Equivalent Breadths of Fraunhofer Lines in the Sun's Spectrum.

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The equivalent breadths are given of 462 Fraunhofer lines, distributed over eight different regions of the spectrum of the centre of the Sun's disc. With the aid of these measurements, a calibration in equivalent breadth is given of Rowland's scale of intensities for solar lines, ranging from 3900 Å to 8600 Å.

1. *Definition.*

The intensity of an absorption line, even when it is impossible to determine its true profile, can be suitably expressed in „equivalent breadth", i. e. the total amount of energy absorbed in the line, expressed in terms of the energy contained in one milliangstrom of the adjacent continuous spectrum. This figure should be independent of the finite resolving power of the instrument and, therefore, furnishes an adequate definition of an absorption line intensity.

2. *Apparatus.*

The plates are taken with the vertical solar telescope at Utrecht[1]), focal length 13 m, combined with a spectrograph of the auto-collimation type, focal length 4.5 m and fitted with a Rowland plane grating of $5 \times 8\ \mathrm{cm}^2$ with 568 lines to the mm. In the second order spectrum the dispersion obtained with this instrument is 2 Å pro mm and the theoretical resolving power is 90,000.

3. *Method of measurement.*

The light intensities are obtained from the densities on the photographic plates by methods, developed at the Utrecht Physical Laboratory[2]). Each spectrogram at the same time furnishes its own intensity marks, a Zeiss step-weakener with six steps being put on the slit of the spectrograph. Only „backed" plates have been used to eliminate reflection.

The spectrograms are examined with Moll's microphotometer and the tracings recorded by it are converted into intensity curves in the usual way. Then the equivalent breadth of each line may be found by measuring with a planimeter the area of the profile. We have always tried to investigate only such lines, which are free from blends as much as possible.

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[1]) W. H. Julius, B. A. N. 1, 119, 1922. — [2]) Ornstein, Moll, Burger, Objektive Spektralphotometrie, Braunschweig 1932.

Lines of intensities — 1, — 2 and — 3 on ROWLAND's scale are for the most part so weak, that it is difficult to observe the profile with sufficient accuracy. In such cases we have followed another method: as the contour of these lines is practically determined by the spectrograph, their equivalent breadths can be found with the aid of an empirical relation between equivalent breadth and central intensity, obtained from slightly stronger lines and extrapolated to the point, where both central intensity and equivalent breadth are zero. When it is impossible to observe even the central intensity (as is mostly the case for lines of ROWLAND intensity — 3), the equivalent breadth may sometimes be obtained by comparison with slightly stronger lines of the same multiplet, assuming the equivalent breadths to be proportional to the multiplet numbers, which is true in the case of weak lines.

The influence of the light, scattered in the spectrograph, is diminished by the use of diaphragms and colour filters.

4. *Sources of Error.*

The principal sources of error in measurements of intensity are:

a. The ghosts of the grating, filling up the lines and making the measured equivalent breadths too small; for our grating the correction in the second order is 4 per cent.

b. Effects of development, especially those decribed by EBERHARD; we always avoided strong contrasts and from the parallelism of the standardising curves of the same plate concluded that the effects were small.

c. Uncertainty about the hypothetical continuous background, especially in regions where the lines are crowded together.

d. Blends — of which the wings of FRAUNHOFER lines are practically never free; together with c. this may cause a considerable error in the equivalent breadth.

5. *Preliminary measurements.*

Several spectrograms of the same spectral region have been taken under quite different circumstances.

a. Order of the grating. 21 lines at λ 5200 were examined both in the first and second order spectrum. Mean value of I/II = 1.05 indicating a systematic difference of 5 per cent. After allowing for this the remaining accidental errors average 7 per cent. 15 lines at λ 3900 were examined both in the second and third order spectrum. Mean value of II/III = 1.16 indicating a systematic difference of 16 per cent. The remaining accidental errors average 8 per cent.

b. Magnifying camera[1]). 27 lines at λ 4500 were recorded with a camera, enlarging the spectrum about six times and thus diminishing the effects of development, grain of the plate, etc. The mean ratio of the equivalent breadths thus measured, to the equivalent breadths obtained without enlargment in the usual way, is 1.05, indicating a systematic difference of 5 per cent. The remaining accidental errors average 18 per cent.

