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ASTRONOMY AND ASTROPHYSICS

# Fe I oscillator strengths of lines of astrophysical interest

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**Abstract.** Oscillator strengths of 114 Fe I lines in the wavelength range 260–1170 nm are presented which were obtained by means of emission measurements on a high-current hollow-cathode and by using a high-resolution Fourier-transform spectrometer, in conjunction with literature data of lifetime that are considered reliable. In order to comprise a large number of lines of astrophysical interest we have included some branching fractions from Bridges & Kornblith; May et al., and Kock et al. in this analysis. As a result the uncertainty of the *f*-values typically is between 7 and 12%, and it is 33% at the most. The data are compared with literature data, especially with those of the Oxford group.

**Key words:** atomic and molecular data – plasmas – spectroscopy – stars: abundances – Sun (the): abundances

## 1. Introduction

In recent papers Holweger et al. (1990) and Pauls et al. (1990) derived solar abundances from faint Fe II lines which, however, differ by more than 50% from each other. As discussed in detail by Holweger et al. possible reasons for this discrepancy may be inadequate assumptions made in the solar model and/or uncertain *f*-values.

For Fe I the data situation is fairly satisfactory. Since the publication by Garz & Kock (1969) the spread of the solar iron abundance $\log N(\mathrm{Fe})$ obtained with Fe I *f*-values has been from 7.6 to 7.67 where the highest figure corresponds to the very precise *f*-values measured by the Oxford group (see, e.g. Blackwell et al. 1970, 1972, 1979a, b, 1980, 1982).

Since there is a continuing interest in *f*-values of faint solar Fe I lines we have resumed the investigation of Fe I spectra, using measurement and evaluation techniques comparable to those applied by Heise & Kock (1990) for the determination of Fe II *f*-values. In a preliminary abundance study Holweger (1990) obtained $\log N(\mathrm{Fe}) = 7.50$ or even less by making use of our laboratory Fe I *f*-values, in accordance with the result based on our Fe II data. We have taken this surprising outcome as an incentive to investigate still more Fe I lines. In this paper we present a large set of *f*-values and compare them with recent literature data. As a matter of fact, we also have been looking for systematic errors that might be hidden in the results given by other authors. However, whatever error source we conceived of, the magnitude of the effects were insufficient to explain the 50% discrepancy in the solar iron abundance.

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## 2. Experimental procedure

The state of the art method for a reliable determination of *f*-values of lines of astrophysical interest is the combination of measurements of lifetimes and branching fractions (see, e.g. Huber & Sandeman 1988).

As to the lifetimes, modern laser techniques allow selective population of excited states, thus avoiding cascade effects. The influence of buffer gas atoms on the measurement can be accounted for. The accuracy of such lifetime measurements is in the percent range (see, e.g. Marek et al. 1979).

The measurement of branching fractions is a straight-forward technique that avoids virtually all systematic errors. Since only lines are involved originating from a common upper level, plasma parameters need not be known, and non-equilibrium light sources can be used. An absolute radiance calibration is not required. Only three error sources have to be considered:

i) If a line is not emitted from an optically thin layer selfabsorption will falsify the result. Spatially inhomogeneous plasma layers can also cause self-reversal in the lines, especially in transitions to the ground state and to metastable states.

ii) Strongly overlapping lines, or blends, may lead to erroneous results. Misidentification is still another problem.

iii) Faint to very faint lines may be recorded with a poor $S/N$ ratio leading to large statistical incertainties.

We have applied a high-current hollow-cathode (HC) as the light source a detailed description of which was given by Danzmann et al. (1988). The discharge has been burned in argon (1.6 hPa) at a current of 1.5 Å. The burning voltage was about 430 V. The iron atoms were sputtered from a metallic cylinder made of very pure iron (VP 99.95%).

Most of the measurements have been performed with the high-resolution Fourier-transform spectrometer (Brault 1985) at Kitt Peak, Arizona. By adding up several runs and by using band pass filters the $S/N$ ratio in the spectra could be increased considerably. The line intensities were calibrated with a tungsten strip lamp (Optronics) and with a Deuterium lamp (Cathodeon).

