Achievements in the quantum electrical effects - CCEM report

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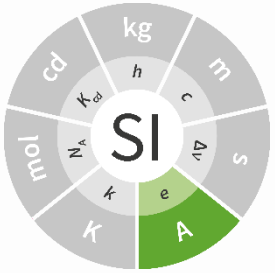
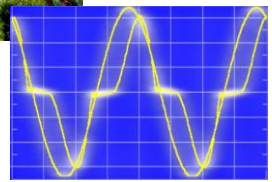


Bureau International des Poids et Mesures

Electrical measurements in daily life

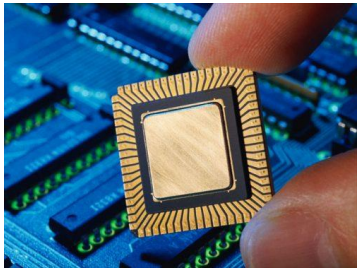


Sustainable society

Telecom

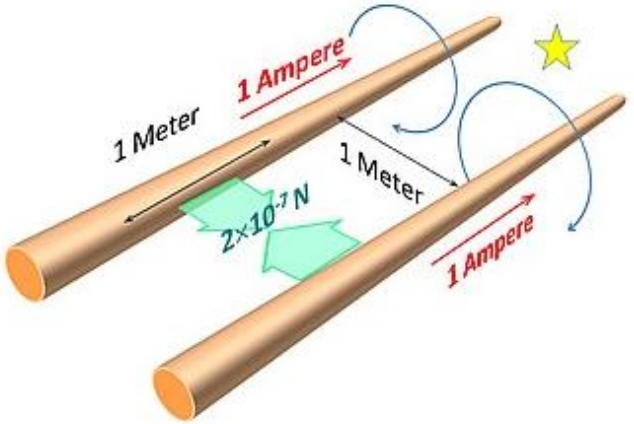
Fair trade

Nanoelectronics



Present definition of the ampere

"The ampere is that constant current which, if maintained in two straight parallel conductors of infinite length, of negligible circular cross-section, and placed 1 metre apart in vacuum, would produce between these conductors a force equal to 2 × 10^{-7} Newton per metre of length."



The ampere will never be better than the IPK

⇒ CCEM scientific challenge is to improve this!

Introducing the CCEM community

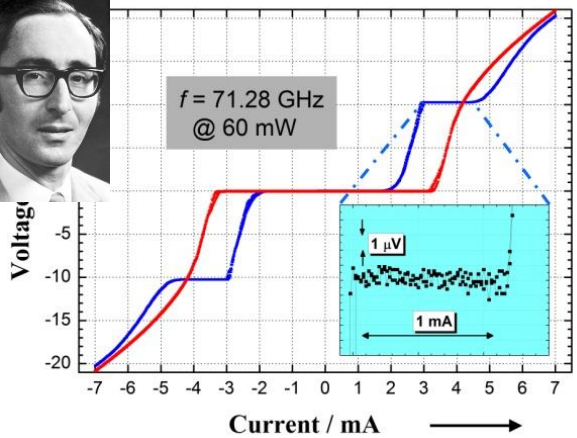
Key objective: advise CIPM on electromagnetic metrology

- 25 members
- Meetings: 2015, 2017
- WGLF + GTRF, WGRMO
- WGKG, WGSI: preparations for the revised SI!

- Scientific presentations on graphene, waveform metrology, ampere
- Workshop on future EM challenges (2017) and on microwave measurements (2019)

Global forum for progressing the state-of-the-art

Quantum standards for voltage and resistance:

