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On the solar oscillator strength of SiH^+

Chetna Trivedi and K. Sinha

U. P. State Observatory, Manora Peak, Naini Tal 263 129, India

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Abstract. Rather contrasting values of the oscillator strengths for the (0,0) band of SiH^+ molecules for the A $^1\Pi$ - $X^1\Sigma^+$ transition have been reported in the literature. We investigate these with the help of a new set of solar photospheric models, abundances and molecular parameters. The results are found to be in agreement with the earlier solar studies. In view of the extremely weak nature of the SiH^+ features, it appears probable to scale up the solar oscillator strengths by a factor of 2.

Key words : oscillator strengths - photospheric spectrum - SiH^+

1. Introduction

The sun has been proved to be a good "laboratory" source for spectroscopic work on molecules (*cf.* Sinha 1991). There has been a continous effort to derive accurate data for the molecular species of astrophysical interest from the solar spectra (Grevesse and Sauval 1992; Sinha 1993; Sauval and Grevesse 1994). The oscillator strength is one of the important parameters whose accurate value is required for calculations in molecular as well as atomic spectroscopy.

SiH^+ was the first molecular ion to be detected and studied in solar photospheric spectra (Grevesse and Sauval 1970; abbreviated as GS). GS examined the presence of the (0,0), (0,1), (0,2), (1,0) and (1,1) bands of $A^1\Pi$ - $X^1\Sigma^+$ transition of the molecule. Finding the (0,0) and the (0,1) bands observable, they estimated the oscillator strengths to be $f_{00} = 5\times10^{-4}$ and $f_{01} = 4\times10^{-4}$ by fitting line profiles to features in the solar spectrum. Using the high frequency deflection (HFD) technique, investigations by Carlson et al. (1980) led to an identification of two more bands (2,0) and (3,0) in laboratory and the f_{00} value given by them was $(2.4 \pm 1)\times10^{-3}$, a factor of 5 higher than the solar estimate. Carlson et al. (1980) further state that the large discrepancy compared to the solar result is unexplained. Believing that the measured lifetimes involved in Carlson et al.'s (1980) investigations are not free from objections, Matos et al. (1988) used complete active space self consistent field (CASSCF) method and computed f_{00}=1.2 X 10^{-3}. They also remark that their result falls between the laboratory result of Carlson et al. (1980) and the value deduced from the solar spectrum by GS, indicating that both these experimental estimates are considerably affected by a variety of assumptions of uncertain validity.

The experiments performed by Hishikawa and Karawajczyk (1993) yield f_{00}=(1.4 ± 0.2) X10^{-3}. Further, Hishikawa and Karawajczyk (1993) state that their result is close to the theoretical result of Matos et al. (1988) and the discrepancy with Carlson et al.'s (1980) result is due to ambiguity in lifetime measurements by the latter authors. However, the possible causes for discrepancy with the solar estimate (GS) are not pointed out by them. This makes the laboratory investigations appear in conflict with the solar studies and the practice of deriving oscillator strengths from the solar spectrum might seem questionable. In view of this circumstance and the availability of better photospheric models than those availalble to GS, and reliable Si abundance, we attempt here a re-examination of the oscillator strengths for the (0,0) and the (0,1) bands of SiH^+ derived from the solar spectrum.

2. Method of calculation

The photospheric models by Holweger and Müller (1974; abbreviated as HM) and Maltby et al. (1986; abbreviated as MACKKL) were used to compute the ratio of equivalent width (EW) to the oscillator strength for the lines of the (0,0) and (0,1) bands. Dividing the observed photospheric equivalent width of these lines by the corresponding ratio yields average values of f_{00} and f_{01}. The SiH^+ lines used by GS in this investigation are chosen by us along with their equivalent widths for the present study.

We have used the standard procedure for EW calculations of weak lines (Sotoriovski 1971) under the assumption of LTE for the model based calculation of EW/$f_{v'v''}$. Saturation effects, though very small, were taken into account and lines were assumed to be Doppler broadened. The Si abundance. based on an analysis of a large number of atomic lines, was taken to be 7.63 (Lambert and Luck 1978) for both the models and the dissociation energy was taken as 3.17 eV (Huber and Herzberg 1979). To evaluate the atomic partition functions, the coefficients given by Sauval and Tatum (1984). The opacity sources listed by Tsuji (1966) were included in opacity calculations.

