that are described by interesting physics (statistical physics or, more classical, thermodynamics). These absolute thermometers are also called thermodynamic thermometers.

One such thermometer system is the gas thermometer that relates pressure (another intensive quantity) to temperature and the volume containing the gas. Applying a constant volume and an ideal gas renders a thermometer that can as accurately measure temperatures as it can measure pressure.

Later in this paper we discuss that volumes are not constant and gases are not ideal. This requires corrections to be made. All these precautions make these so-called absolute thermometers laborious in their use. One experimental series can take years to complete.

2. Temperature Measurement in Practice

In everyday life we need to do temperature measurements that give results within a reasonable waiting time, usually within minutes or seconds. Absolute thermometers are clearly not suitable for this and fortunately we can use many alternative systems as there are numerous temperature sensitive

effects. We find that nowadays most thermometers are based on resistance (of platinum in Pt100 thermometers) or on thermal electricity (thermal electromotive force of thermocouples).

2.1 Resistance Thermometers

Platinum resistance thermometers (PRTs) require a straightforward electrical measurement of the electrical resistance of a platinum wire wound around or fitted in an isolating carrier or platinum layer deposited on an isolating substrate. The resistivity of platinum, like that of many other materials, depends on temperature.

Because platinum can easily be made pure and because platinum is very resistive to corrosion and oxidation, this resistance is very reproducible. This makes platinum the best suited material for making resistance thermometers.

Platinum thermometers are sensitive to shocks. This can change their calibration depending on their construction. You cannot bend a PRT, unless the PRT has been designed for this.

A fast-and-easy check on thermometer stability is by measuring the ice point resistance called R_0 ("r-naught"), also called $R_{0\text{ }^\circ\text{C}}$. The ice point resistance is usually almost $100\ \Omega$ which is why they are called Pt100. There are platinum thermometer types with different nominal resistances such as Pt25, Pt2.5 and Pt0.25 to be used as standard platinum resistance thermometers (SPRTs). Choosing Pt500 or Pt1000 to measure room conditions allow the use of lower currents and reduction of self heating.

2.1.1 Self Heating

When measuring platinum resistance thermometers, an important effect to know is the self heating. The effect is caused by the power generated by the current flowing through the resistor. Just as in any electric heater this power heats the conducting wire. The self heating can be a few tenths of degrees when measuring the thermometers in air. If properly cooled the effect will be much smaller, but it depends on the construction and resistance of the thermometer and the cooling

capacity around the thermometer. Just decreasing the current to reduce self heating is not always an option as, amongst others, the measurement system gets less sensitive. One good way is to measure the self heating by increasing the current. The resistance difference relates to the square of the applied currents.

2.1.2 Wiring

Depending on the application (and the budget), you will find PRTs with two, three or four lead wires (Figure 3). Two wires can be used when the measurement is not critical. The lead wire resistances are added to the resistance of the PRT and a measurement off-set has to be taken into account. This offset can be as large as $0.7\ \Omega$ for each meter of 30 AWG (wire diameter 0.25 mm) lead wire, which is equivalent to almost $2\ ^\circ\text{C}$.

Many industrial applications use three-wire measurement for better accuracy. The three-wire system in Figure 3 applies two identical current sources. These currents cause compensating voltage drops over the top two lead wires. This leaves only the voltage drop over the thermometer to

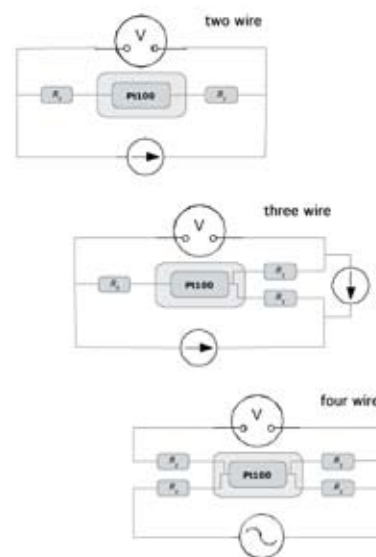


Figure 3. Lead wires are a necessary evil. To work around their resistance, alternative measurement techniques can be applied.

be measured by the voltmeter.

The best measurements are made using four-wire configuration with a resistance bridge compensating for lead wire. Current reversal or alternating current allows compensation of thermal EMF in the measurement system, as does a measurement with interrupted current of the residual voltage of the system.

