

# CCM Progress Report for 2003-2007

## Mass and Related Quantities

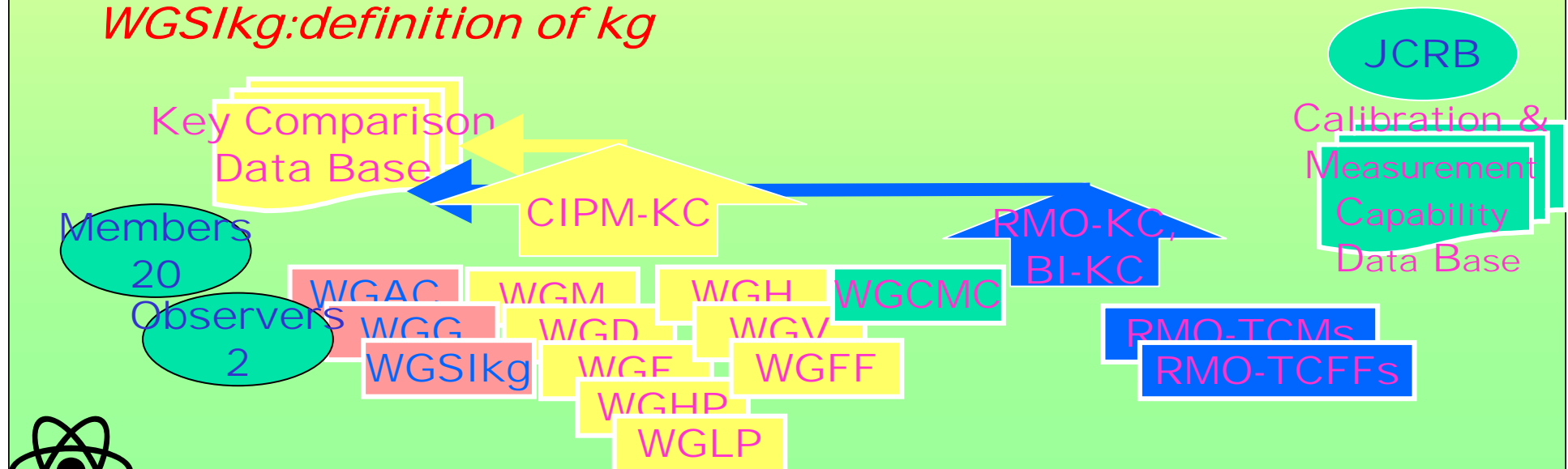
Implementation of MRA ← NMIs, BIPM, RMO-TCs  
Improvement of Global Measurement Standards  
← NMIs, BIPM

1. Structure & functions
2. Progress in CIPM-KC's
3. International Avogadro Coordination/CIPM
4. Redefinition of kg
5. Other works for improvements



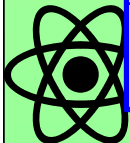
# 1. Its structure & functions

- WGM: mass standards,  
(*TG1:u<sub>r</sub> for BIPM, TG2:mass transfer to vacuum*),
- WGD: density
- WGF: force
- WGHP: high & *midium pressure*
- WGLP: vacuum
- WGH: hardness
- WGAC: Avogadro constant
- WGFF: fluid flow
- WGG: gravity
- WGV: viscosity*
- WGCMC: reviewing on capabilities of NMIs*
- WGS1kg: definition of kg*



## 2. Progress in CIPM-KC's/CCM

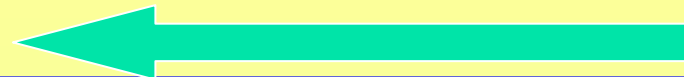
	Rep. Done	On DraftB	On DraftA	On Calib.	Prot. Done	Plan	Pilot-Study	
WGM	3	1			1			Mass
WGD	1		1			2		Density
WGF		1	4	2				Force
WGHP	5							High Press.
WGMP	1		1					Medium P.
WGLP	1		1		1			Low P.
WGH	3	7						Hardness
WGFF	5		1	1				Fluid Flow
WGG							1	Gravity
WGV	5		2					Viscosity