c. Development. 30 lines at λ 5800 were investigated from two plates, both taken in the second order spectrum; the one was developed with adurol (strong contrast, A), the other with rodinal (little contrast, R). The mean value of the ratio A/R is 1.08, the remaining accidental errors average 9 per cent.

d. Investigation of standardising curves. Several times auxiliary intensity marks were obtained with a much wider slit, combined with a neutral filter so that the same exposure time could be used as for the spectrogram under investigation. The resulting standardising curve was practically the same as the curve from the original spectrogram with narrow slit on the same plate, showing that the slit jaws were sufficiently parallel. A standardising curve was never used over a region greater than 100 Å. Besides, a difference of 100 or 200 Å did not much alter the form of the curve. Often the equivalent breadth of a FRAUNHOFER line was examined from photometer tracings of each of the six steps of a same spectrogram. The results always were consistent within about 10 per cent, showing the correctness of the standardising curve.

e. Resolving power of the spectrograph. From the spectrograms with narrow and wide slit, mentioned above, resulted that the equivalent breadths did not depend upon the resolving power of the instrument. This was also shown by MINNAERT[2]).

f. Photometer. Variation of velocity, width of the slit, etc. of the microphotometer within certain limits did not affect the results.

g. Comparison of grating and prism spectrograph. MINNAERT and VAN ASSENBERG have found[3]), that the equivalent breadths, obtained with a grating and with a prism spectrograph, did not differ systematically.

h. Accidental errors. A special investigation of the accidental errors has been carried out by photographing a certain spectral region several times under the same circumstances. The results are put together in Table I. The first column gives the number of lines, each of which is measured

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[1]) B A N. **5**, 175, 1930. — [2]) MINNAERT, ZS. f. Phys. **45**, 610, 1927. — [3]) MINNAERT and VAN ASSENBERG, ZS. f. Phys. **53**, 248, 1929.

twice in circumstances, described in the second column. The third one gives the mean accidental error. From the total number of 47 lines a mean accidental error follows of 8 per cent.

Table 1.

Number	Circumstances	Mean acc. error
13	2 spectrograms on 1 plate, first order	8 per cent
21	2 „ „ 1 plate, second order	9 „ „
13	2 „ „ 2 plates, „ „	7 „ „

Conclusion. It is difficult, to estimate the error in the final results of measurement, because it is impossible to make a quantitative investigation of most of the sources of error. It seems improbable to us, however, that the deviations from the real equivalent breadths should be more than 20 per cent. Within a certain spectral region the systematic errors are about the same for all the lines and the ratios of the equivalent breadths will have a greater precision.

6. *The set of Plates.*

First we shall give a table of the set of plates, from which the final results were obtained. In the columns of Table II are to be found:

1. the mean wave-length of the spectral region;
2. the order of the grating;
3. particulars about the plates; the meaning of the symbols is:
   Isp. = Ilford special rapid;
   Ip. = Ilford rapid proces panchromatic;
   Ke. r. = Eastman Kodak extreme red;
   Ki. r. = Eastman Kodak infra red, sensibilised with ammonia;
4. the width of the slit — unity 0.01 mm;
5. the exposure time in seconds; at λ 3900 two spectrograms had to be taken with different exposure time, because of the rapid change of the sensibility of the plate;
6. the developer that was used:
   R = Rodinal (little contrast),
   A = Adurol (strong contrast);
7. the date of exposure;
8. particulars of the spectrograms:
   Z = intensity marks obtained with wide slit and special filter;
   V = spectrogram obtained with magnifying camera.

Table 2. The set of plates.

λ	Order	Plate	Slit in 0.01 mm	Exposure time in sec	Devel.	Date	
3900	II	Isp.	5	10; 20	*R*	2—11—'29	
	III	Isp.	3	90; 270	*R*	2—10—'30	*Z*
4500	II	Ip.	5	360	*R*	3— 2—'30	*V*
	II	Ip.	5	420	*R*	3— 2—'30	*V*
5200	I	Ip.	3	90	*R*	1—10—'29	
	II	Ip.	5	120	*R*	21—10—'29	
5700	II	Ip.	4	390	*R*	27— 3—'31	*Z*
	II	Ip.	5	300	*A*	21— 5—'31	
5900	II	Ip.	5	300	*R*	27— 3—'31	*Z*
	II	Ip.	5	300	*A*	21— 5—'31	
6650	II	Ip.	5	600	*A*	13—10—'31	*Z*
	II	Ip.	4	600	*R*	22—10—'31	*Z*
7750	II	Ke. r.	5	600	*R*	28— 9—'33	
8600	II	Ki. r.	5	2700	*R*	19—10—'33	

7. *Equivalent breadths of* 462 *FRAUNHOFER lines.*

(Table 3 as for as 9 incl.).

