

# Setting the Stage: Is a Big G Consortium the Right Way?

Carl J. Williams, Chief  
Quantum Measurement Division



# Quantum Measurement Division (QMD)

- QMD is at the center of the redefinition of the “Quantum SI”
  - Mohr, Taylor, and E. Williams instrumental in basic idea
  - CODATA (Committee on Data for Science and Technology) recommended values will be basis for fixing the constants
- QMD realizes electrical, mass, and force units
  - Reorganization creates a *unique* opportunity for the mise-en-pratique for mass!
  - Quantum based measurements provides foundation for advances in all units including beyond the standard quantum limit

INSTITUTE OF PHYSICS PUBLISHING  
Metrologia 43 (2006) 227–246

METROLOGIA  
doi:10.1088/0026-1394/43/3/006

## Redefinition of the kilogram, ampere, kelvin and mole: a proposed approach to implementing CIPM recommendation 1 (CI-2005)

Ian M Mills<sup>1</sup>, Peter J Mohr<sup>2</sup>, Terry J Quinn<sup>3</sup>, Barry N Taylor<sup>2</sup> and Edwin R Williams<sup>2</sup>

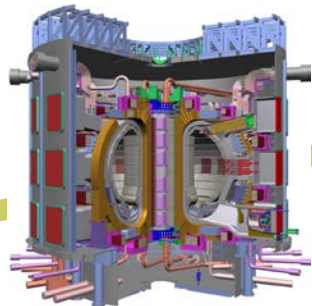
### 2010 CODATA RECOMMENDED VALUES OF THE FUNDAMENTAL CONSTANTS OF PHYSICS AND CHEMISTRY NIST SP 959 (Dec 2012)

Values from: P. J. Mohr, B. N. Taylor, and D. B. Newell, *Rev. Mod. Phys.* **84**, 1527 (2012) and *J. Phys. Chem. Ref. Data* **41**, 043109 (2012). The number in parentheses is the one-sigma ( $1\sigma$ ) uncertainty in the last two digits of the given value.

Quantity	Symbol	Numerical value	Unit
speed of light in vacuum	$c, c_0$	299 792 458 (exact)	$\text{m s}^{-1}$
magnetic constant	$\mu_0$	$4\pi \times 10^{-7}$ (exact)	$\text{N A}^{-2}$
electric constant $1/\mu_0 c^2$	$\epsilon_0$	$8.854 187 817... \times 10^{-12}$	$\text{F m}^{-1}$
Newtonian constant of gravitation	$G$	$6.673 84(80) \times 10^{-11}$	$\text{m}^3 \text{kg}^{-1} \text{s}^{-2}$
Planck constant	$h$	$6.626 069 57(29) \times 10^{-34}$	J s
$h/2\pi$	$\hbar$	$1.054 571 726(47) \times 10^{-34}$	J s
elementary charge	$e$	$1.602 176 565(35) \times 10^{-19}$	C
fine-structure constant $e^2/4\pi\epsilon_0\hbar c$	$\alpha$	$7.297 352 5698(24) \times 10^{-3}$	
inverse fine-structure constant	$\alpha^{-1}$	137.035 999 074(44)	
Rydberg constant $\alpha^2 m_e c/2h$	$R_\infty$	10 973 731.568 539(55)	$\text{m}^{-1}$
Bohr radius $\alpha/4\pi R_\infty$	$a_0$	$0.529 177 210 92(17) \times 10^{-10}$	m
Bohr magneton $e\hbar/2m_e$	$\mu_B$	$927.400 968(20) \times 10^{-26}$	$\text{J T}^{-1}$

# Vertically Integrated Measurements and Services within the Quantum Measurement Division

Research for Advanced Technology



Standards Dissemination



## NIST Atomic Spectra Database

Fe XV: 84 Lines of Data Found

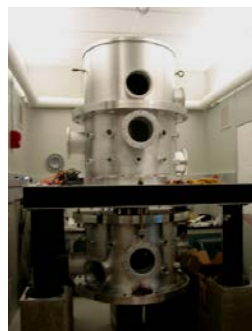
Wavelengths: 180 - 800 Å

Reference: *J. Res. Natl. Bur. Stand.* 2002, 107, 2002-2003 and 2003, 108, 2003-2004

