CCM Working Group on the Avogadro Constant

Horst Bettin

Physikalisch-Technische Bundesanstalt

Germany

Bundesministerium für Wirtschaft und Technologie

WG on the Avogadro Constant

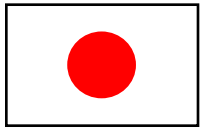
- Established in 1995 (ad hoc WGAC)
- Last meeting: 28 - 29 June 2012 in the USA
- Periodicity: Once a year
- Next meeting: probably September 2013 during the kg workshop of the EMRP project “kNOW” (Realisation of the awaited definition of the kilogram - resolving the discrepancies)

Members of the CCM WGAC

CCM WG on the Avogadro Constant: Members

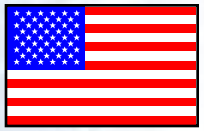
- **BIPM** **INRIM** **NIM** **NMI-A** **NMIJ** **PTB**




Cooperation in the determination of molar mass, invited to become members

- **NIST** **NRC**




WGAC: Terms of Reference

Terms of Reference

- Determination of the Avogadro constant (XRCD)
- International cooperation and comparisons
- Conferences, publications
- Cooperation with watt balance experiments
- Advise to CCM, *mise en pratique*
- Monitor the international prototype of the kilogram
- Help to realise and disseminate the new kilogram

Avogadro constant - kilogram

Definition of Avogadro constant N_A

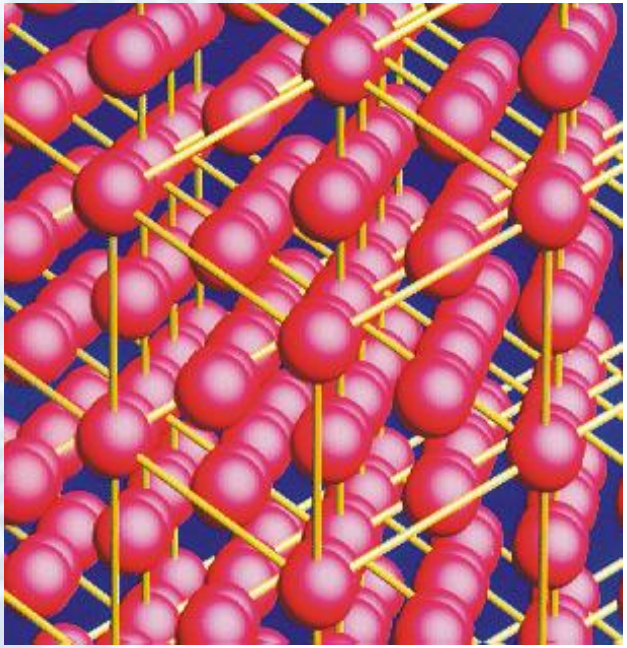
- Number of molecules per mol
- $6.022... \times 10^{23}\ mol^{-1}$

Current definition of mol

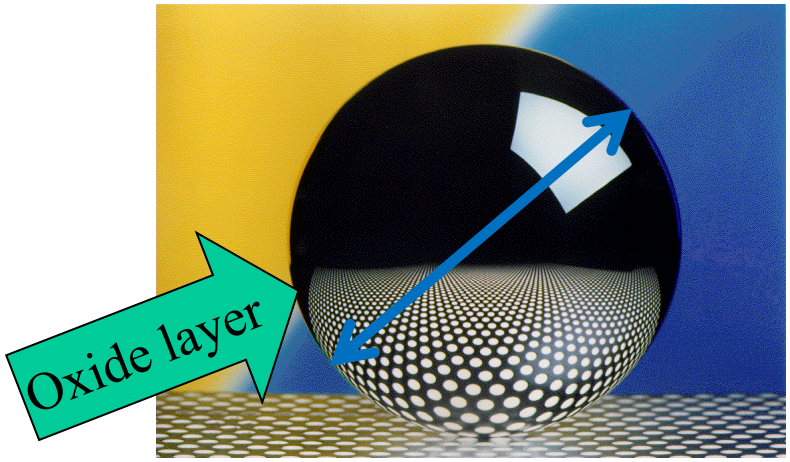
- Number “entities” like ^{12}C atoms in 12 g
- i. e. $6.022... \times 10^{23}$ ^{12}C atoms have a mass of 12 g

How to count 10^{23} atoms?

