International Temperature Scale of 1990

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The **International Temperature Scale of 1990** (**ITS-90**) published by the Consultative Committee for Thermometry (CCT) of the International Committee for Weights and Measures (CIPM) is an equipment calibration standard for making measurements on the Kelvin and Celsius temperature scales. ITS–90 is an approximation of the thermodynamic temperature scale that facilitates the comparability and compatibility of temperature measurements internationally. It offers defined calibration points ranging from 0.65 K to approximately 1358 K (–272.5 °C to 1085 °C) and is subdivided into multiple temperature ranges which overlap in some instances.

ITS-90 is the latest (as of 2014) of a series of International Temperature Scales adopted by CIPM since 1927.[1] Adopted at the 1989 General Conference on Weights and Measures, it supersedes the International Practical Temperature Scale of 1968 (amended edition of 1975) and the 1976 "Provisional 0,5 K to 30 K Temperature Scale". CCT has also adopted a *mise en pratique* (practical instructions) in 2011.[2] The lowest temperature covered by ITS-90 is 0.65 K. In 2000, the temperature scale was extended further, to 0.9 mK, by the adoption of a supplemental scale, known as the Provisional Low Temperature Scale of 2000 (PLTS-2000).[3]

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Details

CCT ITS-90 is designed to represent the thermodynamic (absolute) temperature scale (referencing absolute zero) as closely as possible throughout its range. Many different thermometer designs are required to cover the entire range. These include helium vapor pressure thermometers, helium gas thermometers, standard platinum resistance thermometers (known as SPRTs, PRTs or Platinum RTDs) and monochromatic radiation thermometers.

Although the Kelvin and Celsius scales are defined using absolute zero (0 K) and the triple point of water (273.16 K and 0.01 °C), it is impractical to use this definition at temperatures that are very different from the triple point of water. Accordingly, ITS–90 uses numerous defined points, all of which are based on various thermodynamic equilibrium states of fourteen pure chemical elements and one compound (water). Most of the defined points are based on a phase transition; specifically the melting/freezing point of a pure chemical element. However, the deepest cryogenic points are based exclusively on the vapor pressure/temperature relationship of helium and its isotopes whereas the remainder of its cold points (those less than room temperature) are based on triple points.

Examples of other defining points are the triple point of hydrogen (−259.3467 °C) and the freezing point of aluminum (660.323 °C).

Thermometers calibrated per ITS–90 use complex mathematical formulas to interpolate between its defined points. ITS–90 specifies rigorous control over variables to ensure reproducibility from lab to lab. For instance, the small effect that atmospheric pressure has upon the various melting points is compensated for (an effect that typically amounts to no more than half a millikelvin across the different altitudes and barometric pressures likely to be encountered). The standard even compensates for the pressure effect due to how deeply the temperature probe is immersed into the sample. ITS–90 also draws a distinction between "freezing" and "melting" points. The distinction depends on whether heat is going *into* (melting) or *out of* (freezing) the sample when the measurement is made. Only gallium is measured while melting, all the other metals are measured while the samples are freezing.

A practical effect of ITS–90 is the triple points and the freezing/melting points of its thirteen chemical elements are precisely known for all temperature measurements calibrated per ITS–90 since these thirteen values are fixed by its definition. Only the triple point of Vienna Standard Mean Ocean Water (VSMOW) is known with absolute precision—regardless of the calibration standard employed—because the very definitions of both the Kelvin and Celsius scales are fixed by international agreement based, in part, on this point.

Limitations

There are often small differences between measurements calibrated per ITS–90 and thermodynamic temperature. For instance, precise measurements show that the boiling point of VSMOW water under one standard atmosphere of pressure is actually 373.1339 K (99.9839 °C) when adhering *strictly* to the two-point definition of thermodynamic temperature. When calibrated to ITS–90, where one must interpolate between the defining points of gallium and indium, the boiling point of VSMOW water is about 10 mK less, about 99.974 °C. The virtue of ITS–90 is that another lab in another part of the world will measure the very same temperature with ease due to the advantages of a comprehensive international calibration standard featuring many conveniently spaced, reproducible, defining points spanning a wide range of temperatures.

