Serb. Astron. J. № 179 (2009), 95 - 99 **UDC 523.982.2–335.7**
DOI: 10.2298/SAJ0979095S Preliminary report

ON THE EFFECTIVE TEMPERATURE OF SUNSPOT UMBRAE USING BERYLLIUM HYDRIDE ISOTOPOMER LINES

R. Sangeetha[1], P. Sriramachandran[1], S. P. Bagare[2], N. Rajamanickam[1] and R. Shanmugavel[1*]

[1] *Physics Research Centre, V.H.N.S.N College, Virudhunagar - 626 001*

[*] E–mail: *rsvel67@gmail.com*

[2] *Indian Institute of Astrophysics, Kodaikanal & Bangalore - 560 034*

(Received: March 31, 2009; Accepted: July 8, 2009)

SUMMARY: A search for fourteen bands of the visible and infrared systems of the beryllium hydride isotopomers, in addition to the previously identified bands A - X(0, 0; 1, 1; 2, 2) for BeH, A - X(0, 0; 1, 1; 2, 2) for BeD and A - X(0, 0; 1, 1; 2, 2) for BeT molecules was conducted. The equivalent widths were measured for the well isolated identified lines of the strongest band and the effective temperatures were estimated for the systems for which the presence of hints is confirmed.

Key words. Sunspots – Line: identification

1. INTRODUCTION

For the fact that hydrogen is so much more abundant than any other element, diatomic hydride molecules of the general form XH are usually the first species synthesized in interstellar chemical networks (Brewster et al. 2001). Several diatomic hydrides have been identified via their electronic transitions at optical wavelengths (e.g. NH; Meyer and Roth 1991), but many have escaped observation because they are light molecules and their rotational transitions lie in the sub-millimeter and infrared regions.

The beryllium isotopomer lines of some selected bands have previously been identified in visible and infrared region of the spectra of sunspot umbra (Shanmugavel et al. 2008). A rich collection of twenty two bands of the visible and infrared systems by Olsson (1932) for BeH, Focsa et al. (1998) for BeD and DeGreef and Colin (1974) for BeT, now allow for quantitative identification of all the remaining bands and estimation of effective temperatures to be studied in more detail.

The molecular lines are extremely temperature sensitive; they can be used to probe the thermal and magnetic structure of the coolest parts of sunspots at field strengths of 2 - 3.5 KG (Berdyugina et al 2003). A large number of molecules have been identified and effective temperatures reported. For AlF, the lower limit of effective temperature has been reported as 1240 K (Bagare et al. 2006). A mean value $\sim$ 4000 K was given by Shanmugavel et al. (2008) for beryllium hydride isotopomers. Sriramachandran et al. (2008) have also reported that the estimated effective temperatures lie within the range of 1240 K to 4000 K for the metal oxides like LaO, ScO and VO.

[1*] To whom all the correspondence is to be addressed.

The significant values of transition probabilities reported by Shanmugavel et al. (2008), the availability of reliable molecular data, and the access to FTS umbral spectra with high resolution and high S/N ratio, prompted us to take up an extensive search for the presence of further rotational lines of beryllium hydride isotopomers. This led to confirmation of the presence of all the transitions searched for. From the confirmed transitions for a selected set, equivalent widths have been measured for well resolved lines, and thereby the effective temperature of the source has been estimated. But for others, the well resolved lines are very rare; these transitions were not adopted for evaluation of effective temperature.

2. OBSERVATION AND METHODOLOGY

The sunspot umbral spectrum was taken during March 1981, and published by Wallace et al. (1998) for the red region, and by Wallace et al. (2000) for the infrared region. These are rich sources of many identified as well as unidentified molecular lines. Studies of various sunspot spectra show that there is no unique spectrum which represents all sunspot umbrae. In fact, umbrae in sunspots of large size are found to be cooler than smaller ones, and the temperature is found to vary with position within a given umbra (Wallace and Hinkle, 2001). The general procedure adopted is similar to that followed by us earlier (Shanmugavel et al. 2008, Bagare et al. 2006).

