UNITED STATES DEPARTMENT OF COMMERCE • John T. Connor, *Secretary*
NATIONAL BUREAU OF STANDARDS • A. V. Astin, *Director*

THE SOLAR SPECTRUM 2935 Å to 8770 Å

Second Revision of Rowland's Preliminary Table of Solar Spectrum Wavelengths

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VISIBILITY OF THE LINES IN THE SPECTRUM

With a medium sized solar spectroscope, about 4000 spectral lines can be seen from the violet to the red, about 3900Å to 7100Å wavelength. Optics assume a grating of 32x30mm ruled area with 1200 gr/mm, 5000Å blazed, 90% theoretical resolution, ten micron slit, lens of about two meters f. l. For a reduced width of less than 1.0, the spectral lines will be very faint and will not be seen. For about 1.0, the lines will be a faint grey and barely seen. For greater than 2.0, the lines will be black and easily seen.

Fredrick N. Veio, 2002

Foreword

The present Monograph has been prepared in response to a request by the International Astronomical Union. At the Seventh General Assembly of this Union, held in 1948 in Zürich, Switzerland, the following proposal from the Commission on Solar Radiation and Spectroscopy was adopted: "La Commission considère que la publication d'une table révisée du spectre solaire dans le plus court délai possible est de la plus haute importance pour les astronomes qui s'occupent de recherches sur le soleil et sur les spectres stellaires . . . .".

It was further stipulated that such a revision should "contain wavelengths on the scale of 1928, measured intensities or equivalent widths from Utrecht, and definitive identifications from Moore-Sitterly".

The authors have made every effort to carry out the above recommendations. Throughout the span of years since this solar program was started the data collected for the *Atomic Energy Levels* project, which has been carried out simultaneously, have aided greatly in the identification work.

The generous support of the International Astronomical Union is warmly acknowledged. This compendium could not have been completed without the equally cordial cooperation of the Utrecht Observatory and the Spectroscopy Section at the National Bureau of Standards.

A. V. Astin, *Director*

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Contents

List of Tables

List of Figures

The Solar Spectrum 2935 Å to 8770 Å

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The present compendium of solar spectrum wavelengths and intensities is essentially a second revision of Rowland's Table, corrected and supplemented by material from the Utrecht Photometric Atlas [1].[1] Approximately 24,000 lines are listed. In a number of cases new wavelengths were determined. Measured equivalent widths from the Atlas records replace the Rowland estimated line intensities recorded in the 1928 revision. From these directly measured equivalent widths have been derived reduced widths, which, if necessary, were corrected for disturbing influences. The intensity behavior of atomic lines in the spot spectrum as compared with the spectrum of the solar disk is indicated by letters denoting strengthening, weakening, and the like. Atomic lines present only in the spot spectrum are, also, included, 223 in all.

Revised identifications of the lines, as to chemical origin, are given for both atomic and molecular lines. For classified atomic lines the lower excitation potential and multiplet number are listed. For molecular lines the rotation branch and quantum number, and the vibration band are indicated. Note numbers refer to notes in which the complete designation of the band is given.

An introductory text gives a detailed description of each column of the solar ledger. Figures are included to illustrate the procedure used to derive the observed equivalent widths Δλ (mÅ) and the reduced widths Δλ/λ(F).

Tables include counts of lines of each spectrum recorded in the identification column, leading lines in the first and second spectra, and summaries of molecules and elements present in the sun. About 73 percent of the lines are wholly or partially identified. Sixty-three elements are recorded as present. A number need further study. The number of molecules identified in the sun totals 11.

Key Words: Elements in sun, equivalent widths of solar lines, identification of solar lines, molecules in sun, solar spectrum, wavelengths of solar lines.

1. Introduction

In 1895–1897 Rowland published a Preliminary Table of Solar Spectum Wavelengths that is still a challenge to spectroscopists [2].[1] The span of observations was from 2975 Å to 7330 Å. Many features of this rich spectrum still defy interpretation. Throughout the years this classical work has provided a threefold incentive: (1) to extend laboratory observations and interpretations of atomic and molecular spectra of various chemical elements, for the purpose of identifying more of the observed solar lines as to chemical origin; (2) to extend Rowland's observations in both directions, to shorter and to longer wavelength-regions by means of modern observing techniques, photographic developments, and the like; (3) finally, to reobserve the solar spectrum in the "accessible" range. All of these incentives are still being carried out.

The first revision of the Rowland Table was made at the Mount Wilson Observatory in 1928 by C. E. St. John, and others [3]. At this time the Rowland wavelength-scale was converted to the international scale. The correction curve used for this conversion is described in detail in the text to the 1928 publication. Further minor corrections to the international scale are discussed in § 2.1.

By comparing the observed solar lines with laboratory spectra, Rowland reported the presence of 39 chemical elements in the sun, all but 2 of which have since been confirmed. In 1928, 57 elements were reported as present and 57% of the lines in the solar spectrum were identified. The number of known chemical elements in the sun is now 63, with 2 others dubiously identified. To date some 73% of the lines are wholly or partially identified as to chemical origin. This is described more fully in §§ 3.2, 3.3.

In the 1928 revision no attempt was made to replace the estimated line intensities from Rowland's Table by measured equivalent widths. Provisional graphs for the approximate conversion of the Rowland scale into equivalent widths were published by Mulders [4]. In 1943, however, the staff at the Utrecht Observatory started to prepare a catalogue of measured equivalent widths, based primarily on the Utrecht Photometric Atlas of the Solar Spectrum [5], in which the profiles of all Fraunhofer lines between 3612 Å and 8771 Å are recorded. The spectrograms were obtained by Mulders at the Mount Wilson Observatory, and the photometric data were elaborated under the direction of Minnaert and Houtgast. This Utrecht program became part of the cooperative project suggested by the International Astronomical Union in 1948. The catalogue, just as the Atlas on which it is based, refers to the spectrum of the center of the solar disk, little different from the spectrum of integrated sunlight. The Utrecht contribution, consisting of a list of photometric data has already, to a large extent, been published separately [6]

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[1] Figures in brackets indicate the literature references in § 4.

because the data are so urgently needed for abundance determinations and for comparisons with other stellar spectra.

The range of the present table has been limited to that long span of the solar spectrum that overlaps the more recent and current observations from rocket and orbiting-solar-observatory spectra in the ultraviolet (short of 3000 Å), and from the Jungfraujoch spectra in the infrared (long of 7500 Å). It is essentially a second revision of Rowland's Table corrected and supplemented by the Utrecht Atlas material. Even in this range the work is far from completed. Many more solar lines will doubtless be added when the spectrum has been completely reobserved under the best observing conditions and with the best available modern instruments. The task of remeasuring the complex spectrum and of extending identifications and intensity measurements is a heavy one in itself, and one that requires, also, much additional work on the analysis of individual laboratory spectra. The present contribution is intended as a convenient handbook for the astrophysicist until the ideal self-contained compendium of the solar spectrum from the x-ray to the microwave region becomes a reality.

2. Description of the Solar Spectrum Compendium

The successive columns of the solar ledger are described. The general procedure by which the data on measured intensities have been obtained is fully explained. The many users require, also, more detailed information on the analyses of individual spectra than can be recorded here, for the many lines classified from laboratory investigations. Sufficient information is given in the ledger to provide convenient cross reference to the separate papers on spectrum analysis. For special details concerning individual lines the column headed "Notes" should be consulted.

2.1 The Wavelengths: Column One

A comprehensive revision of Rowland's *Preliminary Table of Solar Spectrum Wavelengths* entails a thorough study of the wavelengths of the lines reported by Rowland. These remarkably accurate measurements by Jewell, that date back to 1895–97 [2], were reduced to the International Scale of Wavelengths in the first revision of Rowland's Table in 1928 [3].

The tremendous amount of work that has gone into interferometric observations for precise wavelength standards need not be discussed here. Details may be found in the early Transactions of the International Astronomical Union [7], in the Allegheny Publications by Burns, Meggers, and Kiess [8], and in the Mount Wilson Contributions by St. John, H. D. Babcock and others. St. John discussed the method used for the reduction to the international system, and has published the correction curve based on the International Standard Wavelength Scale of 1922 [3]. The wavelengths listed in the 1928 edition are based on this curve. They are in three categories: (1) Lines marked "m". These lines were observed by Rowland, but remeasured for use in correcting Rowland's wavelength scale. (2) Lines marked "w", denoting weighted means of remeasured lines and Rowland's corrected values. (3) Undesignated wavelengths; these formed the great majority. They were lines listed by Rowland but corrected to the international scale of 1922 by means of the correction curve adopted in 1928.

