LIMB EMISSION LINES NEAR SOLAR H AND K: $\lambda\lambda$3900 TO 4000 Å

(Research Note)

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Seventy-one spectral emission features within the wavelength region 3900 to 4000 Å have been observed on the solar disk for values of μ ($\cos\vartheta$) less than 0.4. These emission lines have been systematically measured for wavelength and intensity from a series of photographic observations obtained at Kitt Peak and McMath-Hulbert Observatories. Many arise from low excitation transitions of singly ionized rare-earths, particularly Ce II and Nd II. Jewell (1898) and Evershed (1927) originally observed the strongest of these emission lines near the cores of H (3968.5 Å) and K (3933.7 Å) lines of singly ionized calcium, and more recent photographic surveys (e.g., Jensen and Orrall, 1963; Engvold and Halvorsen, 1973) have revealed several more. Generally, these lines appear in absorption near disk center but change over into emission near the limb, for $\mu < 0.4$. A few show no absorption counterparts at $\mu = 1$. Canfield (1971) has explained these emission lines as arising from radiative interlocking effects occurring in singly ionized rare-earth elements, and proposed that differences in center-limb variations, as a function of wavelength around the H and K cores, will result. In order to test this idea, it seems desirable to identify as many emission lines near H and K as can be detected.

Nineteen calibrated spectrum plates, each containing up to six spectra at various limb distances, were secured during moments of good seeing and transparency with the McGregor Vacuum Spectrograph of the McMath-Hulbert Observatory. Further, Dr R. Teske kindly made available a calibrated series of limb spectra, covering the same wavelength interval, taken with the McMath Solar Telescope at Kitt Peak. The latter exposures have better spatial resolution, but increased scattered light levels as compared to the McGregor plates. All spectra were traced on the Mark II microdensitometer at Lake Angelus, using a tracing slit size of approximately 2.5″ perpendicular to the dispersion and 10 mÅ along the dispersion.

On the microdensitometer tracings, the emission lines were measured relative to nearby unblended Fraunhofer lines for which wavelengths were taken from *The Second Revised Rowland Table of Solar Spectrum Wavelengths* (Moore *et al.*, 1966). All lines listed in Table I were measured on up to fifteen tracings with a typical rms scatter in the wavelength determinations under ± 0.007 Å. To account for the limb effect, 0.003 Å were subtracted from each measured wavelength to bring it into agreement with the IAU (Babcock, 1928) wavelength scale at disk center.

From the calibration spectra, the tracings were reduced to intensities. For tracings

TABLE I

Solar limb emission lines: $\lambda\lambda$3900 to 4000 Å

No.	Wavelength (Å)	Relative intensity (at $\mu = 0.1$)	Identification	Multiplet	Excitation potential (eV)	Notes
1	3900.223	1.29	Nd II	–	–	
	01.150	1.10	V I	126	2.26	
	03.410	1.13	Sm II	–	–	
	04.335	1.08	Ce II	91	0.55	
5	07.111	1.41	Eu II	5	0.21	
	07.229	1.32	?	–	–	
	07.289	1.17	Ce II	253	1.11	
	07.840	1.21	Nd II	–	–	
	08.433	1.09w	Pr II, Ce II	11, 65	0.00, 0.86	bl.
10	11.172	1.15	Nd II	–	–	
	12.210	1.06	V I	42, 43	1.04	
	12.432	1.10	Ce II	60	0.30	
	16.030	1.10	La II ?	42	0.32	
	16.508	1.06	Gd II ?	20	0.60	
15	17.650	1.06	Ce, Nd II	–	–	bl.
	19.811	1.08	Ce II	60	0.70	
	21.895	1.06	V I	42	1.05	
	23.102	1.11	Ce II	191	0.56	
	24.647	1.10	Ce II	190	0.56	
20	27.109	1.10	Nd II	–	–	
	29.520	1.05	Zr I, II	7, 142	0.07, 2.43	
	31.358	1.05	Ce II	61	0.30	
	31.526	1.15	Dy II ?	–	–	
	31.818	1.03	Ce II	–	–	
25	32.809	1.05 ±	Ce ?	–	–	
	34.808	1.18	Zr II	43	0.71	d
	36.222	1.05	La II	13	0.13	
	38.088	1.11	Ce II	205	0.56	
	38.243	1.21	Fe II ?	–	–	a
30	40.325	1.14	Ce II	50	0.32	
	42.150	1.08	Ce II	37	0.00	b
	42.751	1.19	Ce II	57	0.86	
	45.213	1.13	Fe IIp	3	1.69	
	48.823	1.04	?	–	–	
35	50.414	1.02	Nd, Ce II	–	–	bl.
	52.194	1.11	Nd II	23	0.00	
	53.650	1.06	Ce II	141	0.49	
	55.848	1.04	Zr II ?	17	0.52	
	56.823	1.04 ±	Nd ?	–	–	
40	57.471	1.08w	Nd II	–	–	bl.?
	57.797	1.04	Dy II	–	–	
	58.010	1.05	Nd II	25	0.06	
	58.865	1.11	Rh I ?	7	0.97	
	60.909	1.10	Ce II	84	0.32	
45	63.910	1.05	Nd II	–	–	
	64.765	1.05w	?	–	–	
	67.045	1.06	Ce II	84	0.33	
	67.173	1.04	Ce II	–	–	
	3969.407	1.50	Fe IIp	3	1.68	d

