COMMENTS ON THE MEASUREMENT OF TRANSITION PROBABILITIES

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Developments in the measurements of oscillator strengths, that are of current and future interest to astrophysics, have taken place in the past few years:

- there is increased emphasis on methods which are independent of level populations (i.e., of number densities and thus equilibrium in the vapour or plasma under investigation),
- clear progress has been made towards higher precision (and accuracy) and
- the dynamic range of astrophysically relevant oscillator strengths was further extended towards weaker lines.

Efforts have expanded to determine branching fractions*, which can be used - together with the numerous, already measured lifetimes - to obtain absolute transition probabilities (see e.g. Whaling 1976, Wiese 1979, Hannaford et al. 1982). In addition, several methods - summarised under the name "Ladenburg methods" (Humber and Sandeman 1986) - have been developed, which combine data from emission and absorption or dispersion measurements to form a set of oscillator strengths that is independent of number densities (see e.g., Cardon, Smith and Whaling 1979, Cardon et al. 1982, Kock, Kroll and Schnehage 1984).

Techniques for evaluating spectral interferograms, as they are produced for dispersion measurements - particularly with the hook method (cf. Huber and Sandeman 1986) - have been perfected: the hook vernier (Sandeman 1979), for example, increases the sensitivity (and thus also the precision) of hook measurements by a factor of 25 over that of the conventional hook evaluation. High precision is also obtained by fitting calculated patterns to the observed spectral interferograms (Hill 1986).

Precision measurements based on low-noise spectroscopy in absorption have been reported for several 3d-elements by the Oxford Group [see, e.g., for Ti I and II Blackwell, Menon and Petford (1983 and 1982, respectively), for Cr I Blackwell, Booth, Menon and Petford (1986), for Mn I Booth et al. (1984) and for Fe I Blackwell, Petford and Simmons (1982)]. An important astrophysical result based on such precision laboratory-data was the unequivocal demonstration of an enery-dependence of the solar photospheric iron-abundance, if determined by use of local thermal equilibrium (LTE) from Fe-I lines (Blackwell, Booth and Petford 1984). Accordingly, non-LTE effects must now be taken into consideration in modelling the solar photosphere. By use of precision data, Simmons and Blackwell (1982) have also obtained evidence on the complex nature of the microturbulence parameter.

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* The designation "branching fraction" is used here - instead of the more common "branching ratio" - to indicate the measures of relative photon flux for a complete set of decay channels from a common upper level: the sum of all branching fractions belonging to a given upper level adds up to one. "Branching ratio", accordingly, can be used for relative photon fluxes without this constraint.

Use of a Fourier-transform spectrometer (FTS) can even further reduce the noise in spectra. The signal-to-noise (S/N) ratio that can be achieved by a FTS is in principle equivalent to that of a scanning spectrometer with the same spectral resolution and optical aperture ratio; but given the entrance apertures, namely a sizeable hole versus a narrow slit, the FTS can work with a considerably higher photon flux than a conventional spectrometer: it has a throughput advantage (Brault 1985). This advantage is further enhanced in the case of an emission spectrum, and especially, if a narrow wavelength band is isolated by use of a suitable filter (Brault 1985). An example of the dramatic gain in S/N obtained by restricting the wavelength window seen by the FTS detectors is shown in figure 1. From such a spectrum, the photon flux of extremely weak Fe-II lines (solar equivalent widths $W_\lambda/\lambda \simeq 3.10^{-6}$ and transition probabilities $A \approx 10^4$ s^{-1}) originating in a hollow-cathode discharge can be measured and subsequently branching fractions can be determined. (Note that the majority of the weak lines observed in figure 1 is unidentified; the single lines appearing in the low-noise spectrum can be assigned to Fe or the Ne carrier gas, based on their Doppler widths, but most of these lines represent hitherto unknown transitions).

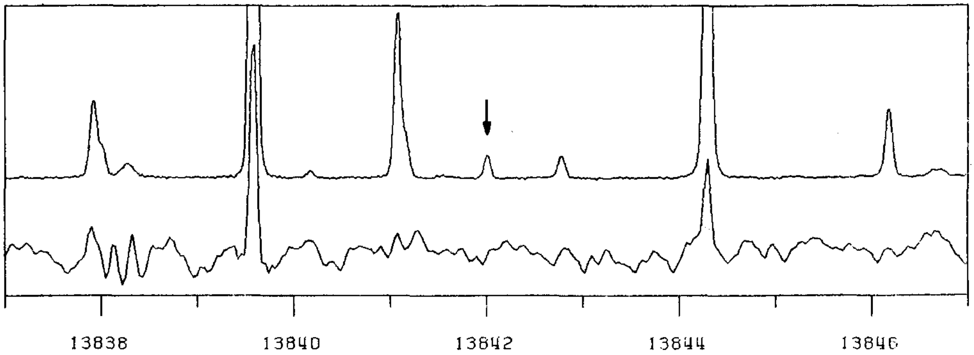

Figure 1

Comparison of two spectra (13838-13846 cm^{-1}) of the same hollow-cathode source recorded by us on the Fourier-transform spectrometer (FTS) at the U.S. National Solar Observatory on Kitt Peak (Brault 1979). The bandwidth seen by the FTS detectors is 2 nm in the upper and 300 nm - 1 μm in the lower spectrum: a dramatic lowering of the noise level results. Note that the intensity scale is linear, and is expanded by a factor of ca. ten for the low-noise spectrum. The Fe-II line at 722.2394 nm (W_λ = 20 mÅ, A ≃ 10^4 s^{-1}) is marked by an arrow.

One of the problems of precision measurements is that the stated precision - in the case of the Oxford measures this reaches 0.5 percent - cannot easily be assessed by independent measurements. To date, independent emission measures have shown agreement with the Oxford absorption data for Cr I (Blackwell, Menon and Petford 1984) to the three-percent level (Tozzi, Brunner and Huber 1985).

A further extension of the dynamic range of the Oxford Fe-I measures by a factor of ten has just been reported (Blackwell, Booth, Haddock and Petford 1986). Such measurements are of great importance for stars cooler than the Sun. There, Fe-I lines that are suitable for solar studies become too strong for the stellar-atmosphere work that can be performed with the great photon collectors of the future. However, assessing the precision is again very difficult, because even a test by use of low-noise solar spectra is unreliable, given the extremely small equivalent widths of the solar Fe-I lines in question.

In conclusion, we mention that several methods for measuring oscillator strengths, which are based on non-linear processes, have been demonstrated in the past years. [Note that for linear as well as for non-linear optical processes, the coupling of the electronmagnetic field with atoms or molecules takes place through electric-dipole (and higher-order) moments and thus can be expressed in terms of oscillator strengths.] Non-linear methods have, of course, not yet reached the maturity and experimental perfection of the classical dispersion, absorption and emission methods, yet they have been proven in concept.

In view of their potential it would be worthwhile exploring the suitability of non-linear processes for the measurements of oscillator strengths of astrophysical interest. A review of the relevant processes and applications is given by Huber and Sandeman (1986).

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MEASUREMENTS OF TRANSITION PROBABILITIES FOR INTERSYSTEMS LINES OF ATOMIC IONS USED IN DIAGNOSIS OF ASTROPHYSICAL PLASMAS.

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