Throughout the years in which the 1928 edition has been actively used, several problems regarding wavelengths have arisen. Further work on the International Standards has indicated that a small running correction is required to reduce the wavelengths based on the 1922 scale to the scale adopted in 1928 by the International Astronomical Union. These corrections, reported by H. D. Babcock [9] are as follows:

Table 1. Wavelength Corrections for Reduction to the 1928 Scale of Standards

Region (Å)	Correction to 1922 Scale (Å)	Region (Å)	Correction to 1922 Scale (Å)
2995–3133	−0.0012	6125–6290	−0.006
3133–3370	*(−0.0010)	6290–6455	−0.007
3370–3705	−0.0006	6455–6630	−0.008
3719–3849	−0.0015	6630	−0.009
3850–3969	−0.0015	6800	−0.010
4000–5600	−0.002	6900	−0.012
5600–5780	*(−0.003)	7000	−0.014
5780–5960	*(−0.004)	7100	−0.016
5960–6125	−0.005		

* Values in parentheses are interpolated.

They must be applied to all wavelengths published in the 1928 edition, in order to comply with the standards recommended by Commission 14 of the Union.

Although Rowland's observations extend from 2975 Å to 7330 Å, his spectrograms did not record the solar spectrum completely in the ranges short of 3060 Å and long of 6600 Å. With the development of new photographic emulsions, Rowland's work has been superseded in the short- and long-wave regions. Meggers made a thorough study of the spectrum from 6500 Å to 9000 Å in 1919 [10] and by means of Doppler displacements, carefully separated the solar lines from the telluric lines. This work was subsequently extended at Mount Wilson by H. D. Babcock and others, by comparing line intensities at high and low sun. In the present table the

Table 2. Spectrograms from the Utrecht-Mount Wilson Collection used for Wavelength Measurement

Plate No.	Wavelength Range (Å)	Plate No.	Wavelength Range (Å)	Plate No.	Wavelength Range (Å)
82	3949 to 4035	54	5205 to 5290	60	4690 to 4775
206	3994 to 4081	52	5260 to 5345	56	4875 to 4960
83	4071 to 4158	55	5320 to 5406	66	4933 to 5018
79	4144 to 4228	93	5367 to 5450	89	5018 to 5045
196	4190 to 4275	241	5740 to 5820	90	5070 to 5155
75	4262 to 4347	36	5885 to 5970	46	5395 to 5480
197	4315 to 4400	98	5953 to 6037	49	5462 to 5547
190	4375 to 4460	37	6004 to 6088	A	5520 to 5595
210	4430 to 4516	40	6055 to 6140	B	5580 to 5650
191	4495 to 4580	250	6195 to 6275	C	5635 to 5715
195	4560 to 4640	248	6250 to 6330	41	5663 to 5749
70	4592 to 4678	251	6305 to 6385	42	5800 to 5885
73	4655 to 4738	249	6370 to 6450	18	6125 to 6210
67	4753 to 4840	252	6420 to 6500	120	6582 to 6664
65	4820 to 4907	119	6497 to 6578		
59	5044 to 5130	102	6575 to 6655		
51	5145 to 5230				

wavelengths from 6600 Å to 8770 Å are mostly taken from the 1947 Monograph by H. D. Babcock and C. E. Moore [11]. Details regarding the wavelength scale in this region are given in the Introduction to this Monograph.

In the interval 2935 Å to 3060 Å, H. D. Babcock has reobserved the solar spectrum. New measurements for some 665 lines have been reported [12] and used for the present work. The reference standards for this region require a correction of −0.002 Å according to Babcock [9]. In this interval Babcock's measurements thus corrected have been adopted with Standards indicated by "S". See Table 3.

Table 3. References to Standard Wavelengths in the Solar Spectrum

Wavelength Range (Å)	Reference: Trans. Intern. Astron. Union	Comments
2995 to 3133	7, 150, 1950	Reference Standards to be corrected by −0.002 Å.
3592 to 7122	3, 93, 1928	Recommended λ.
7568 to 9889	6, 90, 1938	Recommended λ.

In the course of the work on intensities by Minnaert and his staff, many questions have arisen regarding new lines not listed by Rowland, the reality of faint Rowland lines, the resolution of close pairs, and the like. A set of spectrograms taken from the collection made for the preparation of the Atlas has been measured by C. E. Moore in an effort to settle some questions about apparent inconsistencies between the Atlas and the Rowland lines, and also because it seems desirable to examine further the lines recorded heretofore only by Rowland. These measurements extend from 3949 Å to 6600 Å.

The spectrograms from the Utrecht-Mount Wilson collection that have been measured, are listed in Table 2. In the last column a list of auxiliary spectrograms of poorer quality than the others is given. These were used only to supplement the good ones.

Finally, two Mount Wilson sun-spot spectrograms T′ 1969 and T′ 1971 were used to cover the respective intervals 4732 Å to 4755 Å and 4900 Å to 4933 Å. The reciprocal dispersion of the Atlas plates is 0.35 Å/mm; that of the T′ plates is 0.22 Å/mm. The measurements have been made on comparators at the National Bureau of Standards, partly by visual and partly by oscilloscope settings. An attempt has been made to obtain at least two measurements for every line.

The standards have been taken from the second reference of Table 3. This table contains a complete list of references to solar standards given by Commission 14 in the Transactions of the International Astronomical Union.

A supplementary list of "temporary" standards in the interval 7333 Å to 11204 Å is given in these Transactions 4, 83, 1932, but these are not designated by "S" in column one, as are those from Table 3.

In drawing the correction curves for the measurements described above, the lines marked "m" in the 1928 solar table as corrected from Table 1, have also been utilized in addition to the "Standards" mentioned above. These lines were all measured at Mount Wilson prior to 1928.

It is evident that many of the fainter lines that can be detected on the spectrograms under low-power magnification and in the Atlas, are too faint to measure on the comparators. Some of these faint lines can, however, be measured to 0.01 Å on high-dispersion spectrograms, with the aid of handscales.

For one region, 5000 Å to 6000 Å, Zalubas [13] has made spectrograms at the Georgetown University Observatory, especially for the purpose of observing faint lines. He used a 21-foot concave Rowland grating having 20,000 lines to the inch, in a Wadsworth mounting; the reciprocal dispersion (first order) was about 3 Å/mm. The spectrograms were made in the second order and have a reciprocal dispersion of 1.4 Å/mm. He has remeasured some 4,072 previously known lines, and added 234 new faint lines, many of which may be of atmospheric origin. All of his wavelengths represent means of measurements made on three spectrograms. Of these new lines, 55 that were clear and also measurable in the Atlas records have been included here.

For the remeasured lines, a weighting system was devised to combine the various kinds of measurements available. The weighting factors are described in Table 4.

The authors have had, also, the benefit of unpublished notes from H. D. Babcock regarding close pairs, new lines, improved wavelengths of atmospheric and other molecular lines, identifications, reality of faint lines, and other details. The wavelengths published by him and L. Herzberg [14] in their analysis of the Atm O_2 bands have been adopted with the label "m" (see Table 5).

In examining the Atlas, Minnaert and Houtgast have measured a number of lines to ±0.01 Å. Some of these indicate further corrections to Rowland's list; many others are new lines (see § 3.1 and Table 8). Long of 6600 Å it seemed inefficient to include all of the faintest lines in the catalogue, which are mostly of atmospheric origin. Many of them have been dropped, especially if they were not included in the 1928 edition or in the 1947 catalogue of H. D. Babcock and C. E. Moore. All identified solar lines have been kept. The wavelengths determined from the Atlas cannot be compared in precision with those measured by means of a modern comparator. If precise wavelengths are needed, the positions of several neighboring lines should be checked, and the scale, if necessary, slightly adjusted by fractions of a millimeter. The Atlas is superior, however, when faint lines appear on the slopes of strong lines, when lines are broad and assymetric, or when they are revealed only by a tracing, which, being flat, nevertheless fails to reach the continuum line.

Table 4. Weighting Factors for Measurements

Weight	Description of Source Material
10	Wavelengths marked "w" in the 1928 edition as corrected from Table 1.
5	Rowland wavelength from the 1928 edition as corrected from Table 1.
5	Measurement by Zalubas [13].
5	Three or more measurements by C. E. Moore.
3	Two measurements by C. E. Moore.
1	One measurement by C. E. Moore.
½	One dubious measurement by C. E. Moore.