2.1.3 Hysteresis

PRTs show a different response dependent upon if they experience increasing or decreasing temperature change. The size of this hysteresis effect relates to the particular construction of the thermometer because of the construction of the platinum conductor on its mount. What it comes down to is that a thermometer can differ in its reading at 200 °C after exposure to 400 °C by 0.4 °C compared to its reading at 200 °C before the exposure. As said, this effect depends very much on the fixture of the platinum wire to the carrier or substrate. Typical hysteresis can be of the order of 0.05% of the range for a fully supported PRT. Thermometers with partial support of the platinum wire can have hysteresis as low as 0.0002%.

2.1.4 Characteristic

Calibration of PRT's is to determine the resistance as a function of temperature and the uncertainty associated with that determination. The simpler part of this is to find the function. At the beginning of the previous century Callendar discovered that the resistance of platinum follows a quadratic function of temperature. Van Dusen found that this is not quite true below 0 °C and added an extra term with a factor C only to be used for temperatures below 0 °C. This combined into the Callendar-Van Dusen equation that is still used in the IEC 60751:2008 reference for platinum resistance thermometers:

$$R_t = R_{0\text{ °C}} \left(1 + At_{90} + B \cdot t_{90}^2 + C(t_{90} - 100\text{ °C})t_{90}^3 \right)$$

$$\alpha = \frac{R_{100\text{ °C}} - R_{0\text{ °C}}}{100\text{ °C} \cdot R_{100\text{ °C}}} = A + B \cdot 100\text{ °C}$$

coefficient	IEC 60751
$A / \text{°C}^{-1}$	3.9083×10^{-3}
$B / \text{°C}^{-2}$	-5.7750×10^{-7}
$C / \text{°C}^{-4}$	$\begin{cases} -4.1830 \times 10^{-12} \\ 0 & t_{90} > 0\text{ °C} \end{cases}$
$\alpha / \text{°C}^{-1}$	3.8506×10^{-3}

It is useful to realise that the sensitivity of a regular PRT is approximately $0.4\% \cdot \text{°C}^{-1}$ ($\alpha_{0.385}$) of its ice point resistance. R_0 must be distinguished from the triple point of water resistance $R_{0.01\text{ °C}}$ which is used when calibrating SPRTs according to best (but complex) algorithm of the temperature scale definition. SPRTs must be made from purer platinum than common PRTs, this results in higher sensitivity ($\alpha_{0.3927}$).

2.2 Thermistors

Other resistive thermometers are thermistors that have much higher sensitivity than platinum thermometers. When measured over a limited range (for example between 10 and 50 °C), top class thermistors can even achieve reproducibilities of within a hundredth of a degree over a year. The main advantage is the use of cheaper measurement equipment as thermistors are ten times as sensitive as platinum-based resistance thermometers. While platinum resistance thermometers (PRT's) have positive temperature coefficients (PTC, resistance increases with temperature) thermistors are part of the group of thermometers with negative resistance coefficients (NTC, decreasing resistance with temperature). More details about resistance thermometers can be found in Traceable Temperatures of Nicholas [2].

2.3 Thermocouple

Thermocouples are based on the voltage that is generated by two dissimilar metals in an inhomogeneous temperature field with a short-circuit at the ends of both wires by a weld (Figure 4a). Contrary to general perception thermal EMF is not generated at the junction of a thermocouple. It is unfortunate that this misperception is even still today taught at many educational institutes.

It is a simple concept to understand, but untrue as it requires that significant voltages are generated over very small dimensions (Figure 4b) resulting in extremely large electric field strengths. Considering that such fields would cause compensating currents in any normal conductor, including those used for thermocouple materials, this belief has to be abandoned.

How does it work? The temperature changing field (gradient) of Figure 4a causes a voltage drop across both wires of the thermocouple. As the thermocouple is short circuited at the hot junction, the voltage measured on the thermocouple is the difference between these two voltage drops, being -x minus -y in the figure.

Then, what are we left with? A thermocouple has a junction that is there to short-circuit the wires, no more. The junction is only critical when exposure to high temperatures or an aggressive environment causes the junction to corrode, crack or in other ways cause the resistance to go up dramatically. The most important problem with thermocouples is that they corrode or in other ways age along the wires.

