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Redefinition of the kelvin

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Outlines

I. Previous definition of the kelvin and practical temperature scales

II. The kelvin redefinition and the *MeP*-K

III. The practical implementations of the redefined kelvin

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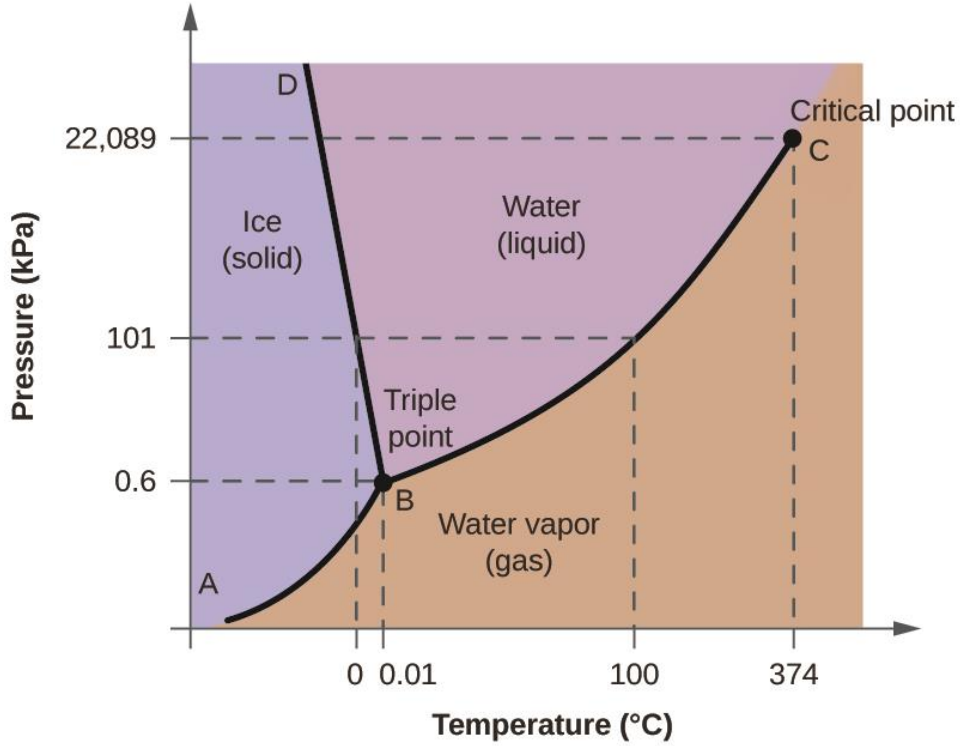
I. Previous definition of the kelvin and practical temperature scales

The 13th CGPM meeting in 1967/68 (Resolution 4)

The kelvin, unit of thermodynamic temperature, is the fraction 1/273.16 of the thermodynamic temperature of the triple point of water.

$$T_{\mathrm{TPW}} = 273.160\,000\,000 \ldots \mathrm{K}$$
$$= 0.01\ ^{\circ}\mathrm{C}$$



https://chem.libretexts.org

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www.nist.gov

https://en.wikipedia.org

Weakness of the definition
Dependence on isotropic composition of the water sample

The CIPM 2005 meeting (Recommendation 2)

"This definition refers to water having the isotopic composition defined exactly by the following amount of substance ratios: 0.000 155 76 mole of ^{2}H per mole of ^{1}H,
0.000 379 9 mole of ^{17}O per mole of ^{16}O
0.002 005 2 mole of ^{18}O per mole of ^{16}O".

Composition of IAEA reference material Vienna Standard Mean Ocean Water (VSMOW) as recommended by IUPAC

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Weakness of the definition

Every temperature measurement is a comparison of the temperature of an object being measured with T_{TPW}.

Before 1990, the constant volume gas thermometer (CVGT) was the most common technique of primary thermometry used.

$$p = \frac{n}{V} kT \quad \Rightarrow \quad T_x = \frac{p(x)}{p(TPW)} T_{TPW}$$

n = amount of gas (molecules)

