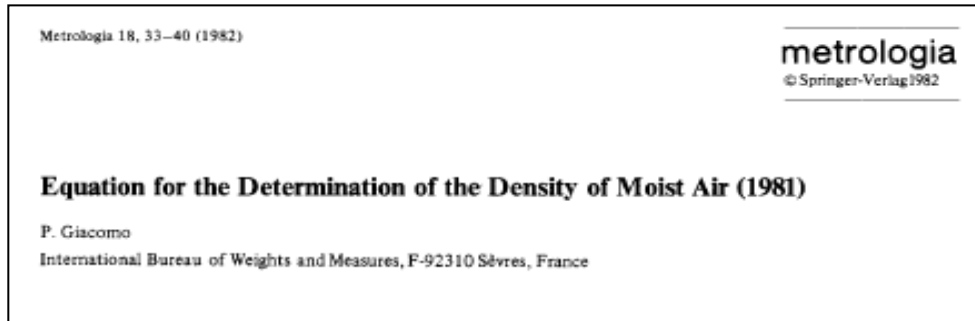


# The CIPM-2007 formula for the density of moist air

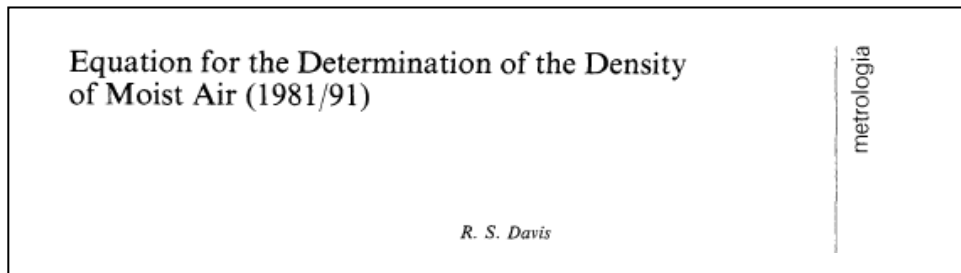
# Need for a new air-density formula

## “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 ?)

# “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”

- 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.**

# 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> and K Fujii<sup>3</sup>

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

<sup>2</sup> Physikalisch-Technische Bundesanstalt, Bundesallee 100, D-38116 Braunschweig, Germany

<sup>3</sup> 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

Received 8 January 2008

→ Published 18 February 2008

Online at [stacks.iop.org/Met/45/149](http://stacks.iop.org/Met/45/149)

## Abstract

Measurements of air density determined gravimetrically and by using the CIPM-81/91 formula, an equation of state, have a relative deviation of  $6.4 \times 10^{-5}$ .

This difference is consistent with a new determination of the mole fraction of argon  $x_{Ar}$  carried out in 2002 by the Korea Research Institute of Standards and Science (KRISS) and with recently published results from the LNE. The CIPM equation is based on the molar mass of dry

## But there are consequences...

$$\rho_a = \frac{pM_a}{ZRT} \left[ 1 - x_v \left( 1 - \frac{M_v}{M_a} \right) \right]$$

The significant difference is in :  $\left( \frac{M_a}{R} \right) / (10^{-3} \text{s}^2 \text{m}^{-2} \text{K})$ .

For  $x_{\text{CO}_2} = 400 \mu\text{mol/mol}$  ,

CIPM-81/91

3.483 488 5

CIPM-2007

3.483 740 2

(relative increase is  
always **+72 × 10<sup>-6</sup>**)

Therefore,

- The buoyancy correction for 1 kg of stainless steel with respect to a national prototype will increase by about

$$(125 - 46.4)\text{cm}^3 \times 0.0012 \text{ g cm}^{-3} \times 72 \cdot 10^{-6}$$
$$= 6.8 \mu\text{g (approx.)}$$

- We must deal with this change.

# Suggestions

- State in future calibration reports that the CIPM-2007 formula for the air density has been used, giving appropriate references.
- If appropriate, state in future calibration reports that the CIPM-2007 formula results in a small upward shift (less than 10  $\mu\text{g}/\text{kg}$ ) in the mass of stainless steel standards derived from the international prototype through the national prototypes.
- Update databases and Quality Procedures.