

A SPECTROPHOTOMETRIC ANALYSIS OF PROCYON

I. EQUIVALENT WIDTHS AND LINE PROFILES*

FRANK N. EDMONDS, JR.

Department of Astronomy and McDonald Observatory, The University of Texas, Austin

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ABSTRACT

The equivalent widths of 152 lines (22 chemical elements) and the profiles of H α , H β and Ca II K measured from high-dispersion spectrograms of the F5 IV–V subgiant Procyon are tabulated. Various limitations on the accuracy of these results are discussed, including photographic adjacency effects (Appendix I) and scattering of light in the coude spectrograph at McDonald Observatory (Appendix II).

I. OBSERVATIONS

Nineteen high-dispersion spectrograms of the F5 IV–V subgiant Procyon ($\alpha = 7^{\text{h}}32^{\text{m}}2$, $\delta = +5^{\circ}20'$, $V = 0^{\text{m}}37$), taken with the A camera of the coude spectrograph of the 82-inch reflector at McDonald Observatory, were selected for this analysis. Pertinent data concerning these spectrograms are given in Table 1, the selection being made to cover the wavelength range $\lambda\lambda$ 3260–6610 with at least four spectrograms. All spectrograms were calibrated using the same emulsion batch but separate plates and keeping exposure times within a factor of 2 of the effective exposure time of the spectrogram in order to minimize second-order reciprocity failure effects. These second-order effects would be deviations from the Schwarzschild expression for reciprocity failure, $I t^p = \text{constant}$, since effects which are described by this expression (I being intensity, t exposure time, and p a constant) will cancel out in residual intensity measurements. For most spectrograms the calibration was obtained from a spot sensitometer with filters of 200–300-Å half-transmission widths and transmission peaks separated by no more than 400 Å, but for three spectrograms a calibration spectrograph was used.

Spectrograms and calibration plates were developed simultaneously in D-19 (3 min. at 65° F) at least 24 hours after exposure to minimize differences due to the Brush effect. During development one of two techniques to reduce photographic adjacency effects was employed: either the rocking of the developer tray along the dispersion or the placing of spectrograms and calibration plates upright in a rack and moving them back and forth through the developer. The edges of the calibration spots provided a measure of adjacency effects, and it was found that (a) although the effects were small, neither technique eliminated them, (b) the rocking technique was not quite as satisfactory as the agitation technique, and (c) variations of the effects over a plate were as large as the effects, thereby eliminating the possibility of correcting line profiles or equivalent widths for them. An estimate of the magnitude of these effects for spectral lines is reported in Appendix I. Whereas the changes to profiles could be large enough to prevent their use in a spectrophotometric analysis, the changes in equivalent widths for the sharpest lines are on the average less than 7 per cent and for most lines less than 4 per cent.

Two other effects which could introduce uncertainties into the observations were also investigated. First, scattered light within the spectrograph and the similar effect of grating ghosts were found to be satisfactorily small. First-order grating ghosts are about 1/1700 the main-line strength (Strong 1959) and so should not give appreciable effects for the first three orders which were used. Tests for scattered light in the spectrograph with the filters used for exposure of the spectrograms are described in Appendix II and

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indicate that the level of scattered light was less than 4 per cent and quite possibly less than 1 per cent.

Finally, the effects of uneven trailing of the star image along the spectrograph slit were evaluated, using a spectrogram in which density varied by as much as a factor of 3 across the spectrum. The difference between the spectrogram's calibration-curve and an effective calibration-curve for the average density $\bar{D}$ measured by the microphotometer slit was calculated by determining the density across the spectrum at various density levels, averaging at each density level for $\bar{D}$ as a function of the density at a given distance across the spectrum $D(x_1)$, and then constructing the effective calibration-curve

TABLE 1
OBSERVATIONS OF PROCYON

Plate No	Date	Emulsion	Disper- sion (Å/mm)	Slit (Height × Width in mm)	Filter (Corning unless Otherwise Noted)	Wavelength Range Used (Å)
1828	Jan. 24, 1956	IIa-F	9 6	3×0 04	Wratten No. 4	5840-6610
1830	Jan. 24, 1956	IIa-O	4 8	3×0 04	None	3890-4510
2853	Jan. 17, 1957	IIa-O	4 8	2×0 04	None	4400-4675
2855	Jan. 17, 1957	103a-O	4 8	2×0 04	None	3260-3370
2856	Jan. 17, 1957	103a-O	3 2	2×0 04	None	3550-3680
2865	Jan. 19, 1957	IIa-O	4 8	1 5×0 02	3060	3890-4510
3102	Nov. 29, 1957	IIa-O*	3 2	2×0 04	9863	3170-3785
3107	Nov. 30, 1957	IIa-O*	3 2	2×0 04	9863	3170-3785
3117	Dec. 1, 1957	103a-J*	4 8	2×0 04	Wratten No. 2A	4695-4970†
3118	Dec. 1, 1957	103a-J*	4 8	2×0 04	Wratten No. 2A	4695-4970†
3120	Dec. 1, 1957	103a-J*	4 8	2×0 04	Wratten No. 2A	4695-4970
3121	Dec. 1, 1957	103a-J*	4 8	2×0 04	Wratten No. 2A	4695-5020
3122	Dec. 1, 1957	103a-E*	4 8	1×0 04	3385	5845-6610†
3128	Dec. 2, 1957	IIa-O	3 2	2×0 04	9863	3000-3680
3141	Dec. 4, 1957	103a-E(2)	4 8	2×0 04	3385	4990-5790
3147	Dec. 7, 1957	103a-E(2)	4 8	2×0 04	3385	4990-6610
3158	Dec. 9, 1957	103a-E(2)	4 8	2×0 04	3385	4990-5780
3159	Dec. 9, 1957	103a-E(2)	4 8	2×0 04	3385	4990-6680
3160	Dec. 9, 1957	IIa-O*	3 2	2×0 04	9863	3350-3961

* Plate rocked during development rather than agitated.

† Calibration spectrograph rather than spot sensitometer used for calibration

for $\bar{D}$ from this relation between $\bar{D}$ and $D(x_1)$ together with applying the normal calibration-curve for the spectrogram to $D(x_1)$. The differences between the two calibration-curves were smaller than the uncertainties of the curves and led to a difference in the equivalent width of a strong line of only 1.2 per cent.

II. MEASUREMENTS

Microphotometer tracings were made of the spectrograms listed in Table 1 using the intensity-recording microphotometer at the Yerkes Observatory. Two difficulties were encountered with microphotometering the spectrogram. A slow drift plus occasional small but sudden changes in microphotometer sensitivity necessitated rather frequent checking of the clear plate setting and, when this setting varied by more than 1 per cent, the tracing was repeated. The calibration of the spectrogram was put into the microphotometer by placing the calibration-curve into a function generator which approximated it (using a sequence of diode circuits) as a sequence of straight-line segments. The activation of a new diode circuit as the instrument went through a turning point (joining point of two successive line segments) would in some cases be accompanied by a small oscillation which could not be removed, and so would effectively produce a small varia-

tion of the calibration-curve in this region. This had only a very minor effect on the intensity tracings except when a weak line happened to lie in such a region, since for such lines the equivalent width would be roughly proportional to the slope of the calibration-curve. Unfortunately, this situation was not easily detected, so a few weak-line measurements may be affected by this difficulty.

The line-identification table of Swensson (1946) was used to select lines and to locate them on the tracings for $\lambda > 3800 \text{ \AA}$. For $\lambda < 3800 \text{ \AA}$ the Revised Rowland Table (St. John, Moore, Ware, Adams, and Babcock 1928) proved to be satisfactory. Equivalent widths were measured from the microphotometer tracings, using a self-compensating planimeter. In each case, a profile was drawn first through the plate grain, estimating a correction for small blends where necessary. If a line was appreciably blended, usually only the unblended half of the profile was measured, and the area doubled to give the

TABLE 2

WAVELENGTHS (λ) AND RESIDUAL INTENSITIES (R^*) DEFINING THE APPARENT CONTINUUM

λ ($\text{\AA}$)	R	λ ($\text{\AA}$)	R	λ ($\text{\AA}$)	R	λ ($\text{\AA}$)	R
3052 ..	.	3429 .	(0 99)	3810 .	0 83	4396	
3089 .	.	3435 .	(96)	3812 .	0 86	4429 .	0 98
3108 .	..	3451 .	(94)	3857 .	0 98	4537 ..	
3112 .	..	3455 .	(.93)	3915 .	0 96	4544 ..	1 00
3125 .	..	3470 .	(.99)	3950 .	0 94	4570 .	1 00
3190 .	..	3487 .	(94)	4020 .	0 98	4607 .	1 00
3218 .	..	3504 .	(98)	4039 .	0 96	4631 .	
3259 .	..	3518 .	(96)	4043 .	1 00	4653 .	1.02
3290 .	..	3519 5	(95)	4136 .	0 99	4660 .	1 01
3300 .	..	3540 .	(93)	4163 .	1 01	4676 .	1.02
3326 .	..	3600 .	(92)	4193 .	0 98	4697 ..	0 98
3348 .	..	3665 .	67	4214 .	0 98	4725 .	1 00
3365 .	..	3717 .	.77	4257 .	1 01	4776 ..	1 02
3382 .	..	3741 .	.74	4282 .	0 98	4796 ...	1 00
3390 .	(1 02)	3783 .	79	4316 .	1 03	4820 ...	1 00
3400 .	(1 01)	3784 .	0 79	4372 ..	1 01		

* For certain wavelengths R has not been determined, those at the ultraviolet end because of lack of satisfactory photoelectric measurements of the continuum. Values given in parentheses involve an extrapolation (Talbert and Edmonds 1965).

equivalent width. An attempt was made to measure the equivalent width by fitting the line profile to a Voigt profile (Elste 1953), but it was not carried out because the profiles of some lines had weaker wings than a Gaussian profile, presumably because of photographic adjacency effects.