**Table 1.** Absolute oscillator strength for Fe I

| λ (nm) | Transition | $E_i$ ($cm^{-1}$) | $A_{ki}$ ($10^4 s^{-1}$) | log(gf) | Error (%) |
|---|---|---|---|---|---|
| $z^5D_1^o$ | $E_k$ = 26479.39 $cm^{-1}$ | | $\tau_k$ = 83.5 ± 5.0 ns | | a) |
| 387.8570 | $a^5D_2$ | 704.00 | 663 | -1.348 | 10 |
| 390.6477 | $a^5D_1$ | 888.13 | 105 | -2.144 | 11 |
| 392.0256 | $a^5D_0$ | 978.07 | 261 | -1.744 | 10 |
| 540.5774 | $a^5F_2$ | 7985.80 | 101.0 | -1.877 | 8 |
| 545.5609 | $a^5F_1$ | 8154.73 | 60.0 | -2.098 | 8 |
| 1168.9997 | $a^5P_1$ | 17927.41 | 6.0 | -2.433 | 21 |
| $z^5D_0^o$ | $E_k$ = 26550.50 $cm^{-1}$ | | $\tau_k$ = 85.6 ± 5.0 ns | | a) |
| 389.5654 | $a^5D_1$ | 888.13 | 986 | -1.649 | 9 |
| 543.4522 | $a^5F_1$ | 8154.73 | 176 | -2.109 | 8 |
| 1159.3606 | $a^5P_1$ | 17927.41 | 6.0 | -2.930 | 33 |
| $z^5F_4^o$ | $E_k$ = 27166.84 $cm^{-1}$ | | $\tau_k$ = 64.9 ± 4.0 ns | | b) |
| 367.9911 | $a^5D_4$ | 0.00 | 149 | -1.564* | 12 |
| 373.7129 | $a^5D_3$ | 415.93 | 1380 | -0.584* | 12 |
| 493.9685 | $a^5F_5$ | 6928.28 | 1.47 | -3.315 | 9 |
| 505.1633 | $a^5F_4$ | 7376.78 | 5.16 | -2.750 | 9 |
| 514.2927 | $a^5F_3$ | 7728.07 | 2.33 | -3.080+ | 9 |
| 658.1211 | $a^3F_4$ | 11976.26 | 0.0358 | -4.679 | 10 |
| $z^5F_3^o$ | $E_k$ = 27394.70 $cm^{-1}$ | | $\tau_k$ = 65.1 ± 4.0 ns | | a) |
| 370.5564 | $a^5D_3$ | 415.93 | 353 | -1.294* | 12 |
| 374.5559 | $a^5D_2$ | 704.00 | 1170 | -0.764* | 12 |
| 499.4129 | $a^5F_4$ | 7376.78 | 4.23 | -2.956 | 9 |
| 508.3338 | $a^5F_3$ | 7728.07 | 5.66 | -2.814+ | 9 |
| 515.0838 | $a^5F_2$ | 7985.80 | 3.57 | -3.003 | 9 |
| 673.9523 | $a^3F_3$ | 12560.95 | 0.0337 | -4.794 | 15 |
| $z^3P_2^o$ | $E_k$ = 33946.97 $cm^{-1}$ | | $\tau_k$ = 37.8 ± 2.0 ns | | c) |
| 298.1442 | $a^5D_3$ | 415.93 | 683 | -1.342 | 9 |
| 300.7279 | $a^5D_2$ | 704.00 | 286 | -1.712 | 9 |
| 302.4030 | $a^5D_1$ | 888.13 | 461 | -1.500 | 9 |
| 381.2961 | $a^5F_3$ | 7728.07 | 897 | -1.010 | 10 |
| 385.0814 | $a^5F_2$ | 7985.80 | 162 | -1.745 | 9 |
| 387.6036 | $a^5F_1$ | 8154.73 | 13.0 | -2.835 | 10 |
| 616.3542 | $a^5P_2$ | 17727.02 | 0.844 | -3.619 | 8 |
| 624.0645 | $a^5P_1$ | 17927.41 | 2.00 | -3.233 | 7 |
| 642.1348 | $a^3P_2$ | 18378.22 | 37.0 | -1.945 | 7 |
| 694.5196 | $a^3P_1$ | 19552.49 | 10.16 | -2.435 | 7 |
| 899.9560 | $b^3P_2$ | 22838.36 | 79.0 | -1.321 | 7 |
| 908.8328 | $b^3P_1$ | 22946.86 | 17.0 | -1.986 | 7 |