V = volume

p = pressure

k = Boltzmann constant

T = thermodynamic temperature

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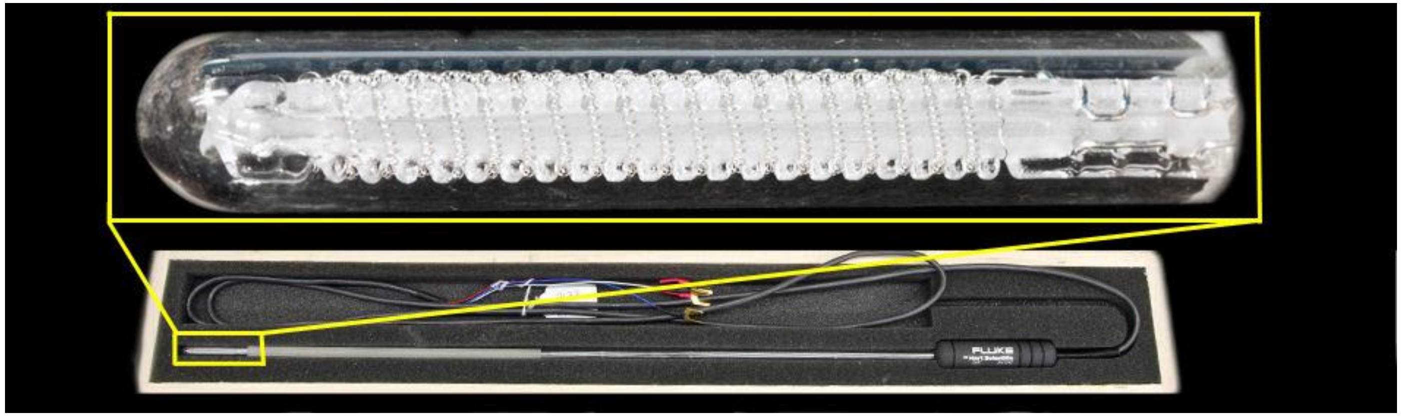
Primary thermometers - realisation the kelvin based on fundamental laws of physics

- extremely difficult and time-consuming.
- not practical for a customer's thermometer calibration

Secondary thermometers - the temperature-dependence of physical properties, i.e., Platinum resistance thermometers (PRTs) – Resistance Vs T

- need calibration for setting temperature scale.



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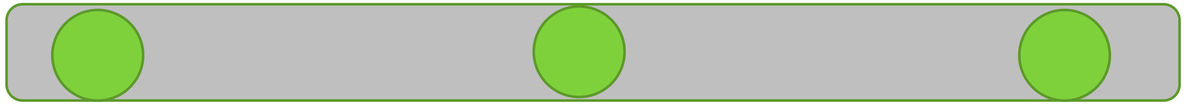
Practical temperature scale

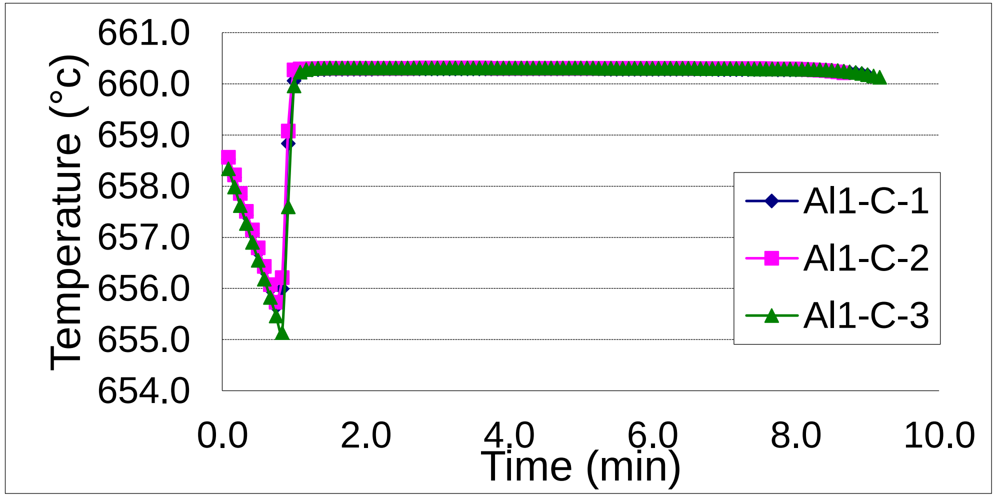
Defined fixed point



$T=T_1$ $T=T_2$ $T=T_3$

Fixed-point cells

- the melting, boiling and triple points of pure substances
- highly reproducible