The behavior of atomic lines in the spot spectrum is discussed in § 2.4. A study of such lines was made by C. E. Moore in 1932 [15], and a list was published by her in 1933 [16]. Atomic lines appearing only in the spot spectrum are entered to two decimals only. They are taken from the 1933 paper. Her measurements of spot lines have been supplemented by those included in the 1928 revision, and also by unpublished measurements by R. S. Richardson in the interval from 4900 Å to 5403 Å [17]. The rounded-off wavelengths of spot lines quoted from Richardson are indicated by a dagger in note 13. His wavelengths have also been utilized for a number of lines formerly listed as spot lines and later seen on the Atlas spectrograms.

Table 5 contains the letters used in column one to indicate wavelengths in the different categories discussed above.

In two special cases, laboratory wavelengths are quoted with special notes:

Note 10. The Balmer series of H, $n=8$ through 17.
Note 31. The Paschen series of H, $n=12$ through 18.

All other wavelengths not designated by the letters in Table 5, are weighted means. All wavelengths are in air.

More remains to be done, especially on improving wavelengths of faint solar lines, and, above all, on extending the list to include many more faint solar lines that appear on spectrograms and photometric records made with the finest solar instruments available today. The demand for the present compendium is so great that the further delay that would be necessary to make a more detailed study of new faint solar lines, does not appear justifiable. This is one of the most challenging problems of the near future.

Table 5. Letters in Column One: Wavelengths

S	Standard Wavelength, see Table 3.
m	This letter is used: (1) To denote lines measured at Mount Wilson, recorded as "m" in the 1928 revision, in the interval 3062 Å to 6600 Å. The 1928 entries corrected from Table 1 are recorded here. For lines longer than 6600 Å, many have been remeasured, but the letter "m" has been retained only for those solar lines thus noted in the 1928 edition. (2) For wavelengths of lines in the Atm O_2 bands as reported by H. D. Babcock and L. Herzberg [14]. (3) For a few unpublished measurements by H. D. Babcock. (4) For measurements of sun-spot lines [16], and for other measurements taken from Richardson. (5) For selected lines having special notes.
r	Lines whose wavelengths are from Rowland's Table. Short of 6600 Å the listed wavelengths are from the 1928 edition corrected as described in Table 1. To longer waves, the lines in this category are quoted from the 1947 Solar Table [11], where the correction factors occasionally deviate slightly from those listed in Table 1.
a	Two-place measurements furnished by Minnaert and Houtgast, from their study of the photometric tracings. All of these lines have been seen as traces on the solar spectrograms as well as in the Atlas recordings.

2.2 The Measured Equivalent Widths, $\Delta\lambda$(mÅ): Column Two

According to the general use in astrophysics, the *equivalent width* of a Fraunhofer line is the width of a hypothetical absorption line, which, being perfectly black and having sharp edges, would absorb from the neighbouring continuum the same amount of energy as the real line (Fig. 1). Another measure for the line strength called the *reduced width*, which will be defined in § 2.3, is listed in column three [18].

The present table has the short-wave limit 2935 Å, in order to provide an overlap with subsequent solar tables that extend to shorter wavelengths. From 2935 Å to 3061 Å no calibrated plates were available for intensity measurements. In this range, eye-estimates of the line intensities are entered in brackets between the two columns containing measured intensities. The quoted estimated intensities are from H. D. Babcock [12]. They are not to be confused with the measured equivalent widths.

In the present volume, several errors in the provisional publication [6] have been corrected. The ultraviolet data have been modified, taking into account the more recently published Göttingen Atlas [19]. In the red part of the spectrum a number of dubious faint lines have been rejected, others have been added, and wavelengths have been adjusted, so that the catalogue is now a better description of the Atlas.

The intensity measurements were based on the Utrecht Photometric Atlas of the Solar Spectrum [5], in which the profiles of all Fraunhofer Lines between 3612 Å and 8771 Å are recorded, from spectrograms made by G. F. W. Mulders at the Mount Wilson Observatory, Pasadena. In the introduction of this Atlas, full details about the microphotometric work are found. The region from 3612 Å to 6977 Å was photographed in the 2nd order; the one from 6923 Å to 8771 Å in the 1st order. For the atmospheric lines it may be useful to remember that sec ζ varied between 1.26 and 4.92, as listed in the introduction of the Atlas. Longer than 5560 Å it did not exceed 2.22. In the small stretches where two spectrograms overlap, that with the greatest value of ζ was selected.

The spectral region short of 3612 Å was included in the Atlas only as an Appendix based on Utrecht spectra with much less resolution. It proved surprisingly difficult to find an observatory provided with adequate instruments for an improved study of this part of the solar spectrum. Fortunately the Dunsink Observatory was so kind as to obtain a complete set of the ultraviolet region between 3100 Å and 3650 Å and to record these spectra with a direct intensity microphotometer, similar to that originally used for the Utrecht Atlas. It is clearly an advantage that the same institute that made the spectrograms also recorded them, making all necessary photometric checks. For some sections, plates kindly taken by H. D. Babcock at the Mount Wilson Observatory were also used. On the Dublin records the lines have a total half-width only slightly (5%) greater than that of the Mount Wilson-Utrecht records; 10 lines in the region of overlap yielded $h=27.8$ (Mount Wilson) and 29.1 (Dublin), expressed in micro-wavelengths ($\mu\lambda$). An analysis of the apparatus curve in this