**Table 1** (continued)

| λ (nm) | Transition | $E_i$ ($cm^{-1}$) | $A_{ki}$ ($10^4 s^{-1}$) | log(gf) | Error (%) |
|---|---|---|---|---|---|
| $z^3P_1^o$ | $E_k$ = 34362.89 $cm^{-1}$ | | $\tau_k$ = 103.1 ± 8.0 ns | | c) |
| 297.0116 | $a^5D_2$ | 704.00 | 274 | -1.964 | 10 |
| 298.6454 | $a^5D_1$ | 888.13 | 20.0 | -3.088 | 11 |
| 299.4500 | $a^5D_0$ | 978.07 | 159 | -2.192 | 11 |
| 379.0092 | $a^5F_2$ | 7985.80 | 292 | -1.724 | 11 |
| 381.4522 | $a^5F_1$ | 8154.73 | 73.0 | -2.322 | 10 |
| 608.2714 | $a^5P_1$ | 17927.41 | 1.53 | -3.593 | 9 |
| 625.4262 | $a^3P_2$ | 18378.22 | 20.0 | -2.443 | 9 |
| 675.0150 | $a^3P_1$ | 19552.49 | 12.0 | -2.608 | 9 |
| 697.8863 | $a^3P_0$ | 20037.86 | 15.0 | -2.484 | 9 |
| 867.4761 | $b^3P_2$ | 22838.36 | 47.0 | -1.800 | 9 |
| 875.7208 | $b^3P_1$ | 22946.86 | 25.0 | -2.059 | 10 |
| 883.8446 | $b^3P_0$ | 23051.79 | 25.0 | -2.050 | 10 |
| $z^3P_0^o$ | $E_k$ = 34555.64 $cm^{-1}$ | | $\tau_k$ = 109.8 ± 6.0 ns | | c) |
| 296.9356 | $a^5D_1$ | 888.13 | 423 | -2.252 | 9 |
| 378.6672 | $a^5F_1$ | 8154.73 | 322 | -2.160 | 9 |
| 601.2204 | $a^5P_1$ | 17927.41 | 1.69 | -4.038 | 8 |
| 666.3428 | $a^3P_1$ | 19552.49 | 53.0 | -2.453 | 7 |
| 861.1804 | $b^3P_1$ | 22946.86 | 107.0 | -1.926 | 7 |
| $z^5G_4^o$ | $E_k$ = 35257.35 $cm^{-1}$ | | $\tau_k$ = 11.2 ± 0.7 ns | | a) |
| 283.5454 | $a^5D_4$ | 0.00 | 60.0 | -2.184 | 10 |
| 286.9305 | $a^5D_3$ | 415.93 | 159 | -1.752 | 10 |
| 358.5704 | $a^5F_4$ | 7376.78 | 668 | -0.936 f) | 11 |
| 363.1462 | $a^5F_3$ | 7728.07 | 4530 | -0.094 | 13 |
| 429.4124 | $a^3F_4$ | 11976.26 | 435 | -0.966 | 11 |
| 440.4749 | $a^3F_3$ | 12560.95 | 3000 | -0.105 | 11 |
| 639.3604 | $a^3H_5$ | 19621.04 | 67.0 | -1.432 | 9 |
| 646.2729 | $a^3H_4$ | 19788.28 | 7.62 | -2.367 | 9 |
| 871.3198 | $b^3G_5$ | 23783.65 | 3.33 | -2.467 | 16 |
| 897.5413 | $b^3G_4$ | 24118.85 | 5.38 | -2.233 | 11 |
| $y^3D_3^o$ | $E_k$ = 38175.38 $cm^{-1}$ | | $\tau_k$ = 6.9 ± 0.5 ns | | d) |
| 261.8708 | $a^5D_4$ | 0.00 | 475 | -1.466 | 12 |
| 264.7555 | $a^5D_3$ | 415.93 | 144 | -1.976 | 12 |
| 266.7910 | $a^5D_2$ | 704.00 | 32.0 | -2.623 | 16 |
| 381.5839 | $a^3F_4$ | 11976.26 | 11000 | 0.226* | 13 |
| 390.2944 | $a^3F_3$ | 12560.95 | 2410 | -0.414* | 13 |
| 396.6060 | $a^3F_2$ | 12968.57 | 190 | -1.504* | 13 |
| 488.9001 | $a^5P_2$ | 17727.02 | 16.0 | -2.387 | 11 |
| 504.9820 | $a^3P_2$ | 18378.22 | 169 | -1.344+ | 10 |
| 570.1546 | $b^3F_4$ | 20641.14 | 22.0 | -2.131 | 10 |

