Notes to the Solar Spectrum Ledger (See § 2.8)

Note Number

Designations for molecular lines in the solar spectrum; notes 1, 2, 3, 4, 6:

	Spectrum	Electronic Transition	Vibration Band	Spectral Range (Å)	References for Analysis
1	OH	$A^2\Sigma^+ - X^2\Pi$	0, 0 1, 1 2, 2	3021 to 3362 3109 to 3378 3184 to 3375	G. H. Dieke and H. M. Crosswhite, The Johns Hopkins University Bumblebee Series Report No. 87, 118 pp. (1948). See also C. E. Moore and H. P. Broida, J. Research Nat. Bur. Std. **63A,** 279 to 295 (1959).
2	CH	$C^2\Sigma^+ - X^2\Pi$	0, 0 1, 1	3086 to 3219 3119 to 3222	T. Heimer, Zeit. Phys. **78,** 771 to 780 (1932). See, also, C.E. Moore and H. P. Broida, J. Research Nat. Bur. Std. **63A,** 19 to 53 (1959).
3	CH	$B^2\Sigma^- - X^2\Pi$	0, 0 1, 0 1, 1	3871 to 4084 3627 to 3710 4025 to 4119	L. Gerö, Zeit. Phys. **118,** 27 to 36 (1941). See also, C. E. Moore and H. P. Broida, Ref. in Note 2.
4	CH	$A^2\Delta - X^2\Pi$	0, 0 1, 1 2, 2	4133 to 4413 4185 to 4446 4238 to 4468	L. Gerö, Zeit. Phys. **118,** 27 to 36 (1941).
			0, 1	4726 to 4941	N. H. Kiess and H. P. Broida, Astroph. J. **123,** 166 to 171 (1956). See also, C. E. Moore and H. P. Broida, Ref. in Note 2.

5 Wavelength measurement by J. L. Greenstein and E. Tanbderg-Hanssen, Astroph. J. **119,** 113 to 119 (1954):

Be II 3130.414 Å; 3131.058 Å.
Be I 3321.043 Å; 3321.252 Å.
3321.430 Å.

	Spectrum	Electronic Transition	Vibration Band	Spectral Range (Å)	References for Analysis
6	NH	$A^3\Pi_i - X^3\Sigma^-$	0, 0 1, 1	3280 to 3487 3307 to 3485	R. N. Dixon, Canadian J. Phys. **37,** 1171 to 1186 (1959). G. W. Funke, Zeit. Phys. **96,** 787 to 798 (1935). G. W. Funke, Zeit. Phys. **101,** 104 to 112 (1936). A. Fowler and C. C. L. Gregory, Phil. Trans. Roy. Soc. London [A] **218,** 351 to 372 (1919).

7 Lines recorded in Rowland's Table as double, but not resolved in Atlas. For lines short of 4000 Å the adopted wavelength is a mean of the Rowland lines weighted according to the estimated Rowland intensity. To longer waves, additional measurements are included in the adopted values.

Some of these lines are probably single but broadened by hyperfine structure or isotope effect. cf A. Abt, Astroph. J. **115,** 199 to 205 (1952).

λ Recorded Pair (Å)	λ Adopted (Å)	λ Recorded Pair (Å)	λ Adopted (Å)	λ Recorded Pair (Å)	λ Adopted (Å)	λ Recorded Pair (Å)	λ Adopted (Å)
3310. 913r 3310. 923r	3310. 918	3413. 465r 3413. 519r	3413. 492	3602. 068r 3602. 111r	3602. 085	4526. 412r 4526. 465r	4526. 442
3322. 927r 3322. 987r	3322. 949	3433. 028r 3433. 077r	3433. 048	3630. 736r 3630. 778r	3630. 754	4535. 711r 4535. 741r	4535. 712
3335. 168r 3335. 219r	3335. 185	3472. 544r 3472. 594r	3472. 558	3642. 774r 3642. 827r	3642. 806	5457. 435r 5457. 496r	5457. 474
3340. 332r 3340. 391r	3340. 356	3502. 255r 3502. 327r	3502. 291	3645. 290r 3645. 336r	3645. 313	5782. 099r 5782. 176r	5782. 136
3646. 728r 3346. 772r	3346. 746	3504. 876r 3504. 917r	3504. 892	3847. 826r 3847. 871r	3847. 848	5790. 959r 5791. 028r	5790. 990
3349. 386r 3349. 464r	3349. 447	3547. 178r 3547. 220r	3547. 199	4018. 085r 4018. 120r	4018. 104		
3372. 765r 3372. 858r	3372. 812	3564. 936r 3564. 989r	3564. 959	4030. 729r 4030. 798r	4030. 763		
3395. 370r 3395. 409r	3395. 386	3575. 355r 3575. 394r	3575. 374	4052. 453r 4052. 500r	4052. 482		
3405. 084r 3405. 169r	3405. 126	3590. 468r 3590. 510r	3590. 489	4187. 785r 4187. 861r	4187. 812		