All measurements were made with respect to an apparent continuum obtained from the tracings. For wavelengths greater than $\lambda 4800$ there is no reason for believing that this continuum is not also the true continuum. However, the congestion of lines for shorter wavelengths raises the possibility that the apparent and true continua do not coincide to the violet of $\lambda 4800$, particularly as the tracings were made with a magnification of 100 with respect to the plates. A determination of the continuum from photoelectric spectral scans of Procyon (together with line-blanketing measurements made from the tracings) has made possible the fixing of the true continuum in the violet and near-ultraviolet by employing the straight-line extrapolation method of Canavaggia and Chalonge (1946). An independent fixing of the true continuum has also been carried out by analyzing profiles of the upper members of the Balmer series obtained from the Procyon spectrograms (Edmonds 1965). These results will be reported in a second article of this series (Talbert and Edmonds 1965). In Table 2 the wavelengths of "windows" or points on the tracings which appeared to be continuum are listed. The apparent con-

tinuum was drawn between these points. Also listed is the residual intensity of these points on the apparent continuum with respect to the true continuum, as determined by Talbert and Edmonds.

III. EQUIVALENT WIDTHS

The measured equivalent widths are given in Table 3, arranged as to chemical element and wavelength (first column). Lines were selected for high profile quality, for reasonably high excitation, for lying below the flat portion on the curve of growth, and for having a determined oscillator strength. Except for a few elements, these criteria had to be compromised to obtain the desired minimum of four lines. The *Revised Multiplet Table* (Moore 1945) multiplet number and the excitation potential of the lower state are also given (second and third columns). The fourth and fifth columns give $\log gf$ for each line together with the source, based on a literature search by Mr. Peter R. Jordahl. Remarks concerning these oscillator strengths are presented at the end of the table. The equivalent width in mÅ and $\log W/\lambda$ are given in the sixth and seventh columns, while the weight assigned to each value and its probable error are given in the eighth and ninth columns. The weight is the sum of weights (in the range 0–1) assigned to the measurement made from each spectrogram, these individual weights being the product of three factors (on a scale 0–1) which evaluated profile quality (blends, plate grain, etc.), accuracy of continuum location at the line, and accuracy of the calibration-curve used during microphotometry. The probable error was determined from the range of measurements made from the different spectrograms in a manner proposed by Schlesinger (1938).

Between spectrograms the scatter of the measured equivalent widths is moderate as the probable errors exceed 10 per cent for only eleven of the 152 lines and 15 per cent for only three. Systematic differences were found between spectrograms covering $\lambda > 5000$ Å (but not for the other spectrograms), and the measurements were corrected so that the mean for each spectrogram equaled the mean of all spectrograms. This introduced moderate reductions in the probable errors but changed the average equivalent widths given in Table 3 very little.

A comparison between these measurements and those obtained in other investigations is shown in Figure 1. Certain systematic differences can be detected through the scatter of points. The equivalent widths measured by Greenstein (1948) are slightly larger, while measurements obtained by other investigators (primarily by Wright 1948) tend to be smaller for small equivalent widths. Since fixing of continuum, method of measurement, and dispersion can cause systematic differences, it would be difficult to identify the cause of these small differences for Greenstein's measurements. The larger differences for weak lines probably result from the manner of drawing profiles for planimetry through the photographic plate grain. Higher dispersion could also contribute to these differences.

There is no reason for believing that the equivalent widths in Table 3 have less than normal accuracy (except possibly for being systematically larger for $W \lesssim 50$ mÅ). On the other hand, there is no evidence that the desired goal of a relatively small number of equivalent widths with better than normal accuracy has been obtained, this goal being set for the fine analysis of the equivalent widths (Aller 1960) which will be reported on in a later article of this series. It is felt that the limitations on accuracy arise from three effects. First is the graininess of the fast emulsions used. Baked IIA emulsions should have been used instead of 103a, but it is doubtful if further improvement could be obtained without making the exposure times too long. Second, the variation in adjacency effects measured over the calibration plates suggests the possibility of non-uniform development of the plates in spite of normal precautions to eliminate such variations. This effectively means that the calibration-curves will not be accurate and cannot be applied with equal accuracy over the pertinent wavelength range of the spectrogram. This effect is probably small, but the related effect of separate plates for calibration probably introduces larger errors, in spite of extensive efforts to minimize such errors. It

TABLE 3
MEASURED EQUIVALENT WIDTHS*

Element and Line Wavelength (Å)	RMT Multiplet No.	Excitation Potential (ev)	Oscillator Strength		Equivalent Width				Remarks
			Log gf	Source†	W (mÅ)	-log W/λ	Wt.	p.e. of W (mÅ)	
Cl									
4775.87	6	(11.26) ‡	-2.05	Foster (1962)	50.2	4.978	1.1	5.0	#,
4932.00	13	7.46	-1.93	Foster (1963)	72.8	4.831	2.3	5.7	
5052.12	12	7.65	-1.62	Foster (1963)	78.5	4.808	1.5	7.6	#,
5380.24	11	7.65	-1.86	Foster (1963)	52.6	5.010	1.8	2.1	#,
NaI									
3302.34	2	(5.14) ‡	-1.72	Allen (1963), Heavens (1961)	202.7	4.212	1.4	7.9	#,
3302.94	2	0	-2.04	Allen (1963), Heavens (1961)	142.3	4.366	1.6	3.9	#,
4668.56	12	2.10	-1.41	Goldberg et al. (1960)	50.5	4.966	0.8	7.8	#,
5688.20	6	2.10	-0.47	Goldberg et al. (1960), Allen (1963)	129.5	4.643	2.7	6.3	
5889.95	1	0	+0.11	Goldberg et al. (1)	400.1	4.168	2.8	6.1	
5895.92	1	0	-0.19	Goldberg et al. (1)	329.2	4.253	2.7	2.7	
6154.23	5	2.09	-1.56	Goldberg et al. (1960), Allen (1963)	38.3	5.206	1.2	4.2	
6160.75	5	2.10	-1.22	Goldberg et al. (1960), Allen (1963)	51.9	5.074	1.5	1.8	#,
MgI									
4702.99	11	(7.64) ‡	-0.72	(2)	201.4	4.368	2.5	8.0	
4730.03	10	4.33	-2.06	Goldberg et al. (1960), Griem (1964b)	52.1	4.958	1.2	3.6	#,
5528.41	9	4.33	-0.74	(2)	200.2	4.441	3.0	4.9	
5711.09	8	4.33	-1.55	(3)	78.5	4.862	2.8	2.5	
MgII									
4481.13 } 4481.33 }	4	8.33	+0.97	Allen (1963), Griem (1964b)	310.6	4.159	1.6	10.9	
AlI									
3082.16	3	(5.98) ‡	-0.38	(4)	183.8	4.224	0.3	§ §	
3944.01	1	0	-0.58	(5)	261.5	4.178	3.9	5.2	#, , *f _w = 0.918 ± 0.008
3961.52	1	0.01	-0.28	(5)	203.4	4.280	3.3	9.4	#, , *f _w = 0.767 ± 0.006
SiI									
3905.53	3	(8.15) ‡	-0.89	Allen (1963)	295.1	4.122	3.5	39.2	
5645.66	10	4.91	-1.65	Goldberg et al. (1960), Griem (1964b)	40.3	5.146	1.8	3.4	
5690.47	10	4.91	-1.93	Goldberg et al. (1960), Griem (1964b)	43.0	5.122	2.2	3.2	
5708.44	10	4.93	-1.19	Goldberg et al. (1960), Griem (1964b)	65.9	4.811	1.7	2.9	#

* Determined with respect to the apparent continuum (see Table 2) or, if in the wing of a strong line, with respect to the wing. The residual intensity r_w of the wing with respect to the apparent continuum is given in the Remarks column.