**Table 1** (continued)

| λ (nm) | Transition | $E_i$ ($cm^{-1}$) | $A_{ki}$ ($10^4 s^{-1}$) | log(gf) | Error (%) |
|---|---|---|---|---|---|
| 577.8457 | $b^3F_3$ | 20874.52 | 1.04 | -3.440 | 12 |
| 618.0206 | $a^3G_4$ | 21999.17 | 6.32 | -2.596 | 10 |
| 651.8370 | $b^3P_2$ | 22838.36 | 7.78 | -2.460 | 10 |
| 711.2172 | $b^3G_4$ | 24118.85 | 1.89 | -2.998 | 24 |
| 722.3663 | $c^3P_2$ | 24335.80 | 11.0 | -2.225 | 10 |
| 836.5655 | $a^3D_3$ | 26225.03 | 12.0 | -2.047 | 16 |
| $y^3D_2^o$ | $E_k$ = 38678.07 $cm^{-1}$ | | $\tau_k$ = 7.1 ± 0.5 ns | | d) |
| 261.2770 | $a^5D_3$ | 415.93 | 138 | -2.150 | 13 |
| 263.2591 | $a^5D_2$ | 704.00 | 198 | -1.987 | 12 |
| 264.5419 | $a^5D_1$ | 888.13 | 59.0 | -2.510 | 15 |
| 382.7830 | $a^3F_3$ | 12560.95 | 10800 | 0.075* | 13 |
| 388.8520 | $a^3F_2$ | 12968.57 | 2570 | -0.535* | 13 |
| 477.1696 | $a^5P_2$ | 17727.02 | 3.30 | -3.249 | 20 |
| 492.4769 | $a^3P_2$ | 18378.22 | 31.0 | -2.256 | 11 |
| 522.7146 | $a^3P_1$ | 19552.49 | 210 | -1.367 | 23 |
| 561.5300 | $b^3F_3$ | 20874.52 | 15.0 | -2.453 | 10 |
| 608.5259 | $a^3G_3$ | 22249.46 | 2.80 | -3.110 | 12 |
| 631.1503 | $b^3P_2$ | 22838.36 | 2.34 | -3.156 | 10 |
| 635.5034 | $b^3P_1$ | 22946.86 | 14.0 | -2.365+ | 10 |
| 829.3490 | $a^3D_2$ | 26623.73 | 13.0 | -2.190 | 18 |
| $y^3D_1^o$ | $E_k$ = 38995.76 $cm^{-1}$ | | $\tau_k$ = 7.2 ± 0.7 ns | | e) |
| 261.0748 | $a^5D_2$ | 704.00 | 148 | -2.342 | 19 |
| 262.3364 | $a^5D_1$ | 888.13 | 341 | -1.976 | 16 |
| 262.9570 | $a^5D_0$ | 978.07 | 200 | -2.207 | 18 |
| 384.1050 | $a^3F_2$ | 12968.57 | 13000 | -0.065* | 16 |
| 514.1735 | $a^3P_1$ | 19552.49 | 91 | -1.964 | 15 |
| 527.3377 | $a^3P_0$ | 20037.86 | 87 | -1.965+ | 13 |
| 556.7393 | $b^3F_2$ | 21039.02 | 20.0 | -2.564 | 13 |
| 622.9232 | $b^3P_1$ | 22946.86 | 9.0 | -2.805 | 20 |
| 627.0228 | $b^3P_0$ | 23051.79 | 19.0 | -2.464 | 13 |
| 794.1085 | $a^3D_1$ | 26406.49 | 18.0 | -2.286 | 17 |
| $e^5D_4$ | $E_k$ = 44677.01 $cm^{-1}$ | | $\tau_k$ = 15.6 ± 0.9 ns | | a) |
| 461.1185 | $z^7F_4^o$ | 22996.69 | 7.0 | -2.720 | 19 |
| 476.8398 | $z^7P_4^o$ | 23711.47 | 11.0 | -2.461 | 14 |
| 532.4181 | $z^5D_4^o$ | 25900.00 | 2060 | -0.103 | 7 |
| 539.3170 | $z^5D_3^o$ | 26140.19 | 491 | -0.715 | 7 |
| 561.5646 | $z^5F_5^o$ | 26874.56 | 2640 | 0.050 | 7 |
| 570.9382 | $z^5F_4^o$ | 27166.84 | 213 | -1.028 | 7 |
| 578.4660 | $z^5F_3^o$ | 27394.70 | 6.51 | -2.532 | 7 |
| 640.0005 | $z^5P_3^o$ | 29056.34 | 928 | -0.290 | 7 |