The rotational analyses of five A - X bands of the BeH and nine A - X bands of the BeD were used. Following the method of coincidences described in detail in Shanmugavel et al. (2008), a total of 1349 lines of the isotopomers were carefully searched, detailed, classified and tabulated.

From the lines classified as present, well resolved and isolated lines were selected for measurements to calculate the equivalent width using the triangular profile approximation method as described in Shanmugavel et al.(2008). The effective rotational temperature of the source was evaluated for bands which have a significant number of lines whose equivalent widths were calculated. The equivalent width of molecular lines in a rotational band depends on the rotational quantum number and the temperature. A list of the strongest beryllium hydride isotopomer lines and their measured equivalent widths is given in the tables.

Even the strongest beryllium hydride isotopomer lines in the sunspot umbral spectrum are fairly weak so they are assumed to lie on the straight line portion of the curve of growth. The effective temperature was determined using the method described in Herzberg (1950), that is by plotting for each line log(W/J) against J(J+1) and using the method of least squares to obtain the slope of the resulting straight line. This slope is found to be equal to $0.625B_v/T$ (Schadee 1964), where B_v is the rotational constant and T is the effective temperature. The rotational constants of beryllium hydride isotopomers were taken from Shanmugavel et al. (2008). The values of effective temperature were estimated only for the strongest bands and tabulated. Few bands were left out because of the lack of strong enough and well resolved lines.

Table 1. Parameters to evaluate the presence of BeH isotopomers

Molecule	Band	W.No. range(cm^{-1})	C-index	I-parameter[a]	B_v	T (K)
BeH	(0-1)	17848.07-19734.83	9	41(82)		1869± 51
(A - X)	(2-3)	17848.07-19734.83	7	31(64)		1644± 43
	(3-4)	18138.18-18745.94	5	20(37)	10.457	2110± 164
	(4-4)	19694.32-20429.46	7	18(35)		3928± 376
	(5-5)	19720.34-20351.15	8	16(26)		1211± 45
BeD	(0-1)	18409.16-18950.22	8	23(57)		1540± 219
(A - X)	(1-2)	18468.46-18977.77	13	32(70)		1610± 101
	(2-3)	18523.88-18953.01	15	26(63)		1968± 78
	(3-4)	18579.14-18977.77	11	24(58)		3221± 365
	(4-5)	18624.67-18971.07	10	20(58)	5.761	1771± 134
	(5-6)	18671.40-18980.00	9	19(41)		1107± 116
	(4-4)	19779.01-20437.80	22	44(94)		1865± 94
	(5-5)	19802.21-20385.97	19	32(62)		1540± 71
	(6-6)	19843.94-20282.70	11	17(46)		2084± 196

[a]Total number of lines searched for is given in parentheses.

Notes:
In all the Tables,
W.No. - Wavenumber (cm^{-1});
Tol - Tolerance;
Rem - Remark;
p - present;
s - shoulder;
m - merge;
W - Equivalent Width (mÅ).

3. RESULTS AND DISCUSSION

The number of present lines and number of merged lines are tabulated in Table 1. It is evident that in all the molecular bands, the number of lines identified as present is nearly 50% of the lines searched for. Also, Shanmugavel et al. (2008), have previously reported that eleven molecular bands of beryllium hydride isotopomer lines were present in the sunspot umbral spectrum. In the present study of the 812 laboratory lines, 359 lines were found present, and most of the missing lines were accounted as merged with nearby strong atomic and other molecular lines due to MgH, FeH, CaH and TiO. It can, therefore, be stated without doubt that these additional beryllium hydride isotopomer lines are present in the observed umbral spectrum.

For the bands identified as present, those that are clearly resolved and have an absorption intensity of at least one-tenth the maximum of the scale, were selected for the measurements to calculate equivalent widths. A significant number of lines met the requirement in the case of A - X (0,1; 2, 3; 3, 4; 4, 4; 5, 5) of BeH, and A - X (4, 4; 5, 5; 6, 6; 0, 1; 1, 2; 2, 3; 3, 4; 4, 5; 5, 6) of BeD. The method of triangular profile approximation was used to calculate equivalent widths. A list of these values is presented in Tables 2 to 15.[2] These band lines were fitted by using the least squares method to obtain the slope of the resulting straight line. A few sample plots are shown in Figs. 1 to 5 for A - X(0, 1; 2, 3; 5, 5) of BeH and A - X(4, 4; 5, 5) of BeD, respectively. The values of effective temperature were estimated for the respective bands and are given in Table 1.

