Astron. Astrophys. 64, 111—113 (1978)

ASTRONOMY AND ASTROPHYSICS

Oscillator Strengths of Ti I from Hook and Emission Measurements

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Received September 15, 1977

Summary. By a combination of hook and emission measurements it is possible to determine a large set of relative oscillator strengths of Ti I lines without any assumption concerning the plasma state. As plasma light sources, modified cascaded arcs have been used for both hook and emission measurements. The relative *f*-values have been converted to an absolute scale by means of literature data. The overall uncertainties of the *f*-values are within 13–33%. Comparisons with other experimental data are made indicating excellent to fair agreement.

Key words: oscillator strengths — Ti I — arc

1. Introduction

A frequently used method to obtain large sets of atomic oscillator strengths from lines of considerably different excitation potentials is that based upon emission spectroscopy on suitable plasma light sources like cascaded arcs.

However, the necessary LTE assumption in conjunction with a temperature determination complicates the application of the method and the measured *f*-values are possibly affected with the common uncertainty whether LTE was sufficiently attained in the particular experiment.

If one restricts emission measurements to lines with the same upper level, or if one applies the hook technique or absorption spectroscopy to lines with the same lower level, no assumption on the plasma state is required. But then only a multiple number of independent small sets of relative *f*-values can be determined which still need to be linked.

As firstly pointed out by Ladenburg (1933) it is possible to combine emission measurements of lines from a common upper level with hook or absorption measurements of lines from a common lower level, if both sets have one transition in common. In the present paper we will demonstrate the feasibility of this method to get a large set of Ti I *f*-values without any assumption on the state of the plasma used.

2. Experimental Procedure

We have used cascaded arcs for both the hook and emission measurements. The set-up and the procedure of our hook experiment have been described in detail by Kock and Kühne (1977). 24 relative *f*-values of Ti I resonance lines have been determined and have been normalized by means of absolute data given by Bell et al. (1975).

The emission measurements have been performed with a three-chamber-arc especially designed to excite metallic components in an argon plasma. The technique is well-known and is described, e.g., by Bell et al. (1965), Kock and Richter (1968), Garz and Kock (1969), Bridges and Wiese (1970).

Since no LTE plasma is required we have used an arc with a bore of 16 mm, which allows the generation of a plasma at lower temperatures and electron densities. Thus one obtains better conditions for the excitation of the neutral titanium atoms. The arc length was limited to 120 mm by a ring anode and three tapered cathodes, all made of tungsten. The arc has been operated in argon at atmospheric pressure and at a current of 30 A, supplied by a dc-generator, 480 V/120 A.

The continuous mixing of a fixed proportion of titanium chloride vapour with the carrier gas, argon, was achieved by passing carefully dried argon over a surface of liquid $TiCl_4$, which could be kept at a fixed temperature. Thus, it was possible to measure line intensities photoelectrically for a period of several hours.

Only relative intensities of lines from the same upper level have been measured using a carbon arc for intensity calibration. The spectral lines of interest were checked to be free from self-absorption by estimating the maximum optical thickness in the following manner. Since the line half widths were of the order of that of the apparatus

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profile, we assumed the Doppler effect as the only significantly broadening mechanism. Then an upper limit of the optical depth is given by the relationship

$$\tau_{max} \leqq I/(\sqrt{\pi}\Delta\lambda_D B),$$

where I is the integrated line intensity, B the Kirchhoff-Planck-function and $\Delta\lambda_D$ the calculated Doppler half width of the line under investigation. For the calculation of $\Delta\lambda_D$ a rough temperature determination was carried out from Ar I and Ti I line intensities yielding temperatures of 8000–8500 K in the arc axis.

3. Results and Discussion

Starting from the 24 hooked resonance lines we have determined 11 sets of relative f-values with a total of 33 additional lines in the wavelength range from 3900 to 7900 Å. They are normalized by using the f-values of the resonance lines, because in each set one of these lines is included.

The total set comprising 57 lines is listed in Table 1. The accuracies are estimated to within 13–33% considering the statistical uncertainties of the emission measurements (standard deviation of the mean, evaluated from five independent runs) and the errors in the f-values of the resonance lines (Kock and Kühne, 1977).

We have compared the method of measuring f-values as described in this paper with that requiring an LTE plasma. For this reason we used a three-chamber-arc with a bore of 5 mm. At a current of 70 A we determined an electron temperature of 12 000 K in the arc axis, and the electron density was $8 \cdot 10^{16}$ cm^{-3}. Under the assumption that a Boltzmann distribution holds for all energy levels we determined relative f-values normalized by using the absolute data of Bell et al. (1975). The comparison is shown in Figure 1. No systematic deviation is detectable and the statistical spread is less than 0.05 dex. The excellent agreement is—in our opinion—a corroboration of both methods of measurement.

