



# CCM Working Group on the Avogadro Constant

Horst Bettin

Physikalisch-Technische Bundesanstalt  
Germany



Naturkonstanten

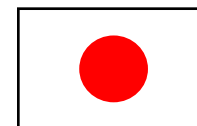


## WG on the Avogadro Constant

- **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)**

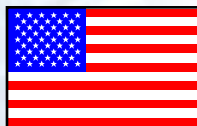
## CCM WG on the Avogadro Constant: Members

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



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

- **NIST**      **NRC**



## 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**

## Definition of Avogadro constant $N_A$

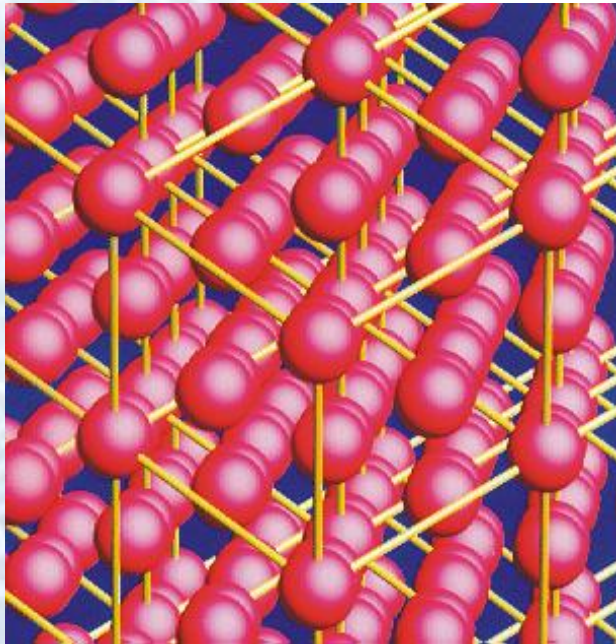
- Number of molecules per mol
- $6.022... \times 10^{23} \text{ mol}^{-1}$

## Current definition of mol

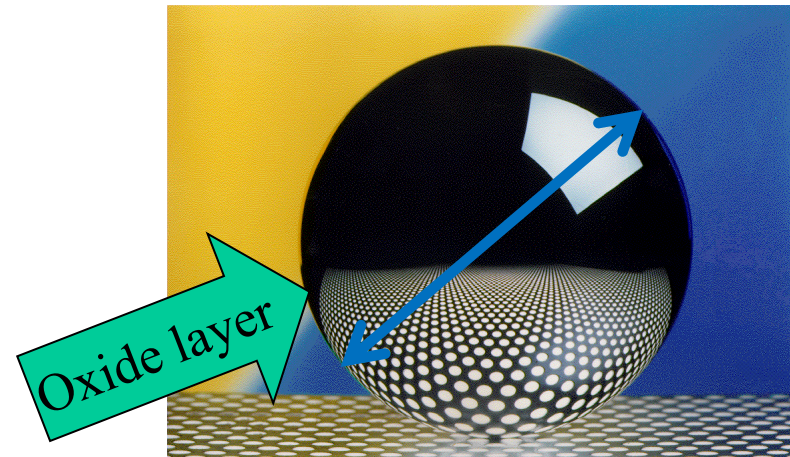
- Number “entities” like  $^{12}\text{C}$  atoms in 12 g
- i. e.  $6.022... \times 10^{23}$   $^{12}\text{C}$  atoms have a mass of 12 g