Interpolating thermometers

Interpolating equations

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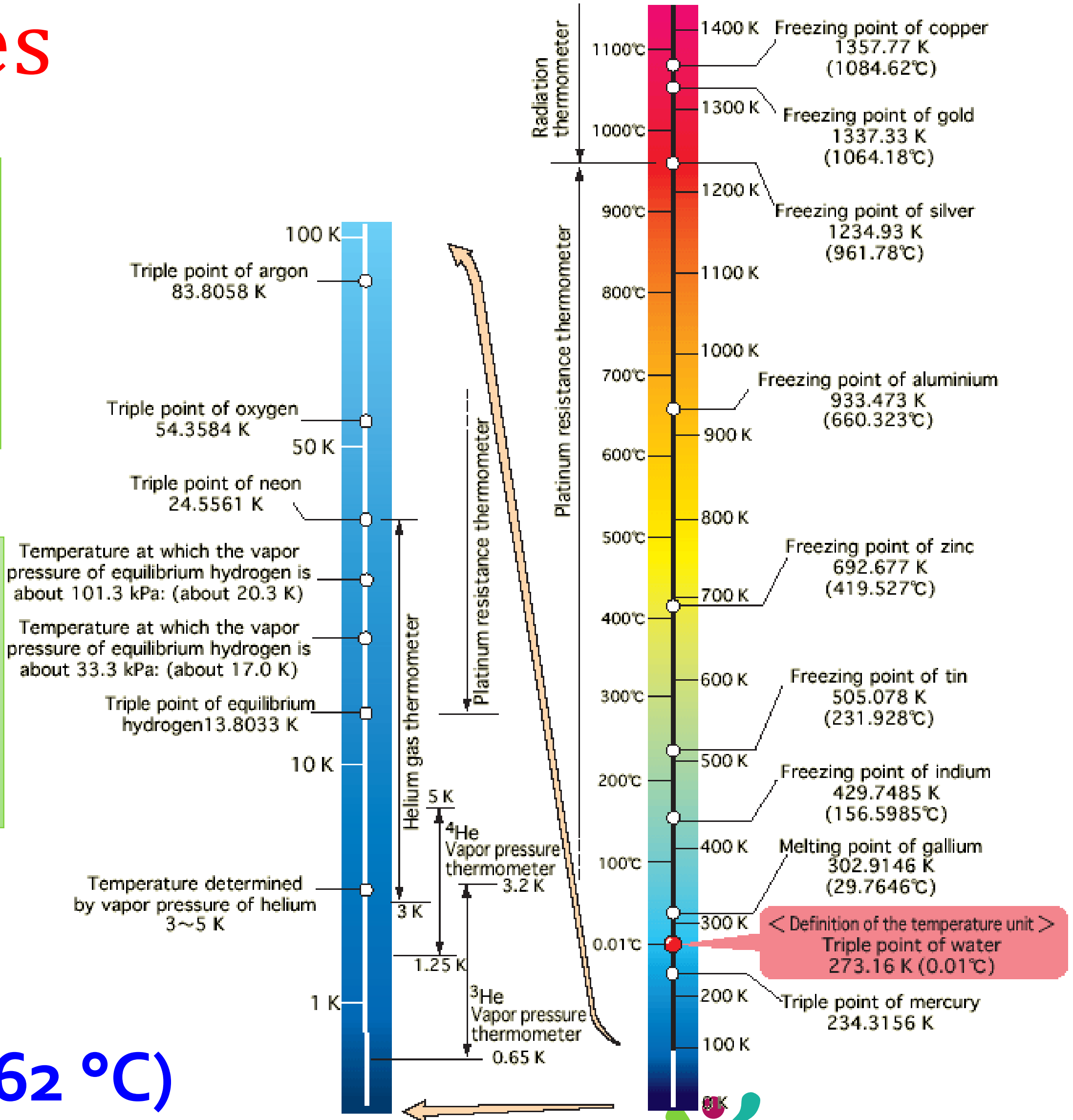
Defined temperature scales

1. International Temperature Scale of 1990 (ITS-90) for temperatures above 0.65 K (T_{90})
14 Fixed points

2. Provisional Low Temperature Scale (PLTS-2000) for temperature range 0.9 mK to 1 K (T_{2000})

NIMT - Provides traceability for ITS-90 only
- 10 FPs
- Ar FP (-189.344 2 °C) to Cu FP (1084.62 °C)



https://www.nmij.jp/english/library/units/temperature/

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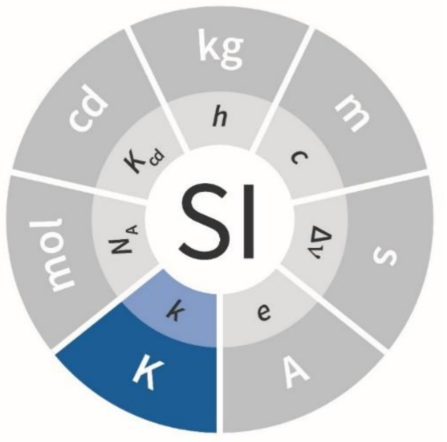
II. The kelvin redefinition and the *MeP*-K