For a comparison with literature data we will restrict ourselves only to two papers. Klemt (1973) has performed

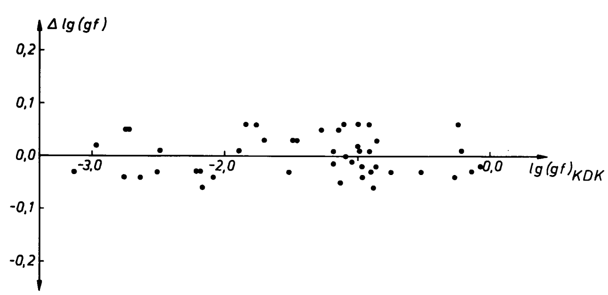

Fig. 1. The difference $\Delta \log (gf)$ between our data measured under LTE assumption and those from Table 1. The abscissa is our measurement from Table 1 (KDK)

Table 1. Absolute f-Values for Ti I

Wavelength [Å]	Mult. No.	Transition	log (gf)	Error [%]
3 635.46	19	a^3F_2–$y^3G^0_3$	0.00	18
3 642.68	19	a^3F_3–$y^3G^0_4$	0.11	30
3 653.50	19	a^3F_4–$y^3G^0_5$	0.22	16
3 671.67	19	a^3F_4–$y^3G^0_4$	−1.07	23
3 689.91	18	a^3F_4–$x^3D^0_3$	−1.16	30
3 729.81	17	a^3F_2–$x^3F^0_2$	−0.39	24
3 741.06	17	a^3F_3–$x^3F^0_3$	−0.22	18
3 752.86	17	a^3F_4–$x^3F^0_4$	0.03	13
3 771.66	17	a^3F_4–$x^3F^0_3$	−0.99	22
3 898.49	13	a^3F_2–$y^3D^0_3$	−2.18	31
3 921.42	14	a^3F_2–$z^3P^0_2$	−1.49	30
3 924.53	13	a^3F_3–$y^3D^0_3$	−0.90	29
3 929.88	13	a^3F_2–$y^3D^0_2$	−0.99	27
3 947.78	14	a^3F_3–$z^3P^0_2$	−0.85	30
3 956.34	13	a^3F_3–$y^3D^0_2$	−0.44	27
3 958.21	13	a^3F_4–$y^3D^0_3$	−0.14	29
3 962.85	12	a^3F_2–$y^3F^0_3$	−1.18	21
3 964.27	12	a^3F_3–$y^3F^0_4$	−1.18	23
3 981.76	12	a^3F_2–$y^3F^0_2$	−0.27	20
3 989.76	12	a^3F_3–$y^3F^0_3$	−0.22	20
3 998.64	12	a^3F_4–$y^3F^0_4$	−0.07	13
4 008.93	12	a^3F_3–$y^3F^0_2$	−0.96	22
4 024.57	12	a^3F_4–$y^3F^0_3$	−0.91	24
4 112.71	9	a^3F_4–$z^1G^0_4$	−1.58	14
4 656.47	6	a^3F_2–$z^3G^0_3$	−1.27	25
4 667.49	6	a^3F_3–$z^3G^0_4$	−1.14	30
4 681.91	6	a^3F_4–$z^3G^0_5$	−1.00	24
4 693.68	6	a^3F_3–$z^3G^0_3$	−2.75	28
4 715.30	6	a^3F_4–$z^3G^0_4$	−2.75	33
5 009.65	5	a^3F_3–$z^3D^0_3$	−2.17	20
5 064.66	5	a^3F_4–$z^3D^0_3$	−0.88	16
5 173.74	4	a^3F_2–$z^3F^0_2$	−1.09	28
5 192.98	4	a^3F_3–$z^3F^0_3$	−1.04	26
5 210.39	4	a^3F_4–$z^3F^0_4$	−0.86	26
5 361.72	35	a^5F_4–$y^3F^0_4$	−2.97	20
5 366.65	35	a^5F_2–$y^3F^0_3$	−2.49	26
5 389.18	35	a^5F_1–$y^3F^0_2$	−2.09	25
5 401.32	35	a^5F_2–$y^3F^0_2$	−2.76	26
5 436.70	51	a^1D_2–$y^3D^0_3$	−2.51	31
5 866.45	72	a^3P_2–$y^3D^0_3$	−0.75	30
5 880.27	71	a^3P_1–$z^3P^0_2$	−1.70	31
5 899.30	72	a^3P_1–$y^3D^0_2$	−1.10	28
5 918.55	71	a^3P_2–$z^3P^0_2$	−1.46	31
5 937.81	72	a^3P_2–$y^3D^0_2$	−1.84	29
7 084.26	99	b^3F_2–$y^3D^0_3$	−3.14	31
7 138.91	99	b^3F_3–$y^3D^0_3$	−1.51	28
7 188.55	99	b^3F_2–$y^3D^0_2$	−1.76	29
7 209.44	99	b^3F_4–$y^3D^0_3$	−0.52	30
7 244.86	99	b^3F_3–$y^3D^0_2$	−0.91	28
7 271.41	97	b^3F_3–$y^3F^0_4$	−2.21	19
7 299.67	97	b^3F_2–$y^3F^0_3$	−1.89	24
7 344.72	97	b^3F_4–$y^3F^0_4$	−0.97	17
7 357.74	97	b^3F_3–$y^3F^0_3$	−0.99	24
7 364.11	97	b^3F_2–$y^3F^0_2$	−1.13	23
7 423.17	97	b^3F_3–$y^3F^0_2$	−2.64	26
7 949.17		a^1G_4–$z^1G^0_4$	−1.26	17