With a crystal!



1. Volume a_0^3 of the unit cell
2. Volume of an atom: $a_0^3/8$
3. Volume V of a sphere
4. Number n of the atoms



$$N_A = \frac{8V}{a_0^3} \cdot \frac{M_{mol}}{m_{sphere}}$$

Molar Planck constant

Avogadro constant · Planck constant

$$N_A h = \frac{M(e)}{m(e)} \cdot h = \frac{M(e) c \alpha^2}{2 R_\infty}$$

CODATA 2010:

$N_A h$ **= 3.990 312 7176(28) × 10^{-10} J s mol^{-1}**

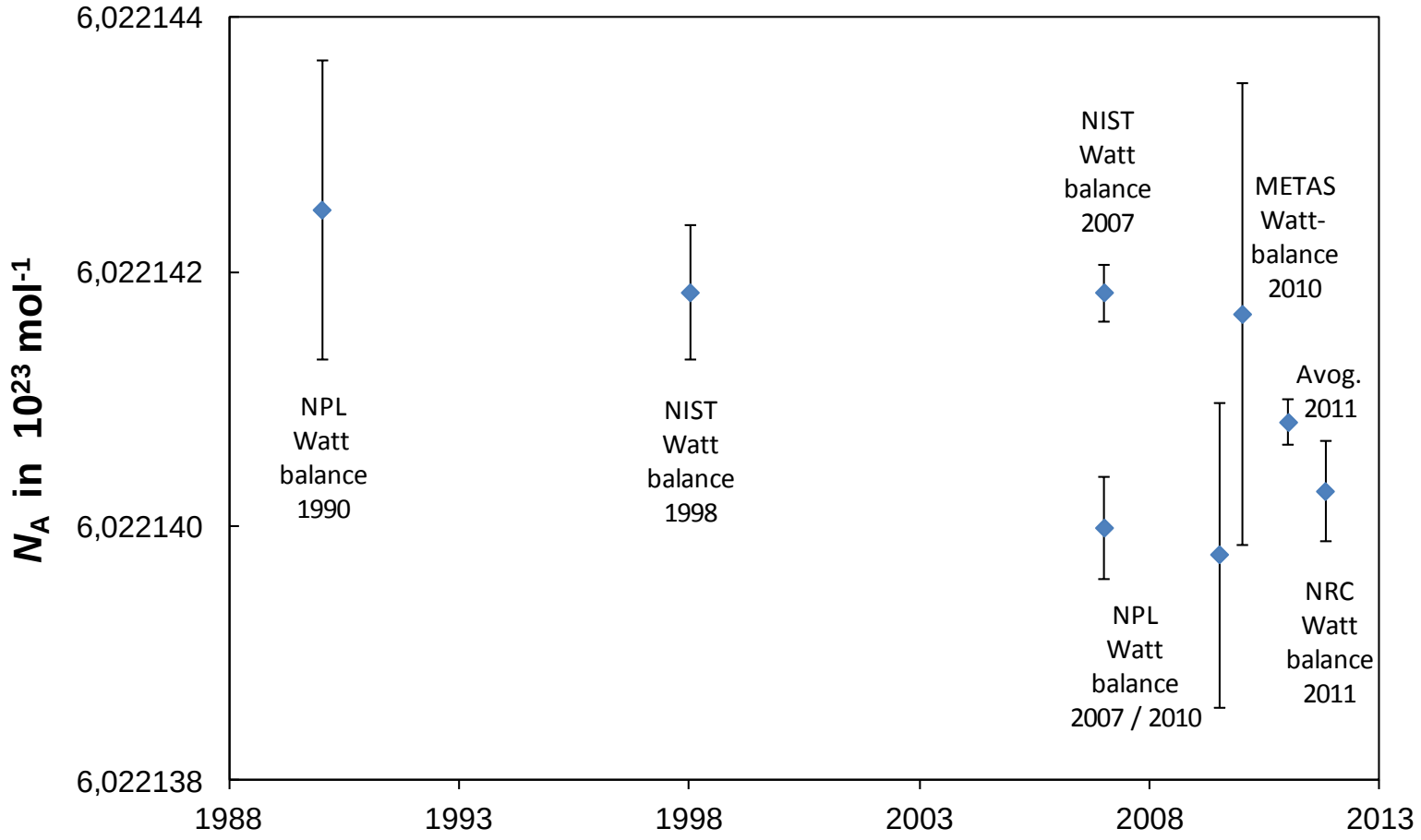
Relative standard uncertainty: 7 × 10^{-10} !