† Based on a literature search by Peter R. Jordahl.

‡ Ionization potential (eV) for element (Allen 1963).

§ Stark broadening parameters calculated by Griem (1964a).

§§ From measurements only.

TABLE 3 - continued

Element and Line Wavelength (Å)	RMT Multi-plet No.	Excitation Potential (ev)	Log gf	Oscillator Strength Source†	Equivalent Width				Remarks
					W ₀ (mÅ)	-log W/λ	Wt.	p.e. of W (mÅ)	
SIII 6347.09	2	(16.34) ‡	+0.22	(6)	118.1	4.730	2.6	4.8	
	2	8.09	-0.06	(6)	86.5	4.867	2.4	3.7	
SII 6046.04	10	(10.36) ‡	-0.96	Goldberg et al. (1960)	44.7	5.131	1.5	3.6	
	10	7.83	-0.67	Goldberg et al. (1960)	39.4	5.186	1.1	3.4	
CaII 4094.93	25	(6.11) ‡	-0.63	(7)	76.2	4.730	2.0	5.3	* r _w = 0.832 ± 0.005
	39	2.51	-0.67	(7)	54.5	4.877	1.9	2.4	* r _w = 0.845 ± 0.005
4108.55	2	0	+0.16	(7)	374.2	4.053	2.3	17.1	
4226.73	4	1.88	-0.43	(7)	126.8	4.544	2.3	2.2	#
4435.69	21	2.51	-0.29	(7)	102.4	4.738	2.6	2.9	
5601.28	1	0	-4.35	(7)	27.7	5.375	0.6	3.7	#, , * r _w = 0.932 ± 0.013
6572.78	4	(11.87) ‡	+0.53	Allen (1963), Griem (1964b)	506.8	3.798	0.6	5.0	#
3179.33	4	3.14	-0.42	Allen (1963), Griem (1964b)	307.8	4.014	0.2	8	
3181.28	7	(12.80) ‡	+0.16	(8)	187.7	4.355	3.2	1.1	
4246.83	26	0.31	-0.72	(8)	82.5	4.803	2.5	4.2	
5239.82	29	1.45	-1.21	(8)	55.7	5.008	2.6	2.3	
5669.03	19	1.49	-1.50	(8)	43.4	5.182	1.5	1.4	#
6604.60	56	(6.82) ‡	+0.16	King & King (1938), Tatum (1961)	113.5	4.537	3.3	13.2	#
TII 3904.79	4	0.90	-1.09	Goldberg et al. (1960), Allen (1963)	61.9	4.922	1.8	5.4	#
5173.74	4	0	-0.82	Goldberg et al. (1960), Allen (1963)	60.9	4.932	2.3	2.9	
5210.39	4	0.05	-0.43	Goldberg et al. (1960), Allen (1963)	25.0	5.398	1.2	2.0	#
6258.10	104	1.44	-0.32	Goldberg et al. (1960), Allen (1963)	35.1	5.251	1.3	1.8	#
6258.71	104	1.45	-0.53	Goldberg et al. (1960), Allen (1963)	19.4	5.509	0.9	1.1	
6261.10	104	1.42	-0.53	Goldberg et al. (1960), Allen (1963)					

* Determined with respect to the apparent continuum (see Table 2) or, if in the wing of a strong line, with respect to the wing. The residual intensity r_w of the wing with respect to the apparent continuum is given in the Remarks column.

†Based on a literature search by Peter R. Jordahl.

‡Ionization potential (eV) for element (Allen 1963).

||Stark broadening parameters calculated by Griem (1964a).

Only half of the line profile measured on some or all of the plates because of line blending or plate blemishes.

§§One measurement only.

TABLE 3 - continued

Element and Line Wavelength (Å)	RMT Multi-plet No.	Excitation Potential (ev)	Log gf	Oscillator Strength Source†	Equivalent Width				Remarks
					W (mÅ)	-log W/λ	Wt.	p.e. of W (mÅ)	
TiII									
4312.86	41	(13.57) ‡	-1.14	Wobig (1962), Tatum (1961)	181.7	4.375	2.4	4.9	* $r_w = 0.917 \pm 0.004$ #
4330.71	41	1.18	-2.09	Wobig (1962), Tatum (1961)	93.8	4.664	2.0	2.6	
4395.85	61	1.24	-1.64	Boyarchuk & Boyarchuk (1960)	92.7	4.676	2.4	2.7	
4421.95	93	2.05	-1.16	Boyarchuk & Boyarchuk (1960)	84.4	4.719	2.4	3.6	
4544.01	60	1.24	-2.32	Boyarchuk & Boyarchuk (1960)	63.9	4.852	2.4	3.5	
4545.14	30	1.13	-2.17	Boyarchuk & Boyarchuk (1960)	88.1	4.713	2.6	2.7	* $r_w = 0.909 \pm 0.006$ #
5418.80	69	1.57	-2.09	Boyarchuk & Boyarchuk (1960)	64.2	4.916	2.6	2.9	
VI									
4111.78	27	(6.74) ‡	+0.44	(9)	58.1	4.850	2.3	3.1	
4379.24	22	0.30	+0.64	(9)	66.9	4.816	2.3	3.6	
4389.97	22	0.27	+0.27	(9)	55.8	4.896	1.7	2.4	
4406.64	22	0.30	-0.20	(9)	37.5	5.070	1.6	4.1	
5234.09	131	2.35	+0.72	(10)	12.9	5.608	0.2	4.1	
VII									
3916.42	10	(14.65) ‡	-0.56	Boyarchuk & Boyarchuk (1960)	79.6	4.692	2.5	5.6	#
4023.39	32	1.42	-0.40	Boyarchuk & Boyarchuk (1960)	92.1	4.640	2.6	3.6	
4036.78	9	1.80	-1.46	Boyarchuk & Boyarchuk (1960)	45.6	4.947	2.4	3.4	
4183.44	37	2.04	-0.70	Boyarchuk & Boyarchuk (1960)	69.7	4.778	2.2	4.9	
4947.58	197	3.74	----	----	30.7	5.207	0.9	4.7	
CrI									
4274.80	1	(6.76) ‡	-0.32	(11)	188.5	4.356	2.5	3.4	#
4545.96	10	0	-1.26	(11)	66.6	4.834	2.5	2.6	
4652.16	21	0.94	-0.90	(11)	88.1	4.723	2.5	6.5	
4718.43	186	1.00	-0.17	(12)	52.2	4.956	2.0	1.6	
5297.36	94	3.18	-0.08	(12)	79.2	4.825	2.7	3.5	
CrII									
5237.34	43	(16.49) ‡	-0.15	Charatis (1962)	96.9	4.733	2.7	4.0	#
5334.88	43	4.06	-0.62	Charatis (1962)	71.7	4.872	3.4	5.1	

* Determined with respect to the apparent continuum (see Table 2) or, if in the wing of a strong line, with respect to the wing. The residual intensity r_w of the wing with respect to the apparent continuum is given in the Remarks column.

† Based on a literature search by Peter R. Jordahl.

‡ Ionization potential (eV) for element (Allen 1963).

Only half of the line profile measured on some or all of the plates because of line blending or plate blemishes.