an arc experiment under LTE conditions. The comparison is given in Figure 2. While good agreement in large f-values can be found, there is a strong deviation to

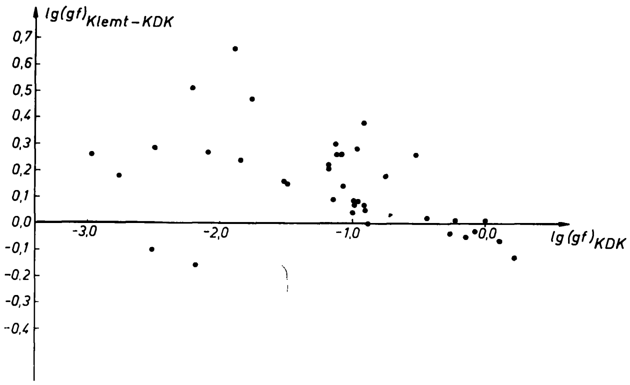

Fig. 2. A comparison of log (gf)-values measured by Klemt (1973) with our data (KDK)

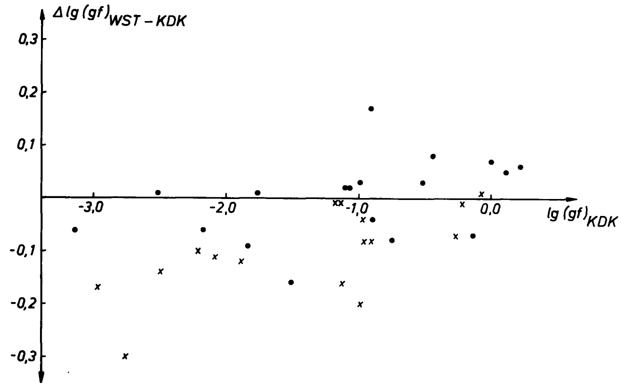

Fig. 3. A comparison of log (gf)-values measured by Whaling, Scalo, and Testerman (1977) (WST) with our data (KDK). The crosses belong to lines from levels $y^3F_{2,3,4}$.

smaller f-values. From our LTE emission measurements we found, that Klemt has determined the f-values of one of his reference lines, λ3962 Å, too high by 0.22 dex. That is supported by results of Whaling et al. (1977), who measured the intensity ratio of the two lines λ3989 Å and λ3962 Å (both starting from y^3F_3) to be 9.11. We found a ratio of 9.12. Klemt obtained a value of 5.6. A correction of the small log (gf)-values of Klemt by 0.22 dex eliminates the systematic deviation. In our opinion the residual large scatter is due to his photographic recording.

Whaling, Scalo, and Testerman (1977) measured branching ratios in a hollow cathode. The data have been converted to absolute scales by means of measured or calculated lifetimes. The comparison is shown in Figure 3. The agreement is much better than that with Klemt. The scatter is within the predicted uncertainties. The small systematic tendency to smaller f-values is—as we found—only related to the levels $y^3F_{2,3,4}$. The lines originating from these levels are marked by crosses (see Fig. 3).

An application of our data to astrophysics with further comparisons with other data is given in a paper by Gehlsen et al. (1977).

Acknowledgements. We gratefully acknowledge fruitful discussions with W. Bötticher and E. Schulz-Gulde.

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