**Table 1** (continued)

| λ (nm) | Transition | $E_i$ ($cm^{-1}$) | $A_{ki}$ ($10^4 s^{-1}$) | log(gf) | Error (%) |
|---|---|---|---|---|---|
| $e^5D_3$ | $E_k$ = 45061.33 $cm^{-1}$ | | $\tau_k$ = 15.8 ± 0.9 ns | | a) |
| 478.7828 | $z^7P^o_3$ | 24180.88 | 12.0 | −2.530 | 26 |
| 521.7391 | $z^5D^o_4$ | 25900.00 | 298 | −1.070 | 7 |
| 528.3623 | $z^5D^o_3$ | 26140.19 | 1262 | −0.432 | 7 |
| 533.9931 | $z^5D^o_2$ | 26339.71 | 753 | −0.647 | 7 |
| 558.6759 | $z^5F^o_4$ | 27166.84 | 2450 | −0.096 | 7 |
| 565.8818 | $z^5F^o_3$ | 27394.70 | 479 | −0.793 | 7 |
| 571.2134 | $z^5F^o_2$ | 27559.60 | 30.0 | −1.990 | 7 |
| 624.6322 | $z^5P^o_3$ | 29056.34 | 452 | −0.733 | 7 |
| 641.1649 | $z^5P^o_2$ | 29469.03 | 589 | −0.595 | 7 |
| $e^5D_2$ | $E_k$ = 45333.88 $cm^{-1}$ | | $\tau_k$ = 15.7 ± 0.9 ns | | a) |
| 520.8596 | $z^5D^o_3$ | 26140.19 | 623 | −0.897 | 7 |
| 526.3308 | $z^5D^o_2$ | 26339.71 | 636 | −0.879 | 7 |
| 530.2302 | $z^5D^o_1$ | 26479.39 | 904 | −0.720 | 7 |
| 557.2844 | $z^5F^o_3$ | 27394.70 | 2280 | −0.275 | 7 |
| 562.4545 | $z^5F^o_2$ | 27559.60 | 741 | −0.755 | 7 |
| 565.8534 | $z^5F^o_1$ | 27666.36 | 58.0 | −1.856 | 8 |
| 614.1735 | $z^5P^o_3$ | 29056.34 | 123.0 | −1.459 | 7 |
| 630.1501 | $z^5P^o_2$ | 29469.03 | 643 | −0.718 | 7 |
| 640.8020 | $z^5P^o_1$ | 29732.75 | 312 | −1.018 | 7 |

a) Marek et al. (1979)

b) Averaged Lifetimes of Marek et al. (1979) and Kwiatkowski et al. (1983)

c) Averaged Lifetimes of Marek et al. (1979) and Figger et al. (1975)

d) Kwiatkowski et al. (1983). Because the authors didn't give any errors for their lifetime measurements, we estimated the errors to be 7% which is typical for laser fluorescence experiments of this type.

e) Andersen and Sörensen (1971)

f) Possibly blended in our spectra.

*) Lines for which ratios of f-values have been used which where taken from other authors (Bridges and Kornblith (1974), May et al. (1974), Kock et al. (1984)).

+) Reference lines used to link the data of the present study to those of the other authors.

The influence of selfabsorption in the lines was checked with two different methods:

i) By varying the discharge current the intensity ratios of lines with a common upper level have to be constant. This method has been applied to measurements in our laboratory because we were not able to resolve the line profiles with our grating monochromator.

ii) With the FTS the purely Doppler broadened lines of the HC are resolved so that their profiles can be used for a test: Lines affected by selfabsorption are broadened with respect to optically thin lines. We have fitted Gaussian profiles to the lines. If necessary the intensities have been corrected to optically thin layer by the following formula:

$$I_c = I\alpha/(1-\exp(-\alpha)),$$

where $\alpha$ is the measured optical depth. Maximum correction of line intensity was no more than 10% for a few critical lines.

