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Recalculation of the Faraday Constant Due to A New Value for the Atomic Weight of Silver

V. E. Bower,* R. S. Davis,* T. J. Murphy,† P. J. Paulsen,† J. W. Gramlich,† and L. J. Powell†,**

National Bureau of Standards, Washington, DC 20234

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A report of the Faraday constant as determined at NBS via silver coulometry and atomic weight measurements is presented. The uncertainty of the reported result represents a five-fold improvement over measurements made at NBS 20 years ago. The result should contribute to an analysis of the self-consistency of several other fundamental constants measurements. Experimental details have been reported in other publications which are cited in the text.

Key words: Atomic weight; atomic weight of silver; coulometer; electrochemical equivalent; Faraday constant; fundamental constants; silver; silver coulometer.

The Faraday constant, F, may be derived from the following relation:

$$F = \frac{A_r(\mathrm{Ag})}{E_{\mathrm{Ag}}},$$

where E_{Ag} is the electrochemical equivalent of pure silver and $A_r(\mathrm{Ag})$ is the atomic weight of the silver used in determining E_{Ag}. In 1975, coulometric measurements of E_{Ag} undertaken at the National Bureau of Standards [1][1] achieved sufficiently high precision to warrant a careful re-evaluation of the purity of the silver used [2] as well as a more accurate redetermination of its atomic weight [3]. This last work, which is the previous paper published in this issue of the Journal of Research, completes our efforts to measure F via the silver coulometer. Our results are:

$$F_{\mathrm{NBS75}} = 96\,486.17(13)\ A_{\mathrm{NBS75}}\cdot\mathrm{s}\cdot\mathrm{mol}^{-1}\ (1.3\ \mathrm{ppm})$$

$$F_{\mathrm{BI69}} = 96\,486.06(13)\ A_{\mathrm{BI69}}\cdot\mathrm{s}\cdot\mathrm{mol}^{-1}\ (1.3\ \mathrm{ppm})$$

$$F_{\mathrm{SI}} = 96\,485.44(14)\ A_{\mathrm{SI}}\cdot\mathrm{s}\cdot\mathrm{mol}^{-1}\ (1.4\ \mathrm{ppm})$$

where the subscripts identify the electrical units used; that is,

NBS75—electrical units as maintained at the National Bureau of Standards in March of 1975, the time of the coulometric measurements.

BI69—a convenient reference set of "as maintained" electrical units defined in ref. [4]. (BI is an abbreviation for Bureau International des Poids et Mesures (BIPM), the International Bureau of Weights and Measures in Sèvres, France.) We use $A_{\mathrm{NBS75}}/A_{\mathrm{BI69}} = 1-(1.2\pm0.1)\times10^{-6}$ [5].

SI—electrical units as defined in the Système International (i.e., absolute units). The transformation from NBS75 to SI amperes has been made by using what we believe to be the best available conversion factor, $A_{\mathrm{NBS75}}/A_{\mathrm{SI}} = 1-(7.6\pm0.5)\times10^{-6}$ [5], although this is by no means a closed question [6,7].

All uncertainties, which have been given above in parentheses, are meant to correspond to one standard deviation. In addition, the draft recommendations of the BIPM [8] regarding the calculation of uncertainty have been followed, the most noteworthy being that all uncertainties are combined by taking the square root of the sum of their squares to produce a total uncertainty. These procedures for computing uncertainty were also adhered to in reporting the most recent measurements of the electrochemical equivalent of silver [1,2] as well as in recent compilations of the fundamental constants [4,6]. In reporting the new atomic weight of silver [3], however, a more conservative approach has been taken. That is, if the BIPM recommendations were followed, the total uncertainty (at a level of one standard deviation) in the atomic weight of silver reported in ref. [3] would shrink from 0.5 ppm to 0.3 ppm [9]. It is this latter uncertainty which we have used in the results reported above. The total uncertainty at a level of one standard deviation for F_{NBS75}, calculated

* Center for Absolute Physical Quantities, National Measurement Laboratory. V. E. Bower's present address: 9906 Pomona Drive, Bethesda, MD 20034.

† Center for Analytical Chemistry, National Measurement Laboratory.

** Previous publications of this author have been under the name of L. P. Dunstan.

[1] Figures in brackets indicate literature references at the end of this paper.

according to the BIPM recommendations, is shown in table 1. Thus the new measurement of the atomic weight of silver reported in ref. [3] has reduced the role of atomic weight in the uncertainty calculation of the Faraday experiment from dominance to insignificance.

TABLE 1. *Estimate of Uncertainties in F_{NBS75} from Known Sources*

Source	Uncertainty (ppm)
Electrochemical equivalent of silver	1.3[a]
Atomic weight of silver	0.3
Combined uncertainty	1.3

[a] Further details in Ref. [2].