TABLE 3 - continued

Element and Line Wavelength (Å)	RMT Multi-plet No.	Excitation Potential (ev)	Log gf	Oscillator Strength		Equivalent Width					Remarks
				Source†	W (mÅ)	-log W/λ	Wt.	P.e. of W (mÅ)			
MnI		(7.43) ‡									
4082.94	5	2.17	+0.13	Allen & Asaad (1957)	87.6	4.669	2.1	4.2		#, * $r_w = 0.971 \pm 0.006$	
4502.22	22	2.91	-0.13	Allen & Asaad (1957)	39.7	5.055	2.0	2.5			
4709.72	21	2.88	-0.33	Allen & Asaad (1957)	45.5	5.014	0.7	4.8			
4739.11	21	2.93	-0.34	Allen & Asaad (1957)	46.4	5.009	2.0	2.8			
5377.63	42	3.83	+0.21	Boyarchuk & Boyarchuk (1960)	36.4	5.170	1.7	2.2			
6013.50	27	3.06	-0.15	Boyarchuk & Boyarchuk (1960)	76.3	4.897	2.2	6.4			
FeI		(7.87) ‡									
4427.31	2	0.05	-2.71	(13)	142.0	4.494	3.4	2.8			
4447.72	68	2.21	-0.78	(13)	131.0	4.531	2.2	0.9			
4872.14	318	2.87	-0.25	(13)	165.7	4.468	2.3	6.9		, * $r_w = 0.918 \pm 0.007$	
4890.76	318	2.86	-0.29	(13)	187.4	4.417	2.3	9.8			
4891.50	318	2.84	-0.03	(13)	194.8	4.400	2.3	6.0			
5191.46	383	3.03	-0.16	(13)	166.6	4.494	2.6	6.4			
5192.35	383	2.99	-0.02	(13)	175.1	4.472	2.6	9.9			
5307.37	36	1.60	-2.66	(13)	96.5	4.740	3.5	1.6			
5397.13	15	0.91	-2.08	(13)	148.2	4.561	0.8	8.6			
5429.70	15	0.95	-1.98	(13)	220.0	4.392	3.0	10.2			
5554.90	1183	4.53	-0.20	(13)	73.7	4.877	2.8	3.2			
5565.71	1183	4.59	-0.06	(13)	84.5	4.819	2.1	6.1		#	
5679.02	1183	4.63	-0.22	(13)	46.4	5.089	2.3	2.0			
FeII		(16.18) ‡									
4620.51	38	2.82	-2.15	Kohl (1964)	79.5	4.764	2.6	5.9			
5169.03	42	2.88	-0.41	Kohl (1964)	346.5	4.174	1.9	14.7		#	
6456.38	74	3.89	-1.26	Kohl (1964)	115.5	4.747	1.4	4.5		#	
CoI		(7.86) ‡									
3564.95	19	0.58	-1.10	(14)	87.3	4.611	1.0	3.3			
3652.54	4	0.17	-2.03	(14)	38.3	4.980	1.7	1.8			
4020.90	16	0.43	-2.09	(14)	41.3	4.988	2.5	1.3			
4110.53	29	1.04	-1.21	(14)	55.7	4.868	1.9	1.8			
4693.19	156	3.22	+0.32	Corliss & Bozman (1962)	15.0	5.495	0.1	4.1		* $r_w = 0.886 \pm 0.005$	
5342.70	190	4.00	+1.05	Corliss & Bozman (1962)	26.2	5.309	0.2	3.5		#	
5524.99	192	4.10	+0.22	Corliss & Bozman (1962)	28.6	5.286	0.9	3.8		#	

* Determined with respect to the apparent continuum (see Table 2) or, if in the wing of a strong line, with respect to the wing.
 The residual intensity r_w of the wing with respect to the apparent continuum is given in the Remarks column.

† Based on a literature search by Peter R. Jordahl.

‡ Ionization potential (ev) for element (Allen 1963).

§ Damping constant measured by Kusch (1958).

Only half of the line profile measured on some or all of the plates because of line blending or plate blemishes.

\$\$ One measurement only.

TABLE 3 - continued

Element and Line Wavelength (Å)	RMT Multi-plet No.	Excitation Potential (ev)	Log gf	Oscillator Strength Source†	Equivalent Width				Remarks
					W ₀ (mÅ)	-log W/λ	Wt.	p.e. of W (mÅ)	
NiII		(7.63) ‡							
3243.06	22	0.03	-1.55	(15)	105.4	4.488	1.2	3.1	
3320.26	9	0.16	-1.58	(15)	97.9	4.530	1.8	4.3	#
3366.17	8	0.16	-1.42	(15)	86.9	4.588	2.3	6.1	
3670.43	4	0.16	-2.15	(15)	104.3	4.546	1.1	1.5	#
4998.23	111	3.59	-0.58	Goldberg et al. (1960)	47.4	5.023	2.1	3.4	
5010.96	144	3.62	-0.74	Goldberg et al. (1960)	39.9	5.099	1.9	3.3	
5082.35	130	3.64	-0.43	Goldberg et al. (1960)	46.5	5.039	2.4	3.0	
5115.40	177	3.82	-0.10	Goldberg et al. (1960)	72.4	4.853	2.3	1.5	#
5176.56	209	3.88	-0.60	Goldberg et al. (1960)	42.4	5.091	2.0	3.3	
CuII		(7.72) ‡							
3273.96	1	0	-0.49	Goldberg et al. (1960)	130.2	4.400	1.5	4.1	
5105.54	2	1.38	-2.39	Goldberg et al. (1960)	62.0	4.916	2.3	4.1	
5218.20	7	3.80	-0.63	Goldberg et al. (1960)	65.1	4.904	0.9	3.6	#
5782.13	2	1.64	-2.85	Goldberg et al. (1960)	37.4	5.189	1.8	3.5	
ZnII		(9.39) ‡							
4722.16	2	4.01	-0.33	Schuttevaer & Smit (1943)	70.2	4.828	2.5	1.7	
4810.53	2	4.06	-0.09	Schuttevaer & Smit (1943)	99.2	4.686	2.3	3.4	
SrII		(11.03) ‡							
4077.71	1	0	+0.19	Ostrovskii & Penkin (1961b)	379.2	4.032	2.0	11.5	#
4215.52	1	0	-0.11	Ostrovskii & Penkin (1961b)	274.1	4.187	2.6	17.5	#
YII		(12.23) ‡							
3774.33	7	0.13	-0.16	Corliss & Bozman (1962)	108.2	4.543	1.8	3.1	#, *
3982.59	6	0.13	-0.79	Corliss & Bozman (1962)	104.1	4.583	2.3	5.5	#, *
5087.42	20	1.08	-0.87	Corliss & Bozman (1962)	73.6	4.840	2.1	1.9	#, *
5200.42	20	0.99	-1.05	Corliss & Bozman (1962)	73.4	4.850	2.4	4.4	#
ZrII		(13.13) ‡							
4208.99	41	0.71	-0.22	Houziaux & Sadoine (1961)	55.7	4.878	2.6	2.5	
4211.88	15	0.52	-1.21	Corliss & Bozman (1962)	52.4	4.906	2.7	3.2	
4613.95	67	0.97	-1.30	Corliss & Bozman (1962)	21.1	5.340	1.4	2.1	
5112.28	95	1.66	-1.00	Corliss & Bozman (1962)	26.7	5.282	0.6	1.9	
5311.78	95	1.75	-1.87	Corliss & Bozman (1962)	12.4	5.632	0.6	1.1	

* Determined with respect to the apparent continuum (see Table 2) or, if in the wing of a strong line, with respect to the wing. The residual intensity I_w of the wing with respect to the apparent continuum is given in the Remarks column.

† Based on a literature search by Peter R. Jordahl.

‡ Ionization potential (eV) for element (Allen 1963).

Only half of the line profile measured on some or all of the plates because of line blending or plate blemishes.

Element and Line Wavelength (Å)	RMT Multi- plet No.	Excitation Potential (ev)	Log gf	Oscillator Strength		Equivalent Width			
				Source†	W ₀ (mÅ)	-log W/λ	Wt.	p.e. $\frac{gf}{W}$ (mÅ)	Remarks
Nb(Cb)II									
3163.40	1	(14.32) ‡	-0.10	Corliss & Bozman (1962)	58.3	4.734	0.2	§ §	#
BaII									
4554.03	1	0.37	+0.12	(16)	194.0	4.371	2.6	6.9	
4934.09	1	0	-0.18	(16)	230.7	4.330	2.9	3.1	
5853.68	2	0.60	-1.26	Goldberg et al. (1960)	87.7	4.824	2.6	4.0	
LaII									
3988.51	40	(11.43) ‡	-0.26	Corliss & Bozman (1962)	45.5	4.943	2.3	2.8	* $r_w = 0.940 \pm 0.007$
4086.72	10	0	-0.60	Corliss & Bozman (1962)	51.5	4.900	1.7	2.2	#, * $r_w = 0.949 \pm 0.006$
4333.76	24	0.17	-0.60	Corliss & Bozman (1962)	39.3	5.042	1.7	2.9	#, * $r_w = 0.862 \pm 0.002$
4559.28	53	0.77	-1.71	Corliss & Bozman (1962)	10.7	5.629	0.1	1.5	
5863.70	62	0.92	-2.09	Corliss & Bozman (1962)	9.7	5.781	0.1	§ §	
CeII									
3781.62	163	0.53	-0.18	Corliss & Bozman (1962)	52.0	4.862	1.8	2.9	#
4081.22	4	0.47**	-0.39	Corliss & Bozman (1962)	47.0	4.959	1.9	2.9	
4560.96	2	0.67**	-0.70	Corliss & Bozman (1962)	27.9	5.213	0.5	3.8	#
4562.36	1	0.47**	-0.07	Corliss & Bozman (1962)	23.8	5.283	1.6	2.1	#
4628.16	1	0.51**	-0.14	Corliss & Bozman (1962)	18.8	5.391	1.3	1.4	
NdII									
3784.25	+ +	-----	-----	-----	10.9	5.540	0.5	1.2	
4061.08	10	0.47	+0.03	Corliss & Bozman (1962)	55.7	4.863	2.5	1.5	
4109.46	10	0.32	-0.41	Corliss & Bozman (1962)	39.4	5.018	1.1	2.5	#, * $r_w = 0.868 \pm 0.005$
4797.16	60	0.56	-1.58	Corliss & Bozman (1962)	21.0	5.359	1.1	1.5	
4820.34	47	0.20	-1.86	Corliss & Bozman (1962)	23.4	5.314	1.1	0.5	
4959.13	1	0.06	-1.60	Corliss & Bozman (1962)	24.3	5.310	0.8	1.7	
SmII									
4615.69	22	(11.3) ‡	-1.57	Corliss & Bozman (1962)	32.8	5.148	0.8	2.9	
4704.40	1	0	-1.55	Corliss & Bozman (1962)	14.3	5.517	0.1	4.1	
EuI									
4627.22	1	(5.67) ‡	+0.25	Corliss & Bozman (1962)	13.9	5.522	1.0	0.8	Identification uncertain
EuII									
4129.73	1	(11.2) ‡	-0.31	Corliss & Bozman (1962)	57.4	4.857	1.1	4.0	#
GdII									
3763.00	1	(12) ‡	-0.24	Corliss & Bozman (1962)	59.8	4.799	1.5	2.9	* $r_w = 0.966 \pm 0.001$
3768.39	2	0.08	+0.25	Corliss & Bozman (1962)	36.7	5.011	0.9	3.2	* $r_w = 0.689 \pm 0.007$
DyII	‡ ‡	(-----) ‡	-----	(17)	46.7	5.046	1.8	3.1	#
5192.87	‡ ‡	(-----) ‡	-----						