Observed Wavelength (nm)	Wavelength (Å)	Ion	Term	$J^{\pi}$	$J_1^{\pi_1}$	$J_2^{\pi_2}$	Configuration	Source	$\lambda$	$\lambda$	$\lambda$	$\lambda$	Type	Ref.	Ref.
180.210	180210	D	$^1P$	$1^{\circ}$	$^1P^{\circ}$	$1^{\circ}$	$3d^5 4s^1$	$3d^5 4s^1$	$3d^5 4s^1$	$3d^5 4s^1$	$3d^5 4s^1$	$3d^5 4s^1$	$3d^5 4s^1$	1	1
181.210	181210	D	$^1P$	$1^{\circ}$	$^1P^{\circ}$	$1^{\circ}$	$3d^5 4s^1$	$3d^5 4s^1$	$3d^5 4s^1$	$3d^5 4s^1$	$3d^5 4s^1$	$3d^5 4s^1$	$3d^5 4s^1$	1	1
182.210	182210	D	$^1P$	$1^{\circ}$	$^1P^{\circ}$	$1^{\circ}$	$3d^5 4s^1$	$3d^5 4s^1$	$3d^5 4s^1$	$3d^5 4s^1$	$3d^5 4s^1$	$3d^5 4s^1$	$3d^5 4s^1$	1	1
183.210	183210	D	$^1P$	$1^{\circ}$	$^1P^{\circ}$	$1^{\circ}$	$3d^5 4s^1$	$3d^5 4s^1$	$3d^5 4s^1$	$3d^5 4s^1$	$3d^5 4s^1$	$3d^5 4s^1$	$3d^5 4s^1$	1	1
184.210	184210	D	$^1P$	$1^{\circ}$	$^1P^{\circ}$	$1^{\circ}$	$3d^5 4s^1$	$3d^5 4s^1$	$3d^5 4s^1$	$3d^5 4s^1$	$3d^5 4s^1$	$3d^5 4s^1$	$3d^5 4s^1$	1	1
185.210	185210	D	$^1P$	$1^{\circ}$	$^1P^{\circ}$	$1^{\circ}$	$3d^5 4s^1$	$3d^5 4s^1$	$3d^5 4s^1$	$3d^5 4s^1$	$3d^5 4s^1$	$3d^5 4s^1$	$3d^5 4s^1$	1	1
186.210	186210	D	$^1P$	$1^{\circ}$	$^1P^{\circ}$	$1^{\circ}$	$3d^5 4s^1$	$3d^5 4s^1$	$3d^5 4s^1$	$3d^5 4s^1$	$3d^5 4s^1$	$3d^5 4s^1$	$3d^5 4s^1$	1	1
187.210	187210	D	$^1P$	$1^{\circ}$	$^1P^{\circ}$	$1^{\circ}$	$3d^5 4s^1$	$3d^5 4s^1$	$3d^5 4s^1$	$3d^5 4s^1$	$3d^5 4s^1$	$3d^5 4s^1$	$3d^5 4s^1$	1	1
188.210	188210	D	$^1P$	$1^{\circ}$	$^1P^{\circ}$	$1^{\circ}$	$3d^5 4s^1$	$3d^5 4s^1$	$3d^5 4s^1$	$3d^5 4s^1$	$3d^5 4s^1$	$3d^5 4s^1$	$3d^5 4s^1$	1	1
189.210	189210	D	$^1P$	$1^{\circ}$	$^1P^{\circ}$	$1^{\circ}$	$3d^5 4s^1$	$3d^5 4s^1$	$3d^5 4s^1$	$3d^5 4s^1$	$3d^5 4s^1$	$3d^5 4s^1$	$3d^5 4s^1$	1	1
190.210	190210	D	$^1P$	$1^{\circ}$	$^1P^{\circ}$	$1^{\circ}$	$3d^5 4s^1$	$3d^5 4s^1$	$3d^5 4s^1$	$3d^5 4s^1$	$3d^5 4s^1$	$3d^5 4s^1$	$3d^5 4s^1$	1	1
191.210	191210	D	$^1P$	$1^{\circ}$	$^1P^{\circ}$	$1^{\circ}$	$3d^5 4s^1$	$3d^5 4s^1$	$3d^5 4s^1$	$3d^5 4s^1$	$3d^5 4s^1$	$3d^5 4s^1$	$3d^5 4s^1$	1	1
192.210	192210	D	$^1P$	$1^{\circ}$	$^1P^{\circ}$	$1^{\circ}$	$3d^5 4s^1$	$3d^5 4s^1$	$3d^5 4s^1$	$3d^5 4s^1$	$3d^5 4s^1$	$3d^5 4s^1$	$3d^5 4s^1$	1	1
193.210	193210	D	$^1P$	$1^{\circ}$	$^1P^{\circ}$	$1^{\circ}$	$3d^5 4s^1$	$3d^5 4s^1$	$3d^5 4s^1$	$3d^5 4s^1$	$3d^5 4s^1$	$3d^5 4s^1$	$3d^5 4s^1$	1	1
194.210	194210	D	$^1P$	$1^{\circ}$	$^1P^{\circ}$	$1^{\circ}$	$3d^5 4s^1$	$3d^5 4s^1$	$3d^5 4s^1$	$3d^5 4s^1$	$3d^5 4s^1$	$3d^5 4s^1$	$3d^5 4s^1$	1	1
195.210	195210	D	$^1P$	$1^{\circ}$	$^1P^{\circ}$	$1^{\circ}$	$3d^5 4s^1$	$3d^5 4s^1$	$3d^5 4s^1$	$3d^5 4s^1$	$3d^5 4s^1$	$3d^5 4s^1$	$3d^5 4s^1$	1	1
196.210	196210	D	$^1P$	$1^{\circ}$	$^1P^{\circ}$	$1^{\circ}$	$3d^5 4s^1$	$3d^5 4s^1$	$3d^5 4s^1$	$3d^5 4s^1$	$3d^5 4s^1$	$3d^5 4s^1$	$3d^5 4s^1$	1	1
197.210	197210	D	$^1P$	$1^{\circ}$	$^1P^{\circ}$	$1^{\circ}$	$3d^5 4s^1$	$3d^5 4s^1$	$3d^5 4s^1$	$3d^5 4s^1$	$3d^5 4s^1$	$3d^5 4s^1$	$3d^5 4s^1$	1	1
198.210	198210	D	$^1P$	$1^{\circ}$	$^1P^{\circ}$	$1^{\circ}$	$3d^5 4s^1$	$3d^5 4s^1$	$3d^5 4s^1$	$3d^5 4s^1$	$3d^5 4s^1$	$3d^5 4s^1$	$3d^5 4s^1$	1	1
199.210	199210	D	$^1P$	$1^{\circ}$	$^1P^{\circ}$	$1^{\circ}$	$3d^5 4s^1$	$3d^5 4s^1$	$3d^5 4s^1$	$3d^5 4s^1$	$3d^5 4s^1$	$3d^5 4s^1$	$3d^5 4s^1$	1	1
200.210	200210	D	$^1P$	$1^{\circ}$	$^1P^{\circ}$	$1^{\circ}$	$3d^5 4s^1$	$3d^5 4s^1$	$3d^5 4s^1$	$3d^5 4s^1$	$3d^5 4s^1$	$3d^5 4s^1$	$3d^5 4s^1$	1	1