Table 1 (Continued)

No.	Wavelength (Å)	Relative intensity (at $\mu = 0.1$)	Identification	Multiplet	Excitation potential (eV)	Notes
50	3971.436	1.03	?	–	–	
	71.675	1.05	Ce II	133	0.49	b
	71.998	1.07	Eu II	5	0.21	b
	72.772	1.03	?	–	–	
	73.269	1.15	Nd II	19	0.63	
55	76.272	1.10	Sm II	9	0.10	
	77.984	1.08	Nd ?	–	–	
	78.565	1.15	Dy II	–	–	
	79.206	1.10	Sm II	51	0.54	
	80.894	1.17	Ce II	194	0.71	
60	82.114	1.08	Pr ?	–	–	
	82.355	1.06	Nd II	67	0.38	
	82.891	1.02	Ce II	172	0.82	
	83.664	1.15	Dy II	–	0.54	
	88.516	1.19w	La II	40	0.40	c
65	89.438	1.09	Ce II	240	0.90	
	90.102	1.17	Nd II	19	0.47	
	90.600	1.04 ±	?	–	–	
	91.751	1.15	Nd II	19	0.00	
	92.565	1.15	Nd II	–	–	
70	93.824	1.20	Ce II	12	0.91	
	3999.247	1.17	Ce II	57	0.30	

[a] Marked wavelength shift redward with decreasing strength of Fe IIp line at 3938.286 Å.
[b] Possibly showing core reversal in the absorption line as μ approaches zero.
[c] La II trio: λ3988.473, 3988.516, 3988.563.
[d] Observed in flare spectra. See Švestka (1972).

with $0<\mu<0.1$, the emission peak intensities were measured relative to the average intensity of the adjacent spectrum and it is these ratios which are listed in Table I as 'relative intensity'. The symbol 'w' denotes an unusually wide emission line (often a blend, 'bl', upon identification). As was first noted by Jewell, only slight increases in intensity of the emission lines occur over bright plages as compared to quiet areas.

The emission lines were identified by using *The Second Revised Rowland Table of Solar Spectrum Wavelengths*, *The Multiplet Tables* (Moore, 1945), *The Tables of Spectral Line Intensities* (Meggers *et al.*, 1961) and the *MIT Wavelength Tables* (Harrison, 1939), plus a confirming cross-check of multiplets whenever possible. Among the reasonably certain identifications over the one-hundred ångströms are 24 emission lines of Ce II and 14 of Nd II. Nevertheless, all identifications listed in Table I should still be regarded as preliminary.

Earlier studies of these lines have tended to examine only the immediate cores of H and K and have listed fewer than two dozen lines in emission near the limb. The present study surveys up to 30 Å on either side of the H and K Ca II lines and reveals many more limb emission features. Following Canfield's suggestion, one would expect that singly ionized rare-earths experiencing radiative interlocking should be visible in emission against the disk near the limb and that their center-limb behavior should be dependent on their proximity to the H and K cores. The radiation field of H and K should encourage lines closer to the cores of H and K to come into emission nearer disk center and to show stronger intensity at a given μ. Visual inspection of the plates suggests that lines nearer the cores of H and K do come into emission closer to disk center than those farther from the H and K cores. However, quantitative comparison of intensities at $\mu = 0.1$ for lines of the same multiplet with similar excitation potentials yields possible discrepancies. While the line intensities for Fe IIp (apparently capable of radiative interlocking) at λ3945 (23 Å blue of H) and λ3969 (1 Å red of H) agree with prediction, the Ce II lines at λ3960 (7 Å blue of H) and λ3967 (1 Å blue of H) possibly disagree. In order to test Canfield's idea, an examination of the center-limb variations of these emission lines, as well as of the wings of H and K on which they superpose, seems appropriate for further study.

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