## 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



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

## 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:**

$$N_A h = 3.990\,312\,7176(28) \times 10^{-10} \text{ J s mol}^{-1}$$

**Relative standard uncertainty:  $7 \times 10^{-10}$  !**

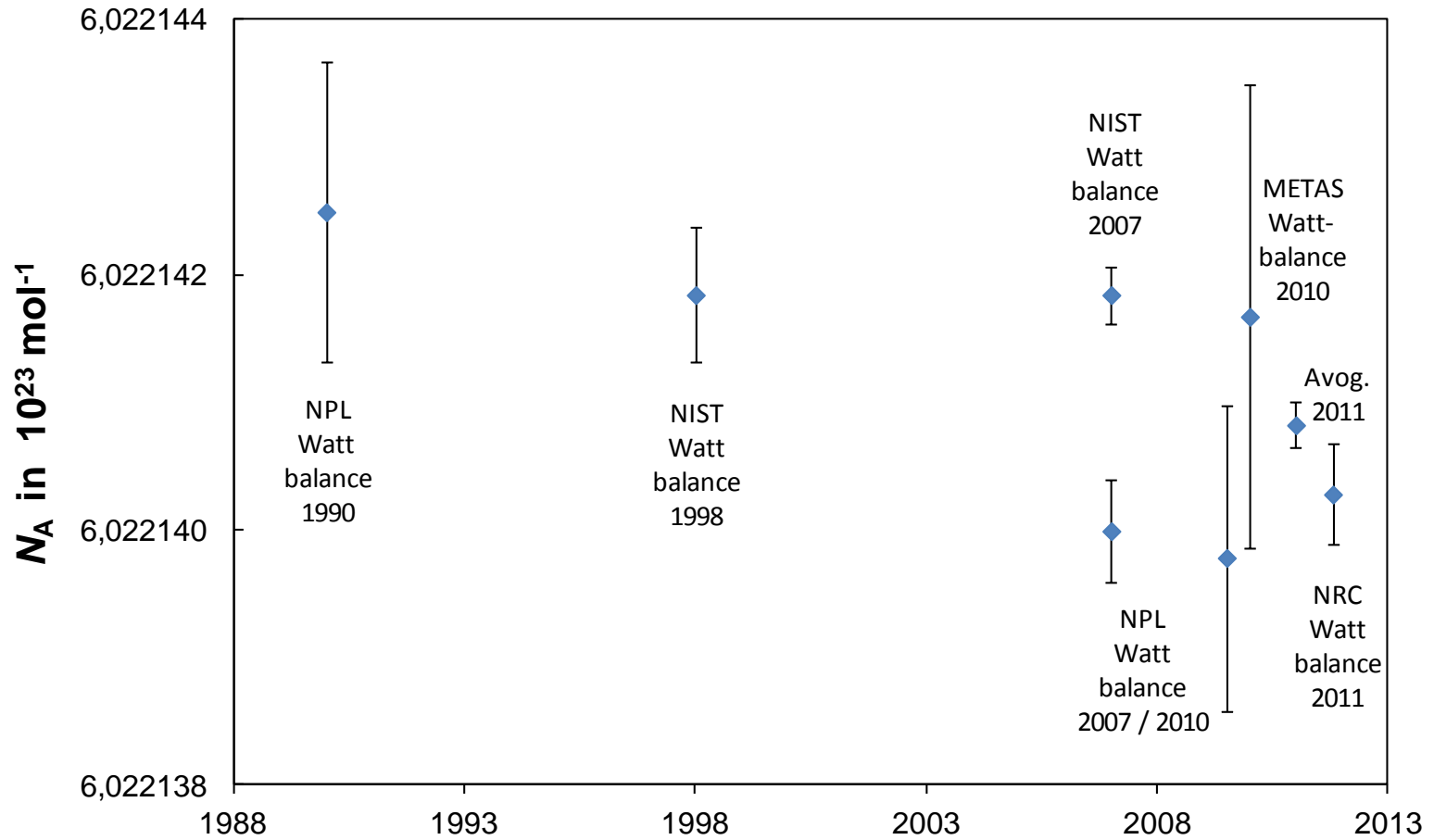
# : How many $N_A$ determinations?