Eight regions of the solar spectrum have been chosen (Table 2) and in each of these a number of FRAUNHOFER lines has been measured. The wave-length of the lines, taken from the *Revised ROWLAND Table* (R. R. T.) is given in the first column of the following tables. The second column gives the measured equivalent breadth in milliangstroms.

Table 3. Equivalent breadth (I) of 62 FRAUNHOFER lines at $\lambda = 3900$ Å.

λ (R. R. T.)	I in mA	λ (R. R. T.)	I in mA	λ (R. R. T.)	I in mA	λ (R. R. T.)	I in mA
3856.383	545	3901.600	74	3922.925	315	3948.284	39
59.924	1070	02.264	85	24.535	89	48.476	5
85.521	73	02.958	470	24.792	4	49.963	118
86.296	832	05.534	662	25.016	4	51.966	59
86.806	24	06.492	260	25.211	84	53.505	43
87.061	273	07.480	77	33.684	15900	53.865	52
90.851	77	03.764	110	37.339*	40	54.544	20
91.200	57	09.287	23	40.043*	27	54.721	30
91.513	43	12.296	76	40 892*	102	55.022	6
91.936	105	12.983	57	41.498*	65	55.347	117
92.593	44	14.015	60	44.018	384	55.768	8
94.495	40	14.956	10	46.461	5	55.965	62
96.783	16	15.220	46	46.555	9	57.043	124
97.462	120	16.739	116	46.662	12	68.494	11000[1])
99.721	426	17.593	23	47.004	97		
3900.543	202	20.271	281	48.111	110		

[1]) Determined from the equivalent breadth of the K line by dividing this value by $\sqrt{2}$.

Table 4. Equivalent breadth (I) of 57 FRAUNHOFER lines at $\lambda = 4500$ Å.

λ (R. R. T.)	I in mA	λ (R. R. T.)	I in mA	λ (R. R. T.)	I in mA	λ (R. R. T.)	I in mA
4383.559	1044	4470.489	74	4497.682	22	4523.409	33
4404.763	649	70.860	57	4500.644	13	27.789	17
15.137	405	71.246	34	01.280	151	28.629	260
42.351	181	75.309	12	02.226	52	31.634	60
43.814	155	78.027	18	04.840	41	34.789	110
47.730	181	80.590	32	08.691	13	45.964	84
56.335	49	80.828	32	09.744	35	47.856	92
56.629	75	84.229	92	11.902	45	48.775	61
57.044	32	85.685	78	15.345	88	50.776	68
59.757	42	89.750	85	16.273	16	51.231	16
61.662	136	90.091	74	16.662	20	54.038	175
65.816	31	91.410	79	17.157	30	4602.951	111
66.942	59	92.690	25	17.537	68		
68.502	140	94.575	191	18.034	61		
70.140	53	96.862	128	18.344	48		

Table 5. Equivalent breadth (I) of 47 FRAUNHOFER lines at $\lambda = 5200$ Å.

λ (R. R. T.)	I in mA	λ (R. R. T.)	I in mA	λ (R. R. T.)	I in mA	λ (R. R. T.)	I in mA
5154.077	86	5180.071	48	5213.353	6	5239.825	55
55.134	50	83.621	1500	14.620	12	42.501	93
55.773	83	85.910	64	15.190	156	43.785	66
59.065	82	87.919	59	16.285	135	47.060	64
62.283	190	91.467	242	17.398	115	47.576	77
65.417	111	92.355	276	18.211	57	50.656	101
66.286	137	92.980	96	21.770	24	53.470	82
67.330	600	94.951	142	23.193	26	61.710	109
71.612	164	98.718	98	25.535	68	63.316	138
72.700	1140	5206.046	244	29.862	123	66.565	242
73.751	70	10.394	89	32.954	323	69.552	429
76.567	59	11.537	29	34.632	92		

8. Comparison with measurements of other investigators.

Systematic measurements of equivalent breadths of FRAUNHOFER lines have also been carried out by RIGHINI at Arcetri[1]) and by WOOLLEY at Cambridge[2]).