3. Results and discussions

Oscillator strengths for every line, obtained in the present study are given in Table 1 for the MACKKL and HM models along with the average values for the (0,0) and the (0,1) bands. We find that our values of oscillator strengths i.e. f_{00}= (6.3±1.7) X10^{-4}, f_{01}= (4.2±1.5) X 10^{-4} for the MACKKL model and f_{00} = (6.7±1.8)X10^{-4}, f_{01}= (4.4 ± 1.6) X 10^{-4} for the HM model are in agreement with the solar estimate i.e., f_{00}= 5 X 10^{-4} and f_{01} = 4 X 10^{-4} given by GS. Utilizing different models, GS have shown that their results for oscillator strengths are model independent. This too is in conformity with our results presented in Table 1. Further, utilizing the same values of abundance and dissociation energy as used by GS i.e. N(Si) = 7.55 and D_0^0 = 3.20 eV, we get f_{00}=(7.0 ± 2) X 10^{-4}, f_{01} = (4.7 ± 2) X 10^{-4} for the MACKKL model and

f_{00} = (7.4 ± 2) X 10^{-4}, f_{01}=(5.0±2) X 10^{-4} for the HM model. If we use D_0^0 =3.30 eV from matos et al. (1988) and N(Si)=7.63, the derived results are f_{00}=(4.8±1)X10^{-4} and f_{01}=(3.2±1)X10^{-4} for the MACKKL model and f_{00}= (5.1±1)X10^{-4} and f_{01}=(3.4±1) X 10^{-4} for the HM model. This pair of D_0^0 and N(Si) gives the lower limit on f_{00} and f_{01}. Thus, within the uncertainty limits, our results appear independent of the choice of Silicon abundance and the choice of dissociation energy.

Table 1. Derived oscillator strengths (X 10^4) for the (0,0) and the (0,1) bands of SiH^+.

Line	λ	$EW_{(obs)}$	Present study	
	(Å)	(mÅ)	MACKKL	HM
(0,0) band				
P (6)	4024.209	0.7	5.63	6.01
P (11)	4079.046	1.0	4.79	5.10
Q (3)	4000.706	1.1	6.02	6.43
Q (4)	4004.659	1.8	7.82	8.34
Q (7)	4022.946	1.5	4.23	4.51
Q (9)	4041.005	3.5	8.36	8.91
Q (13)	4094.114	2.0	4.01	4.27
R (6)	4005.921	1.5	7.63	8.14
R (7)	4011.841	1.7	7.91	8.43
Average value of oscillator strengths			f_{00}=6.3±1.7	f_{00}=6.7±1.8
(0,1) band				
P (8)	4412.536	0.6	5.80	6.13
P (12)	4470.770	0.8	5.73	6.05
Q (8)	4399.321	0.8	3.23	3.42
Q (12)	4452.138	0.6	1.93	2.04
Q (14)	4489.532	1.2	3.67	3.87
R (3)	4358.337	0.4	4.86	5.14
Average value of oscillator strengths			f_{01}=4.2±1.5	f_{01}= 4.4±1.6

Larsson (1987, personal communication), one of the authors in the paper by Carlson et al. (1980), calculated the electronic transition moment function for the $A\,^1\Pi - X\,^1\Sigma^+/e$ transition of SiH^+ and found f_{00}=(1.186) x 10^{-3}. He also states that the oscillator strength derived in Carlson et al. (1980) is unreliable due to a breakdown of the r-centroid approximation. These calculations have not been published. Also, his calculations indicate that D_0^0 (SiH^+) should be increased to at least 3.26 eV.