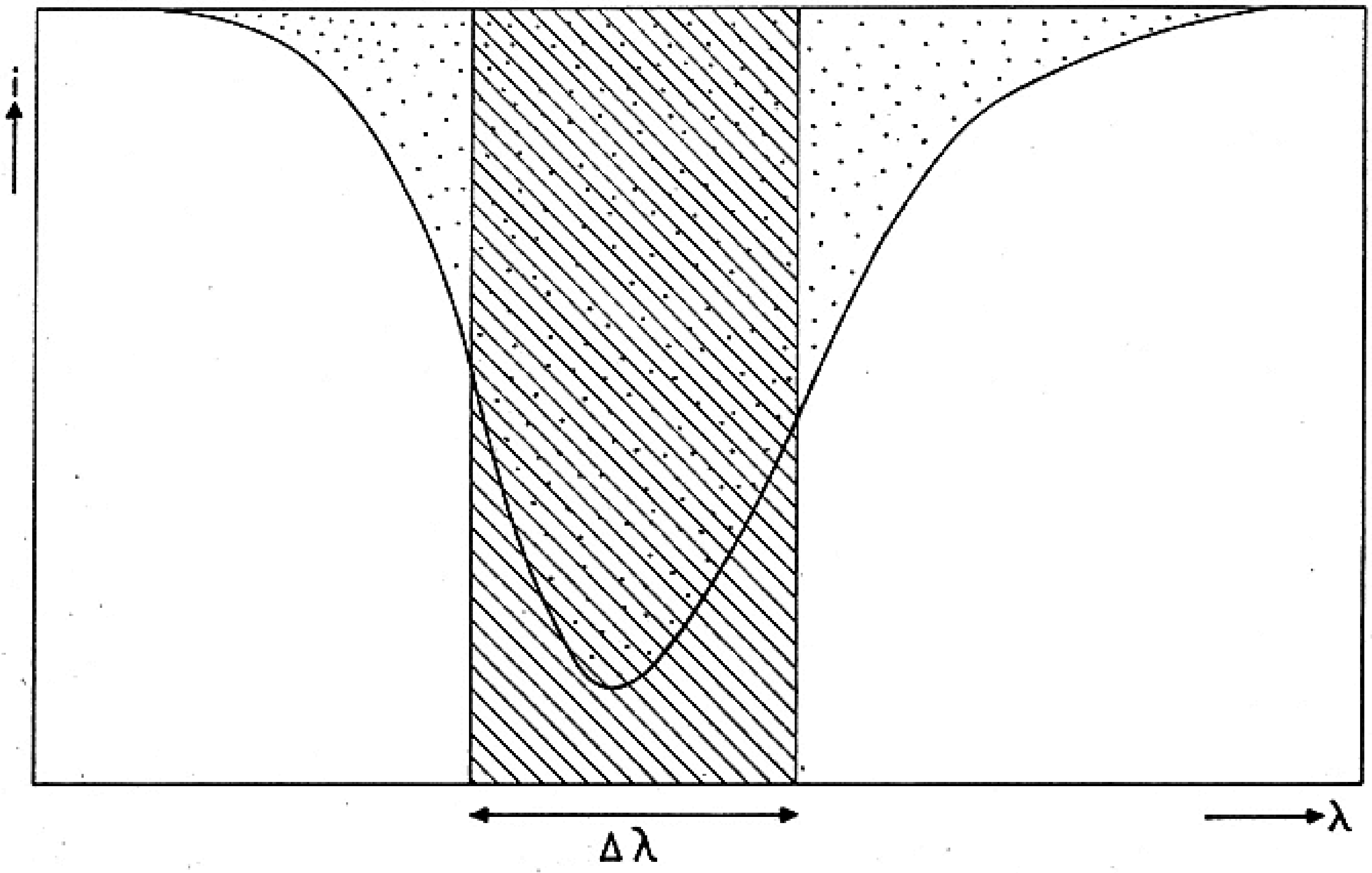

Figure 1. *Definition of equivalent width.*

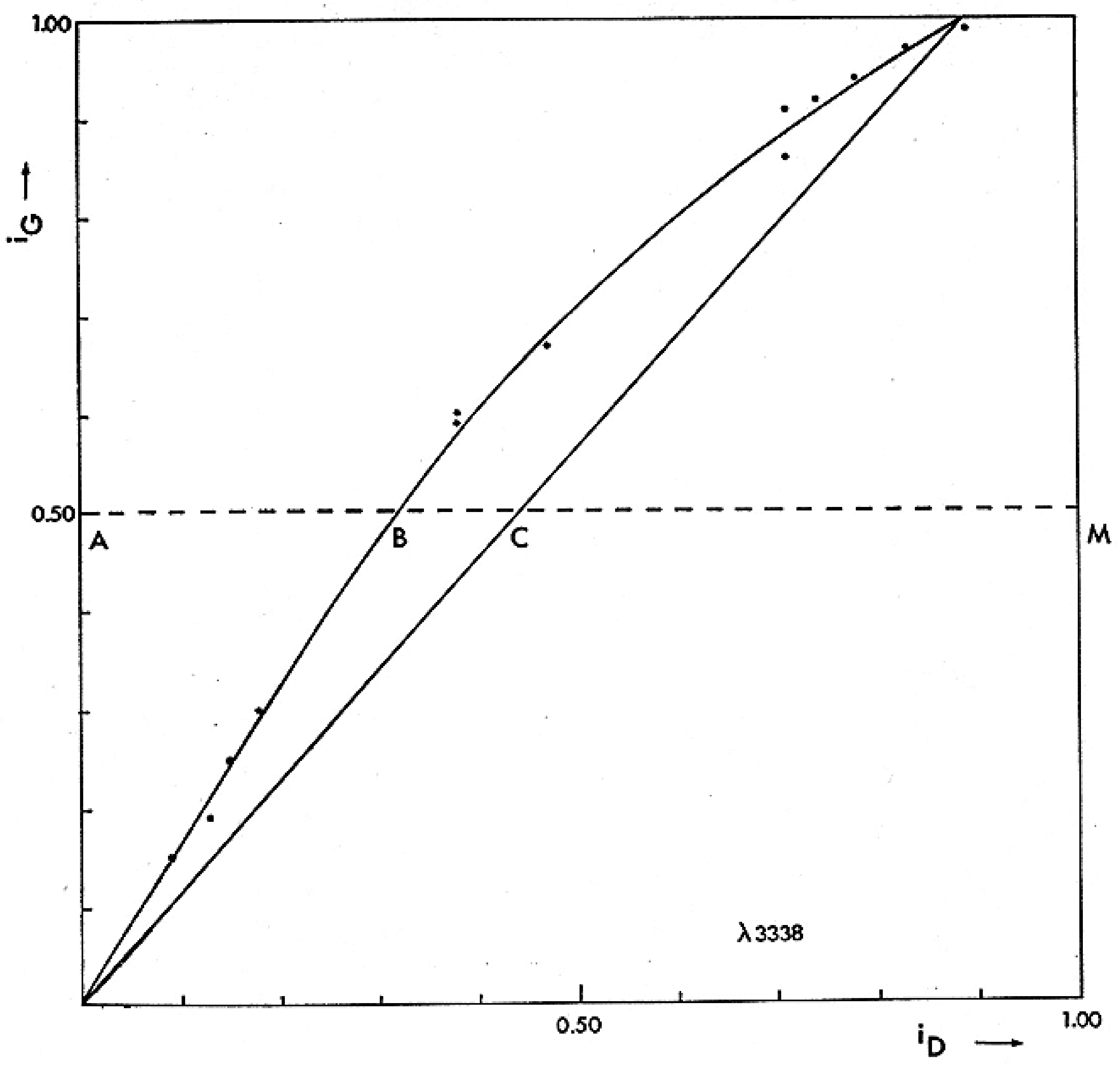

FIGURE 2. *Comparison of UV monochromatic intensity measurements at Göttingen and at Dunsink.* Coordinates i_G and i_D in arbitrary units.

region, approximated by a Voigt profile, showed that the Dublin damping coefficient (β_1) was much smaller, practically absent, while the Doppler coefficient (β_2) was considerably greater. (Mount Wilson: $\beta_1=2.19$; $\beta_2=3.48$. Dublin: $\beta_1=0.01$; $\beta_2=11.0$). The curve relating the half-width to the central intensity, was practically the same for both series. This was a fortunate circumstance, owing to which we felt justified at first in applying to the whole of the material the same tables and graphs.

After the Preliminary Photometric Catalogue was published by the Utrecht Observatory, an Atlas was published at Göttingen that provided new photometric tracings for the ultraviolet region [19]. It seemed important to check against these new records the results which had been obtained on the basis of the Dublin registrations. Both series of tracings were direct intensity records.

On first inspection it became clear that the resolving power of the Dublin records is slightly better than that obtained at Göttingen. More important, however, was the photometric comparison, the more so, since we had been warned by the Dublin observers that there might be some deviations.

A plot of *E.W.* (Dublin) against *E.W.* (Göttingen), for 210 lines near 3330 Å, showed a systematic difference, the ratio *D/G* varying between 1.2 and 1.4. By plotting for individual, well selected points the intensities in arbitrary units i_D against i_G, it was also shown that this difference was due to fundamental deviations in the photometric scale. This method of comparison worked quickly and efficiently and was independent of the assumed background intensity, the deviations appearing as a curvature of the plot (Fig. 2). In order to decide which of the two scales was correct, use was made of ultraviolet spectral records obtained by J. Houtgast [23] at the Mount Wilson Observatory in 1960, with the Snow Telescope and the apparatus of W. E. Mitchell for direct photometric recording of the spectrum. Cross-comparisons showed unambiguously that the Göttingen photometry is the correct one.

The effect of a curvature in the photometric scale might be expected to be different according to the *E.W.* of the spectral lines and the intensity of the background on which they are superposed. This was actually found. However in practice these differences in the correction for the individual spectral lines were not important. Considering the necessity of a simple and practical procedure, in view of the great number of lines involved, it seemed sufficient to divide all values of $E.W._D$ by a mean factor of $(1+\Delta)$,

where $$\Delta=\frac{EW_D-EW_G}{EW_G}$$

measures the relative deviation in the *E.W.* Near 3330 Å the factor $(1+\Delta)$ amounted to 1.35.

It was then necessary to ascertain how the factor $(1+\Delta)$ varied with the spectral region. We assumed that the photometric scale would be homogeneous within each Dublin microphotometer record, corresponding to about 10 Å. For each of the 52 records, a graph was made of i_D against i_G (Fig. 2); the curvature, thus the deviation from the right scale, was characterised by the ratio $r=\dfrac{AB-AC}{AM}$, measured at the height $i_G=0.50\, i_{G(\max)}$. The ratio r was 0.130 near 3330 Å and varied between 0 and 0.15 in the wavelength region 3075 Å to 3550 Å, the difference between both scales disappearing at longer wavelengths.

We assumed that Δ is approximately proportional to r, so that, in general,

$$1+\Delta=1+0.35\,\frac{r}{0.13}.$$

The difficult and lengthy determination of Δ was thus replaced by a very quick measurement of r, easily applied at a great number of wavelengths.