Figure 1 shows the value of the Faraday calculated here as well as Faraday constants measured by other scientists. Point D is the present CODATA recommended value of Cohen and Taylor [4], which is calculated from other physical constants via least squares. It may be noted that not only has the overall uncertainty in the Faraday constant been reduced through this determination, but the new value of the Faraday is now essentially the same as that calculated from the proton gyromagnetic ratio determined by Kibble and Hunt [13]. No further work using silver coulometers is planned since it would be extremely difficult to reduce the uncertainty of the measurements below their present values.

References

[1] Bower, V.E.; Davis, R.S. A new determination of the Faraday by means of the silver coulometer, in *Atomic Masses and Fundamental Constants*, Vol. 5. J.H. Sanders; A.H. Wapstra, eds. New York: Plenum Press; 1976. 578–583.

[2] Bower, V.E.; Davis, R.S. The electrochemical equivalent of pure silver—*A value of the Faraday*. J. Res. Nat. Bur. Stand. (U.S.). **85**(3): 175-191; 1980 May–June.

[3] Powell, L.J.; Murphy, T.J.; Gramlich, J.W. The absolute isotopic abundance and atomic weight of a reference sample of silver. J. Res. Nat. Bur. Stand. (U.S.). 87(1): 9–19, 1981 January–February.

[4] Cohen, E.R.; Taylor, B.N. The 1973 least-squares adjustment of the constants. J. Phys. Chem. Ref. Data **2**(4): 663–734; 1973.

[5] Taylor, B.N. private communication.

[6] Cohen, E.R. Status of the fundamental constants, in *Atomic Masses and Fundamental Constants*, Vol. **6**. J.A. Nolan, Jr.; W. Benenson, eds. New York: Plenum Press; 1980. 525–540. See especially p. 533.

[7] Taylor, B.N. Is the present realization of the absolute ampere in error? Metrologia **12**: 81–83; 1976.

[8] Giacomo, P.; News from the BIPM, Meeting of experts on the subject of expression of uncertainties, Draft recommendation on the statement of uncertainties. Metrologia **17**(2): 69–74; 1981.

[9] Eberhardt, Keith R. private communication.

[10] Craig, D.N.; Hoffman, J.I.; Law, C.A.; Hamer, W. J. Determination of a value of the Faraday with a silver perchloric acid coulometer. J. Res. Nat. Bur. Stand. (U.S.). **64A**(5): 381–402; 1960 September-October.

[11] Marinenko, G.; Taylor, J.K. Electrochemical Equivalents of Benzoic and Oxalic Acid. Anal. Chem. **40**(11): 1645–1651; 1968 September.

[12] Koch, W.F. The value of the Faraday via 4-aminopyridene, in *Atomic Masses and Fundamental Constants*, Vol. **6**. J.A. Nolen, Jr. and W. Benenson, eds. New York: Plenum Press; 1980, 167–172.

[13] Kibble, B.P.; Hunt, G.J. A Measurement of the Gyromagnetic Ratio of the Proton in a Strong Magnetic Field. Metrologia **15**: 5–30; 1979.

[14] Deslattes, R.D.; Henins, A.; Bowman, H.A.; Schoonover, R.M.; Carroll, C.L. and Barnes, I.L.; Machlan, L.A.; Moore, L.J.; Shields, W.R. Determination of the Avogadro Constant. Phys. Rev. Lett. **33**(8): 463-466; 1974 August. We have used the authors' most current recalculation of their result.

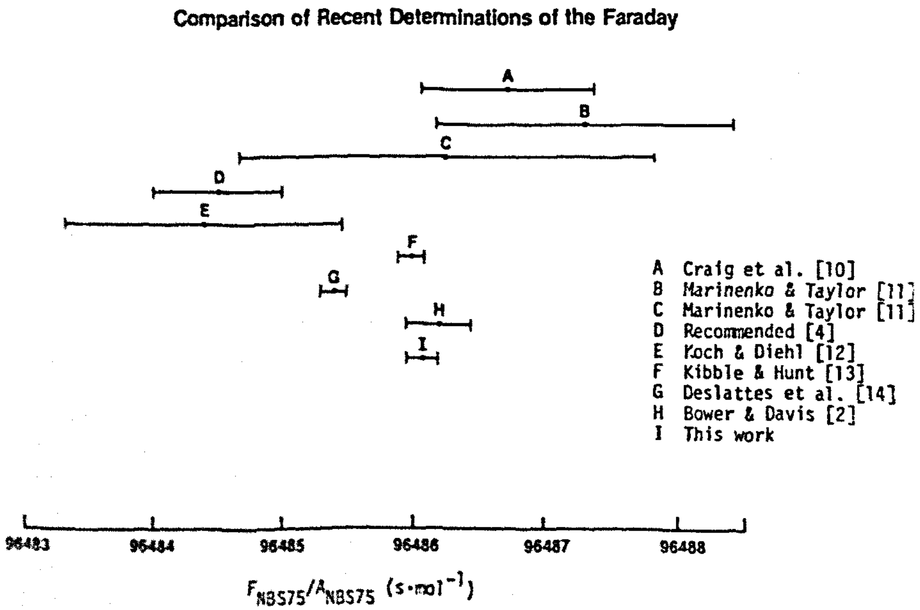

FIGURE 1.