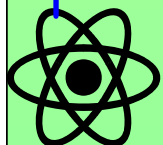
## 2. Progress in CIPM-KC's/CCM



	CGPM2007	CIPM2005	CGPM2003
M-K1	approved	approved	completed
M-K2	approved	approved	completed
M-K3	approved	approved	completed
M-K4	calibration	planned	planned
M-K5	draftB	draftA	calibration
D-K1	approved	completed	draftA
D-K2	draftA	draftA	planned
D-K3	planned	planned	planned
D-K4	planned	planned	planned
F-K1.a	draftB	calibration	draftA
F-K1.b	draftB	calibration	draftA
F-K2.a	draftA	draftA	planned
F-K2.b	draftA	draftA	planned
F-K3.a	draftA	calibration	planned
F-K3.b	calibration	calibration	planned
F-K4.a	draftA	calibration	calibration
F-K4.b	draftA	calibration	calibration
T-K1	draftA	planned	
T-K2	calibration	planned	



	CGPM2007	CIPM2005	CGPM2003
P-K1.a	approved	completed	completed
P-K1.b	approved	completed	completed
P-K1.c	approved	completed	completed
P-K5	approving		
P-K7	approving	completed	planned
P-K8		draftA	planned
P-K2	draftA	calibration	draftA
P-K6	approving		draftA
P-K3	draftA	draftA	draftA
P-K4	approving	completed	draftB
P-K12	calibration	planned	
H-K1.a	approved	approved	draftB
H-K1.b	approved	approved	draftB
H-K1.c	approved	approved	draftB
H-K2	draftB	draftB	calibration
H-S1	draftB	planned	draftB



## 2. Progress in CIPM-KC's/CCM

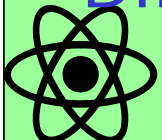


	CGPM2007	CIPM2005	CGPM2003
FF-K1	approved	draftB	planning
FF-K2	calibration	calibraion	planning
FF-K3	approved	calibration	planning
FF-K4	approved	deaftB	planning
FF-K5.a	approved	draftB	planning
FF-K5.b	approved	calibration	planning
FF-K6	draftA	calibration	planning
G-PS	draftA	calibration	draft*
V-K1.a	approved	completed	
V-K1.b1	approved	completed	
V-K1.b2	approved	completed	
V-K1.b3	approved	completed	
V-K1.c	approved	completed	
V-K2.a	draftA	planned	
V-K2.b	draftB	planned	

Reviews on RMO-KC, Other KCs → KCDB

Consultation for CMC dispute/ WGCMC electronic.

Difficulties on KCs: Lists, Transfer Artifact, Carnet

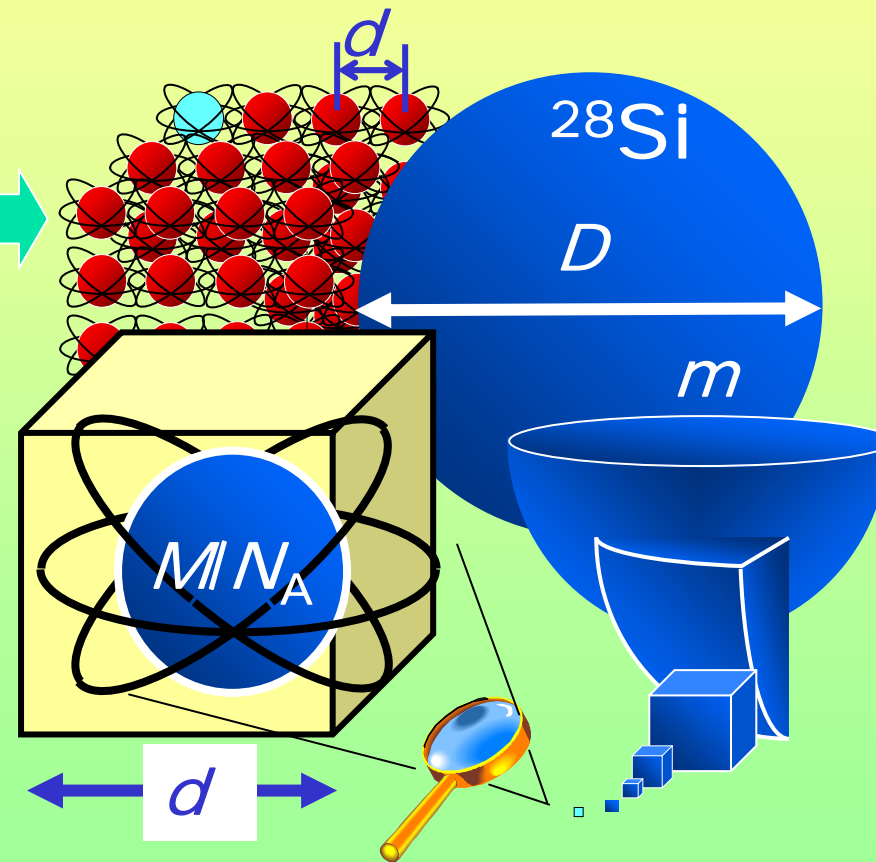
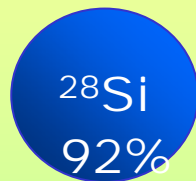
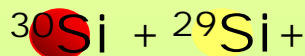
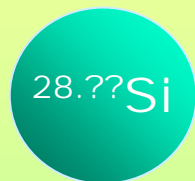
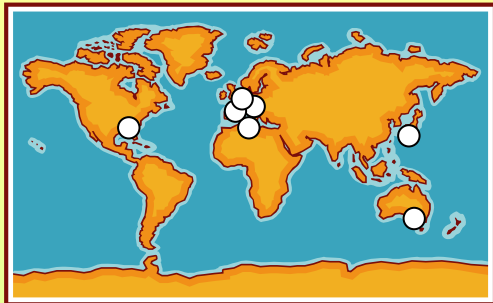