a. RIGHINI has investigated the Mg triplet (5167, 5172, 5183) and 87 other lines between 5290 and 5470 Å. Only a few of these lines have been measured by us[3]), the number being too small for a calibration in that

[1]) RIGHINI, Osserv. e Mem. del R. Osserv. Astrof. di Arcetri 1931, p. 31; 1933, p. 59. — [2]) WOOLLEY, Annals of the Solar Physics Obs., Cambridge III, Part II, p. 79, 1933 — [3]) MINNAERT and MULDERS, ZS. f. Astrophys. 1, 192, 1930

Table 6. Equivalent breadth (I) of 202 FRAUNHOFER lines between $\lambda = 5565$ and 6027 Å.

λ (R. R. T.)	I in mA	λ (R. R. T.)	I in mA	λ (R. R. T.)	I in mA	λ (R. R. T.)	I in mA
5565.715	108	5648.581	14	5748.364	27	5848.126	40
66.088	23	49.090	13	52.043	62	52.232	46
67.402	73	49.684	40	53.135	92	53.691	67
68.872	15	49.999	41	53.649	51	55.090	21
69.633	194	50.697	46	54.669	80	56.100	36
72.853	260	51.477	27	56.831	32	57.462	173
76.101	127	52.330	30	60.362	27	58.790	13
77.035	19	53.877	44	60.843	39	59.600	83
78.731	57	55.186	68	62.426	33	62.371	95
81.981	98	55.502	84	71.609	10	63.956	3
84.775	41	57.883	78	72.152	54	66.464	48
86.773	240	59.605	27	74.039	13	67.091	5
87.583	46	61.358	27	75.091	66	67.573	32
87.870	67	62.527	108	78.466	22	89.977	700
88.766	175	62.942	60	81.190	20	95 944	550
89.368	37	64.012	43	83.077	32	5902.482	16
90.128	105	65.566	42	83.870	45	05.684	64
93.748	50	67.157	41	84.670	33	06.844	17
5601.288	121	69.043	41	84.980	42	16.262	56
03.779	22	70.859	24	85.289	55	27.800	43
07.673	14	75.437	66	85.739	42	29.686	44
08.982	11	77 705	9	87.024	11	30.194	94
14.284	19	78.407	12	87.930	50	34.669	81
14.784	48	79.034	70	93.083	49	43.602	9
15.661	291	82.211	60	93.926	35	48.552	98
18.645	53	82.650	127	5805.228	39	52.730	66
19.611	43	84.201	43	06.736	56	53.174	30
20.500	47	84.496	67	09.228	51	56.709	51
24.033	59	86.543	81	09.878	2	65.840	30
24.559	152	88.220	135	10.798	6	74.279	12
25.331	45	90.435	58	11.927	14	75.356	54
25.691	30	91.508	45	14.016	6	76.791	75
27.646	26	93.653	51	14.819	21	78.554	24
28.358	18	94.994	48	15.229	9	83.693	78
28.654	15	5701.111	42	15.658	5	84.830	97
33.956	75	01.559	97	15.874	2	87.075	80
35.834	36	02.331	27	16.384	81	91.383	36
36.708	27	03.590	34	17.087	14	96.745	21
37.126	36	04.748	22	27.886	10	6003.027	90
37.417	49	05.476	49	31.610	28	05 556	24
38.274	80	08.408	80	34.040	22	07.322	25
40.324	25	11.098	120	35.114	14	07.973	63
40.992	46	11.887	92	35.434	8	08.572	96
41.450	75	12.141	58	36.779	3	12.238	23
41.898	34	15.097	78	37.214	3	13.503	90
42.391	15	17.844	66	37.714	10	16.653	103
43.088	19	39.486	7	38.385	20	21.808	104
45.621	40	39.988	10	43.227	7	24.073	125
46.690	14	41.858	34	45.974	5	27.064	72
47.243	15	42 972	17	46.276	5		
48.289	9	43.943	6	47.010	21		

Table 7. Equivalent breadth (I) of 42 FRAUNHOFER lines at $\lambda = 6650$ Å.