How many N_A determinations?

Partners		Lattice parameter		Sphere volume	Sphere mass	Molar mass	Crystal perfection	Surface	Sphere fabrication
		Abs.	Rel.						
BIPM	BIPM				X			H_2O	
	INRIM	X					X		
	METAS							XPS	
	NIM			2013?	?	2014?		2013?	
	NIST					X			
	NMI-A			X				Ellips.	X
	NMIJ		X	X	X	2014?	X	X	
	NRC					X			
	PTB	2015		X	X	X	X	X	X

Most of the quantities are measured by 3 or more institutes!

Avogadro constant values



Progress in the last two years

Memorandum of Understanding

Special Issue of Metrologia “International determination of the Avogadro constant”

Relative standard uncertainty 3 x 10^{-8}

EMRP Project “Realisation of the awaited definition of the kilogram - resolving the discrepancies” started September 2012

Re-start of the international Avogadro coordination

Program (next 5 years)

Reduction of uncertainty

- Spheres with unroundness below 20 nm
- Improved volume measurements
- Improved surface characterisation
- Improved lattice parameter measurements
- Improved molar mass measurements
- New traceability to the IPK

Target: relative uncertainty 1.5×10^{-8} until 2015

Program (next 5 years)

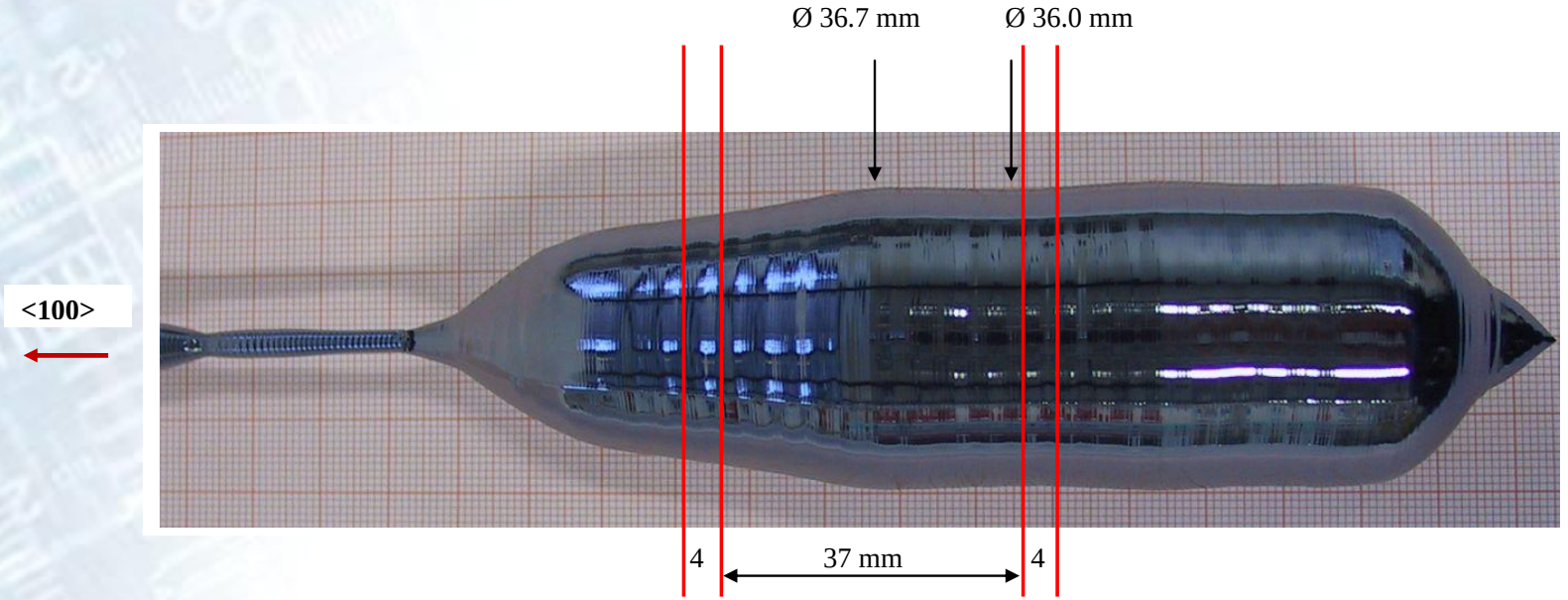
Confirmation of results

- Independent lattice parameter measurement (PTB)
- Impurity concentrations: more chemical elements by nuclear activation analysis (INRIM)
- More ^{28}Si crystals

New silicon-28 crystals

A second (small) ^{28}Si crystal already exists

Si28-10Pr10CzFzCzFzFz V3213 <100> ^{28}Si
(gezüchtet aus Si28-10Pr10CzFzCzFz V3195 und Si-474) (rest von Avogadro, "Tanne")



New silicon-28 crystals

PTB is purchasing 11.4 kg of new ^{28}Si

- 2 different single crystals of 5 kg each
- 2 spheres (1000 g) from each crystal
- First 2 spheres will be ready for measurements in mid 2014
- Second 2 spheres will be available in 2015
- More crystals can be grown in the future

Program (next 5 years)

Resolving discrepancies

- Resolving the discrepancy in molar mass
- Cooperation with watt balance projects, in particular to resolve discrepancies (if necessary)

Kilogram realisation by XRCD method

Measurements for the realisation of the new kg

- Molar Mass (isotopic composition)
- Crystal perfection (impurity contents)
- Lattice parameter

Duration of all values for one crystal: about 6 months.

Have to be measured only once!

Kilogram realisation by XRCD method

Measurements for the realisation of the new kg