### 3. International Avogadro Coordination/CIPM

-Int'l Coordination for Avogadro Constant-  
Cooperation among 7 NMIs + BIPM

on Enriched  $^{28}\text{Si}$ , 04/2004-03/2009

$$h(\text{WB}) - h(\text{NA}) \rightarrow 100 \times 10^{-8}, u_r \rightarrow 5 \times 10^{-8}$$



Calendar : for 2006-2007

6/2007 x Spheres (0.6kg) +  $\Delta\text{MoU}$

5/2007 4.5kg perfect Si-ingot IKZ

2/2007 meeting in IKZ (Berlin)

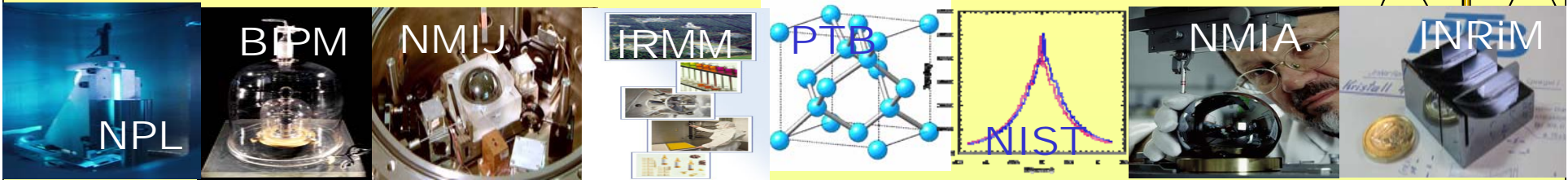
$u_r(\text{mass}) < \text{target } 4 \times 10^{-9}$  BIPM

Micro. Density = Macro. Density

$$(M/N_A) / d^3 = \rho = m / D^3 \rightarrow N_A = M / (2^{3/2} \times \rho \times d_{220}^3)$$



### 3. International Avogadro Coordination/CIPM



#### Measurement technology:

Volume(NMIJ,PTB,NMIA): $8 \rightarrow 3 \times 10^{-8}$

Density comparator(PTB,NMIJ)

Mass(BIPM,PTB,NMIJ,NMIA): $0.6 \rightarrow 0.4 \times 10^{-8}$

Molar Mass(IRMM,ICHPHS): $1 \times 10^{-8}$  (rep.)

Lattice parameter(INRiM): $1.7 \rightarrow 1 \times 10^{-8}$

Lattice comparator (NIST): $0.3 \times 10^{-8}$

Surface SiO<sub>2</sub> layer(XRR:PTB,NMIJ, XPS:NPL, Absorption:BIPM)

#### Enrichment:

*"Large-scale production of highly enriched <sup>28</sup>Si*

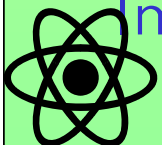
*for the precise determination of the Avogadro constant"*

by P.Becker et al. (PTB,IRMM, CT, (ICHPHS),IKZ)