Although "International Temperature Scale of 1990" has the word "scale" in its title, this is a misnomer that can be misleading. ITS–90 is not a scale; it is an *equipment calibration standard*. Temperatures measured with equipment calibrated per ITS–90 may be expressed using any temperature scale such as Celsius, Kelvin, Fahrenheit, or Rankine. For example, a temperature can be measured using equipment calibrated to the kelvin-based ITS–90 standard, and that value may then be converted to, and expressed as, a value on the Fahrenheit scale (e.g. 211.953 °F).

ITS–90 does not address the highly specialized equipment and procedures used for measuring temperatures extremely close to absolute zero. For instance, to measure temperatures in the nanokelvin range (billionths of a kelvin), scientists using optical lattice laser equipment to adiabatically cool atoms, turn off the entrapment lasers and simply measure how far the atoms drift over time to measure their temperature. A cesium atom with a velocity of 7 mm/s is equivalent to temperature of about 700 nK (which was a record cold temperature achieved by the NIST in 1994).

Estimates of the differences between thermodynamic temperature and the ITS-90 (T-T_{90}) were published in 2010. It had become apparent that ITS-90 deviated considerably from PLTS-2000 in the

overlapping range of 0.65 K to 2 K. To address this, a new ^{3}He vapor pressure scale was adopted, known as PTB-2006. For higher temperatures, expected values for T-T_{90} are below 0.1 mK for temperatures 4.2 K– 8 K, up to 8 mK at temperatures close to 130 K, at 0K by definition at the temperature of the triple point of water (273.16), but rising again to 10 mK at temperatures close to 430 K, and to 46 mK at temperatures close to 1150 K.[4]

Standard interpolating thermometers and their ranges

Lower (K)	Upper (K)	Variations	Thermometer	Calibration and interpolation strategy
0.65	3.2	1	Helium-3 vapor pressure thermometer	Vapor pressure–temperature relationship fixed by a specified function.
1.25	2.1768	1	Helium-4 vapor pressure thermometer	Vapor pressure–temperature relationship fixed by a specified function.
2.1768	5.0	1	Helium-4 vapor pressure thermometer	Vapor pressure–temperature relationship fixed by a specified function.
3.0	24.5561	1	Helium gas thermometer	Calibrated at three fixed points in this range and interpolated in a specified way.
13.8033	1234.93	11	Platinum resistance thermometer	Resistance calibrated at various fixed points and interpolated in a specified way. Eleven distinct calibration procedures are specified.
1234.93	∞	3	Optical pyrometer	Calibrated at one fixed point, and extrapolated according to Planck's law. May be calibrated at Ag, Au, or Cu freezing point.

Defining points

The table below lists the defining fixed points of ITS-90.

Substance and its state	Defining point (range)			
	K	°C	°R	°F
Triple point of hydrogen	13.8033	–259.3467	24.8459	–434.8241
Triple point of neon	24.5561	–248.5939	44.2010	–415.4690
Triple point of oxygen	54.3584	–218.7916	97.8451	–361.8249
Triple point of argon	83.8058	–189.3442	150.8504	–308.8196
Triple point of mercury	234.3156	–38.8344	421.7681	–37.9019
Triple point of water[note 1]	273.16	0.01	491.69	32.02
Melting point[note 2] of gallium	302.9146	29.7646	545.2463	85.5763
Freezing point[note 2] of indium	429.7485	156.5985	773.5473	313.8773
Freezing point[note 2] of tin	505.078	231.928	909.140	449.470
Freezing point[note 2] of zinc	692.677	419.527	1,246.819	787.149
Freezing point[note 2] of aluminum	933.473	660.323	1,680.251	1,220.581
Freezing point[note 2] of silver	1,234.93	961.78	2,222.87	1,763.20
Freezing point[note 2] of gold	1,337.33	1,064.18	2,407.19	1,947.52
Freezing point[note 2] of copper	1,357.77	1,084.62	2,443.99	1,984.32

1. *The triple point of water is frequently approximated by the using the melting point of water at standard conditions for temperature and pressure.*[5]
2. *Melting and freezing points are distinguished by whether heat is entering or leaving the sample when its temperature is measured. See melting point for more information.*