The kelvin, symbol K, is the SI unit of thermodynamic temperature. It is defined by taking the fixed numerical value of the Boltzmann constant k to be 1.380 649 × 10^{-23} when expressed in the unit J K^{-1}, which is equal to kg m^2 s^{-2} K^{-1}, where the kilogram, metre and second are defined in terms of h, c and $\Delta\nu_{Cs}$



one kelvin is equal to the change of thermodynamic temperature that results in a change of thermal energy kT by 1.380 649 x 10^{-23} J

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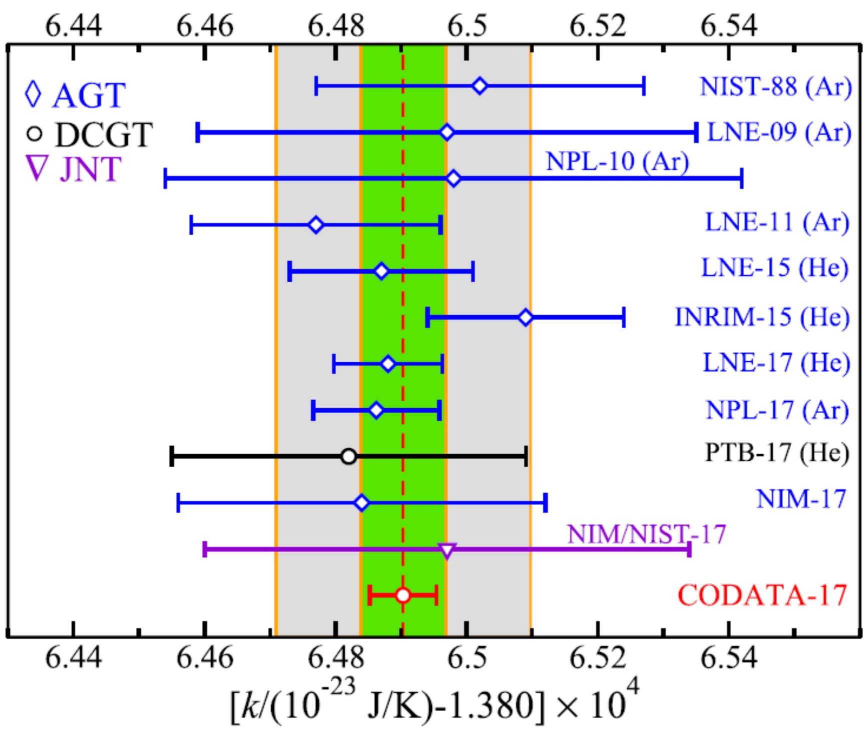
Redefinition of the kelvin



- eliminate the effect from the substance
- make the definition consistency with other units
- in terms of a fixed value of the Boltzmann constant (k)

Methods

- Acoustic gas thermometry (AGT)
- Dielectric-constant gas thermometry (DCGT)
- Johnson noise thermometry (JNT)

$$k = 1.380\,649\,03(51) \times 10^{-23}\ \mathrm{J\ K^{-1}}$$

D. B. Newell *et. al.* 2018 Metrologia 55 L13

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Mise en Pratique of the realization of the kelvin (*MeP*-K)

(Practical realization)

Primary thermometry

a) Absolute primary thermometry

Measurement T directly in terms of the definition, k, no reference to any fixed point (n = 0)

b) Relative primary thermometry

Measurement relatively to fixed points ($n \geq 1$)