Meas. Sci. Technol. 17 (2006) 1854–1860

Poly-X-tal: Mass:5983 g,Enrichment:  $99.9938\% \pm 0.0024\%$ ,

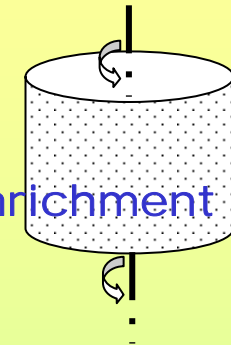
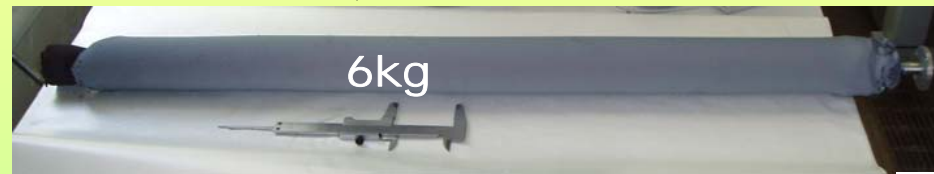
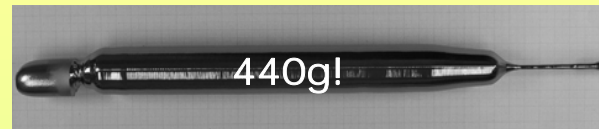
Impurities: $3.7 \times 10^{15} \text{cm}^{-3}(\text{C})$ ,  $6 \times 10^{15} \text{cm}^{-3}(\text{O})$ , 9/2006 to IAC/IKZ



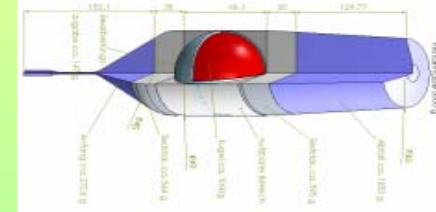
# 3. International Avogadro Coordination/CIPM Enriched Sphere



Fig.1: Final 4.5 kg <sup>28</sup>Si single-crystal, picture taken after 9th FZ run at IKZ



Gas Enrichment



Crystal Si<sub>28-10Pr11</sub>: First cut  
**2007/05/31**

Diameter in mm:  
28 45/49 70/74 98 85 85/86 98 86/84 79/75/43

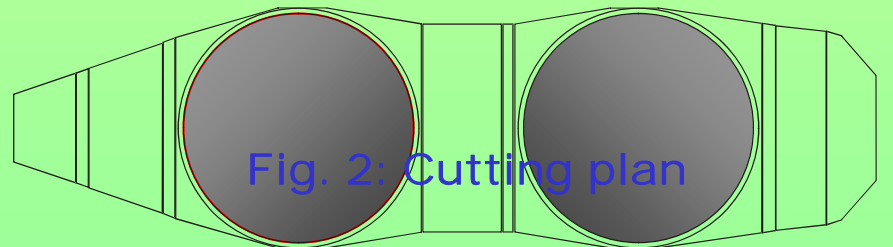
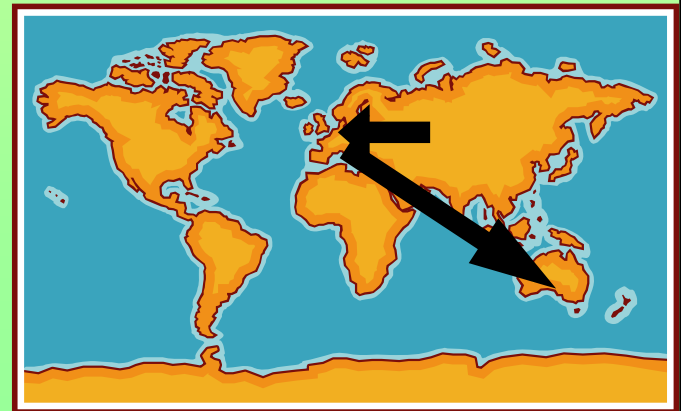


Fig. 2: Cutting plan

Part No.:  
1 2 3 4 5 6 7 8 9 10 11

Cutting Position in mm:  
113 138/144 174/179 279 312/317 418/423/444



### 3. International Avogadro Coordination/CIPM



## Progress and Target

Enrichment 99.9938% 6kg Poly X-tal +1kg for 2 spheres

Measurement Technologies ( $u_p$  multiplied by  $10^8$ .)