An examination of the solar SiH^+ features in the Liège atlas (Delbouille, Roland and Neven 1973) shows that (i) the features are extremely weak, (ii) most of them fall on the wings of some other strong lines and (iii) they are not sharp peaked (*cf.* Figs. 1, 2 and 3 and section

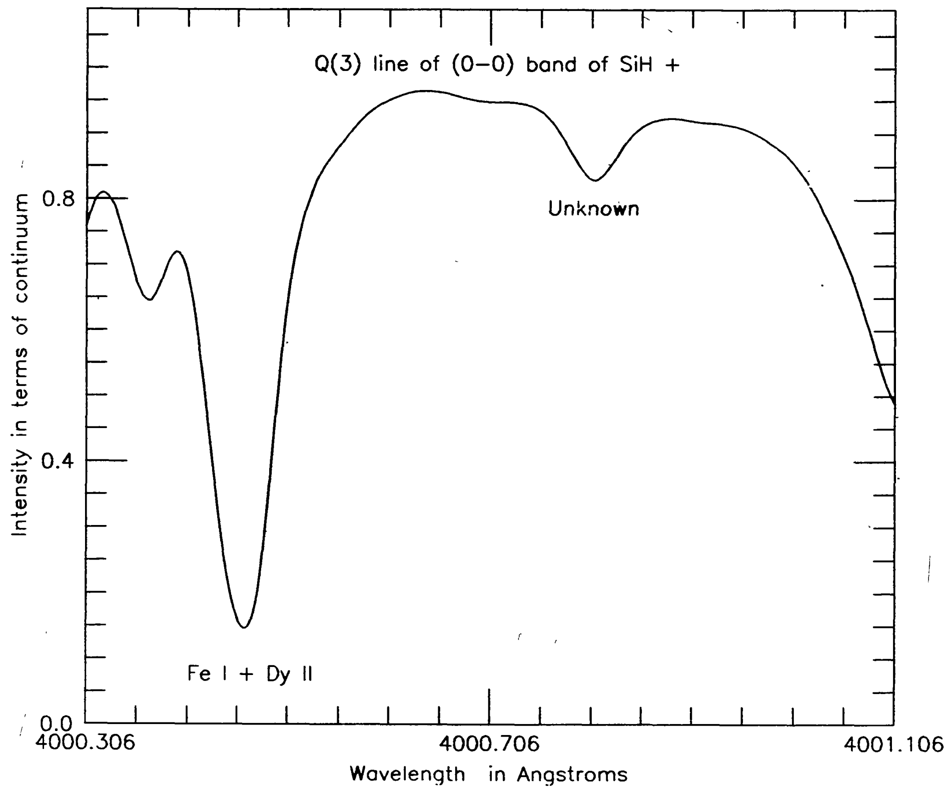

Figure 1. Solar photospheric spectrum around 4000.706 Å taken from the Liège atlas.

4 in GS on identifications and Fig. 1 in the present paper). Consequently, a judicious fixation of the continuum is difficult and we suspect that EW measurements by GS are systematically underestimated. Thus, the oscillator strengths derived from such EWs are also underestimated.

In view of the mutually consistent new results on the oscillator strengths of the (0,0) band of the $A^1\Pi$-$X^1\Sigma^+$ transition of SiH^+ i.e., $f_{00}=1.186 \times 10^{-3}$ (Larsson, 1987 personal communication), $f_{00}=1.2 \times 10^{-3}$ (Matos et al. 1988) and $f_{00}=(1.4 \pm 0.2) \times 10^{-3}$ (Hishikawa and Karawajczyk 1993) and the successes in deriving molecular parameters from the solar spectrum (Sinha 1993; Sauval and Grevesse 1994), it seems reasonable to suggest that in the light of uncertain solar EWs, the GS oscillator strengths and those obtained here by us from the solar spectrum should be scaled up by a factor of 2. This suggestion is supported by the following comment from GS:

"On the basis of the uncertainties of the physical conditions in the solar photosphere, of the possible error upon the physical data and *upon the observations*, we estimate that our results (on oscillator strengths) could be in error by a factor of 2."

4. Conclusions

From the above discussion, we are of the opinion that the solar spectrum can still be used to derive the oscillator strengths and the discrepancy in the case of SiH^+ should be due to the extremely weak nature of these lines in the photospheric spectrum and the associated uncertainties in fitting line profiles to such weak features.

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