8 Wavelength measurements of selected solar lines of NH, from A. Fowler and C. C. L. Gregory, Phil. Trans. Roy. Soc. London [A] **218**, 351 to 372 (1919), corrected to present scale adopted for Rowland lines.

λ Adopted (Å)	Rowland λ Corrected (Å)	Remarks
3360. 808m	3360. 854r	
3364. 651m		Solar line from Higgs
3364. 735m	3364. 697r	
3381. 033m	3381. 065r	
3427. 086m		Solar line from Higgs

9 The two components of this line, 4054.815 Å and 4054.873 Å have in the Atlas and on the plate, intensities which are clearly in the reverse order from that given by Rowland.

10 The Balmer Series of hydrogen extends through H_{17}. Because of the width and diffuseness of these solar lines, the calculated laboratory wavelength is given in column one for the members of this series from H_8 through H_{17}:

H I

Calc.λ (Å)	Series Member	Multiplet No.	Calc.λ (Å)	Series Member	Multiplet No.
3697. 15	H_{17}		3750. 15	H_{12}	
3703. 86	H_{16}		3770. 63	H_{11}	
3711. 97	H_{15}	3	3797. 90	H_{10}	2
3721. 94	H_{14}		3835. 39	H_9	
3734. 37	H_{13}		3889. 05	H_8	

Measurement of the equivalent widths of these difficult wide lines is described in § 2.2.

Designations for molecular lines in the solar spectrum, continued; notes 11, 12:

	Spectrum	Electronic Transition	Vibration Band	Wavelength Range (Å)	References for Analysis
11	CN	$B\,^2\Sigma^+ — X\,^2\Sigma^+$	0, 0 1, 1 2, 2 3, 3 4, 4	3583 to 3883	H. S. Uhler and R. A. Patterson, Astroph. J. **42,** 434 to 468 (1915) Measurement of solar equivalent width (228mÅ) refers to integrated first head of CN band, λ3883.287.
			0, 1 1, 2 2, 3 3, 4	3961 to 4216	T. Heurlinger, Lund Dissertation, Chapter VI, pp. I to XXIX following p. 66 (1918). J. Genard and J. Weinard, Ann. d'Astroph. **18,** 329 to 333 (1955). J. Weinard, Dissertation, Univ. des Saarlandes, 86 pp. (1955); Ann. d'Astroph. **18,** 334 to 353 (1955).
12	CN	$A\,^2\Pi_i — X\,^2\Sigma^+$	0, 0 etc 1, 0 etc.	Beyond range of present publication.	S. P. Davis and J. G. Phillips, Berkeley Analysis of Molecular Spectra, Monograph 1, 1963. Referred to below as "Mono".
			2, 0	7850 to 8798	W. S. Benedict, Unpubl. material, 1964. M. Rigutti and F. Drago-Chiuderi, Ann. d'Astroph. **26,** 253 to 262 (1963). (2, 0) and (3, 1). Mono pp. 168 to 174 and unpubl. material 1964.
			3, 1	8044 to 8812	Mono pp. 175 to 182.
			4, 2	8247 to 9008	Mono pp. 183 to 189.
			3, 0	6910 to 7593	Mono pp. 129 to 134.
			4, 1	7072 to 7588	Mono pp. 138 to 144.
			5, 2	7242 to 7812	Mono pp. 145 to 151.
			6, 3	7423 to 7801	Mono pp. 152 to 156.
			5, 1	6320 to 6741	Mono pp. 99 to 104.
			7, 3	6619 to 7180	Mono pp. 118 to 123.