λ (R. R. T.)	I in mA	λ (R. R. T.)	I in mA	λ (R. R. T.)	I in mA	λ (R. R. T.)	I in mA
6569.232	93	6606.988	13	6669.319	6	6715.395	32
72.804	30	08.053	18	78.007	143	16.261	18
74.243	28	09.126	75	80.164	6	17.697	120
81.226	19	25.048	16	96.041	41	19.640	14
87.638	12	27.569	28	98.678	24	21.853	48
91.349	9	35.146	29	6703.585	39	24.694	8
92.934	120	43.648	98	04.509	6	25.373	24
93.982	86	46.975	9	05.120	49	26.682	55
97.580	45	53.920	11	10.332	12	29.028	9
98.621	24	67.749	11	13.053	33		
6604.609	39	68.409	6	13.754	24		

Table 8 Equivalent breadth (I) of 25 FRAUNHOFER lines at $\lambda = 7750$ Å.

λ (R. R. T.)	I in mA	λ (R. R. T.)	I in mA	λ (R. R. T.)	I in mA	λ (R. R. T.)	I in mA
7680.267	82	7723.211	43	7774.177	74	7832.207	154
91.562	120	27.616	97	75.394	65	36.139	44
98.977	152	42.722	103	80.567	135	49.984	62
7710.367	75	48.284	105	88.933	95	55.392	36
11.737	47	48.894	84	97.587	80		
14 309	115	51.117	45	99.995	51		
15.577	49	71.954	78	7807.915	60		

Table 9. Equivalent breadth (I) of 27 FRAUNHOFER lines at $\lambda = 8600$ Å.

λ (R. R. T.)	I in mA	λ (R. R. T.)	I in mA	λ (R. R. T.)	I in mA	λ (R. R. T.)	I in mA
8468.417	123	8526.675	63	8582.271	72	8616.280	49
96.997	38	36.161	37	92.971	60	21.617	71
98.060	1180	38.023	20	95.967	43	48.472	159
8501.556	28	39.90	24	98.835	63	62.170	2640
02.228	48	42.132	3440	8610.609	42	74.757	126
14.082	107	46.228	26	11.813	105	88.641	248
15.121	73	56.790	135	13.944	42		

region: for this reason they have not been included in the foregoing tables. Nevertheless we can use these lines for a comparison. The columns of Table X give: for the lines resp. the wave-length λ, the ROWLAND intensity R, the equivalent breadth according to MULDERS and to RIGHINI and the ratio of these two values. The mean ratio is found to be 1.11, indicating a systematic difference of about 10 per cent. It is not clear, what may be the cause of this difference. The method of measurement was the same in both cases, though RIGHINI has not corrected for the ghosts of his grating (which he has stated to be weak) and has not used backed plates. Nevertheless we have included the whole of RIGHINI's values, divided by a factor 1.11, in our calibration.

Table 10. Comparison of measurements at Arcetri and at Utrecht.

λ	R	I (Mulders)	I (Righini)	$I_{Righini}$ / $I_{Mulders}$
5171.612	6	164	160	0.97
72.700	20	1140	1380	1.20
73.751	2	70	74	1.06
83.621	30	1500	1580	1.05
5307.371	3	103	108	1.05
24.193	7	272	348	1.28
28.053	8d?	325	401	1.24
71.503	7	288	342	1.19
97.143	7d?	220	274	1.25
5432.550	1Nd?	50	56	1.12
32.956	2	92	91	0.99
34.536	5	226	218	0.96
46.926	6d?	312	291	0.93
63.291	3	138	175	1.27

Table 11. Comparison of measurements at Cambridge and at Utrecht.

λ	R	I (Mulders)	I (Woolley)	$I_{Woolley}$ / $I_{Mulders}$
4383.559	15	1044	924	0,89
4456.629	2	75	57	0,76

b. WOOLLEY's measurements have been carried out between 4040 and 4400 Å. Only two of his lines were also investigated by us and so a comparison is hardly possible (Table 11). A conclusion is, therefore, not justified and we were not able to use WOOLLEY's rich material (131 lines) for our calibration.

In § 10 it will be shown, that there is a systematic difference between WOOLLEY's calibration and the one, obtained by us from interpolation between 3900 and 4500 Å., the causes of which will be discussed.

9. *Calibration of ROWLAND's scale of intensities.*

Each line, of which the equivalent breadth has been measured, can be represented by a dot in a diagram, plotting the equivalent breadth I against the wave-length λ. As ROWLAND's estimates are rather rough, the dots representing lines of a same ROWLAND intensity will show a rather irregular spreading round a mean curve. For the sake of distinctness only these mean curves are reproduced in fig. 1.