* Determined with respect to the apparent continuum (see Table 2) or, if in the wing of a strong line, with respect to the wing.
 ‡ The residual intensity r_w of the wing with respect to the apparent continuum is given in the Remarks column.

† Based on a literature search by Peter R. Jordahl.

‡ Ionization potential (eV) for element (Allen 1963).

Only half of the line profile measured on some or all of the plates because of line blending or plate blemishes.

*** Member of a Group I multiplet and, therefore, excitation potential has been raised 0.47 eV from RMT value (Racah 1955).

NOTES FOR TABLE 3 REGARDING OSCILLATOR STRENGTHS

- (1) Goldberg, Müller, and Aller (1960); Allen (1963); Demtröder (1962); Heavens (1961); Ostrovskii and Penkin (1961a), Krater (1945); using anomalous dispersion (hook) methods obtain $\log gf = +0.20$ for λ 5889.95 and -0.10 for λ 5895.92.
- (2) Allen (1963). Coulomb approximation calculations by Griem (1964b) give $\log gf = -1.39$ for λ 4702.99 and -2.02 for λ 5528.41.
- (3) Goldberg *et al.* (1960); Allen (1963); Griem (1964b).
- (4) Corliss and Bozman (1962); Penkin and Shabanova (1963).
- (5) Allen (1963); Penkin and Shabanova (1963).
- (6) Allen (1963); Hey (1959); Griem (1964b).
- (7) Goldberg *et al.* (1960) where evidence is presented that the $\log gf$ values may possibly be around 0.25 too large.
- (8) Corliss and Bozman (1962); Boyarchuk and Boyarchuk (1960). For λ 4246.83, see also Groth (1961).
- (9) Goldberg *et al.* (1960) to which a correction of -0.25 in converting from relative to absolute has been made for multiplet Nos. 22 and 27; and Allen (1963) plus multiplet calculations.
- (10) Goldberg *et al.* (1960) to which a correction of $+0.12$ in converting from relative to absolute has been made for multiplet 131.
- (11) Penkin (1964) plus the measurements of Hill and King (1951) corrected for temperature error by comparison with those of Charatis and Wilkerson (1962) and reduced to the absolute scale of Lawrence, Link, and King (1965). For λ 4274.81 the measurement of Lawrence *et al.* (1965) is also used.
- (12) Hill and King (1951) corrected and reduced as described in note (11).
- (13) Corliss and Warner (1964) with a correction of -0.20 to adjust their scale to the mean of the absolute determinations for λ 3720 and λ 3737 (Goldberg *et al.* 1960).
- (14) Penkin (1964) and, with lesser weight, King, Parnes, Davis and Olson (1956), each reduced to the absolute scale of Lawrence *et al.* (1965). For all but λ 4020.90 the results of Allen and Asaad (1957) have been considered with low weight.
- (15) The arc measurements of van Driel adjusted by King (1948) and converted to the absolute scale of Lawrence *et al.* (1965). For λ 3243.06 and λ 3320.26 the similarly converted measurements of Penkin (1964) have been given equal weight.
- (16) Ostrovskii and Penkin (1961b); Goldberg *et al.* (1960).
- (17) Relative intensity given by Meggers, Corliss, and Scribner (1961).

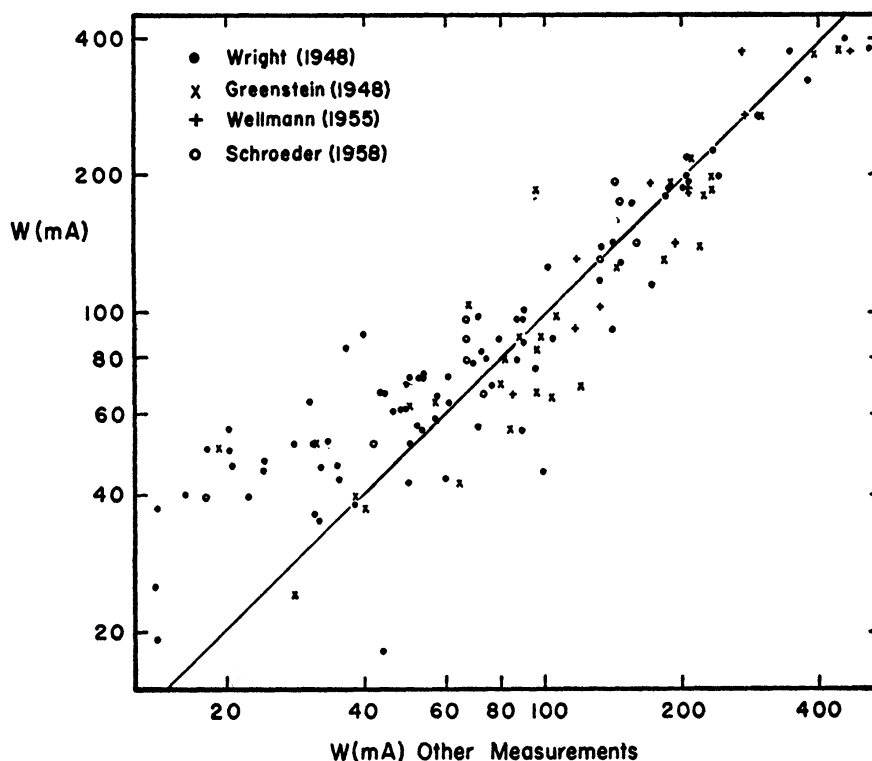


FIG. 1.—Comparison of the equivalent widths W obtained in this investigation with those obtained in previous investigations.

TABLE 4
PROFILES OF H α , H β and Ca II K

H α (4 plates)*			H β (4 plates)†			Ca II K (6 plates)‡		
$\Delta\lambda$ (Å)	Violet		Violet		$\Delta\lambda$ (Å)	Violet		Red
	$r(\Delta\lambda)$	p.e.	$r(\Delta\lambda)$	p.e.		$r(\Delta\lambda)$	p.e.	
00	0.231	0.007	0.141	0.002	00	0.083	0.010	0.010
0.25	.251	.008	.223	.005	0.1	.090	.011	.011
0.50	.379	.034	.368	.005	0.2	.108	.012	.012
0.75	.509	.018	.512	.007	0.3	.122	.011	.012
1.00	.609	.016	.553	.011	0.4	.128	.009	.011
1.25	.655	.014	.567	.014	0.5	.132	.011	.010
1.50	.684	.012	.605	.012	0.6	.139	.012	.010
1.75	.708	.009	.632	.012	0.7	.147	.012	.010
2.00	.727	.010	.654	.012	0.8	.154	.012	.010
2.25	.744	.010	.673	.014	0.9	.164	.011	.009
2.50	.760	.011	.691	.013	1.0	.172	.010	.009
2.75	.776	.012	.705	.013	1.5	.213	.010	.010
3.00	.788	.012	.719	.012	2.0	.260	.010	.011
3.25	.800	.012	.734	.012	2.5	.320	.010	.011
3.50	.810	.012	.762	.014	3.0	.387	.009	.010
3.75	.822	.011	.773	.013	3.5	.457	.009	.009
4.00	.831	.010	.783	.012	4.0	.523	.009	.008
4.50	.846	.009	.793	.011	4.5	.585	.009	.009
5.00	.858	.008	.802	.010	5.0	.640	.009	.008
5.50	.868	.008	.810	.010	5.5	.692	.009	.008
6.00	.880	.007	.817	.010	6.0	.737	.008	.008
6.50	.890	.006	.825	.010	6.5	.776	.007	.008
7.50	.905	.007	.831	.010	7.0	.810	.007	.010
8.50	.917	.006	.838	.009	7.5	.839	.006	.010
9.50	.930	.004	.844	.009	8.0	.864	.006	.010
10.50	.943	.003	.842	.007	9.0	.901	.006	.009
11.50	.949	.007	.857	.008	10.0	.925	.005	.008
12.50	.952	.003	.854	.006	11.0	.939	.004	.006
13.50	.958	.002	.868	.008	12.0	.951	.003	.007
14.50	.966	.002	.880	.008	13.0	.961	.003	.007
15.50	.968	.002	.891	.007	14.0	.969	.003	.008
16.50	.971	.003	.898	.008	15.0	.975	.003	.008