It was pointed out that there is no unique value of effective temperature for sunspot umbrae. The lowest reported value of the rotational temperature is 1240 K for the molecule AlF (Bagare et al. 2006). A temperature value of 4228 K was estimated for BeH by Shanmugavel et al. (2008) using the best lines. The average value of T for FeH is about 1740 K (Mulchaey 1989). In the present study, it is evident that the calculated effective temperatures of beryllium hydride isotopomer bands lie well inside the already reported range of temperatures. Hence, the presence of BeH lines in sunspot umbral spectra offers the possibility to study the different layers in the umbral atmosphere.

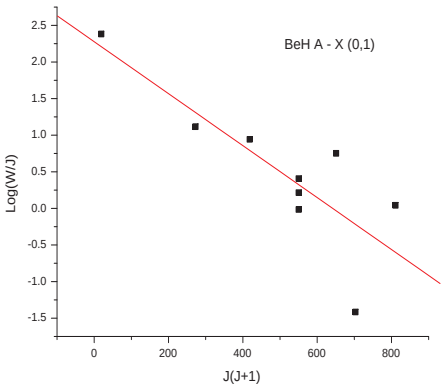

Fig. 1. *Plot of log(W/J) vs J(J+1) for BeH A - X (0, 1) band.*

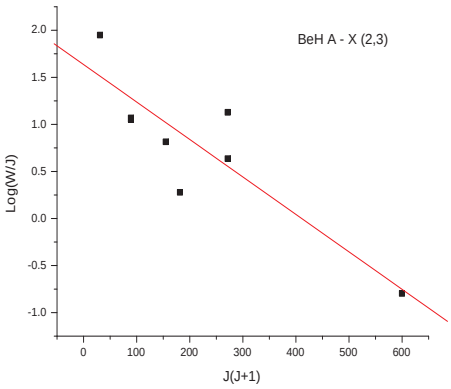

Fig. 2. *Plot of log(W/J) vs J(J+1) for BeH A - X (2, 3) band.*

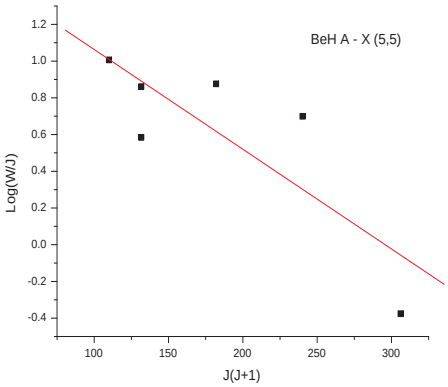

Fig. 3. *Plot of log(W/J) vs J(J+1) for BeH A - X (5,5) band.*

[2]Tables are available at `http://saj.matf.bg.ac.rs/179/pdf/tables.pdf`

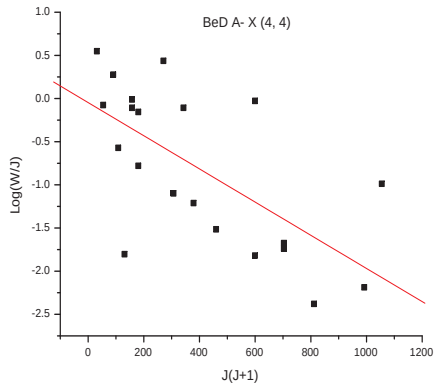

Fig. 4. *Plot of log(W/J) vs J(J+1)for BeD A - X (4, 4) band.*

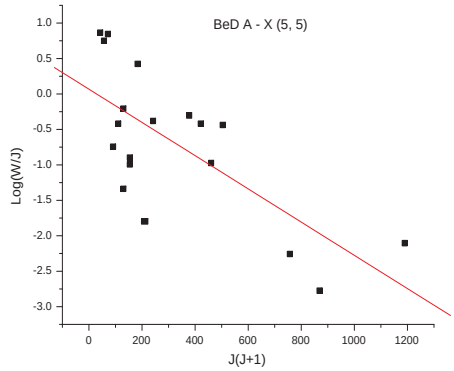

Fig. 5. *Plot of log(W/J) vs J(J+1)for BeD A - X (5, 5) band.*

Acknowledgements – The sunspot spectra used in this study are taken from the technical reports, and from the site ftp://nsokp.nso.edu/pub/atlas, of the National Solar Observatory, operated by the Association of Universities for Research in Astronomy, Inc. (AURA), under cooperative agreement with the National Science Foundation.

REFERENCES

Bagare, S. P., Balachandra Kumar, K. and Rajamanickam, N.: 2006, *Sol. Phys.*, **234**, 1.
Berdyugina, S. V., Berdyugina, S. V., Solanki, S. K. and Frutiger, C.: 2003, *Astron. Astrophys.*, **412**, 513.
Brewster, M. A., Ziurys, L. W.: 2001, *Astrophys. J.*, **559**, 1190.
De Greef, D. and Colin, R.: 1974, *J. Mol. Spectrosc.*, **53**, 455.