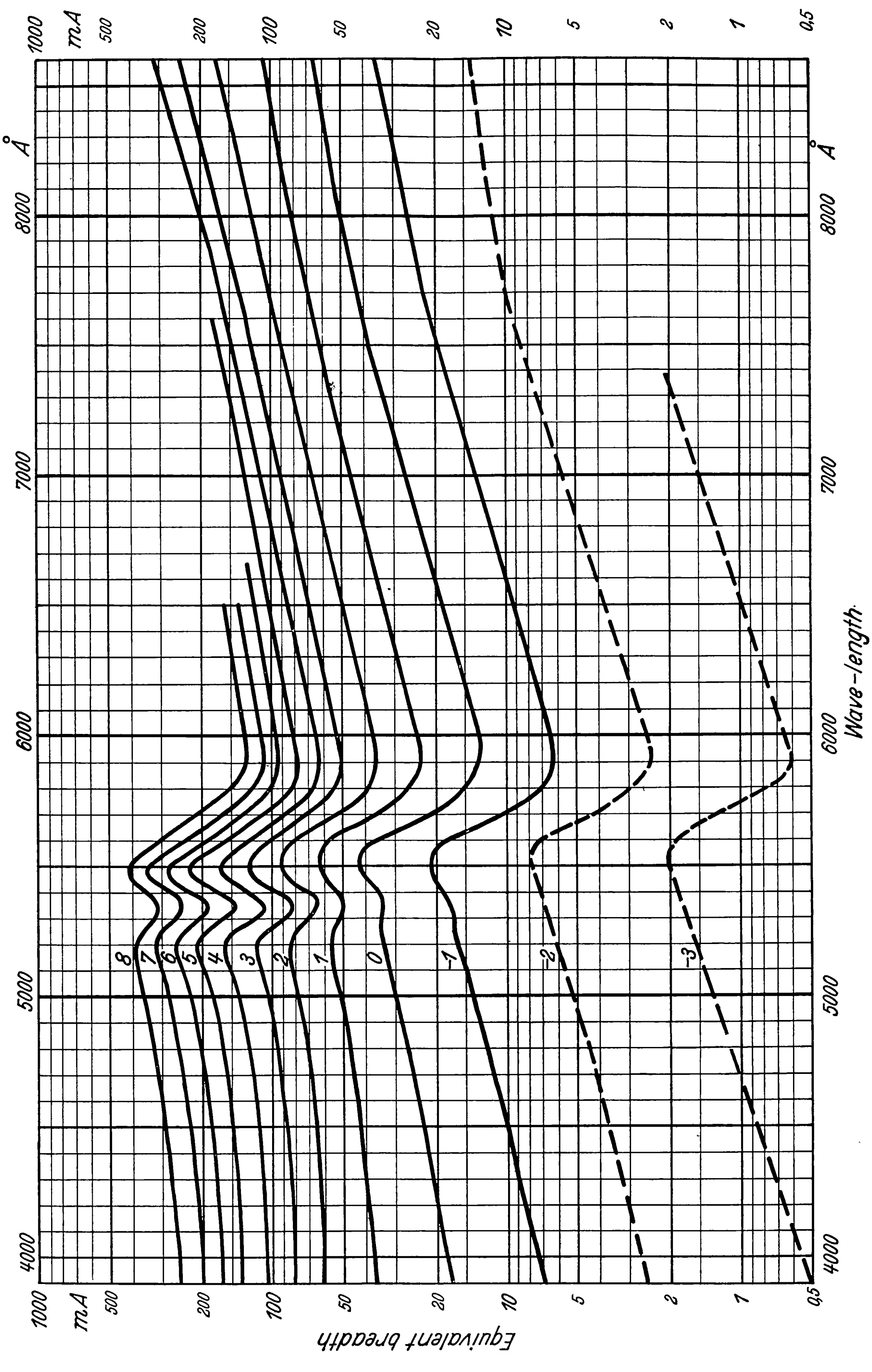

Fig. 1. Calibration of Rowland's scale in equivalent breadth as a function of wave-length.

Lines in the shadow of very strong absorption lines in the solar spectrum, indicated by an asterisk in Table 3, have been omitted. In such cases, taking the wing of the neighbouring line as continuous background, the equivalent breadth seems to be 30 to 50 per cent less than would correspond to the Rowland intensity.