Many users think they can wind thermocouples as frequently as they like, perhaps minding the minimum bending range as stated by the supplier. This frequent cold working causes localised mechanical strain in the wires. These effects can cause the thermal EMF of the thermocouple to change. If you can take a thermocouple deeper in the furnace and see a difference, this indicates inhomogeneity of the thermocouple wire, if the furnace has a homogeneous temperature. Thermocouples of type S have been seen to show ageing effects of 10 °C and

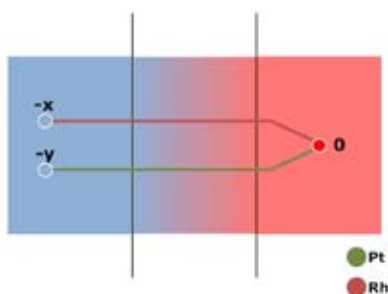


Figure 4a. Contrary to general belief a thermocouple generates voltages in a thermal field between the ends of the wires and not at the junction. The difference between these voltages x and y is the thermal EMF that is measured.

up to 25 °C after prolonged (a year or more) exposure to 1000 °C. Base metal thermocouples are still more sensitive to aging. Calibration requires proper knowledge of this effect for good estimates of the calibration uncertainty.

The second most important effect to realise about thermocouples is that they measure temperature differences. The thermal EMF is related to the temperature of the hot junction and that of the other reference ends (cold junctions) of the thermocouple. The international tables IEC 584-I for thermocouples relate the reference junction of all listed thermocouple types to 0 °C.

Usually the reference temperature part is measured with a thermometer in the meter at room temperature. The meter will do all calculations needed to arrive at a reference temperature of 0 °C. These calculations are not straightforward: a temperature change of 20 °C at room temperature does not generate the same voltage change as when the hot junction temperature is changed by the same 20 °C. This is because thermal EMF is not linear with temperature. This has to be realised in particular when calibrating meters that compensate for cold-junction temperatures. For a description of thermocouple types and other important details, we refer the reader to good introductory books such as Bentley [3].

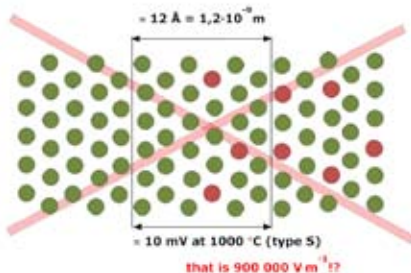


Figure 4b. Atomic structure of a weld between platinum and platinum with 10% rhodium. Assuming that the EMF were only generated at “the junction” then the voltage should occur over limited number of atom layers. We assume this to be six layers for a type S thermocouple at 1000 °C. Then we have an electric field with a strength of almost a million volt per meter.

2.4 General Effects Affecting Thermometers

Contact thermometers will only measure their own temperature. It is your task as experimenter to ensure that the thermometer takes on the temperature that you want to measure. If you can, try to make measurements with the thermometer less immersed in the furnace (Figure 5). In the absence of thermocouple inhomogeneities, the difference will tell you something about the thermal contact between the thermometer and the furnace. If the effect you measure is smaller than the uncertainty you aim for, you are safe. Worry when the effect is larger then

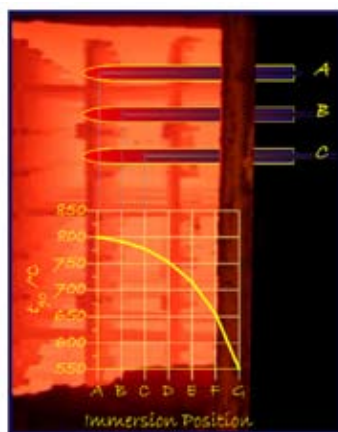


Figure 5: Immersion effects for a thermocouple in a furnace showing three thermowells with thermocouples at different immersion depths. Withdrawing thermocouples from the thermowells shows the size of the misreading the thermocouple has in position A.

the required measurement accuracy. If possible, increase the immersion depth.

Keep in mind that in any temperature measurement the thermal equilibrium has four dimensions. Three of these dimensions refer to the spatial homogeneity and the fourth to the equilibrium that settles with time. The last requires patience of the experimenter, the quality of the measurements increase with waiting time. The spatial homogeneity needs to be estimated from measurements. Understanding these effects and having a feeling for what can be expected in practice probably makes the most important difference between an experienced and a starting thermometrist.