The correction, finally applied, amounted to dividing all equivalent widths and reduced widths of the Preliminary Catalogue (1960) by the factor $(1+\Delta_\lambda)$, which is a function of wavelength; this factor varied in general between 1 and 1.30 and reached higher values, up to 1.43 at only two places.

The equivalent widths, $\Delta\lambda$, in milli-Ångströms, as determined by direct measurement from the records, are tabulated in column two. In the first place the *continuous background* was located, which sometimes deviates a little from the Atlas continuum. This was relatively easy in the infrared and visual regions, but it became increasingly difficult towards the shorter wavelengths. Special difficulties were encountered short of 4000 Å, where the determination of the continuous background has been a matter of serious concern. In general we first traced the profiles of the strongest lines, then the profiles of fainter lines superposed on the first ones, etc. So for each line we obtained a *local continuum.* The local continuum for the strongest lines is determined by the highest points of the stretch of spectrum considered. Of course some indeterminacy resulted from the extent of the interval inside of which these highest points were selected. It is with respect to this local continuum that equivalent widths of column two have been computed.

In view of further reductions, to be explained in § 2.3, we had, also, to locate the true or *maximum continuum,* this being defined as the continuum which would be found theoretically from the tables of κ_c in general use, e.g. from those of Vitense [26]. These tables yield in the UV a continuum which at the Balmer limit jumps discontinuously to a lower value. In the region short of 4000 Å, we have adopted the mean of the continuum as found by Michard [20], and by Rauer [21], later confirmed by Mrs. Pecker [22]. This locates the maximum continuum at an Atlas ordinate, gradually increasing from 100 at 4000 Å to 140 at 3647 Å. There it is considered to jump discontinuously to a lower value, the place of the jump being indicated by parallel horizontal bars in our catalogue. There is no doubt that actually the background is depressed gradually and smoothly, because of the accumulating Balmer lines and (nearer to the limit) by the pre-ionization of the hydrogen atoms. However, these effects are not included in the ordinary tables of the continuous absorption coefficient. In computing a line profile, the theorist will, therefore, refer the spectral line to this high continuum, and consider the profile as formed by the blend between the line proper and the higher Balmer lines. The location of our maximum continuum, as described, conforms to the continuum of the theorists. Short of 3647 Å, we have conservatively assumed that the Atlas ordinate 100 corresponds more or less to the true continuum, as was assumed by Michard. An investigation by Minnaert concerning the profiles of strong lines in the region 3500 Å to 3600 Å suggests that there the real continuum should also be higher. Before accepting the consequences of such a conclusion, more discussion seems to be necessary.

Recent photoelectric measurements of Houtgast on high-dispersion spectra give the detailed absolute intensities of 200 selected points over the range 3000 Å to 4000 Å, which should be used in the future as the basis for the location of the maximum continuum [23].

For each individual line, where necessary, smoothed individual profiles of the wings were traced with a sharp pencil on the Atlas records. In blends, the separation of a line from the neighbouring ones was made there where it could be done without complications by simple application of the "product rule," meaning that an ordinate with relative intensity $\frac{i_2}{i_0}$, superposed on a background $\frac{i_1}{i_0}$, becomes $\frac{i_{12}}{i_0}=\frac{i_1}{i_0}\times\frac{i_2}{i_0}$ (Fig. 3). This applies to the following cases:

1. two telluric lines, or a telluric line combined with a solar line;
2. two solar lines, the overlapping parts of which do not descend below 80% of the continuum.

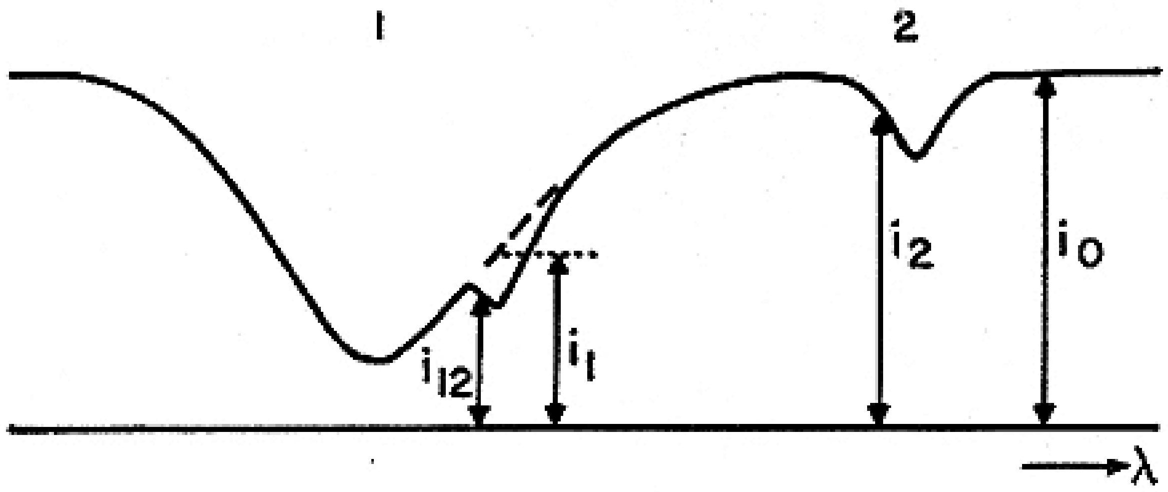

FIGURE 3. *Disturbed and undisturbed Fraunhofer line.*

In all other cases the separation of the blend components was made only in column three (see § 2.3).

The areas of profiles whose dip exceeded 20%, were determined by a Coradi polar planimeter, of which the precision had been tested before. Each profile was measured clockwise and counterclockwise and the mean was taken. For lines with a maximum dip less than 30%, the planimeter measurments were not considered to be sufficiently precise, and the areas were found by counting square millimeters. For a group of medium strong lines there is an overlap, and the mean was taken of the planimeter result and of the counts. The same was done for overlapping parts of the successive Atlas strips; their differences were treated as accidental, though in many cases it was obvious that the deviations were systematic. The *areas* were reduced to *equivalent widths* in mÅ, taking into account the dispersion and the height of the (local) continuum. All single lines and all of the lines which had been directly separated by applying the product rule were treated in this way. For blends not satisfying the conditions mentioned, the equivalent width of the entire blend as a whole is mentioned in the second column.

The Balmer lines of the hydrogen spectrum presented special difficulties near the series limit at 3647 Å. Very striking is the great depth of H_{10}, which we considered as a real anomaly. The lines H_{12}, H_{13}, H_{14} are masked by strong superposed lines; H_{15}, H_{16} and H_{17} are measurable. The line H_{18} is certainly not seen; we assumed, therefore, that H_{19} and H_{20} are also invisible, and that slight depressions there are due to the combination of neighboring lines. The profiles for H_{12}, H_{13} and H_{14} were found by interpolation. For the further reduction in column three, where results of other observers are combined with ours, the results of de Jager (Table 6) have been taken into account up to H_{11}.

2.3 The Reduced Widths, $\Delta\lambda/\lambda \times 10^6$ (F): Column Three

Next to the equivalent width, another measure for line-strength has proved useful for many theoretical investigations: it is the *reduced width*, defined as 10^6 times $\Delta\lambda/\lambda$, and expressed in a unit called the *fraunhofer* (F) [18]. This is a dimensionless number, having a convenient order of magnitude and independent of the unit in which both $\Delta\lambda$ and λ are measured. The reduced width is equal to the equivalent width, expressed in *microwavelengths* ($\mu\lambda = 10^{-6}\lambda$). The reduced widths are found in column three, improved, however, because the directly measured equivalent widths of column two had to be revised, before reduction, taking into account several considerations, now to be explained.

For a number of Fraunhofer lines, equivalent widths have already been determined earlier by other workers. A list of references is found in Table 6, at the end of § 2.3. We assumed, that these measurements are direct determinations of the equivalent width, without the correction for the blend factor to be discussed later. For this reason all comparisons were made with the numbers of our second column, where the blend correction has not yet been applied. We have listed for each line all available measurements, and have taken mean values, assuming double weight for the Atlas determinations, in order to obtain greater homogeneity in the catalogue between lines measured at Utrecht only, and lines also measured elsewhere. For all lines where other measurements have been taken into account, the reduced width in the third column is in italics.