Because of the non-overlapping band filters some connecting measurements have been performed in our laboratory. The equipment is described elsewhere (Heise & Kock 1990; Bard 1989).

## 3. Data reduction

The Fe I spectra were analysed by means of the tables given by Moore (1952). We used the semiemperical calculations by Kurucz

& Peytremann (1975) for blend searching and for checking the contribution of faint lines not measured in an actual run.

For the highly resolved FTS spectra the area under a lines was determined by fitting a Gaussian function to the line profile. As mentioned above, we have corrected a few lines for selfabsorption. For the evaluation of the broadband scans the apparatus profile of the FTS, which is simply a sinc-function, has been taken into account.

We have measured a few connecting lines with our 2 m grating monochromator whose apparatus function with a width of 45 mÅ is too large to resolve the HC lines. Nevertheless, the profile could be approximated sufficiently well by a Gaussian one too, so that the same procedure has been applied.

A few line ratios (labelled in Table 1) have been taken from Bridges & Kornblith (1974), May et al. (1974) as well as from Kock et al. (1984) in order to increase the set of lines applicable for a solar abundance study. Such line ratios derived from literature data will not be affected by systematic errors other than those of types (i) through (iii) mentioned above. Indeed, there is no indication of a systematic error in the respective data.

As a result we present a set of more than 20 lines in Table 1 which can be applied for an abundance study. The uncertainty in the *f*-values is typically 7–33% depending on the line and on the way in which it has been linked.

## 4. Results and discussion

For the 114 Fe I lines listed in Table 1 we have used published lifetime data for the absolute calibration (data and references are given in the table).

We have compared our $\log(gf)$ values with literature data. Thus, mutual deviations of the data sets will be characterized by the mean difference $\Delta$, which is a measure of the shift in the absolute scales. The average deviation in the relative scales will be given by an rms scatter $\sigma$.

The semi-empirical calculations of Kurucz & Peytremann (1975) yield smaller *f*-values ($\Delta = 0.24$ dex) compared to our data. The mutual scatter ($\sigma = 0.31$ dex) is very large.

Bridges & Kornblith (1974) have performed refined measurements on a cascaded arc. Their data set has been enlarged considerably by May et al. (1974) who performed only relative measurements on a free-burning arc. A comparison with our $\log(gf)$ values is given in Fig. 1. Despite a larger scatter ($\sigma = 0.09$ dex) the data are consistent. We cannot find systematic errors.

Of special interest is a comparison with the NBS compilation (Fuhr et al. 1988) because a number of literature data are put together whereby the basic set is that of the Oxford group. Other sets have been renormalized to those precise *f*-values. The comparison is given in Fig. 2. The difference of the $\log(gf)$ values is plotted versus the energy of the lower states of the line transitions. Even though there is a large scatter ($\sigma = 0.12$ dex) the *f*-values are obviously dependent on the exitation energy of the lines. An explanation of such a systematic error is hardly to be expected from the NBS compilation; it should rather follow from a comparison with the basic set.

In Fig. 3 this comparison is made with the data of the Oxford group. Besides a small shift in the absolute scale ($\Delta = 0.034$ dex) and a remarkably small scatter ($\sigma = 0.06$ dex) no energy dependence can be seen. However, for sets like the lines from the level $z^3P_2^0$ the same energy dependence is found as in Fig. 2. Kock et al. (1984) also described a systematic error of this amount and traced it back to a slight temperature bias in the experiments of the Oxford group. Yet we cannot find an error in the procedure by which the Oxford group has determined the axial temperature profile in their oven.

Diffusion, or rather the neglect of diffusion, may however give rise to a systematic error producing a dependence of the *f*-values on the excitation potential of the lines under consideration. It is clearly stated by Blackwell & Collins (1972): "In calculating the oscillator strength from the measured equivalent width it is necessary to integrate an expression of the form $n(T)\exp(-E/kT)$ along the tube." In other words: Not only the temperature distribution but also the local iron density $n(T)$ have to be known. Blackwell & Collins made use of the vapour pressure curve given by Nesmeyanov (1961) under the assumption that diffusion is not substantial. In our opinion, however, axial temperature gradients will cause diffusion of iron atoms to the cooler regions, thus increasing the iron density at the ends of the vapour column.