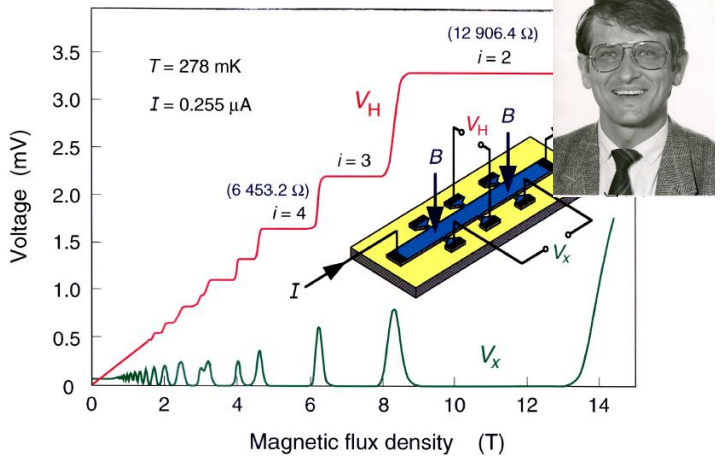


$$V = n \cdot (h/2e) \cdot f$$

$K_{J\text{-}90}$

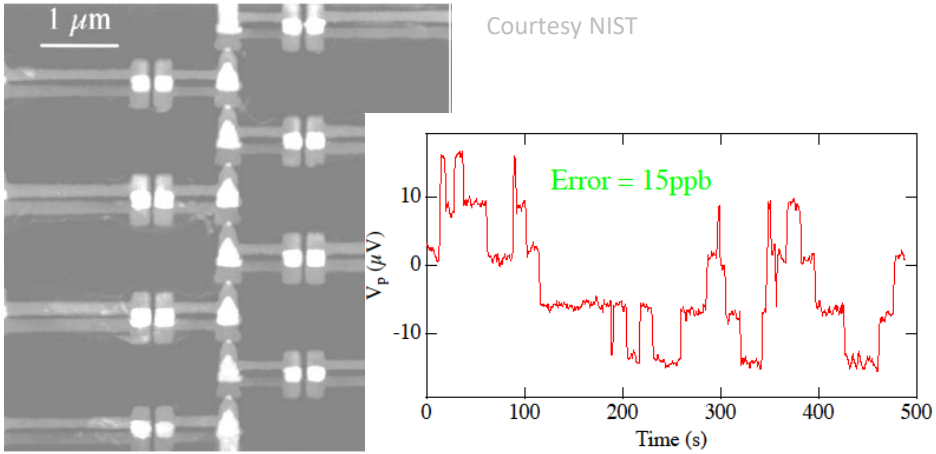
$$R = (h/e^2) \cdot 1/n$$

$R_{K\text{-}90}$

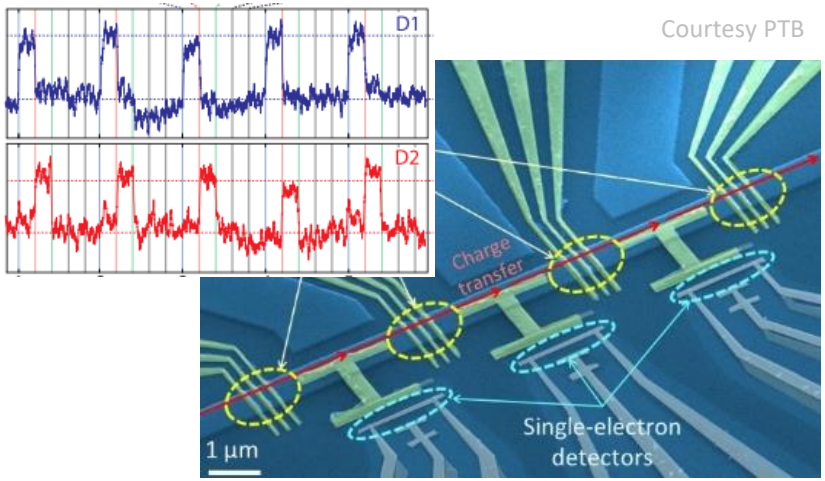


- Conventional 1990 values
- Link to SI "only at 10^{-7} level", internal agreement at < 10^{-9} level
- Recent developments: AC JAVS, QHE in graphene