The following remarks should be made: (*a*) The measurements of Phillips (Table 6) in the ultraviolet have not been used, because his numbers are so much smaller than our results, from both Mount Wilson and Dublin plates, that the homogeneity of the catalogue would have been lost. The same applies to Woolley's measurements (Table 6). Short of 3813 Å, except for the Balmer lines, no measurements other than the Utrecht values were used. (*b*) Of the equivalent widths measured by Allen (Table 6), these have been used which were derived by photometry of the profiles, but not those obtained from depth and halfwidth only. (*c*) No use has been made of profiles determined by some authors, but not converted by them into *E.W.*; in most of these cases the shape of the outer wings had not been ascertained.

The next task was to disentangle those *blends*, which could not be analyzed by the simple product rule. Practically all blends, even in complicated cases, could be reduced: (*a*) to combinations of two lines, or (*b*) to the case of a line, formed on a background lower than the normal continuum. When three lines A, B, C were found combined, it was in general sufficient to consider the interaction of A and B and the interaction of B and C, the mutual influence of A and C being mostly negligible.

It is well known that two Fraunhofer lines combine according to rules more complicated than those of terrestrial absorption lines, as has been shown by Thackeray, Houtgast and Minnaert [24] and later by Unsöld [25] and by Rauer [21].[2] When these last investigations were published, our work, started in 1943, had already progressed so far that it would not have been possible to change the

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[2] In the mean the effects of blending, calculated by Rauer, are less pronounced than those taken into account by us. This is due mainly to our assumption, that both lines originate in the same layers of the solar atmosphere.

method of reduction. Nor would it have been possible, in a treatment of many blends, to consider the individual details of each combination. The explanation and graphs published in paper [24] give more ample information about the methods applied. For the reduction it was assumed that the lines behaved as scattering lines, because some of the strongest ones were resonance lines and because we wished, also, to reduce in the simplest way the very low central intensities. For moderately deep profiles, the choice between absorption and scattering is practically unimportant. Two-dimensional *combination tables* were calculated, giving the resultant intensity i_{12} at a wavelength where the individual intensities i_1 and i_2 are superposed; a first table referred to atoms distributed according to Schwarzschild-Schuster, another to atoms distributed according to Milne-Eddington. Finally, the geometric mean of both combination tables was taken, square by square. Fig. 4 gives $V=\frac{i_1-i_{12}}{i_0-i_2}$ for a hypothetical monochromatic line, indicating in what proportion it is reduced when superposed on a background i_1. If we compare lines superposed on a more or less

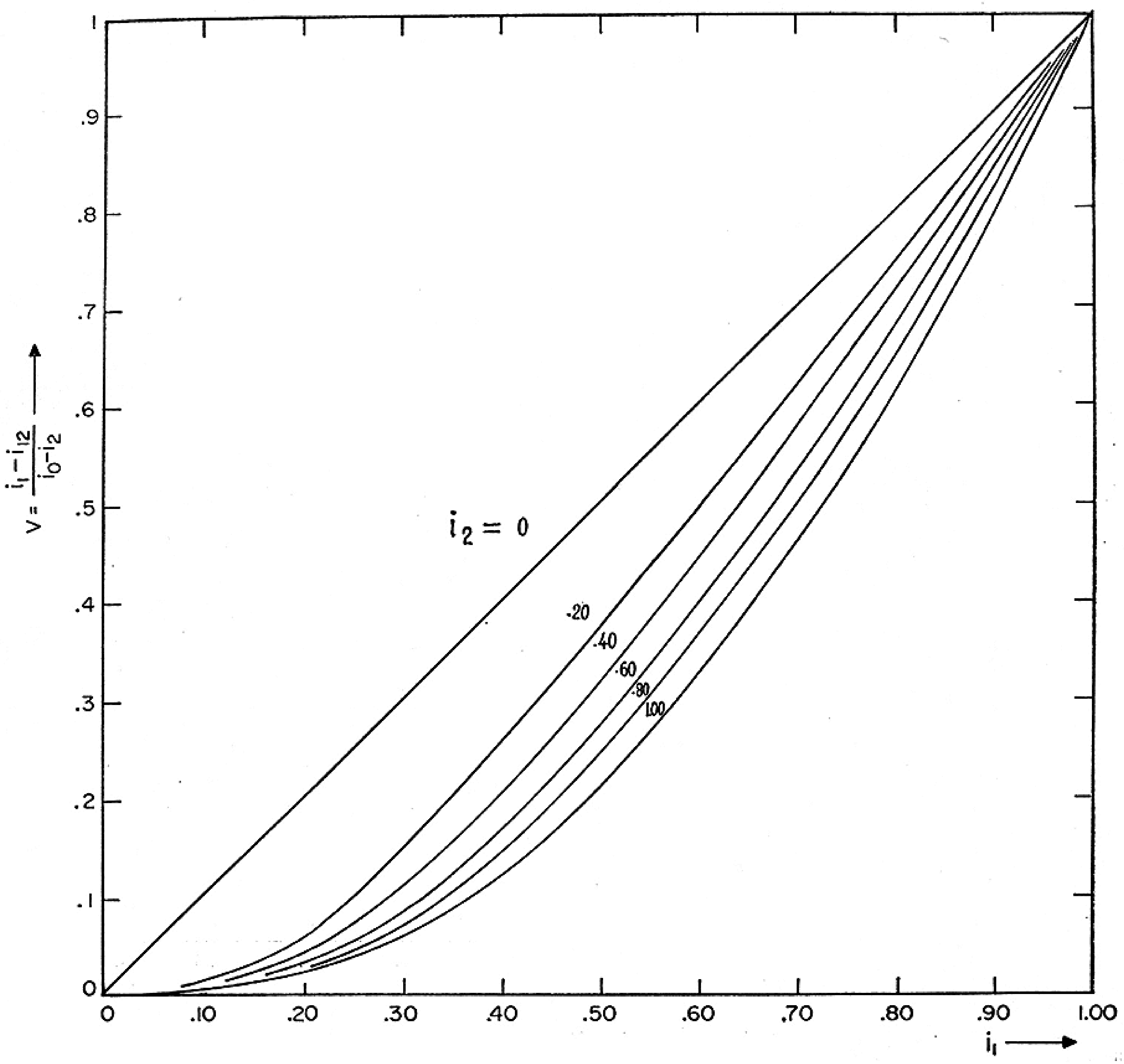

Figure 4. *Monochromatic blend factor.*

homogeneous background i_1, with the lines which would have been formed by the same atoms on the background of the true continuum i_0, we would expect by the product rule that the blend factor would be simply equal to $\frac{i_1}{i_0}$, the area having decreased in this proportion but the equivalent width remaining the same. According to the combination table, however, a further reduction of the area is observed, which affects the equivalent width and which can be computed easily for normal profiles derived from the Atlas for lines of different equivalent widths (Fig. 5). Conversely, the observed equivalent widths $\int\frac{(i_1-i_2)d\lambda}{i_1}$ have to be divided by a factor smaller than unity, and found in the figure quoted.

Lines forming a close doublet were analysed by means of *model doublets*. Two normal profiles, freed from the apparatus function, were drawn at a chosen distance from each other, then combined, ordinate by ordinate, according to the combination table. The resulting doublets, slightly smoothed by combining them with the apparatus