The curves — 2 and — 3 have been dashed, because for such weak lines the equivalent breadths are uncertain. The abrupt end of the curves — 3, 5, 6, 7 and 8 at a certain wave-length means, that no more lines of such Rowland intensities occur beyond that wave-length (apart from atmospheric lines).

As is seen from fig. 1, the equivalent breadth corresponding to a certain Rowland intensity, does not remain a constant for different wave-lengths. Its value increases gradually from the ultra violet to 5200 Å., then follows a decrease of about 40 per cent in total to 5350 Å., the place of the first minimum[1]). At 5500 Å. there is a maximum again, lying somewhat higher than the maximum at 5200 Å. Then follows a strong decrease to 5900 Å., the second minimum, where the equivalent breadth corresponding to a certain Rowland intensity is only $^1/_3$ of its value in the maximum at 5500 Å. From 5900 Å. onwards to the red and infra red follows again a steady increase: at 8600 Å. the equivalent breadths for the same Rowland intensity are nearly 5 times as large as at 5900 Å.

In the region from 5500 Å. to 5900 Å., where the unexpected drop in the curves occurs, practically all the available lines were measured.

The characteristic form of the curves must, undoubtedly, be attributed to some typical qualities of the plates, used by Rowland for his estimates. On looking at a photography of a Fraunhofer line, an observer will get an impression of its intensity, which is a rather complicated function of the real intensity distribution in the line and of the gradation of the photographic plate. When the gradation is weak, a much greater intensity ratio between a point in the line and the continuous background is required in order to give the same contrast. The maxima of our curves near 5200 and 5500 Å. are, therefore, probably due to the small gradation of most plates in this region. The subsequent minima at 5350 and 5900 Å. would then be due to a sensibilised green and yellow region[2]).

[1]) The calibration in this paper is an improvement of our preliminary calibration in ZS. f. Astrophys. **8**, 62, 1934, where this first minimum was not yet found. — [2]) The general character of the curves does not vary much, if the equivalent breadths are expressed in frequency units.

A numerical calibration is given in Table 12. The values are taken from fig. 1 at the wave-lengths, where measurements have been made. The last column gives the error, which may be expected, when the calibration is used to derive the equivalent breadth of a certain FRAUNHOFER line of known ROWLAND intensity. This error is mainly due to the fact, that one unit of ROWLAND's scale corresponds to a difference of 20 to 100 per cent in the equivalent breadth. The values of this error have been obtained by averaging, regardless of sign, for all the investigated lines the differences between the measured equivalent breadths and the mean curves of fig. 1. As one would expect from the parallelism of the calibration curves, the error does not depend much on the wave-length; so for each ROWLAND intensity only one value is given in the last column of Table 12. For the lines of ROWLAND intensities — 2 and — 3 only a very rough estimate was possible.

Table 12. Calibration of ROWLAND's scale in equivalent breadth (mA) for the investigated regions of the spectrum.

$R \backslash \lambda$	3900	4500	5200	5350	5500	5600	5700	5800	5900	6000	6700	7600	8600	Error in %
—3	0.5	0.8	1.5	1.7	2.0	1.8	1.2	0.7	0.6	0.7	1.2	—	—	100
—2	2.5	3.6	6.0	7.0	7.6	7.0	4.0	2.9	2.4	2.5	4.4	9	14	55
—1	7.0	10	16	17	21	18	10	7.0	6.2	6.4	10.6	21	35	34
0	17	23	34	34	42	36	21	15	13	13	21	40	65	25
1	36	42	56	49	63	57	36	26	23	24	38	66	108	20
2	60	65	84	64	92	80	52	38	36	37	56	96	170	19
3	81	88	118	81	127	104	71	53	51	52	75	127	245	16
4	106	115	160	108	168	128	88	66	63	65	94	155	310	15
5	135	150	210	145	225	158	109	82	78	81	110	180	—	15
6	165	184	260	190	280	190	135	102	94	96	128	—	—	16
7	200	230	320	242	340	235	164	121	110	112	—	—	—	17
8	250	285	380	305	410	300	208	150	130	130	—	—	—	20
10	340	649	—	—	—	—	—	—	—	—	—	—	—	—
12	470	—	—	—	—	—	—	—	—	—	—	—	1180	—
15	680	1040	600	—	—	—	—	—	—	—	—	—	2640	—
20	1070	—	1140	—	—	—	—	550	—	—	—	—	3440[1])	—
30	—	—	1500	—	—	—	—	700	—	—	—	—	—	—

10. *Comparison with calibrations of other investigators.*

a. From his material between 5288 and 5472 (§ 8) RIGHINI has given a calibration for this region (second column of Table 13). As a region of 200 Å. is rather large to be averaged. I have divided RIGHINI's material into two groups, each of 100 Å: 5288—5380 Å. and 5380—5472 Å. So we obtain two new calibrations, which are given in the third and fourth column of Table 13.