Quantum current standard: Single Electron Transport



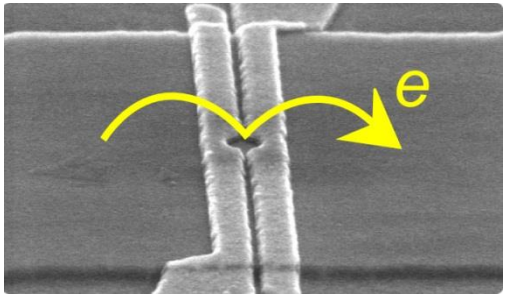
Courtesy NIST



Courtesy PTB

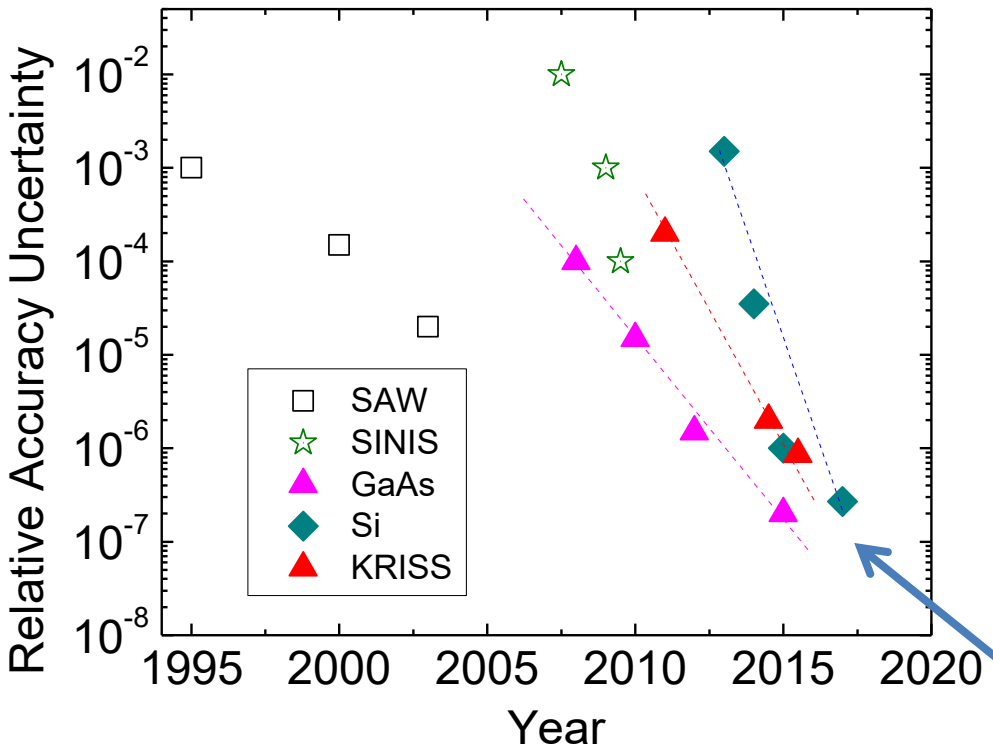
Control of single electrons

⇒ basis for new ampere definition!!