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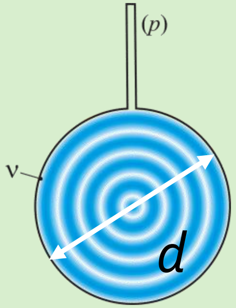
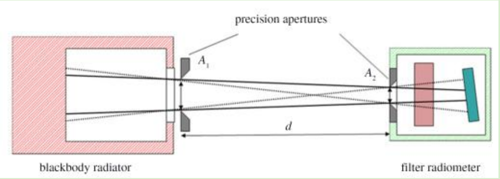
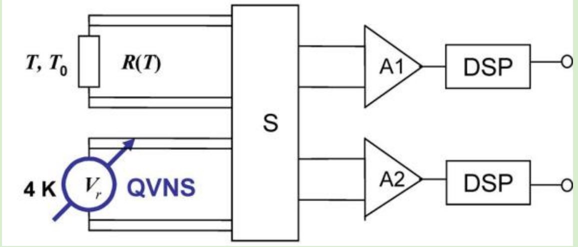
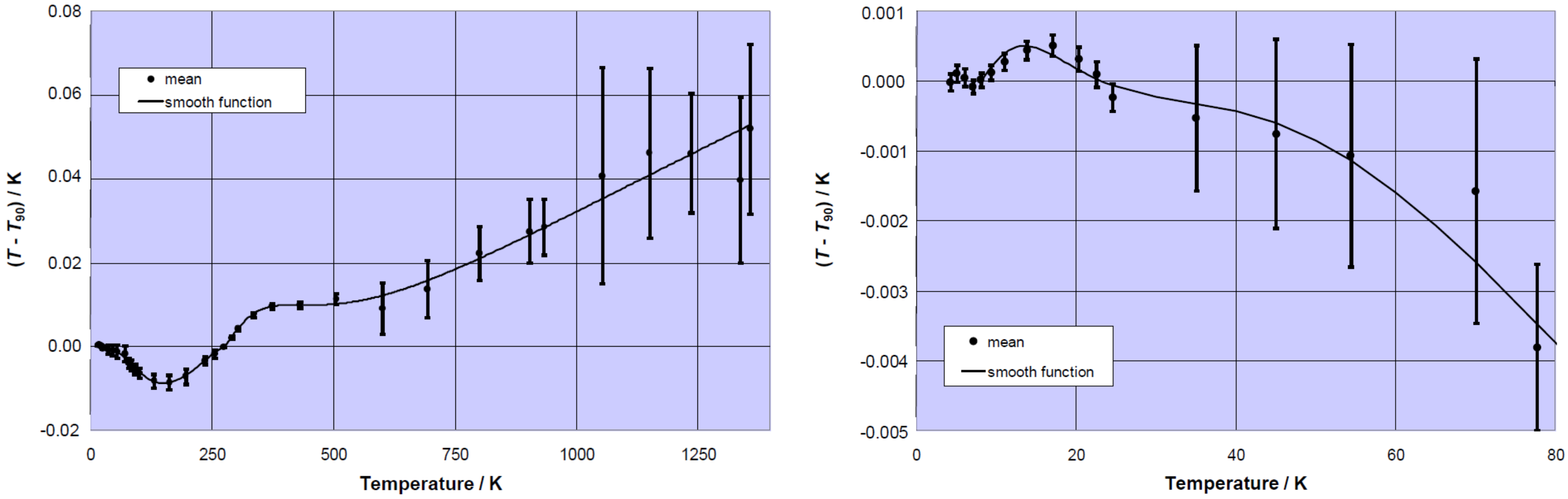
Primary thermometry methods

Acoustic gas thermometry (AGT)	Spectral-band radiometric thermometry (RT)	Polarizing gas thermometry (PGT)	Johnson noise thermometry (JNT)
$u^2 = \frac{\gamma k T}{m}$ 	$L_{b,\lambda}(\lambda,T) = \left(\frac{2hc^2}{\lambda^5}\right)\frac{1}{\exp(hc/\lambda kT)-1}$ 	**Dielectric-constant gas thermometry (DCGT)** $p = kT\frac{\varepsilon - \varepsilon_0}{\alpha_0}$ **Refractive index gas thermometry (RIGS)** $p = kT\frac{(n^2-1)\varepsilon_0}{\alpha_0}$	$\langle V^2 \rangle = 4kTR\Delta f$ 
u = Speed of sound γ = ratio of the heat capacity (c_p / c_V) *k* = Boltzmann constant *T* = Temperature m = average molar mass of the gas	L_λ = Spectral radiance λ = Wavelength in vacuo *T* = Temperature *h* = Planck constant *k* = Boltzmann constant *c* = Speed of light in vacuo	ε = dielectric constant ε_0 = electric constant α_0 = static electrical polarizability *n* = refractive index *p* = pressure *T* = temperature *k* = Boltzmann constant	*V* = noise voltage *k* = Boltzmann constant *T* = Temperature *R* = Resistance Δf = Bandwidth of noise voltage