	2005	2006	2007	2009
Lattice Parameter	1.7	1	1	0.3
Molar Mass (repeatability)	1(rep.)	<1(r.)	<1(r.)	1 (abs.)
Volume	8	3	3	1 (0.5→1)
Mass	0.6	0.6	0.5	0.5
Surface Oxide	3	3	3	1
Total in $N_A$	9	5		2 (1.6→1.8)
$N_A$ on Natural Si-X-tal			20(30)	



## 4. Redefinition of kg/CCM

WGAC 1992-, IAC 2004-2009, Report CCM2005 G1: to CIPM.

**Recommendation CI-2005 to CCM: Report by CIPM2007.**

to consider the implications, to submit a report to the CIPM,

to monitor closely the results of new experiments,

to **identify necessary conditions** to be met

to consider, in particular, the alternative ways,

AHWG-kg/CCM: July 2006, Torino CCM 2007:March 2007:

Preparation of Report and Action Plan

AHWG-kg→WGS1kg,

TG1:Uncertainty in BIPM calibration.

TG2:Technology necessary for redefinition.

1. *“Redefinition of the kilogram: a decision whose time has come”*:
2. *“Redefinition of the kilogram, ampere, kelvin and mole :a proposed approach to implementing CIPM recommendation 1(CI-2005)”*:  
Ian M Mills, Peter J Mohr, Terry J Quinn, Barry N Taylor and Edwin R Williams:  
Metrologia 43 (2006) 227-246
3. *“Considerations on future redefinitions of the kilogram, the mole, and of other units”*:  
P. Becker, P. De Bièvre, K. Fujii, M. Glaeser, B. Inglis, H. Luebbig, G. Mana:  
Metrologia 44 (2007), 1-14

**CCM Report: to CIPM2007**

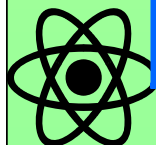


## 4. Redefinition of kg/CCM

Uncertainties, present situation

*after M.GLAESER/PTB*

$u_r(h), u_r(N_A)$ CODATA 2006	$5 \times 10^{-8}$	50 $\mu\text{g}/1 \text{ kg}$
$[h(\text{WB})-h(\text{Si})]_{\text{rel}}$	$100 \times 10^{-8}$	1000 $\mu\text{g}/1 \text{ kg}$
$u_r(1 \text{ kg})$ class $E_1$ weight (OIML)	$8.3 \times 10^{-8}$	$\leq 83 \mu\text{g}/1 \text{ kg}$
$u_r(1 \text{ kg st-st})$ CMC in NMIs	$1.2(2.5) \times 10^{-8}$	12(25) $\mu\text{g}/1 \text{ kg}$
$u_r(1 \text{ kg Pt-Ir})$ CMC in NMIs	$\leq 0.1 \times 10^{-8}$	$\leq 1 \mu\text{g}/1 \text{ kg}$
$u_r(\text{realization, CCM})$	$2 \times 10^{-8}$	20 $\mu\text{g}/1 \text{ kg}$



## 4. Redefinition of kg/CCM

1. A redefinition of the kilogram, based on a **fundamental constant** is desired in general.
2. Possible changes of the international prototype have not yet been observed. A redefinition of the kilogram is therefore **not urgent** for mass metrology in practice.
3. A new definition shall **not** result in an **offset**.
4. A new definition that is **understandable**, also for non-experts, is preferred.

the recommendation to NMIs and the BIPM

to **pursue experiments linking** the fundamental constants to

the current definition of the kilogram and, once redefined,

to **maintain the activity** for practical realization of the new definition, the necessity of a ***mise en pratique*** for the kilogram describing the role of the linking experiments and the **continuing use of current mass artifact technology**,

in addition,

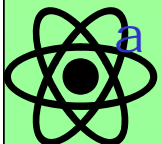
the following specification of technical conditions allowing the redefinition:

**significant discrepancies** among linking experiment **must be removed**;

the uncertainty of the best linking experiment must be better than

$2 \times 10^{-8}$  at the 1 kg level;