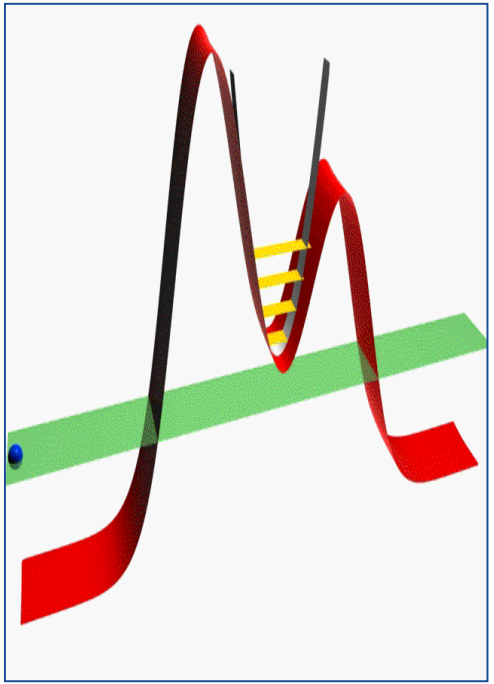


Single Electron Transport – recent progress

Courtesy KRISS



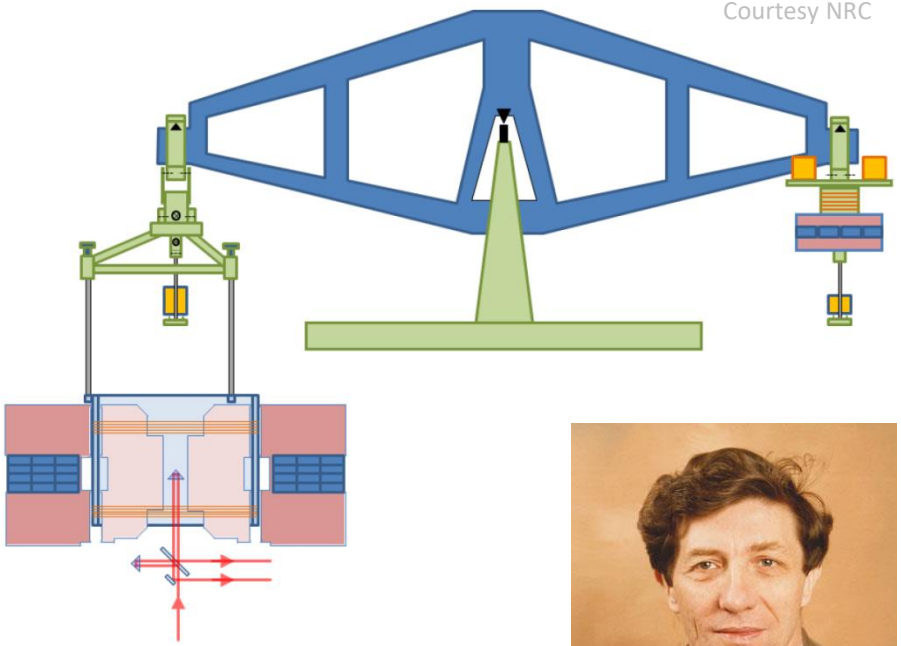
Courtesy PTB



accuracy ~ 2×10^{-7}

Kibble balance – paving the way to the revised SI

Courtesy NRC



Combining 2 steps:

1. Weighing: $M \cdot g = B \cdot L \cdot I_w$
2. Moving: $V_m = v \cdot B \cdot L$

Comparing electrical and mechanical Watt:

$$\Rightarrow M \cdot g \cdot v = V_m \cdot I_w \propto h$$

Josephson, QHE: $V \propto h/2e$, $R \propto h/e^2$

Impact of the revised SI on EM quantities

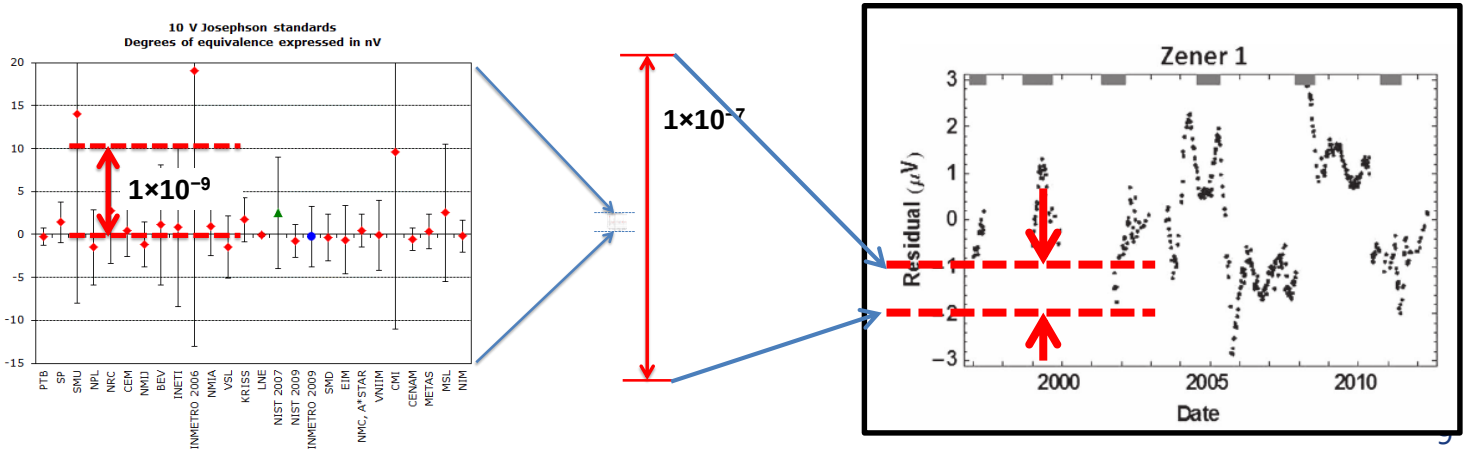
- By fixing values of *h* and *e*, CCEM will be "back in the SI"

However…

- Final values of *h*, *e* do not perfectly align with 1990 values

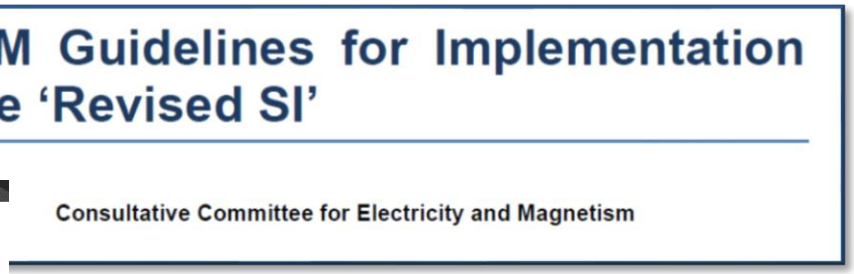
⇒ CCEM will be the only CC with a step change!