Estimates of the Differences between Thermodynamic Temperature (T) and the ITS-90 (T_{90})



Awareness of the scale used!!!

https://www.bipm.org/utils/common/pdf/ITS-90/Estimates_Differences_T-T90_2010.pdf

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III. The practical implementations of the redefined kelvin

Immediate implementation

- No immediate impact on the status of ITS-90 and PLTS-2000
- T-T_{90} data in the *MeP*-K are used to convert defined scale temperatures to thermodynamic temperatures.
- The new definition will no longer linked to the water triple point (WTP).
- TPW becomes 'just' another fixed point.
- $u_r(T_{\mathrm{TPW}}) = u_r(k) = 0.37 \times 10^{-6}$ (~ 0.1 mK)

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Medium and long term implementation

- Primary thermometry will increasingly supplant the defined scales especially for above 1300 K and below 20 K.
- Lower temperature of ITS-90 (0.65 K to 1 K) and the whole of the PLTS-2000 may be supplanted by low temperature primary thermometry.
- Primary thermometry methods become increasingly adopted, with reduced uncertainties, improved ease of use, improvement in the realisation.

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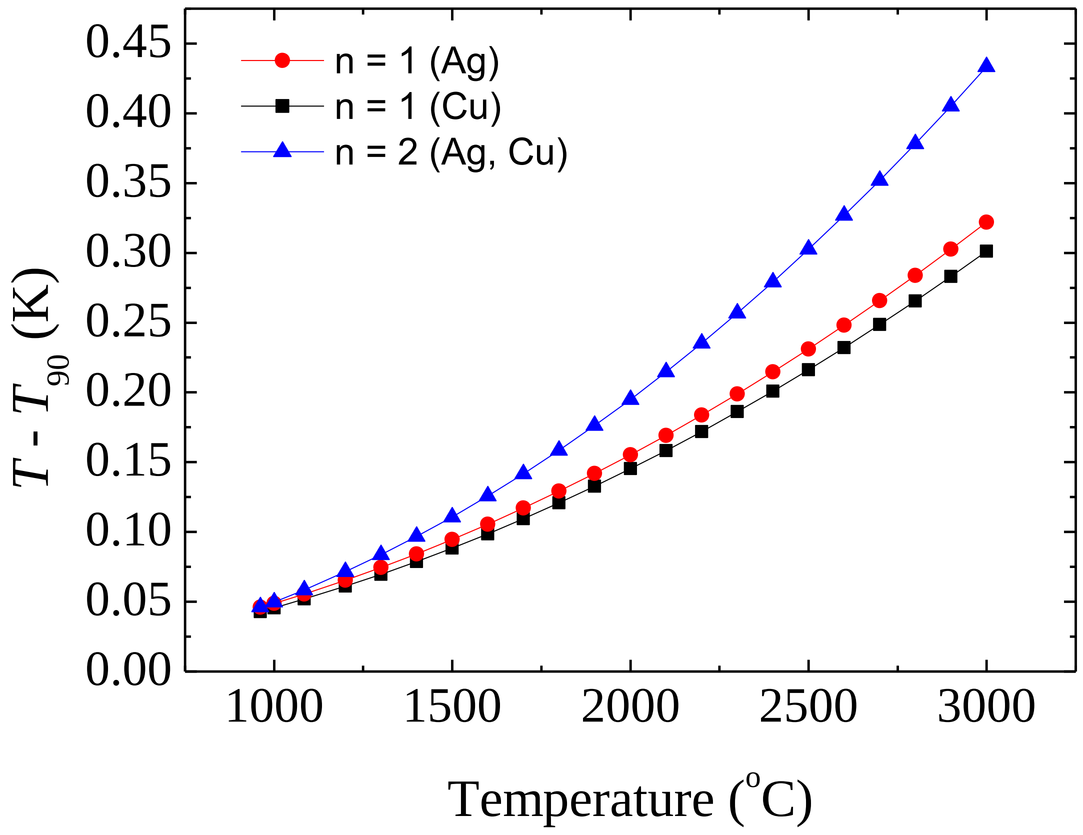
Effect to NIMT



No effect to the calibration service and traceability (Keep using ITS-90).

Any work relates to *T* should be aware of $T - T_{90}$.

Good opportunity for education, research and innovation.

A. Manoi, P. Wongnut, X. Lu, and P. Saunders to be published

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Thank you