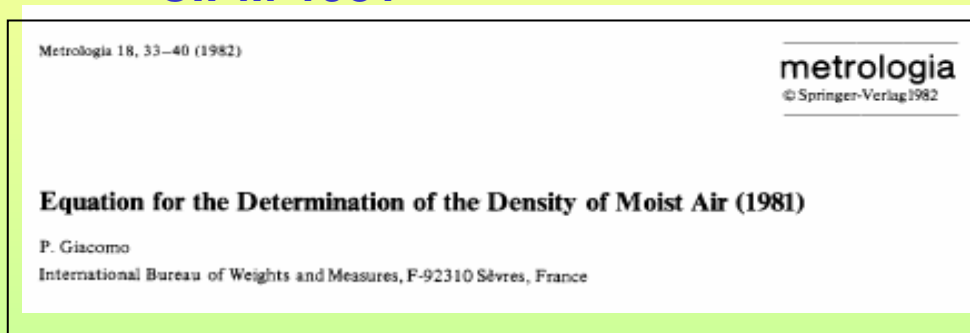
**a sufficient number of independent linking experiments must be available with required uncertainty.**



## 5. Other works for the improvement of global measurement standards example. Air Density Formula /CCM

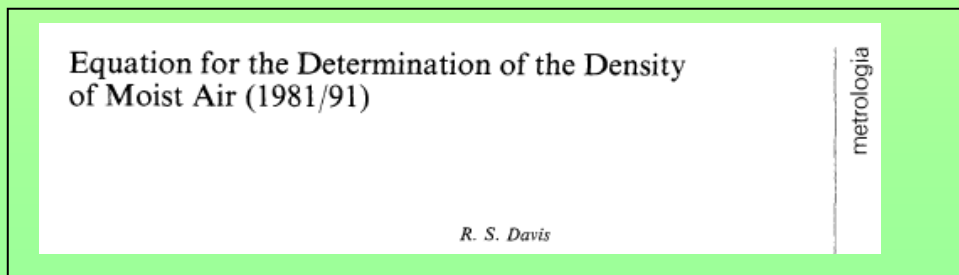
# Need for a new air-density formula

### “CIPM-1981”



- **“Pre- GUM” uncertainty statement**
- $T$  from IPTS-68,  $R$  from CODATA 1973
- *US Standard Atmosphere of 1976 (except for newer value of argon content and fixed  $x_{O_2} + x_{CO_2}$ )*

### “CIPM-1981/91”



- **No change to uncertainty statement**
- $T$  from ITS-90,  $R$  from CODATA 1986
- By 2002, evidence of small, systematic difference with air density measured by Archimedes' Principle (Argon content ?)



## 5. Other works for the improvement

# Proposed “CIPM-2007” equation

### REVISED FORMULA FOR THE DENSITY OF MOIST AIR (CIPM-2007)

A. PICARD<sup>1</sup>, R. S. DAVIS<sup>1</sup>, M. GLÄSER<sup>2</sup>, K. FUJII<sup>3</sup>

1 Bureau International des Poids et Mesures, Pavillon de Breteuil, F-92310 Sèvres Cedex, France

2 Physikalisch-Technische Bundesanstalt, Bundesallee 100, D-38116 Braunschweig, Germany

3 National Metrology Institute of Japan, National Institute of Advanced Industrial Science and Technology (NMIJ/AIST), Central 3,1-1, Umezono 1-chome, Tsukuba, Ibaraki 305-8563, Japan.

CCM hypothesis:  $x_{Ar}$  value used in CIPM-81 explains systematic difference.

Confirmation: new  $x_{Ar}$  values published by **two** CCQM GAWG members, KRISS (2004); LNE (**2007**). (CIPM-2005 advised **two** independent results.)

### Principal advantages of “CIPM-2007”

(note: draft submitted to CIPM has been approved by CCM WG-Density)

- Detailed **uncertainty statements**, which follow *GUM* recommendations.
- All data from **latest references** ( $R$ , virial coefficients, molar masses,  $x_{O_2}+x_{CO_2}$ ).
- **Comparison with experimental** measurement of air density via Archimedes' Principle (publications from several NMIs and the BIPM).
- **Difference between the equation and experiment has been removed.**



## 5. Other works for the improvement

WGM:

A comparison of the magnetic properties of mass standards

WGD:

Absolute measurement of the density of mercury;

WGF:

Improvement in the stability of force transducers,  
Torque measurement standards,  
Dynamic force metrology planned

WGHP:

Calculation of pressure distortion of the pressure balances,  
Dimensional determination of the area of the piston-cylinder,

WGLP:

Spinning rotor gauge, Leak standard,

WGH:

New definition for the Rockwell scale for NMI level

WGV:

Absolute determination of viscosity on reference liquid



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Improvement of Global Measurement Standards  
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