We took the temperature distribution and tube geometry from the papers of the Oxford group and applied a simple diffusion

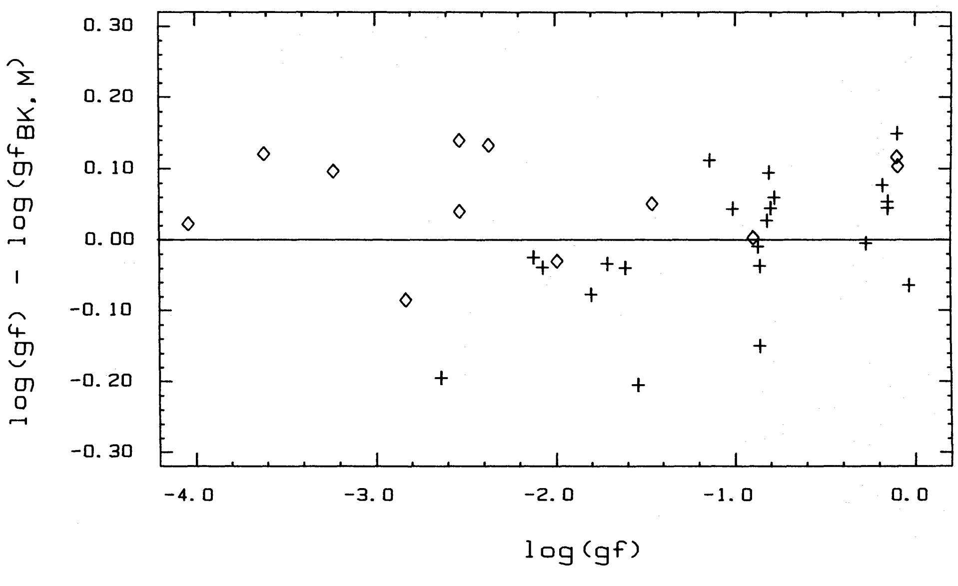


**Fig. 1.** Comparison of our $\log(gf)$ values with the data (+) of Bridges & Kornblith (1974) and the data (◇) of May et al. (1974) who have linked their *f*-values to the values of Bridges & Kornblith. For both sets the scatter is $\sigma = 0.02$ dex. The mutual deviations are characterized by $\Delta(+) = 0.005$ dex and $\Delta(\diamond) = 0.055$ dex

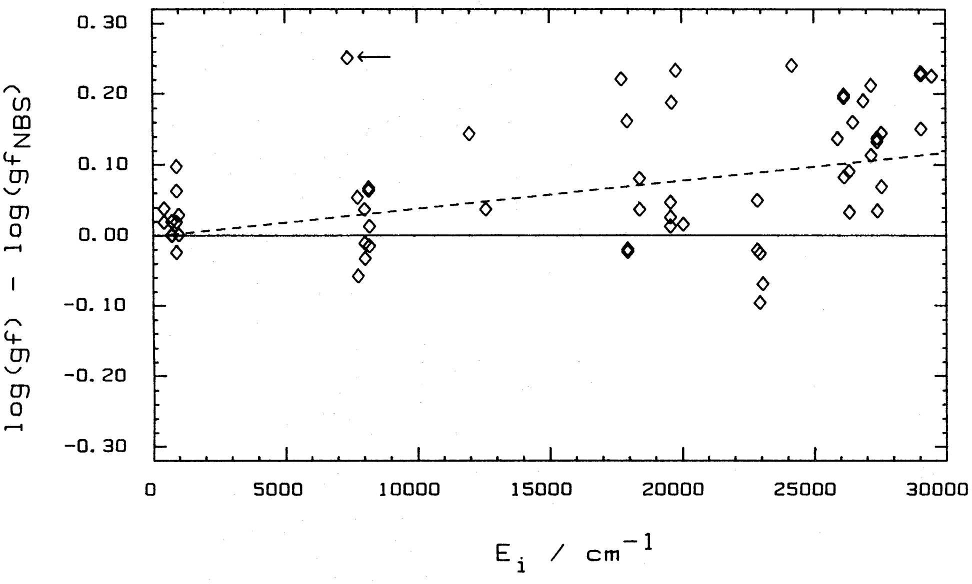


**Fig. 2.** Comparison of our log $(gf)$ values with the data compiled by Fuhr et al. (1988). The difference is shown versus the energy of the lower states of the line transitions. The dashed line has been obtained by a linear regression. The point marked by an arrow refers to the line 358.57 nm which is possibly blended in our laboratory spectra (see also Fig. 3)