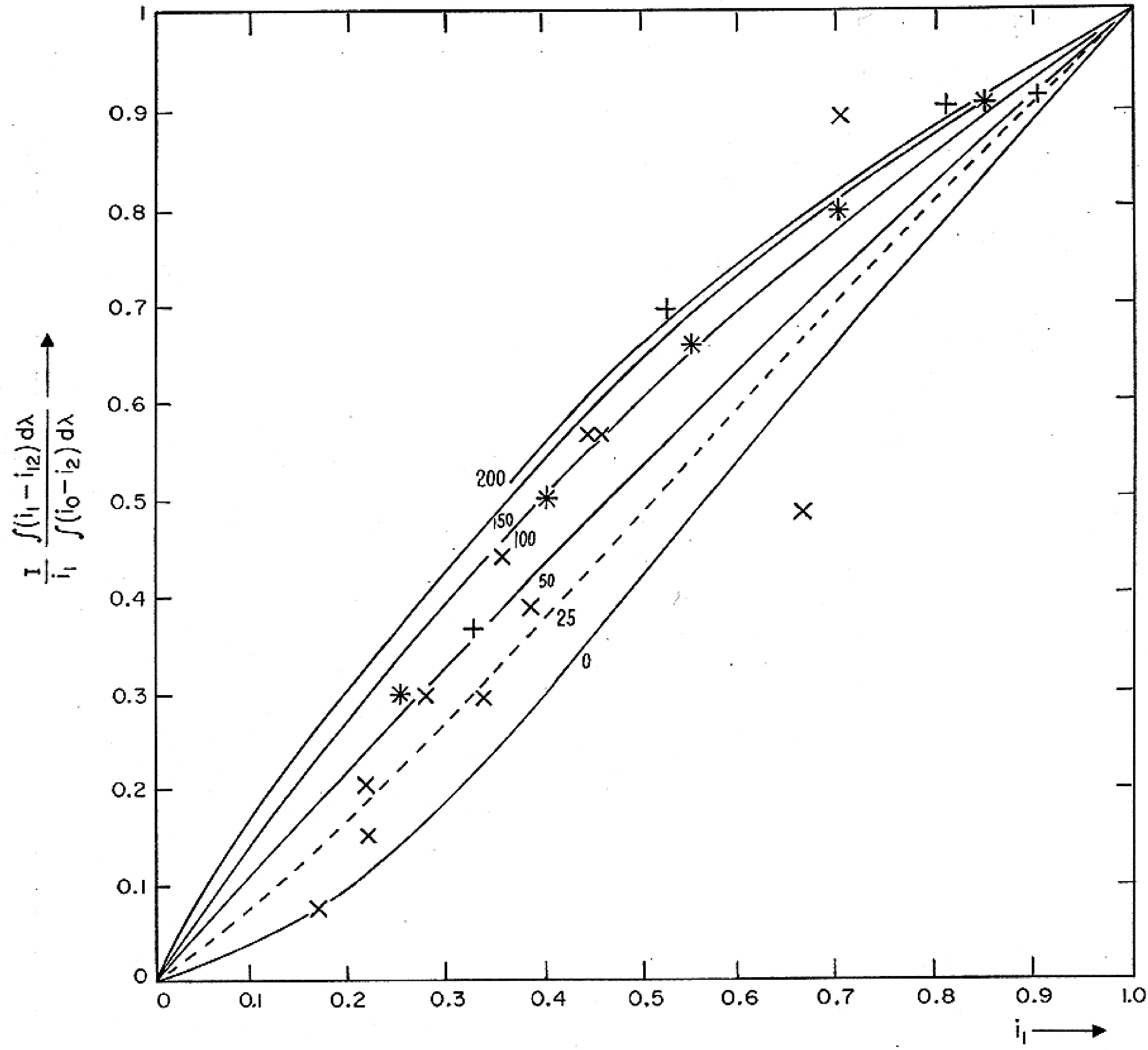

FIGURE 5. *Influence of background on equivalent width.*

Ratio between the equivalent widths of a Fraunhofer line on a background i_1 and the same line undisturbed. Parameter: equivalent width of the disturbed line in mÅ. Asterisks represent calculated values for the strong D_2 line. The crosses correspond to Thackeray's observations; upright crosses for lines stronger than 100 mÅ

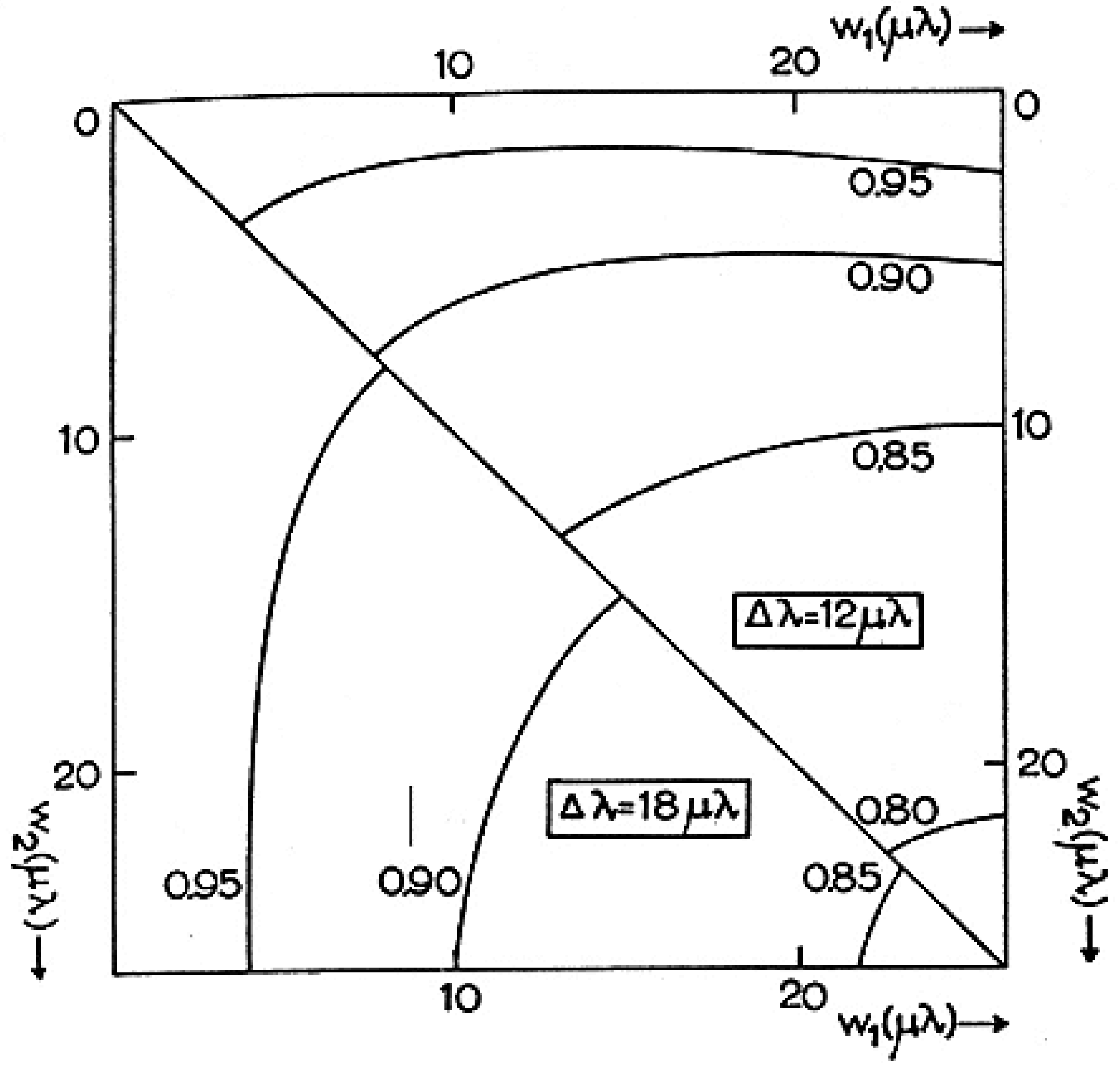

FIGURE 6. *Complementing correction.*

Ratio $\frac{w_{12}}{w_1+w_2}$ of the equivalent width of a blend w_{12} to the sum of the equivalent widths of the undisturbed components w_1 and w_2 (in $\mu\lambda$)

function, were considered to apply to the whole spectrum indiscriminately, provided their abscissae were taken proportional to the wavelength.[3] This was obtained by assuming as a unit the microwavelength $\mu\lambda=10^{-6}\lambda$.

Lines of very different equivalent widths were combined two by two, the profile of each pair being computed for distances of 0, 6, 12, 18, 24 $\mu\lambda$. Atlas doublets could then be compared with the model doublets. This process of comparison was made easier by computing once for all from the model doublets the ratio: equivalent width of fainter line/sum of the two equivalent widths

$$\text{as a function of: } \left\{ \begin{array}{l} \text{minimum intensity in fainter line;} \\ \text{minimum intensity in stronger line;} \end{array} \right.$$

$$\text{or as a function of: } \left\{ \begin{array}{l} \text{width of blend at height 60\% of } i_0\text{;} \\ \text{minimum intensity in stronger line.} \end{array} \right.$$

The first graph was used for the faint lines, the second graph for the strong lines. In many cases both graphs could be used, and the results were, in general, found to agree remarkably well; the mean of the two was taken. The model doublets give only the *ratio* between the two components. When the measured equivalent width of the blend is divided in that ratio, a correction must still be applied because the equivalent width of the blend is less than the sum of the equivalent widths of the components. The amount of this *complementing correction* was also obtained as a byproduct of the construction of the model doublets. As an example we reproduce the graph for two lines at distances of $\Delta\lambda=12\mu\lambda$ or $\Delta\lambda=18\mu\lambda$ (Fig. 6).