3. Thermodynamic Temperature and Temperature Scales

Users of thermometers usually do not have to worry about the origin of the reading of their device. In many cases they just take the specification of the manufacturer to estimate the accuracy of their measurement, or if they need a small uncertainty, they ask for an individual calibration of the device by an accredited calibration laboratory. Calibration laboratories are traceable to a National Metrology Institute (NMI), which disseminate the actual temperature scale (today the International Temperature Scale of 1990, ITS-90) to its customers.

The unit of the fundamental physical quantity known as thermodynamic temperature t is the kelvin, symbol K, defined as the fraction $1/273.16$ of the thermodynamic temperature of the triple point of water (TPW), which can easily be realized in a TPW cell (see Figure 6.) It is nice to know exactly the temperature of the TPW, but of course you need something like a scale to measure temperatures that are different from the temperature of the TPW. This can be done by so-called absolute thermometers which use a well known physical relation between the thermodynamic temperature and a quantity that is easier to measure.



Figure 6. The triple point of water is realized as the equilibrium of the 3 phases of water (ice, liquid and water vapor) in a glass container with a thermometer well.

3.1 Absolute Thermometers

In this chapter the most precise absolute thermometers will be described roughly. Further details can be found in [4] and [5].

3.1.1 Gas Thermometer

The state equation for an ideal gas (known as Gay-Lussac formula) gives a relation between pressure and temperature of the gas: $pV = nRT$. So the temperature measurement can be replaced by a pressure measurement. A gas thermometer (Figure 7) is based upon this principle.

Unfortunately there is no ideal gas, so the stated equation has to be modified to describe a real gas. The interaction between the gas molecules can be taken into account by corrections known as virial coefficients, leading to the relation

$$pV = nRT \left(1 + \frac{B(T)}{V_m} + \frac{C(T)}{V_m^2} + \dots \right)$$

V_m denotes the molar volume V/N , R is the molar gas constant: $R = k N_A$ with the Boltzmann constant k and the Avogadro constant N_A . The temperature dependent second and third density virial coefficients $B(T)$ and $C(T)$ can

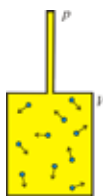


Figure 7. For an ideal gas the pressure is proportional to temperature.

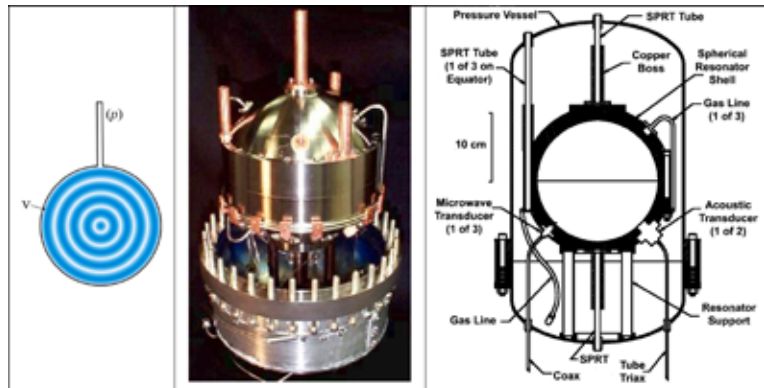


Figure 8. A spherical resonator can be used for high precision determination of the speed of sound. Left: illustration showing the principle of operation, The NIST acoustic thermometer for temperatures between 273 K (0,01 °C) and 550 K (279 °C); Middle NIST thermometer after some hours of use, right: line-drawing version.

be calculated for some cases, but must be derived from measurements at different pressures in most cases. Several effects like absorption of gas on surface and dead spaces have to be taken into account.

Similar modifications of the basic equations for an ideal gas are necessary for all methods that use real gases. They will not be mentioned in this article, but details can be found in literature [4,5].

3.1.2 Acoustic Gas Thermometer

For an ideal gas the speed of sound c_0 is related to the temperature by

$$c_0 \propto \sqrt{T}$$

An acoustic gas thermometer consists of a spherical resonator (Figure 8). The shape of the resonator is carefully designed to realize acoustic standing waves. The speed of sound and therefore the temperature can be determined very accurately. This method allows at present the most precise absolute thermometers at least in the temperature range from -50 °C to 450 °C.