TABLE 4 - Continued

H α (4 plates)*				H β (4 plates) [†]				Ca II K (6 plates) [‡]			
$\Delta\lambda$ ° (A)	Violet		Red	$\Delta\lambda$ ° (A)	Violet		Red	$\Delta\lambda$ ° (A)	Violet		Red
	$r(\Delta\lambda)$	p.e.			$r(\Delta\lambda)$	p.e.			$r(\Delta\lambda)$	p.e.	
17.50	.974	.003	.979	9.00	.908	.008	.911	16.0	.982	.003	0.959
18.50	.977	.002	.983	10.0	.921	.008	.921	17.0	.987	.002	
19.50	.980	.003	.984	11.0	.930	.009	.927	18.0	0.992	0.001	0.008
20.50	.983	.002	.988	12.0	.938	.008	.938				
21.50	.985	.002	.989	13.0	.945	.008	.945				
22.50	.984	.003	.993	14.0	.951	.008	.952				
23.50	.991	.002	0.997	15.0	.957	.006	.960				
24.50	.992	.002		16.0	.960	.006	.964				
25.50	.993	.002		17.0	.963	.005	.969				
26.50	0.996	0.001		18.0	.967	.005	.972				
27.50	1.000	0		19.0	.970	.004	.976				
				20.0	.975	.003	.980				
				21.0	.979	.002	.983				
				22.0	.982	.002	.986				
				23.0	.986	.002	.990				
				24.0	.987	.002	.992				
				25.0	.990	.001	.994				
				26.0	.993	.001	0.998				
				27.0	0.996	0.001					

* $gf = 5.126$ (Allen 1963), RMT multiplet number - (1).+ $gf = 0.955$ (Allen 1963), RMT multiplet number - (1).‡ $gf = 1.5$ (Allen 1963, Ostrovskii and Penkin 1961), RMT multiplet number - (1).

is hoped that modernization of the coudé spectrograph, now in progress at McDonald Observatory, will allow a satisfactory calibration to be placed on the spectrogram.

IV. LINE PROFILES

The instrumental profile of the A camera of the coudé spectrograph was estimated from microphotometer tracings of iron emission lines in the comparison arc. The profiles appeared symmetrical and essentially Gaussian to about 10 per cent of the intensity at the line center, and rough calculations indicate a half-width for the instrumental profile of around 0.11 Å. This, together with representative profile changes caused in sharp lines by adjacency effects as shown in Appendix I (Fig. 5), indicates that reliable line profiles are possible only for the very broad lines. Therefore, profiles are given in Table 4 only for H α and H β (they have appreciably less blending than the other Balmer lines) and for Ca II K. The probable errors of the residual fluxes given in Table 4 have been computed from the range of measured values by the method proposed by Schlesinger (1938). Profiles of the cores of H α and H β have been shown previously (Edmonds 1964),

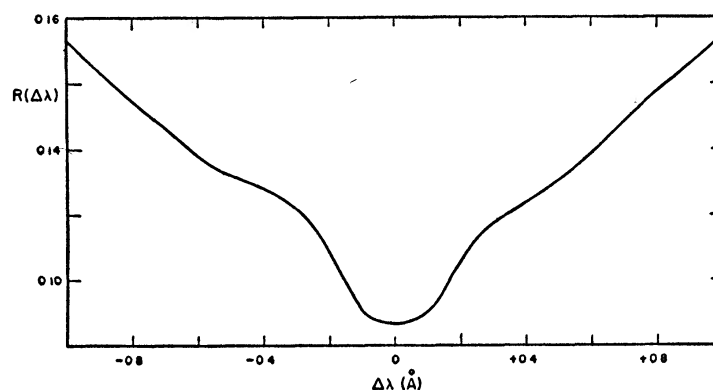


FIG. 2.—The residual flux $R(\Delta\lambda)$ of the center of the Ca II K-line (λ 3933.76) plotted against $\Delta\lambda$, the displacement from the center of the line.

while the center of the Ca II K is shown in Figure 2. The emission in the center of this line, whose width has already been measured (Kraft and Edmonds 1959), is clearly evident in spite of its appreciable reduction by the instrumental profile.

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APPENDIX I

CHANGES IN SPECTRAL-LINE PROFILES AND EQUIVALENT WIDTHS DUE TO PHOTOGRAPHIC ADJACENCY EFFECTS

Photographic adjacency effects have been studied rather extensively (Mees 1954), but because these effects are dependent on the numerous parameters which characterize the development process, their control is primarily a matter of suitable minimizing. For sharp absorption lines the border effect (see Figs. 3 and 6) will increase the density in the wings of lines, thereby reducing the wings, and the fringe effect will reduce the density at the center of the line, thereby increasing the line's central depth. These effects produce changes which are directly opposite to other instrumental effects in that they sharpen the profile. In producing changes in the line's equivalent width the two adjacency effects will tend to cancel, but since the border effect usually predominates, in general, a reduction in equivalent width will occur.

It generally has been accepted that, if care is taken during development to suitably minimize adjacency effects, then their changes to line profiles or equivalent widths will be negligible (Scheffler 1961). On the other hand, there does not seem to be general agreement on a simple development technique which will consistently and uniformly make these effects negligible (except possibly brush development). Rocking of the developer tray during development is one quite commonly used technique, and for conditions fairly representative of the processing of astronomical spectrograms (manual rocking along the dispersion for 3 min. using D-19 developer at 65° F), small but non-negligible adjacency effects were detected at the sharp edges of the calibration spots. Measurements of these effects have been used to calculate the changes that may be expected to the profiles and equivalent widths of sharp spectral lines in order to estimate how adjacency effects will affect the accuracy of line measurements.

It should be emphasized that these calculated changes to line profiles and equivalent widths are for one particular case, and only insofar as this case is typical of the development of astronomical spectrograms do the results of the calculations pertain to other spectrograms, and then only in a qualitative manner. In fact it would be inadvisable to use these results to correct profiles or equivalent widths obtained from this particular spectrogram, as the measurements from the calibration spots indicated that certain aspects of the adjacency effects showed variations over the plate of the same magnitude as the effects themselves. The measurements at the edges of the calibration spots were restricted to the border effect as the fringe effect was almost undetectable because clear plate was nearly zero density. Therefore, a set of pre-exposed calibration plates were also measured for both the fringe and border effects, these plates being of the same emulsion type but from a different batch and being developed in the same manner as, but not simultaneously with, the spectrogram. It was felt that these small differences would not materially affect the desired qualitative results.

Scheffler (1961) has given a semitheoretical analysis of adjacency effects in terms of developer diffusion and its conversion to reaction products. The equations governing these processes were formulated and solutions were obtained, including the case of a sharp edge. The equations neglected any motion induced in the developer (such as rocking the tray) which could not be described as a diffusion process, but this seems reasonable as the adjacency effects result from diffusion which occurred in spite of these motions and so only the effects of these motions on the diffusion need be considered. According to Scheffler's analysis these effects would be accounted for by the empirically determined constants describing the diffusion. His analysis also involved the empirical determination of the additional plate density which would result from a given excess of developer concentration. From measurements and analysis of the sharp edge of a spectrogram, Scheffler found that the border and fringe effects differed only as to magnitude, their variation from the edge being otherwise the same, and that these effects were proportional to the density differences at the edge and to the density, after subtracting out the adjacency effect (D_1 and D_2 in Fig. 3).