13 Atomic lines present only in the sun-spot spectrum, based chiefly on work done by C. E. Moore in 1933 from a study of the Mount Wilson spot spectrograms.

λ(Å)	λ(Å)	λ(Å)	λ(Å)	λ(Å)	λ(Å)	λ(Å)	λ(Å)
3900. 44	4564. 23	4784. 45	5033. 61	†5331. 98	5797. 55	6367. 92	8349. 02
4069. 84	4573. 09	4787. 64	†5046. 55	†5332. 14	5799. 90	6378. 85	8363. 58
4077. 16	4575. 48	4851. 35	†5069. 36	5335. 24	5807. 14	6381. 44	8386. 35
4078. 89?	4578. 47	4861. 19	5070. 23	5335. 36	5807. 30	6383. 44	8417. 51
4116. 60	4581. 30	4862. 26	†5077. 55	†5335. 43	5813. 97	6401. 95?	8443. 00
4117. 56	4583. 90	4862. 90	†5078. 28	5339. 82?	5879. 79	6431. 63	8464. 69
4152. 36	4586. 93	4863. 75	5144. 64	†5354. 68	5955. 16	6452. 08	8494. 44
4179. 86	4590. 55	4881. 24	†5158. 30	†5356. 43	6032. 60	6467. 83?	8550. 52
4186. 84	4594. 50?	4893. 92	5161. 78	†5356. 60	6058. 76	6498. 75	8578. 43
4278. 79	4599. 79	4895. 99	†5190. 19	5359. 05	6077. 37	6506. 39	8608. 98
4281. 71	4609. 97	4900. 02?	†5194. 77	5361. 71	6106. 78?	6527. 30	8611. 11
4306. 18	4626. 49?	4904. 30	†5201. 82	†5377. 35	6106. 98	6557. 37	8612. 90
4306. 91	4643. 72	4908. 45	†5218. 09	†5382. 92	6134. 71	6563. 41	8719. 66
4314. 36	4643. 94	4924. 56	5222. 67	†5392. 06	6192. 95	6607. 90	
4314. 77	4644. 86	†4927. 59	†5222. 98	5401. 92	6193. 69	6637. 24	
4368. 92	4661. 92?	4930. 21	5228. 60	†5403. 98	6230. 85	6646. 20	
4387. 20	4663. 28?	4937. 16	†5231. 52	5444. 85	6241. 31?	6649. 51	
4393. 33	4679. 73	†4937. 99	5232. 82?	5465. 75	6257. 63	6709. 87	
4394. 51	4683. 44	†4940. 30	†5234. 82	5470. 48	6261. 23	6766. 50	
4397. 22	4684. 28	4941. 02	5238. 52	5481. 71	6273. 39	7102. 89	
4420. 46	4684. 50	4941. 38	†5252. 36	5517. 18	6276. 32	7169. 11	
4433. 97	4698. 83	†4944. 82	5273. 43	5535. 51	6285. 42	7213. 41	
4476. 62	4707. 69?	†4947. 33	5288. 40	5548. 76	6295. 28	7219. 40	
4491. 18	4714. 12	4947. 98	†5291. 60	5597. 69	6308. 62	7439. 87	
4497. 73	4737. 66	†4959. 12	†5294. 31	5659. 16	6339. 92	8061. 16	
4511. 82	4747. 27	4967. 32	5311. 20	5664. 26	6342. 26	8063. 10	
4535. 86	4747. 96	†4971. 62	5311. 43	5752. 86	6344. 82	8066. 07	
4541. 35	4751. 58	4973. 06	†5317. 89	5756. 40?	6359. 91	8241. 60	
4541. 61	4757. 48	†4994. 99	†5323. 93	5785. 94	6361. 07	8253. 60	
4563. 66	4779. 34	†4995. 56	†5326. 41	5788. 61	6367. 82	8307. 54	

†Rounded off wavelength measured by R. S. Richardson (unpublished) and kindly furnished to C.E.M. in 1932. Except for one line, at 5377 Å, all were measured independently by C.E.M.