See also

- Thermodynamic (absolute) temperature — the "true temperature" which ITS-90 is attempting to approximate.
- Provisional Low-Temperature Scale of 2000 (PLTS-2000) — A newer temperature scale for the range of 0.0009 K to 1 K, based on the melting pressure of helium-3.
- Kelvin
- Triple point
- Vienna Standard Mean Ocean Water (VSMOW)
- Resistance thermometer
- Platinum resistance thermometer

References

1. "Beginning in 1927, the CIPM, acting under the authority of the General Conference on Weights and Measures (CGPM) and, since 1937, on the advice of its Consultative Committee for Thermometry (CCT), has adopted a series of International Temperature Scales. Subsequent to the 1927 scale, new scales have been adopted in 1948, 1968, and 1990, with occasional minor revisions in intervening years."
2. "In practice, primary thermometry is difficult and time consuming and not a practical means of disseminating the kelvin. As an alternative, the International Temperature Scale provides an internationally accepted recipe for realizing temperature in a practical way." Consultative Committee for

Thermometry, "*Mise en pratique* for the definition of the kelvin", 2011.

3. "Considerable research has been conducted on establishing a temperature scale extending to temperatures lower than 0.65 K; the PLTS-2000 is the resulting outcome, defining temperature from 1 K down to 0.9 mK. The PLTS-2000 is explicitly a provisional scale, recognizing that the data sets comprising the basis of the scale were somewhat inconsistent below 10 mK. In the temperature range 0.65 K to 1 K, temperature may be defined on either the ITS-90 or the PLTS-2000. Either scale is acceptable; the choice of scale typically is dictated by convenience or the attainable uncertainty of realization. In those rare cases where use of either scale is convenient, T_{2000} *is a better approximation of thermodynamic* temperature than T_{90} in the region of overlap." Consultative Committee for Thermometry, "*Mise en pratique* for the definition of the kelvin", 2011.
4. Estimates of the Differences between Thermodynamic Temperature and the ITS-90 (http://www.bipm.org/utils/en/pdf/Estimates_Differences_T-T90_2010.pdf) (2010)
5. Burns Engineering (http://www.burnsengineering.com/document/papers/Ice_Bath_TPW.pdf)

- Preston-Thomas H., Metrologia, 1990, 27(1), 3-10 (amended version). (http://www.bipm.fr/en/publications/its-90.html)
- "*Mise en pratique* for the definition of the kelvin" (http://www.bipm.org/utils/en/pdf/MeP_K.pdf) (PDF). Sèvres, France: Consultative Committee for Thermometry (CCT), International Committee for Weights and Measures (CIPM). 2011. Retrieved 25 June 2013.
- Consultative Committee for Thermometry (CCT) (1989). "The International Temperature Scale of 1990 (ITS-90)" (http://www.bipm.org/utils/en/pdf/ITS-90.pdf) (PDF). *Procès-verbaux du Comité International des Poids et Mesures, 78th meeting* (Sèvres, France: International Committee for Weights and Measures (CIPM)). Retrieved 25 June 2013.

External links

- The Internet ITS-90 Resource (by ISOTech Ltd) (http://www.its-90.com/)
- ITS-90 (by Swedish National Testing and Research Institute) (http://www.sp.se/Metrology/temperature/eng/its-90.htm)
- ITS-90 (by Omega Engineering) (http://www.omega.com/techref/intltemp.html)
- About Temperature Sensors (information repository) (http://www.temperatures.com/stds.html)
- Platinum resistance thermometer By Burns Engineering (http://www.burnsengineering.com)
- Very high-end temperature measurement products (http://www.HartScientific.com)
- Secondary Standard Platinum Resistance Thermometer and Metrology (http://www.burnsengineering.com/pgd.asp?pgid=solmet)
- NIST ITS-90 Thermocouple Database (by United States Department of Commerce, National Institute of Standards & Technology) (http://srdata.nist.gov/its90/main/)
- Conversion among different international temperature scales; equations and algorithms. (http://www.code10.info/index.php?option=com_content&view=article&id=83:conversions-among-international-temperature-scales&catid=60:temperature&Itemid=83)

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