[1]) Ca^+, $\lambda = 8542$, $R = 16$.

Table 13. New reduction of RIGHINI's material.

R	$I_{Righini}$ (5380)	I (5325)	I (5425)	R	$I_{Righini}$ (5380)	I (5325)	I (5425)
—1	15	—	—	4	161	111	176
0	38	39	37	5	198	166	222
1	59	60	56	6	246	203	279
2	77	65	95	7	321	—	—
3	102	90	120	8	401	—	—

It is seen, that the equivalent breadths at 5325 Å. from $R = 2$ are systematically less than at 5425 Å.: this phenomenon is too evident to be accidental and the number of lines is sufficient to consider it as real.

As was already stated in § 8, RIGHINI's measurements, divided by a factor 1.11, have been included in our calibration.

b. WOOLLEY, from the equivalent breadths of 131 lines between 4040 and 4390 Å. (§ 8), has given a calibration for $\lambda = 4200$ Å. (second column of Table 14). A dividing of the material into two groups does not give a difference here. Our calibration for this region, which is obtained by interpolating between 3900 and 4500 Å., is given in the third column. The ratio of the two is given in the last column: it is seen, that WOOLLEY's equivalent breadths are systematically *less* than our values. For lines of ROWLAND intensities 1 as for as 4 incl. this ratio is 0.69 in the mean, indicating a systematic difference of about 30 per cent.

Table 14. Comparison with WOOLLEY's calibration (4200 Å).

R	$I_{Woolley}$	$I_{Mulders}$	$\frac{I_{Woolley}}{I_{Mulders}}$	R	$I_{Woolley}$	$I_{Mulders}$	$\frac{I_{Woolley}}{I_{Mulders}}$
1	30	39	0.77	4	72	110	0.65
2	42	62	0.68	5	114	140	0.81
3	54	83	0.65	6	144	172	0.83

I have written to Dr. WOOLLEY about this disagreement and in a letter, which he has kindly given permission to quote, Dr. WOOLLEY has communicated to me some unpublished material, which is given in Table 15. WOOLLEY's original measurements were made from spectrograms, taken by EVERSHED with liquid prisms (third column). Recently WOOLLEY has made a comparison between these results and measurements of spectrograms, taken by him at Cambridge with glass prisms (fourth column). The equivalent breadths then found by him are much higher indeed than his former measurements would indicate. Excluding the strong Ca line

4227, the mean value of the ratio I_{liquid}/I_{glass} comes out to be 0.71, in good agreement with my results (0.69). For stronger lines the effect seems to become smaller (Table 15, Table 14 and Table 11).

Table 15. Comparison, by WOOLLEY, of equivalent breadths of some FRAUNHOFER lines, measured with liquid and with glass prisms (unpublished).

λ	R	I_{liquid}	I_{glass}	$\frac{I_{liquid}}{I_{glass}}$
4231.956	1	26	41	0.64
31.028	4 N	55	86	0.64
26.742	20 d	1040	1200	0.87
22.223	5	126	163	0.77
12.644	3 N	59	84	0.70
08.612	3	55	85	0.65
07.409	1 N	32	50	0.64
07.135	3	53	72	0.73

WOOLLEY has had no opportunity to continue this investigation. He ends his letter as follows: „What figures there are, however, go to show that the liquid prisms may be unreliable and that they give too small an equivalent breadth.“

Some unpublished measurements of Miss ELINK SCHUURMAN (Utrecht) from spectrograms, taken by MINNAERT at Potsdam, show the same effect: WOOLLEY's values for the same lines are about 40 per cent less.

The effect must have been caused by light, scattered by the liquid from the continuous spectrum into the lines. This may be produced by any irregularity in the liquid, and it will affect a stronger line less than a weaker one.