14 The observed equivalent width, (column two) relates to the combined lines 3968.492 Å, (Ca II) and 3970.076 Å, (H I). The reduced width (column three) for 3968.492 Å, Ca II (*H*), has been derived by theory from 3933.682 Å, Ca II (*K*); for 3970.076 Å, ($H\epsilon$), it has been interpolated between the other Balmer lines.

15 The line may be double.

λ(Å)	λ(Å)	λ(Å)	λ(Å)
3975. 051	4134. 438	5095. 176	6091. 920
3985. 789	4163. 480	5142. 530	6183. 574
3988. 332	4188. 315	5146. 776	6303. 461
4001. 940	4315. 458	5161. 764	6395. 148
4057. 957	4334. 166	5338. 333	6497. 594
4061. 733	4340. 848	5399. 479	6537. 938
4072. 888	5089. 212	5470. 636	

16 Possibly a molecular line in the sun-spot spectrum.

17 Blend of a molecular and an atomic line in the sun-spot spectrum.

18 Special notes pertaining to double lines:

λ(Å)	Remarks
3972. 440	Recorded by Rowland as two lines, but appears as single on Atlas records.
4049. 731	Line is a close unresolved double.
4868. 414	Line is a close unresolved double in the disk spectrum; two lines seen in the spot spectrum.
5040. 890	Line is an unresolved double in the disk spectrum, with separation 0.05 Å (HDB); two lines seen in the spot spectrum.
5342. 504	Line may be a close unresolved double.

Designations for molecular lines in the solar spectrum, continued notes 19, 20, 22, 23, 24, 26.

	Spectrum	Electronic Transition	Vibration Band	Wavelength Range (Å)	References for Analysis
19	C_2	$A\,^3\Pi_g$—$X\,^1\Pi u$	0, 0 1, 1 2, 2 1, 0 2, 1 0, 1 1, 2 2, 3	4831 to 5165 4919 to 5129 4972 to 5097 4671 to 4737 4664 to 4708 5501 to 5635 5499 to 5585 5475 to 5540	R. C. Johnson, Phil. Trans. Roy. Soc. [A] **226,** 157 to 230 (1927). J. G. Phillips, unpublished material (Nov. 1963). Present identifications can be extended when Berkeley Monograph on C_2 has been completed.
20	Mg H	$A\,^1\Pi_{3/2,1/2}$—$X\,^1\Sigma$	0, 0	4956 to 5210	R. H. Fowler, Mon. Not. Roy. Astron. Soc. **67,** 530 to 534 (1907). Phil. Trans. Roy. Soc. [A] **209,** 447 to 478 (1909). R. S. Richardson, Astroph. J. **73,** 216 to 249 (1931). A. Guntsch, Zeit. Phys. **104,** 585 to 591 (1936). A. Schadee, Dissertation, Utrecht (1964); Bull. Astron. Inst. Netherlands **17,** 311 (1964).

21 There are probably regions of continuous absorption from 4643 Å to 4650 Å; 4654 Å to 4658 Å; 4661 Å to 4665 Å; and also from: 4826 Å to 4830 Å; 4831 Å to 4835 Å. The note number appears near the strongest absorption dip in these intervals. The extent of the absorption is indicated by a vertical dashed line in the note column.

	Spectrum	Electronic Transition	Isotope	Vibration Band	Wavelength Range (Å)	References for Analysis
22	Atm O_2	$^1\Sigma_g^+ — ^3\Sigma_g^-$	O^{16} O^{16}	0, 0 1, 1	7593 to 7733 7684 to 7768	H. D. Babcock and L. Herzberg, Astroph. J. **108**, 167 to 190 (1948).
				1, 0 2, 1	6867 to 6967 6954 to 6996	First line in head of B group: 6867.187 Å.
				2, 0 3, 0	6276 to 6353 5788 to 5829	First line of α group: 6276.590 Å.
23	Atm O_2	$^1\Sigma_g^+ — ^3\Sigma_g^-$	O^{16} O^{17}	0, 0 1, 0	7599 to 7675 6876 to 6920	H. D. Babcock and L. Herzberg. See above.
24	Atm O_2	$^1\Sigma_g^+ — ^3\Sigma_g^-$	O^{16} O^{18}	0, 0 1, 0	7594 to 7684 6885 to 6938	H. D. Babcock and L. Herzberg. See above.

