# 14. DONNÉES SPECTROSCOPIQUES FONDAMENTALES (FUNDAMENTAL SPECTROSCOPIC DATA)

PRESIDENT: M. Migeotte.
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ORGANIZING COMMITTEE: R. H. Garstang, G. Herzberg, W. Lochte-Holtgreven, Mrs Ch. Moore-Sitterly, J. G. Phillips, R. Tousey.

## REPORTS

Mrs Ch. Moore-Sitterly has represented the IAU at the Fourth Annual Meeting of CODATA (June 26–27, 1969, Rome, Italy). She also agreed to represent the IAU at the Second International CODATA Conference to be held at St. Andrews (Scotland) from 7 to 11 September 1970 and at the Fifth Annual Meeting of CODATA which follows on September 11–12, 1970.

## COMMITTEE 1: STANDARDS OF WAVELENGTH

### *The primary standard*

Experiments on Lamb-dip stabilization of the 6328 Å He-Ne laser line made at NBS, NPL and PTB and reported in a joint paper (**10**) show that the wavelength from different lasers may differ by as much as one part in $10^7$. Similar work on a $CO_2$ laser line at 10·6 $\mu$m and a xenon line at 3·5 $\mu$m is reported from NPL, the 1·15 $\mu$m line in a pure Ne 20 laser has been investigated at JILA (**5**), and several lines in a xenon ion laser are being studied at PTB. However, the method that holds the greatest promise of accuracy and stability is the use of saturated absorption to lock a laser wavelength to some molecular transition having a sharply defined and stable wavelength. Thus the 6328 Å He-Ne laser line can be fixed on a line in the molecule $^{127}I_2$ (**6, 7**), and the 3·3913 $\mu$m line of a He-Ne laser has been connected to a line of $CH_4$, promising a unique precision and stability according to experiments made at JILA (**5**) and NRC. This technique will evidently yield excellent substitutes for the Kr 86 line, and may, when the time is ripe, lead to the adoption of an improved primary standard.

The wavelength of the primary standard line as emitted by an electrodeless microwave-excited Kr 86 lamp at room temperature (cf. report from the 1967 meeting) has been measured at BIPM (**11**), NPL (**14**) and NRC. The results are somewhat discordant, probably owing partly to differences in the power supplied to the discharge, giving values for the red-shift from 0·0001 to 0·0003 Å. For a provisional value, accurate enough for most applications, we may adopt $\Delta\lambda = +0{\cdot}0002 \pm 0{\cdot}0001$ Å. The Doppler width is as expected about twice that in the standard lamp (**14**). When part of the electrodeless lamp is cooled to 63 K, as in the work by Kaufman and Humphreys (**8**), it was found at NRC that the line broadening is very slight and the red-shift is 0·0001 Å. This shift is equal in magnitude and of opposite sign to the Doppler shift in the standard lamp, showing that the effects of pressure and current density are the same in the two lamps.

### *Secondary standards*

*Krypton 86:* From the averages of all available precision measurements of 233 lines in $^{86}$Kr I, Kaufman and Humphreys (**8**) have made a least-squares derivation of 45 even and 66 odd levels. From these level values they have then calculated and tabulated the wavelengths of 530 lines from



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3345 to 40685 Å, which may be recommended for adoption as secondary standards. Subsequently, measurements made at BIPM by R. Czerwonka on nine infrared $^{86}$Kr I lines have been reported and found to be in perfect agreement with the calculations (**8**). In addition, Humphreys and Paul have measured about 40 wavelengths in $^{86}$Kr II.

*Xenon 136:* According to Humphreys, the advantages derived from the use of xenon 136 are that the large atomic mass permits lines of extreme sharpness to be produced at moderately low temperatures, and that the spectrum includes several lines of high intensity between 2·0 and 3·5 $\mu$m, thus providing an essentially unique example among sources of standards. Humphreys is now preparing a comprehensive report on his measurements in $^{136}$Xe I. He has also developed a method for producing the $^{136}$Xe II spectrum with very sharp lines, and has determined the wavelengths of 108 lines in the range 3800–6500 Å.

*Thorium:* The results of the interferometric measurements of thorium lines that have accumulated during the last decade (latest contributions to be found in **4** and **15**) have been compiled and critically evaluated in a paper by Giacchetti *et al.* (**3**). From weighted averages of all published wavelengths they derive a set of energy levels for Th I by means of which they calculate, with an average standard deviation of 0·0014 cm$^{-1}$, the wavenumbers of 1375 lines covering the range from 2650 to 12381 Å. By adding 181 accurately measured Th I and Th II wavelengths they obtain a total of 1556 lines that may be adopted as standards. This synthesis of all the measurements in the thorium spectrum made to date is a great step forward. At the same time it is evident, as emphasized by the authors, that the present results still come short of a full exploitation of the potential advantages of thorium as a source of standards. They recommend that further measurements be made by using cooled hollow-cathode sources and by direct reference to the primary standard.