A somewhat more empirical approach has been considered here in that the change in density at a point x_1 , $\Delta D(x_1)$, due to a sharp-edge border effect (see Fig. 3) has been considered to be the sum of contributions from locations beyond the sharp edge, i.e.,

$$\Delta D(x_1) = \int_{x_1}^{\infty} F(D_1, D_2, y) dy, \quad (1)$$

where the contribution function $F(D_1, D_2, y)$ represents the total adjacency effect during the development time resulting from the existence at a distance y (or at x_2) of a latent image which after development will have a lower density D_2 (any fringe effect at x_2 not being considered as a first approximation). Presumably a non-zero $F(D_1, D_2, y)$ is caused by the diffusion of the developer across the sharp edge (as modified by systematic motions) which occurred during the development time. An expression for this function can be obtained from equation (1) by differentiation, i.e.,

$$F(D_1, D_2, y = x_2) = -\frac{d}{dx_1} \Delta D(x_1). \quad (2)$$

The following assumptions are made concerning $F(D_1, D_2, y)$:

a) $F(D_1, D_2, y)$ is universal in the sense that it can be applied to situations other than a sharp edge, where D_1 and D_2 are no longer constants. To say that $F(D_1, D_2, y)$ depends only on the variables explicitly stated, $y = |x_2 - x_1|$, $D_1(x_1)$, $D_2(x_2)$, and not on the variation of $D(x)$ for other values of x , is a questionable oversimplification and should be checked by seeing if $F(D_1, D_2, y)$ obtained from one situation (say a sharp edge) would accurately predict the adjacency effects for another situation. The adjacency effects in a sharp spectral line are negligible except at the line center and in the near wings, and at these two locations the developer diffusion should

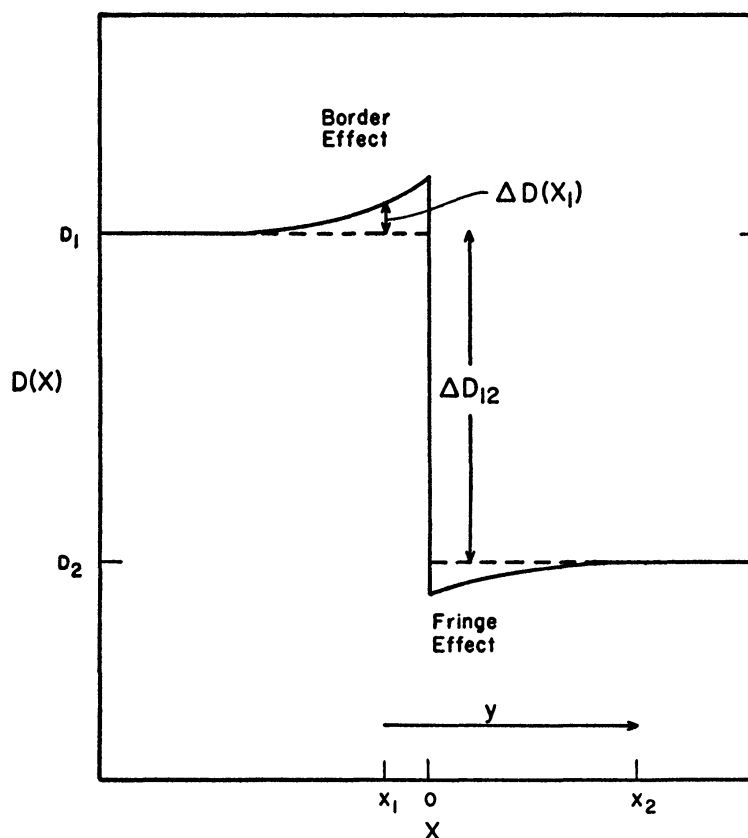


FIG. 3.—An idealized plot of plate density $D(x)$ against displacement x showing the adjacency effects of a sharp edge.

be quite similar to that occurring at a sharp edge. The fact that there are effectively two sharp edges in proximity should give only small deviations from simple additive effects at these locations. Therefore, for the qualitative analysis being carried out, this assumption is considered valid. If this is not the case, the results obtained using this assumption should give an upper limit to adjacency effects, as the sharp edge gives rise to the strongest effects.

b) The fringe effect is considered to be proportional to the border effect for all values of separation y and so both effects can be described by $a(\Delta D_{12}, D_2) F(D_1, D_2, y)$ where $\Delta D_{12} = D_1 - D_2$ and $a(\Delta D_{12}, D_2)$ is negative and generally less than 1 for ΔD_{12} positive (fringe effect) and unity for ΔD_{12} negative (border effect). The measurements of the calibration spots as well as those of Scheffler (1961) confirm this assumption.

c) $F(D_1, D_2, y)$ depends primarily on ΔD_{12} and is essentially independent of the density levels defining ΔD_{12} , and so the final expression describing both adjacency effects would be $a(\Delta D_{12}, D_2) F(\Delta D_{12}, y)$. There was a rather large scatter in the pertinent calibration-spot measurements,

but within the uncertainty associated with such a scatter, no dependence of $F(D_1, D_2, y)$ on the densities, other than the dependence on ΔD_{12} , could be found. Definitely a linear dependence on D_1 , which Scheffler determined from his analysis of sharp edge effects, was not found.

The measurements from the calibration spots of $F(\Delta D_{12}, y)$ and $a(\Delta D_{12}, D_2)$ for ΔD_{12} positive contained some scatter because of the smallness of the effects measured and the variation of the effects over the calibration plates. For $F(\Delta D_{12}, y)$ this scatter was not large except for large values of y and/or ΔD_{12} , and for these values $F(\Delta D_{12}, y)$ either was small or was not used in the spectral-line calculations. A portion of the smooth curves drawn through the measurements are shown in Figure 4. For $a(\Delta D_{12}, D_2)$ the scatter was more serious, and so the resulting smooth

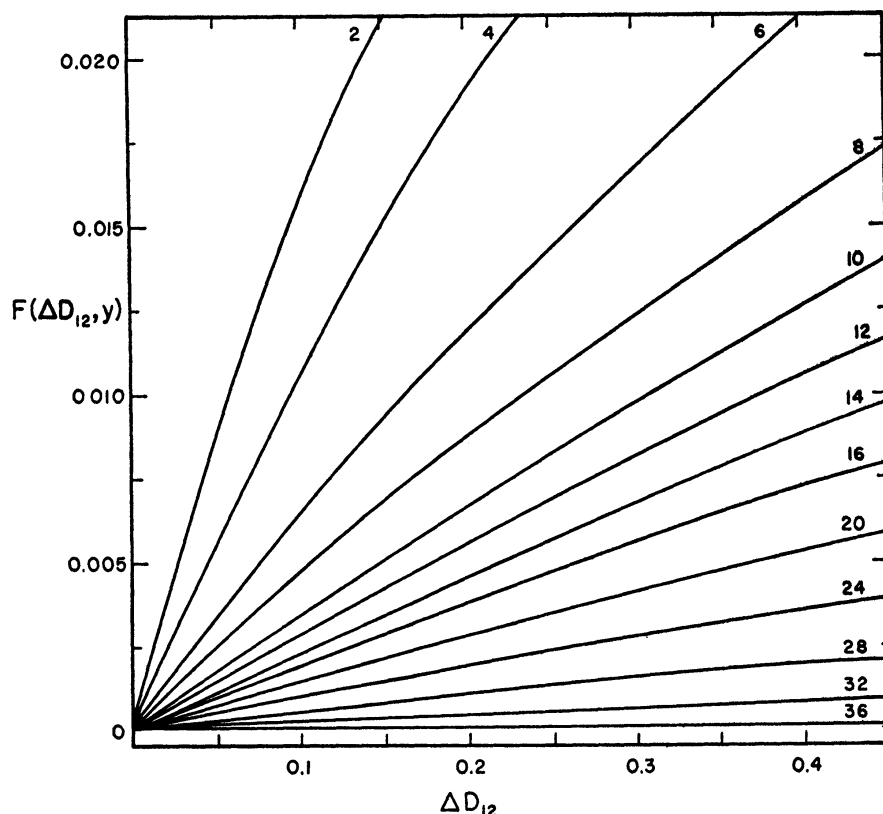


FIG. 4.—The contribution function $F(\Delta D_{12}, y)$ plotted against ΔD_{12} for various values of y . The number identifying each curve is the value of y , the displacement in 10^{-2} mm on the spectrogram.

curves shown in Figure 5 represent the general features of the variations of $a(\Delta D_{12}, D_2)$ but cannot be accepted as quantitatively accurate. Again these results are definitely not in agreement with the relation $a \simeq -D_2/D_1$ obtained by Scheffler.

By use of the results shown in Figures 4 and 5, the adjacency effects on the density within an absorption-line profile can be calculated quite easily from

$$\Delta D(x_1) = \int a(\Delta D_{12}, D_2) F(\Delta D_{12}, y) dy, \quad (3)$$

where now $\Delta D_{12} = D_1(x_1) - D_2(x_2)$, $D_2 = D_2(x_2)$, $y = x_2 - x_1$ and the integration is over the range of y for which $F(\Delta D_{12}, y)$ is non-zero. Because $\Delta D(x_1)$ is quite small, it has been calculated using the measured line profile (including adjacency effects) for $D(x)$. Then the subtracting of $\Delta D(x_1)$ from the measured profile will give an approximate true profile free from adjacency effects. The results are shown in Figure 6 for three representative sharp lines.