Partners		Lattice parameter		Sphere volume	Sphere mass	Molar mass	Crystal perfection	Surface	Sphere fabrication
		Abs.	Rel.						
	BIPM				X			H <sub>2</sub> O	
	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



**Memorandum of Understanding**

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

**Relative standard uncertainty  $3 \times 10^{-8}$**

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

**Re-start of the international Avogadro coordination**

## 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

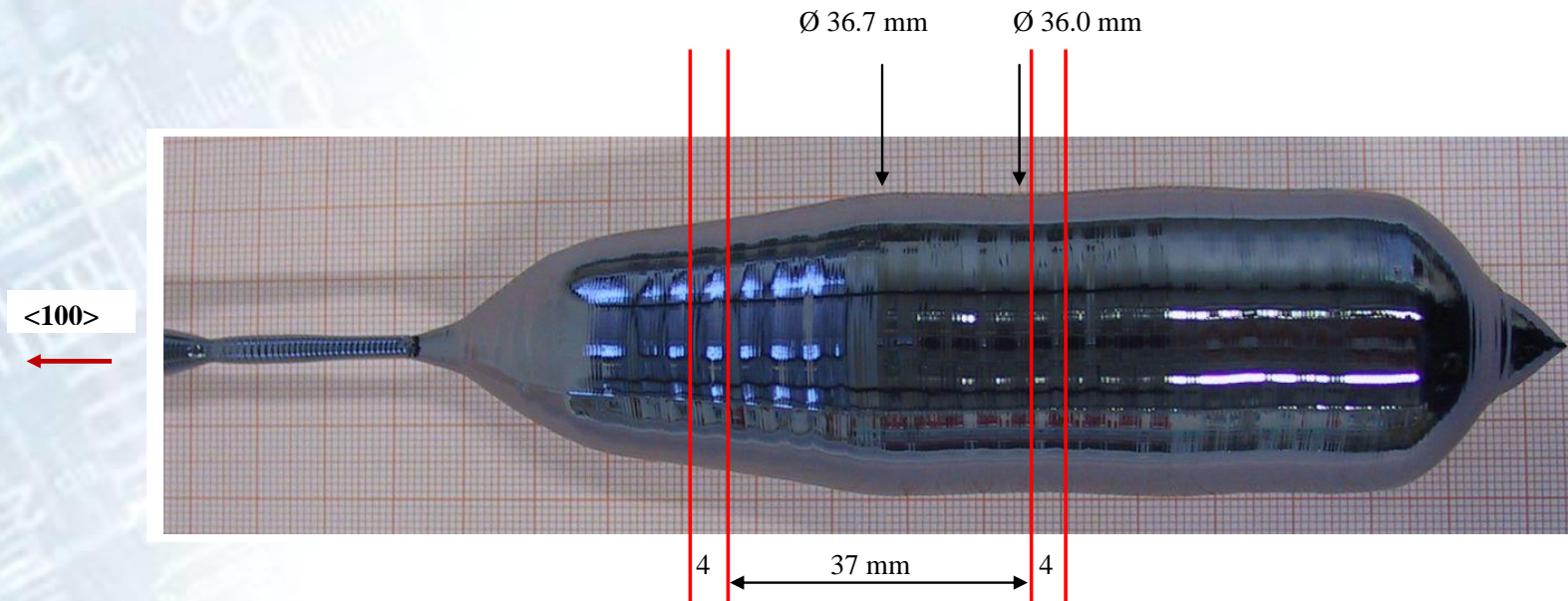
**Target: relative uncertainty  $1.5 \times 10^{-8}$  until 2015**

## Confirmation of results

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

## A second (small) $^{28}\text{Si}$ crystal already exists

**Si28-10Pr10CzFzCzFzFz V3213  $\langle 100 \rangle$   $^{28}\text{Si}$**   
(gezüchtet aus Si28-10Pr10CzFzCzFz V3195 und Si-474) (rest von Avogadro, "Tanne")



**PTB is purchasing 11.4 kg of new  $^{28}\text{Si}$**

- 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**



## **Resolving discrepancies**

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

## **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!**

## **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 the IPK with Si spheres

- Repeated measurements of the surface layers yield the mass change of the sphere
- Uncertainty now about 3  $\mu\text{g}$
- Natural Si can be used

## 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**

## **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**



## **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**

## 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.

## 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**

## 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

## **Working Group on the Realisation of the Kilogram**

- **Members: all members of WGAC and WGS1-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?**

**Thank you very much for your attention!**

**Questions?**

**Comments?**