Focsa, C., Bernath, P. F., Mitzner, R. and Colin.: 1998, *J. Mol. Spectrosc.*, **192**, 348.
Herzberg, G.: 1950, Molecular Spectra and Molecular Structures. D. Van Nostrand Company, New York.
Meyer, D. M. and Roth, K.: 1991, *Astrophys. J.*, **376**, L49.
Mulchaey, J. S.: 1989, *Publ. Astron. Soc. Pacific*, **101**, 211.
Olsson, V. E.: 1932, *Zeitschrift fur Physik*, **73**, 732.
Schadee, A.: 1964, *B. A. N.*, **17(5)**, 311.
Shanmugavel, R., Bagare, S. P., Rajamanickam, N., and Balachandra Kumar, K.: 2008, *Serb. Astron. J.*, **176**, 51.
Sriramachandran, P., Bagare, S. P., Rajamanickam, N., and Balachandrakumar, K.: 2008, *Sol. Phys.*, **252**, 267.
Wallace, L. and Hinkle, K.: 2001, *Astrophys. J.*, **559**, 424.
Wallace, L., Hinkle, K., and Livingston, W.: 2000, An Atlas of Sunspots Umbral spectra in the visible from 15,000 to 25,000 cm^{-1}(3920 to 6664 Å), Tech.Rep.00-001, National Solar Observatory, Tuscon, AZ.
Wallace, L., Livingston, W. C., Bernath, P. F., Ram, R. S.: 1998, An Atlas of the Sunspot Umbral Spectrum in the Red and Infrared from 8900 to 15 050 cm^{-1} (6642 to 11230 Å), Tech. Rep. 98-001 Solar Observatory, Tucson, AZ.

О ЕФЕКТИВНОЈ ТЕМПЕРАТУРИ ЈЕЗГРА СУНЧЕВЕ ПЕГЕ УПОТРЕБОМ ЛИНИЈА ИЗОТОПОМЕРА БЕРИЛИЈУМ ХИДРИДА

R. Sangeetha[1], P. Sriramachandran[1], S. P. Bagare[2], N. Rajamanickam[1] and R. Shanmugavel[1*]

[1] *Physics Research Centre, V.H.N.S.N College, Virudhunagar - 626 001*

[*] E–mail: *rsvel67@gmail.com*

[2] *Indian Institute of Astrophysics, Kodaikanal & Bangalore - 560 034*

УДК 523.982.2–335.7
Претходно саопштење

Поред већ раније идентификованих трака A-X(0,0; 1,1; 2,2) за BeH, A-X(0,0; 1,1, 2,2) за BeD и A-X(0,0; 1,1; 2,2) за BeT, вршена су истраживања изотопомера берилијум хидрида у видљивом и инфрацрвеном делу спектра у још четрнаест система молекулских трака. Мерене су еквивалентне ширине за поуздано идентификоване и изоловане линије у јачим тракама и процењене су температуре за системе чија је присутност потврђена.