3.1.3 Dielectric-Constant Gas Thermometer

The basic idea of a dielectric-constant gas thermometer (DCGT) (Figure 9) is to replace the density in the state equation of a gas by the dielectric constant ϵ and to measure it with a capacitor in the gas bulb. The dielectric

constant of an ideal gas is given by $\epsilon = \epsilon_0 + \alpha_0 N/V$, where α_0 is the static electric dipole polarizability of the gas atom. The state equation of an ideal gas therefore can be written as

$$p = kT(\epsilon - \epsilon_0) / \alpha_0$$

Similar to the AGT, the DCGT avoids the troublesome problems with dead spaces and contamination of the conventional gas thermometer.

3.1.4 Noise Thermometers

Noise thermometers are based on the fact that the mean square noise voltage $\langle U^2 \rangle$ is proportional to temperature:

$$\langle U^2 \rangle \propto T$$

Noise thermometers can be used in particular at high temperature, because otherwise the very small signal requires extremely long measuring time.

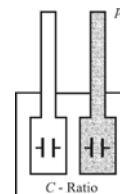


Fig. 9: In a DCGT the ratio of the capacities of a capacitor in vacuum or filled with a gas both at the same temperature is measured against a reference capacitor.

3.1.5 Radiation Thermometers

Radiation thermometers are based on Planck's law that gives the spectral radiance L_s of a black body radiator

$$L_s(\lambda, T) = \frac{2hc^2}{\lambda^5} \left(\exp\left(\frac{hc}{\lambda kT}\right) - 1 \right)^{-1}$$

The measurement of absolute spectral radiation fluxes therefore allows to determine temperatures directly with a radiation thermometer without any reference to other temperatures. In the temperature region above 500 °C this is now the most precise method for measurement of thermodynamic temperatures. Details will be presented in a further paper on radiation thermometry in this magazine.

Further principles of absolute thermometry like the refractive-index gas thermometry, Rayleigh scattering and others are described in [4].

3.2 Temperature Scales

All these absolute thermometers are not suited for practical measurements because it takes too much effort to achieve a result. Moreover, they can only be applied under very specific conditions, and, therefore, not even NMIs will use them for most of their high precision measurements. For a long time it has been the common practice in the thermometry community to define a "practical" or "international" temperature scale as the best approximation to the thermodynamic temperature, which should be much easier to realize and has a better reproducibility than thermodynamic temperature measurements [1]. A general accepted method is to define the temperature of certain "temperature fixed points" together with an interpolation method between these fixed points. Such a scale is a very good approximation to the thermodynamic temperature, but because the metrology is becoming better, it will be necessary to readjust the practical scale from time to time.

The first internationally accepted temperature scale was the normal hydrogen scale of 1887, which was valid in the limited temperature range from -25 °C to 100 °C. The International temperature scale of 1927 (ITS-27) covered the range from -193 °C to 1100 °C. It was replaced by the International Practical Temperature Scale of 1948 with only little changes compared to the previous scale. The International Practical Temperature Scale of 1968 (IPTS-68) introduced major changes. The temperature of several temperature fixed points, mainly freezing points or triple points pure elements have been defined, and also interpolation instruments were defined.

Today the valid temperature scale is the International temperature scale of 1990 (ITS-90), and temperatures measured according to this scale are denoted as T_{90} or t_{90} . It covers the range from 0.65 K up to the highest temperatures that can be measured using radiation thermometers. The

ITS-90 consists of 14 defining temperature fixed points, all of them built from pure substances, mainly rare gases and metals, but also hydrogen and water. Additionally at low temperatures the vapor pressure of helium and hydrogen is used for the definition of the scale. For the low temperature range the PLTS-2000 is the valid scale from 0.9 mK to 1 K [6].

Interpolation instruments are the Standard Platinum Resistance Thermometer (SPRT) in the range from 13.8033 K to 1234.93 K (961.78 °C, freezing point of silver) and the radiation thermometer above 961.78 °C. For the interpolation with an SPRT the deviation function from a defined reference function has to be determined at some of the defining fixed according to a well defined procedure.

The ITS-90 is based on new determinations of thermodynamic temperatures, in particular for the defining fixed points. Also because the realization of the IPTS-68 is precisely described, it is possible to give the difference in temperatures measured according to IPTS-68 and to ITS-90. In the range -200 °C to 350 °C the deviation $|t_{90} - t_{68}| < 20$ mK, but is as large as 260 mK at 1000 °C. The values are tabulated [7], and therefore a correction from one temperature scale to another is possible without problems.