- **Volume of the sphere: Duration about 1 month. Has to be repeated only every few years**
- **Surface layers (oxide etc.): Duration about 1 week. Should be repeated for each realisation**

Thus, realisation of the new kg by the XRCD method usually takes about 1 week.

Monitoring IPK

Monitoring the IPK with Si spheres

- Repeated measurements of the surface layers yield the mass change of the sphere
- Uncertainty now about 3 µg
- Natural Si can be used

Technological trends

Technological trends in the XRCD method

- Higher accuracy
- Concentration of some measurements in one apparatus
- Simplification of apparatuses or method, e. g. for calibration laboratories

New WGR-kg

Working Group on the Realisation of the Kilogram

- **Merging of WGAC and WG on the Changes to the SI kilogram (WGSI-kg)**
- **New memberships**
- **New terms of reference**

WGSI-kg

WG on the Changes to the SI kilogram

- Established in 2006
- Last meetings: 10 May 2011, 19 February 2013
- Next meeting: 2014?
- Members: BIPM, DFM, INRIM, KRISS, LNE, METAS, MSL, NIST, NMIJ, NRC, PTB
- Only personal members

WGSI-kg: Terms of Reference

Terms of Reference

- Advise the CCM on the redefinition of the kg
- Check the impact on mass metrology by the new kg
- Monitor the results of relevant experiments
- Solicit and collate comments from a wider scientific community on the wording of the future definition and on the *mise en pratique*
- Coordinate and assist the work of the WGM Task Groups, within and between the regions.

WGSI-kg: Progress

Progress in the last two years

- Workshop on the *mise en pratique* Nov. 2012
- Draft 7.0 of the *mise en pratique*
- IPK support group

WGSI-kg: Program (next 5 years)

Aims for the next 5 years

- Final version of the *mise en pratique*
- Organise link to the IPK
- Organise key comparison before redefinition
- Organise CMCs for primary realisation of the kg
- Criteria for new experiments to realize the kg

New WGR-kg

Working Group on the Realisation of the Kilogram

- **Members: all members of WGAC and WGSI-kg, all watt balance institutes**
- **First meeting: September 2013 during the kg workshop of the EMRP project “kNOW” ?**
- **Discussion of the terms of reference**
- **Additional separate technical meetings for watt balance and Avogadro projects?**

CCM WGAC, WGSI-kg, WGR-kg

Thank you very much for your attention!

Questions?

Comments?