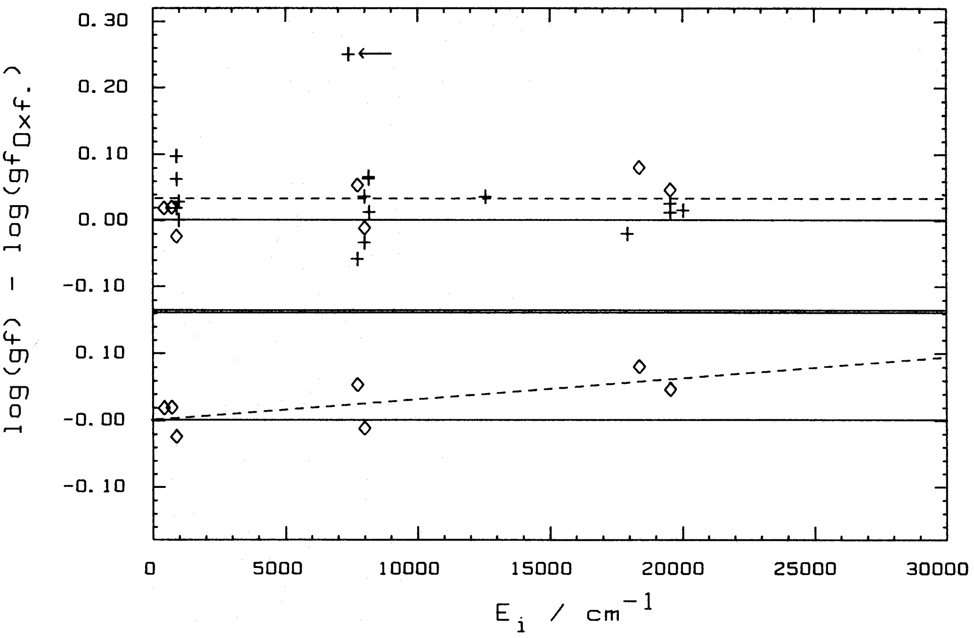


**Fig. 3.** Comparison of our log $(gf)$ values with the data of the Oxford group (Blackwell et al. 1970, 1972, 1979a, b, 1980, 1982). For both frames the difference is shown versus the energy of the lower states of the line transitions. In the upper frame all lines in common are compared and the lines from the $z^2P_2^0$ – level are marked thus: ◇. The data point marked by an arrow belongs to the same line 358.57 nm as in Fig. 2. The dashed line gives the mean difference between both sets ($\Delta = 0.034$). In the lower frame a comparison is made only with lines having the $z^3P_2^0$ – level in common. There is nearly the same energy dependence as in Fig. 2

model (Chen 1974). We then found a cosine-like decrease of the axial density instead of an exponential relationship used by the Oxford group. The resulting dependence of the $f$-values on the excitation potential of the lines readily matches the data in Figs. 2 and 3, as well as the result given by Kock et al. (1984). For the 2.7 eV lines, e.g., this would mean a 12% correction in the $f$-values of the Oxford group and hence a reduction in their solar iron abundance by 0.05 dex. That is still within our mutual scatter but clearly not sufficient to explain the 50% discrepancy.

It should be mentioned, that a deviation from LTE in the Oxford oven as well as a slightly different interpretation of the experimental vapour pressure data would also give contributions in the "right direction", namely larger $f$-values for lines with higher excitation potential. On the other hand, the $f$-values of our weak lines would be too large and hence the solar abundance too small, if we should have underestimated self-absorption in our strong lines.

## 5. Conclusion

By combining branching fraction measurements with reliable lifetime data we present a set of 114 Fe I $f$-values. More than 20 of the measured lines are well suited for a solar iron abundance study.

The agreement with the data of other authors is within the mutual limits of uncertainty. Although the agreement with the data of the Oxford group is by far the best we cannot rule out a possible small systematic error, depending on the excitation potential of the lines, which we trace back to axial diffusion of iron atoms in the Oxford oven. The large discrepancy of 50% in the solar iron abundance as published recently, however, can be explained in part by this possible error source. We conclude that at present a full solution for the discrepancy is still pending.

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