The uncertainty ($k=2$) of the realization of the ITS-90 is between some 100 μ K in the range -40 °C to 30 °C and more than 3 mK for temperatures above 450 °C. The dominating contribution to the uncertainty is in the range $t > 30$ °C, the realization of the fixed point temperatures; among others a large problem is the estimation of the influence of impurities in the fixed point material, because the quantitative determination of the amount of impurities at the ppb level is extremely difficult. Therefore several NMIs are working on the improvement of the defining fixed points of the ITS 90.

3.3 Future Developments

Since 1990 several measurements have been made for new determinations of thermodynamic temperatures t , and values have been published. The values for $(t - t_{90})$ increase more or less continuously from 0 at the TPW (by definition) to 50 mK at 1000 °C. The deviation $(t - t_{90})$ is obviously, and not surprisingly, much larger than the uncertainty of the realization of the ITS-90. Therefore the discussion about the implementation of a new temperature scale ITS-201X has been started some time ago. This issue is discussed in the thermometry community together with a possible new definition of the base unit kelvin.

3.3.1 New Definition of the Kelvin

The idea of a new definition of the kelvin comes together with a revision of several base units of the SI system [8]. Many people feel unhappy with the present definitions of the kilogram and the ampere. The stability of the kilogram prototype is in question, and the realization of the ampere

has uncertainties which are higher than the reproducibility of quantum standards based on the Josephson effect and the quantum Hall effect.

The general trend in the improvement of the SI system is the definition of base units by defining fundamental constants like the Planck constant h or the electron charge e . An obvious procedure for a new definition of the kelvin would be a definition of the Boltzmann constant k , which appears in all formulas and physical laws used for the determination of thermodynamic temperatures.

It is clear that the new definition of the kelvin shall agree with the previous definition within the uncertainty of its realization, so that for practical applications no changes will be necessary. This implies that the Boltzmann constant must be known with a relative uncertainty comparable to the uncertainty of the realization of the TPW. Several methods for thermodynamic temperature measurement are applied, but not all methods described above are suitable for this particular task. Most promising are the acoustic gas thermometer and the dielectric constant gas thermometer.

3.3.2 Mise en Pratique

The previous temperature scales have been somewhat arbitrary and inconsistent— not everybody likes the idea of defining the temperatures of several fixed points. Nevertheless, internationally accepted values for temperature fixed points would be very helpful. As a compromise, together with the new definition of the kelvin there will probably be the implementation of a “mise en pratique,” which to some degree will replace the text of the ITS-90, but will allow more flexibility and changes may be easier [9]. Probably the most important modifications with regard to the text of the ITS-90 will be as follows:

- Calibration of thermometers will also be possible in terms of thermodynamic temperatures. This will apply for instance for radiation thermometers which are calibrated with respect to the spectral radiation flux in absolute units.
- The values for the temperatures of the temperature fixed points will be critically revised and additional new temperature fixed points will be introduced, for instance carbon eutectic fixed points for the temperature range from 1000 °C to 3000 °C. This will allow considerably smaller uncertainties in the high temperature range.

4. Outlook

Conventional temperature measurement is well established in nearly all relevant fields in industry, technology, medicine and daily life. Nevertheless, with the progress of technology there is demand for which new methods in thermometry have to be developed. Examples are the temperature measurement of nanostructures and the measurement of temperature changes on a timescale of milliseconds.

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Recommended for further reading: The Supplementary information to the ITS-90 and Techniques for approximating the ITS-90. These documents can be downloaded from the BIPM website:

www.bipm.org/en/publications/its-90_supplementary.html
www.bipm.org/en/publications/its-90_techniques.html

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Martin de Groot formerly worked at NMI, Netherlands, and was responsible for the contact temperature and humidity laboratories. He represented NMI on the BIPM Consultative Committee for Thermometry and served as chairman of Working Group 8. He has served as chairman of the EUROMET contact persons on temperature. In 2004, he started a consultancy and training company. He has set up a calibration laboratory for temperature, volume and weighing. He is a technical expert for RvA and UKAS in temperature and humidity, and ISRAC for humidity. Presently he is a lead assessor (ISO/IEC17025) for RvA.

Erich Tegeler

Erich Tegeler has retired from PTB after 30 years of work in metrology. In the first part of his career he developed radiometric standards in the spectral range of the vacuum UV, the range between UV radiation and X-rays. He then changed to contact thermometry and enjoyed the contact with the industrial thermometry community. He was responsible for the dissemination of the ITS-90 in Germany, was lead assessor in the German calibration service DKD, and he chaired the IEC standardization working group for temperature sensors.