*Iron:* Concerning the iron standards we note that H. M. Crosswhite is preparing a line list for publication as an NBS Monograph under the title *The Iron-Neon Hollow-Cathode Spectrum.*

## *Vacuum-UV Standards*

The present situation regarding wavelength standards in the vacuum UV was briefly surveyed in a recent review (**1**). The latest contributions concern Cl I, Cu II and Zn II.

In a comprehensive work on Cl I, Radziemski and Kaufman (**12**) have calculated the wavelengths of 108 Cl I lines in the region 978–1397 Å to $\pm$0·0015 Å or better, relying on some precision wavelength measurements made at NBS by L. Minnhagen.

The second spectrum of copper, Cu II, has been the subject of an exhaustive reinvestigation by Ross (**13**). He gives what should be the final list of Cu II Ritz standards, comprising 432 recommended wavelengths down to 675 Å, with uncertainties of 0·0004 Å to 0·0001 Å. There is a close agreement with the values earlier reported to this commission (**2**).

Martin and Kaufman (**9**) give wavelengths accurate to 0·002 or 0·003 Å for 40 lines of Zn II from 2105 to 1400 Å.

In this report we have used the following abbreviations:

BIPM = Bureau International des Poids et Mesures, Sèvres.
JILA = Joint Institute for Laboratory Astrophysics, Boulder, Colorado.
NBS = National Bureau of Standards, Washington, D.C.
NPL = National Physical Laboratory, Teddington.
NRC = National Research Council, Ottawa.
PTB = Physikalisch-Technische Bundesanstalt, Braunschweig.

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B. EDLÉN
*Chairman of the Committee*

## COMMITTEE 2: TRANSITION PROBABILITIES

A very great deal of work has been done during the last three years on the determination of atomic transition probabilities, and complete coverage here is impossible. Wiese and his staff at the National Bureau of Standards, Washington, have continued to collect all numerical results, and they can supply information as to what is available for any particular atom. They have published (**1**) a critical compilation of atomic transition probabilities for the atoms sodium to calcium (inclusive) in essentially the same way as an earlier compilation covered hydrogen to neon. At the time of writing a complete new bibliography is also in preparation (**2**), which will be published as NBS Special Publication 320 and which is complete up to June 1969. Review articles published include that of Layzer and Garstang (**3**) on theoretical allowed and forbidden transition probabilities, and the two volume conference report (**4**) covers beam foil spectroscopy (including lifetime measurements) in some detail. A fairly complete review of forbidden line transition probabilities was given by Garstang (**5**), where references to many original papers may be found. In the following we shall confine ourselves to mentioning a few areas of particular interest; detailed references can be traced through the bibliographies, reviews and abstracting journals.

On the experimental side much attention has been given to the direct measurement of atomic lifetimes, and many individual cases have been studied. Outstanding has been the work by the phase shift technique by Lawrence, Hesser, Cunningham, and others. Atoms studied include O I, N II, Ne I, Ne II, Ne III and Al I. The direct decay of atomic states has been observed in other cases after pulsed electron excitation, after direct optical excitation and after beam-foil excitation. A major problem in these methods is cascading from higher states, and this limits the applicability of the methods, but there are many important states which have been, and could be, studied. As examples of what has been done we quote the work of Lawrence by pulsed electron excitation on Ar I, Ar II, Ar III, Ar IV, S II, Cl II and Xe I, of Wares and his group on various stages of ionization of oxygen by beam-foil spectroscopy, and of Wolff and Davis on decay following optical excitation in Cs I and Na I. The Hanle effect has been used very successfully by Gallagher for the resonance lines and infrared triplets in Ca II, Sr II and Ba II, and by deZafra and Marshall for Sn I and Pb I. Absorption spectroscopy has been used in many investigations, for example the work of Huber and Tobey and of Grasdalen, Huber and Parkinson on Fe I, Fe II, Cr I and Cr II and the work of Parkes, Keyser and Kaufman on the resonance triplet of O I. Emission spectroscopy of stabilised arcs has been used by Bridges and Wiese and by Foster on the S I and S II spectra. Particularly important are the papers by the Kiel group (**6**) on Fe I and Fe II, using a well stabilized argon arc with a small admixture of iron chloride. They derive solar abundances of 7·6 (on the scale with log H = 12) from their results, in agreement with coronal values.

On the theoretical side an important trend has been the inclusion of configuration interaction in

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