The adjacency effects shown in Figure 6 represent an average of such effects over the plate,

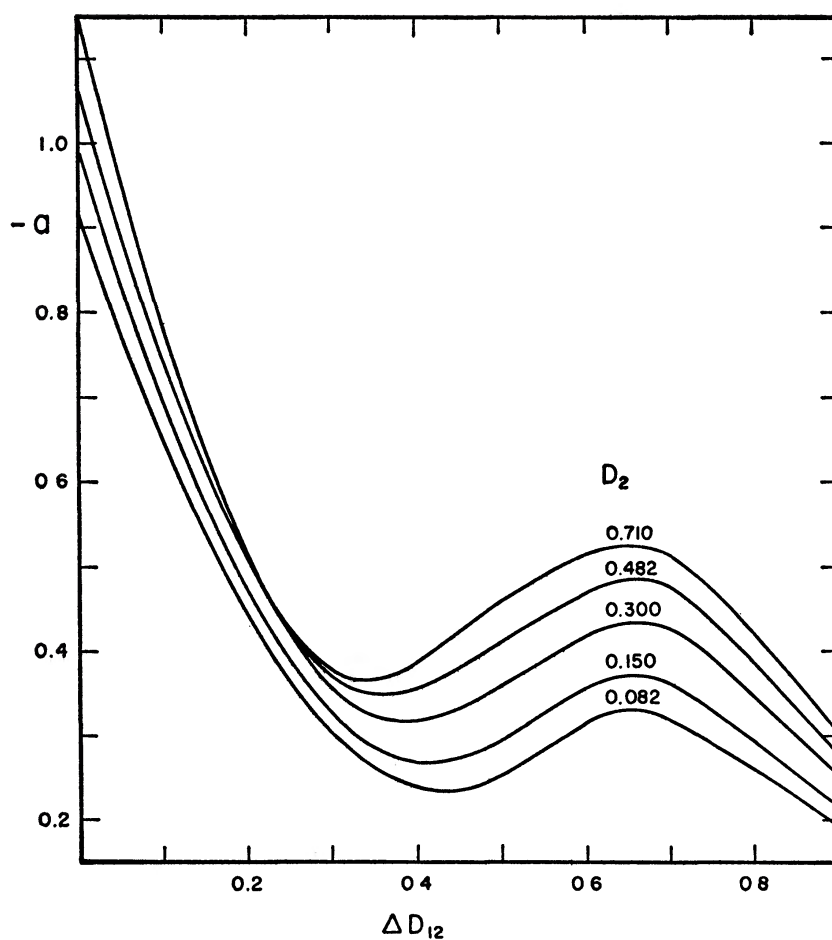


FIG. 5.—The ratio of fringe effect to border effect $a(\Delta D_{12}, D_2)$ plotted against positive ΔD_{12} for the indicated values of D_2 .

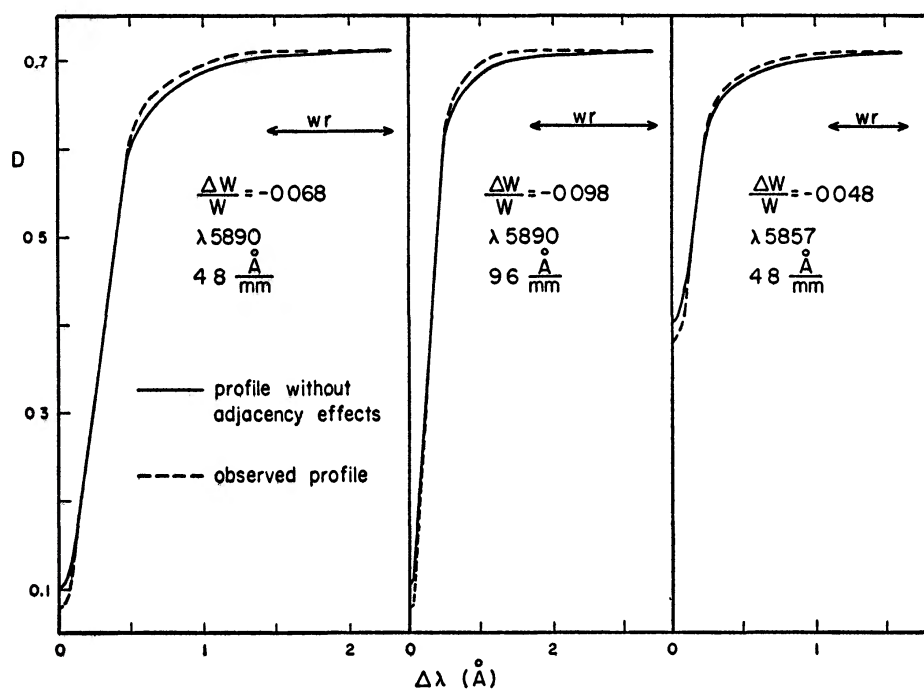


FIG. 6.—The modification of spectral-line profiles by adjacency effects for two representative sharp lines (indicated by wavelength), the changes in one line being shown for two different dispersions. Reductions in equivalent widths $\Delta W/W$ and reduction of wings wr are also shown.

and the scatter in measurements indicates that maximum effects nearly twice as large could occur. The changes in equivalent widths are satisfactorily small, but the changes to profiles are of the same order as other instrumental effects and hence large enough to prevent obtaining accurate profiles. The suppression of the wings of a line is most noticeable and probably explains the triangular profiles or profiles with wings weaker than those of a Gaussian profile which have been noted in spectrophotometric analyses of stellar spectra. Comparing the results obtained for the same line at different dispersions shows that adjacency effects can in part account for the observed systematic decrease in equivalent widths with decreasing dispersion.

APPENDIX II

THE MEASUREMENT OF SCATTERED LIGHT IN THE COUDÉ SPECTROGRAPH AT McDONALD OBSERVATORY

BRETT ROMER* AND JEFFREY D. SCARGLE*

The measurements for the A camera only were made under conditions which matched as nearly as possible the exposure of the Procyon spectrograms. Filters were installed in the spectrograph and grating settings made for proper isolation of the desired dispersions and wavelength regions as indicated in Table 1. The spectral energy distribution of Procyon was roughly matched by observing γ Cygni (cF8p) or using a strip-filament tungsten lamp plus daylight filter. Similar emulsions were used, and all plates were calibrated. Measurements were made from microphotometer tracings of the plates. Two methods for measuring the scattered light were used.

A method proposed by Plaskett (1952) measures the scattered light beyond the sides of the spectrum on the assumption that scattered light in the spectrum is only slightly greater and can be estimated with reasonable accuracy by interpolating between the measurements made at each side. Since this involved comparing a normally exposed plate and a badly overexposed plate, the same exposure time but slit widths differing by a factor of 10 were used, thereby obtaining a known intensity ratio between the plates and avoiding reciprocity failure. It was also necessary to measure the instrumental profile perpendicular to dispersion to correct the scattered-light measurements near the edge of the spectrum. This was done by placing a fine wire of known diameter across the slit (as described by Plaskett). Measurements made from several plates indicated an upper limit for scattered light of 1 per cent for the wavelength ranges indicated in Table 1 and allowed in two cases a determination of the scattered-light level; namely, 0.85 per cent at λ 5800 and 0.7 per cent at λ 4400.

The second method involved placing a 15-cm-long absorption cell in front of the spectrograph which would completely absorb the light in a narrow wavelength band, and thereby allow the measurement of any scattered light which would be detectable on the spectrogram within this band. This method would provide a check on the validity of the assumption underlying the method proposed by Plaskett. The absorbing material used should produce an absorption band at a desired wavelength which will give a transmittance of less than 0.1 per cent, this absorption band should be as narrow as possible and have as sharp cutoffs as possible, and the rest of the visible spectral region should be relatively free of absorption bands. A survey was made of various organic and inorganic solutions, several were tested in the laboratory with a Beckman DK I spectrophotometer, and three were selected. These were (a) anthracene, $C_6H_4:(CH)_2:C_6H_4$, for which a 0.0133 gm/l solution in 95 per cent ethanol gave satisfactory absorption with extremely sharp cutoff for wavelengths below λ 3800, (b) uranyl nitrate $UO_2(NO_3)_2 \cdot 6H_2O$, for which a 10.0 gm/l solution in distilled water gave satisfactory absorption in the wavelength range $\lambda\lambda$ 4000–4300, and (c) praseodymium chloride, $PrCl_3$, for which a 38.93 gm/l solution in distilled water gave satisfactory absorption in the wavelength ranges $\lambda\lambda$ 4400–4700 and $\lambda\lambda$ 5700–5800. Because the tungsten lamp was too faint in the ultraviolet, no results were obtained with

* National Science Foundation Undergraduate Research Participant in the Department of Astronomy of The University of Texas during the summer of 1962.

anthracene plus a Corning 9863 filter. Measurements made with the other two solutions placed an upper limit of around 4 per cent for the strength of scattered light at the wavelengths of their absorption bands. More desirable absorption-cell arrangements could have been obtained employing completely saturated ground-state absorption lines of Na (λ 5890) and K (λ 4044). However, late delivery of unsatisfactory absorption cells prevented the measurement of scattered light with these elements.

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