Calibration Services and Data Dissemination

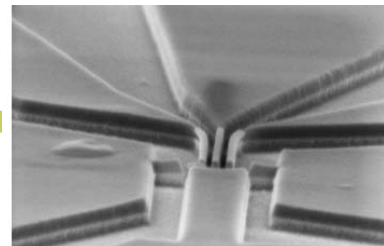
Research to Support *Mise-en-pratique*



Measurement Science Research



Quantum Materials and Quantum Based Measurements

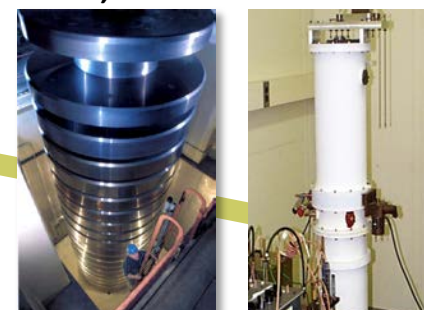


Device Physics and Concept Demonstration



Precision Measurements

Realization of Mass, Force, and Electrical Units



2010 CODATA RECOMMENDED VALUES OF THE FUNDAMENTAL CONSTANTS OF PHYSICS AND CHEMISTRY

Values from: P. J. Mohr, B. N. Taylor, and D. B. Newell, *Rev. Mod. Phys.* 81, 1527 (2012) and *J. Phys. Chem. Ref. Data* 41, 043109 (2012). The number in parentheses is the one-sigma ( $1\sigma$ ) uncertainty in the last two digits of the given value.