Courtesy BIPM



Facilitating dialogue NMIs and stakeholders

- Knowledge transfer to industry in making and operating quantum standards
- Revised SI support



https://www.bipm.org/utils/common/pdf/CC/CCEM/ccem_guidelines_revisedSI.pdf

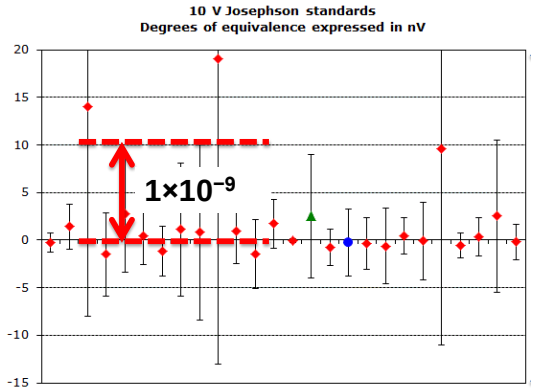
Other 'outreach' activities:

- Future challenges workshop
- Support for CCRI

Global comparability of measurements

- Quantum standards and 1990 conventional values of R_K and K_J greatly increased EM measurement comparability worldwide
- CIPM MRA was a significant second step in enhancing worldwide acceptance of measurement results
- Concluding step: increased MRA efficiency

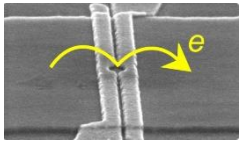
BIPM provides crucial support to CCEM: on-site comparison of quantum standards, calibration services, efficient performance of other comparisons (e.g. capacitance)

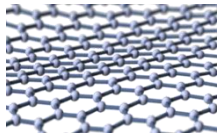


Summary

CCEM is continuously working on its key objectives via

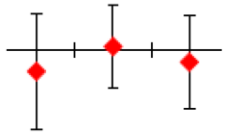
- *Advancing measurement science:*
  - Quantum Technologies
  - Bio- and nanoscience
  - Applied science for societal challenges (e.g. energy)



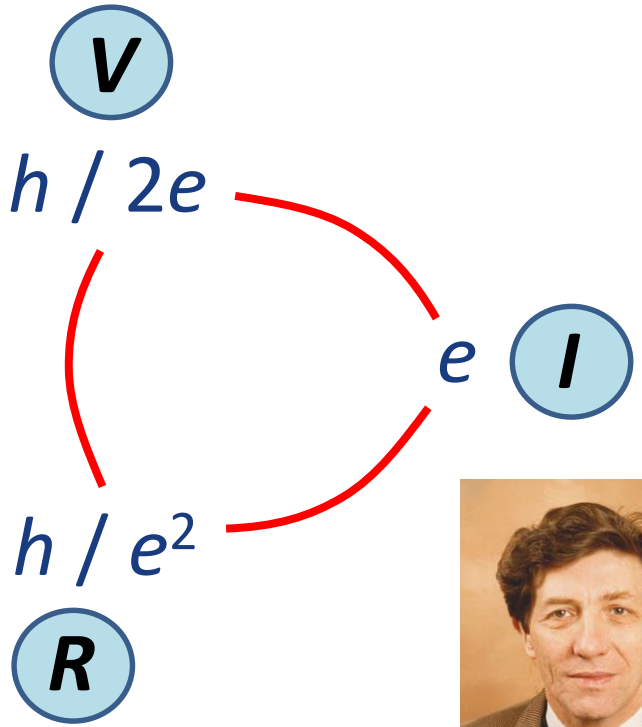


- *Enhancing impact to society:*
  pick up new challenges, increased stakeholder interaction

- *Increased comparability of measurement results:*
  versatile quantum standards
  'run' the CIPM MRA as smoothly and effectively as possible

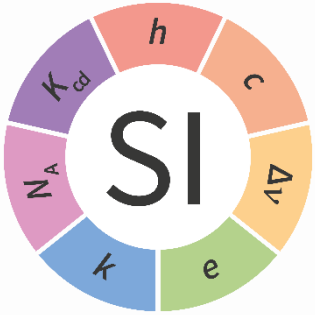


Precise measurements and quantum electrical effects



Please: say

to the
revised SI…



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