25 [O I] Brackets denote forbidden transition. Identification suggested by I. S. Bowen, Rev. Mod. Phys. **20**, 109 to 112 (1948) 5577.341 Å, 6300.311 Å, 6363.79 Å.

26 Unclassified "Atm" lines are probably due to H_2O. They are entered as "Atm" to distinguish them from classified lines in the H_2O Band System. In the present work they start at 5393 Å and extend to 8739 Å. Two short regions in this interval are free from atmospheric lines: 5478 Å to 5665 Å and 6093 Å to 6267 Å.

All lines identified as "Atm H_2O" have been assigned to specific transitions in the vibration-rotation spectrum. The designations are from the detailed analysis kindly furnished in advance of publication by W. S. Benedict (Dec. 1963). These lines occur in the range 5414 Å to 8758 Å. The following bands are represented in the solar table:

Atm H_2O

Vibration-Rotation Band	Range (Å)	Vibration-Rotation Band	Range (Å)	Vibration-Rotation Band	Range (Å)
411	5414 to 5470	212	6424 to 6563	013	7846 to 8093
203	5665 to 5769	231	6565 to 6585	112	7899 to 8211
500	5701 to 5766	103	6845 to 7128	310	8084 to 8383
321	5828 to 6019	400	6903 to 7203	211	7993 to 8448
401	5830 to 5999	301	7059 to 7408	230	8138 to 8370
302	5863 to 5983	221	7099 to 7480	131	8144 to 8573
113	6275 to 6375	202	7131 to 7392	003	8758
311	6408 to 6626	320	7201 to 7358		

This Band System is described by W. S. Benedict in the introduction to the Michigan Table on the infrared solar spectrum: See O. Mohler, *A Table of Solar Spectrum Wave Lengths*, 11984 Å *to* 25578 Å, p. 9, Univ. Michigan Press, 83 pp., 1955. A fuller discussion will appear in a forthcoming Table of Identifications in the Solar Spectrum, which is based on The *Photometric Atlas of the Solar Spectrum from* λ7498 *to* λ12016, by L. Delbouille and G. Roland, Mém. Soc. Roy. Sci. Liège, Special Volume 4 (1963). For the text and ledger accompanying this Atlas see J. W. Swensson, W. S. Benedict, O. C. Mohler, L. Delbouille and G. Roland; ibid 5, in press (1966).

27 The presence of this Ca I multiplet in the solar spectrum was first reported by W. Mitchell and explained by L. Goldberg, cf L. Goldberg, Harvard College Obs. Sci. Report No. 4, 22 pp (1965); W. E. Mitchell, Jr., and O. C. Mohler, Astroph. J. **141**, 1126 to 1130 (1965). See, also, R. F. Griffin, The Obs. **84**, 154 to 156 (1964).

Ca I

Solar λ (Å) Mitchell and Mohler	Lab. λ (Å)	Multiplet No.
6318. 61	6318. 11	53
6343. 71	6343. 29	
6361. 94 [1]	6361. 79	

[1] Equivalent width not measurable; multiplet rules used to determine Δλ and Δλ/λ.

28 The value of Δλ/λ in column three has been interpolated between neighboring lines of the Atm O_2 band: 7601.470 Å, 7602.036 Å, 7612.314 Å, 7623.552 Å.

29 This line, 7657.606 Å, remeasured from the original plate, yields an equivalent width of 113 mÅ, corresponding to Δλ/λ=14.7.

30 The measured intensities correspond to the total area of the band head, 4688.60 Å to 4689.00 Å.

31 For the members of the Paschen series of H having $n=12$ through 18, laboratory wavelengths are entered in column one. In the solar spectrum there is a background haze caused by the first of these Paschen lines.

n	Lab. λ (Å)	Remarks	n	Lab. λ (Å)	Remarks
12	8750. 48	Δλ 220 mÅ; Δλ/λ *34*	16	8502. 49	masked by Ca II
13	8665. 02	masked by Ca II	17	8467. 26	
14	8598. 39		18	8437. 96	
15	8545. 38	masked by Ca II			

32 The equivalent width refers to the central, symmetric component of this complex line, 8071.262 Å.