Quantity	Symbol	Numerical value	Unit
speed of light in vacuum	$c$	299 792 458 (exact)	$m s^{-1}$
magnetic constant	$\mu_0$	$4\pi \times 10^{-7}$ (exact)	$N A^{-2}$
electric constant $1/\mu_0 c^2$	$\epsilon_0$	$8.854 187 817 \times 10^{-12}$	$F m^{-1}$
Newtonian constant of gravitation	$G$	$6.674 30(80) \times 10^{-11}$	$m^3 kg^{-1} s^{-2}$
Planck constant	$h$	$6.626 069 57(29) \times 10^{-34}$	$J s$
$h/2\pi$	$\hbar$	$1.054 571 726(47) \times 10^{-34}$	$J s$
elementary charge	$e$	$1.602 176 565(35) \times 10^{-19}$	$C$
fine-structure constant $e^2/4\pi\epsilon_0\hbar c$	$\alpha$	$7.297 352 5698(44) \times 10^{-18}$	
inverse fine-structure constant	$\alpha^{-1}$	137.035 999 074(44)	
Rydberg constant $\alpha^2 m_e c^2/2h$	$R_\infty$	$10 973 731.568 520(55)$	$m^{-1}$
Bohr radius $a_0/4\pi\epsilon_0$	$a_0$	$0.529 177 210 92(17) \times 10^{-10}$	$m$
Bohr magneton $e\hbar/2m_e$	$\mu_B$	$9.27 400 968(20) \times 10^{-24}$	$J T^{-1}$

Fundamental Constants/CODATA

On the possible future revision of the SI

Towards the "New SI"...

A key activity of the CGPM (2011) was the review of progress towards the realization of the revised SI. It was decided that the SI will be revised in 2018. The revision of the SI will be based on the CGPM's 2011 decision to redefine the seven base units of the SI in terms of fundamental constants of nature. The revision of the SI will be based on the CGPM's 2011 decision to redefine the seven base units of the SI in terms of fundamental constants of nature. The revision of the SI will be based on the CGPM's 2011 decision to redefine the seven base units of the SI in terms of fundamental constants of nature.

Quantum SI

# Why are we here?

- We have a problem with “G”
- As described at the Royal Society meeting the current discrepancy suggests that one more measurement doesn’t help.
- Well a much better measurement could resolve the discrepancy **at least until the 2<sup>nd</sup> improved measurement showed up!**
- General Questions:
  - Do we need an advisory board?
  - Do we want a consortium?

# NIST and G

- Paul Heyl measures G with a torsion balance:
  - 1930:  $6.670(5) \times 10^{-11} \text{ m}^3/\text{kg}/\text{s}^2$
  - 1942:  $6.673(3) \times 10^{-11} \text{ m}^3/\text{kg}/\text{s}^2$
- Gabe Luther & William Towler use a torsion balance: 1982:  $6.6726(5) \times 10^{-11} \text{ m}^3/\text{kg}/\text{s}^2$
- Joshua Schwartz *et al.* (Faller) measure G in free fall: 1998:  $6.6873(94) \times 10^{-11} \text{ m}^3/\text{kg}/\text{s}^2$
- Harold Parks & Jim Faller use a simple pendulum: 2010:  $6.67234(14) \times 10^{-11} \text{ m}^3/\text{kg}/\text{s}^2$

# How to move ahead?

1. Do nothing – just wait
2. Form a consortium (NIST concept on this is on the next slide)\*
3. Wait pending new results and then revisit the question
4. Other ideas for solution

\* If we agree on this choice, NIST Is prepared to consider designing and building one or more instruments as a “Hub member” of a consortium

# Why a consortium?

- Numerous measurements
- More ways to look for systematics
  - Instrument Design
  - Operator Expertise
  - Data Analysis
  - *Undiscovered* physics

# Our Concept of the Approach

- 3 methods – 2 copies each ...
- “Hub members” – willing to design and build multiple instruments
- Members – willing to make independent measurements using an instrument provided
- Lead Members – willing to make measurement on a non-transportable instrument



# Problems and Issues

- Avoid group think
- Avoid intellectual phase locking (double/triple blind measurements)
- How do we do this blind?
- Do we want multiple offsets?
- Blind measurements are they really good?

# International Support Exists

- **Decision CIPM/103-23** The CIPM would welcome the presentation of a formal proposal on the creation of an advisory board on  $G$  experiments at its next meeting.
- **IUPAP** is willing to accept a proposal as well. This may end up under **Commission C2 – SUNAMCO:** (Commission on Symbols, Units, Nomenclature, Atomic Masses and Fundamental Constants)

# Questions