For the closest doublets, the methods thus far described would not suffice. Often the record and the plate showed only slight indications of asymmetry, which it would have been very difficult to translate into quantitative ratios. In these cases we have relied on Rowland's original visual estimates; we transformed them into equivalent widths according to Mulders [4], divided the measured equivalent width in that ratio, and applied the complementing correction. A special investigation showed that for lines of a given Rowland number the equivalent width does not systematically change when they are found superposed on the wings of other lines. This means that Rowland automatically corrected for the influence of the background on the equivalent width.

In all cases, where there is a difference between the local and the maximum background, a reduction was applied, in the same way as explained for "lines, superposed on a more or less homogeneous background" (Fig. 3). This applies especially to the whole stretch between 3647 Å and 4000 Å.

Finally all equivalent widths, already corrected for the effects thus far mentioned, had to be converted to *reduced widths:*

$$\text{reduced width (F)}=\text{equivalent width (mÅ)}\times\frac{1000}{\lambda(\text{Å})}$$

We shall give a few examples of the procedure followed.

3991.121 Å Area=136 mm² (planimeter)

Local background=93 mm. Dispersion=19.8 mm/Å

$$\text{Equivalent width}=\frac{136}{93\times19.8}=0.0739\ \text{Å}=\boxed{73.9}\ \text{mÅ}$$

Measurements by other authors: Thackeray 74, Rauer 80.

Weighted mean=74.5

$$\text{Max. background}=102\ \text{mm.} \quad \text{Thus}\ \frac{\text{local background}}{\text{max. background}}=0.91$$

Reduction to max. background (by Fig. 5)

$$\frac{74.5}{0.93}=80.2$$

$$\text{Reduced width}=\frac{80.2}{3.991}=\boxed{20.1}\ \text{F}$$

$$\left. \begin{array}{l} 4476.021\ \text{Å} \\ 4476.089\ \text{Å} \end{array} \right\} \text{Area}=297\ \text{mm}^2\ \text{(planimeter)}$$

Background=100. Dispersion=19.6 mm/A

$$\text{Equivalent width}=\frac{297}{100\times19.6}=0.152\ \text{Å}=\boxed{152}\ \text{mÅ}$$

Separation not detectable.

$$\text{Rowland estimates: } \begin{array}{c} 4 \\ 3 \end{array} \qquad \left. \begin{array}{r} 115 \\ 87 \end{array} \right\} 202\ \text{(Mulders)}$$

$$\text{Proportional equivalent width of components: } \left. \begin{array}{r} 86.5 \\ 65.5 \end{array} \right\} 152$$

---

[3] The apparatus function of a grating appears to have its abscissae proportional to λ. A special test, made later on near 3800Å, seems to show that the line widths there, measured in $\mu\lambda$, are somewhat narrower than near 6000Å, by a factor varying between 1.00 and 1.30; this means that we might have overestimated somewhat the blending effects in the UV

Complementing correction for mutual influence (by Fig. 6):

$$\frac{86.5}{0.86}=101;\quad \frac{65.5}{0.86}=76$$

$$\text{Reduced width}=\frac{101}{4.476}=\boxed{22.6}\ \text{F};\quad \frac{76}{4.476}=\boxed{17.0}\ \text{F}$$

$$\left.\begin{array}{l}4238.760\ \text{Å}\\4238.816\ \text{Å}\end{array}\right\}\text{Area}=297.5\ \text{mm}^2\ \text{(planimeter)}$$

Local background=99. Dispersion=19.4 mm/Å

$$\text{Equivalent width}=\boxed{155}\ \text{mÅ}$$

Ratio of components from model doublets: 0.15

$$\text{Equivalent width of components: }\frac{155}{1.15}=135;\ \frac{155\times0.15}{1.15}=20.$$

Increase for mutual influence ($\Delta\lambda=0.056$ Å):

$$\frac{135}{0.91}=148;\quad \frac{20}{0.91}=22$$

$$\text{Reduced width}=\frac{148}{4.238}=\boxed{34.9}\ \text{F};\quad \frac{22}{4.238}=\boxed{5.2}\ \text{F}.$$

The computation of the equivalent width and of the reduced width may in some cases increase the importance of a line in a most surprising way; this occurs especially for lines superposed on the deepest parts of a spectral profile. Take e.g. the line 3967.431 Å with an area of only 5 sq. mm in the Atlas, superposed on a local background of 15%. The equivalent width becomes $\frac{5.0}{15\times17.3}=0.0192$ Å=19.2 mÅ. Now consider, that this local background is only 11% of the maximum background, and since we consider a faint line, the reduction factor is very important. We have to divide by 0.08. Eventually the reduced width becomes 240 mÅ or 60.4 F. Even more striking examples could be given.

The reduced widths ($10^6\Delta\lambda/\lambda$), in fraunhofers, obtained by taking into account measurements of other authors and eliminating, as well as possible, perturbing influences of neighboring lines, are directly adapted to the theoretical work, but much more uncertain than the entries in column two. We are well aware of the uncertainties in this process of reduction. Our calculations give at least an idea of the order of the blending effect, and a warning that it may become very important, especially in the ultraviolet spectrum.

In such cases where measurements of different authors are available, great divergencies are sometimes found. While the data in italics may be expected to be, in general, more reliable than the others, they may be worse in individual cases, and they are inevitably less homogeneous.

We have refrained from using question marks for those many cases in which there were doubts concerning the reality of a line, the exact profile, the separation of blends, the correction for the background, etc. Even in the most dubious cases, we have compelled ourselves to make a decision, considering that others would have to struggle with the same difficulties, without having more solid ground than we did. It must be clear that our catalogue is full of weak points in all these respects, and that anyone interested in special lines should study them in detail himself, on several spectrograms and repeated records, by using his own critical sense. Nevertheless we hope that the intensity data of the catalogue will be useful in the present period of solar research.

Symbols and Special Signs Used in Columns Two and Three

—— - - - -	Horizontal separation, indicating the overlap between successive plates in the spectral region where telluric lines occur. Equivalent widths of telluric lines may be compared only on one and the same plate.
$\overset{\frown}{5}$	The line is so closely blended with adjacent faint lines, not mentioned in the RRT or in the BM catalogue, that a separation seems impossible. The equivalent width given refers to the total blend.
|5|	The line is partly blended with adjacent faint lines, not mentioned in the RRT or in the BM catalogue, which have been separated by us. The equivalent width refers to the line alone.
}	The lines have not been analyzed in the second column, either because an analysis of the profile was practically impossible, or because such an analysis required too uncertain theoretical assumptions. The equivalent width relates to the blend as a whole.
5	The reduced width, when entered in italics, is the weighted mean of the Utrecht measurement and of measurements by other observers.
( )	The equivalent width could not be directly measured, but it was derived by interpolation, or from multiplets, or from Rowland's estimates.

Table 6. References to Papers Where Equivalent Widths of Fraunhofer Lines Are Found

Adam, M. G.: Mon. Not. Roy. Astron. Soc. **98**, 112 and 544, 1938; **100**, 595, 1940.
Allen, C. W.: Mem. Commonwealth Solar Obs., Canberra **1**, No. 5, 1934; **2**, No. 6, 1938. Astroph. J. **85**, 165, 1937; **88**, 125, 1938. Mon. Not. Roy. Astron. Soc. **96**, 508 and 843, 1936; **100**, 10, 1939.
Barocas, V. and Righini, G.: Astroph. J. **114**, 443, 1951.
Bretz, M.: Zeit. Astroph. **38**, 259, 1956.
Cherrington, E.: Bull. Lick Obs. **17**, 161, 1935.
Dahme, A.: Zeit. Astroph. **11**, 93, 1935.
Hindmarsh, W. R.: Mon. Not. Roy. Astron. Soc. **115**, 270, 1955.
Houtgast, J.: Dissertation, Utrecht, 1942.
De Jager, C.: Recherch. Astron. Obs. Utrecht, **13** (1), 1952.
Korff, S. A.: Astroph. J. **76**, 294, 1932.
Minnaert, M. and Mulders, G. F. W.: Zeit. Astroph. **1**, 192, 1930.
Mulders, G. F. W.: Dissertation, Utrecht, 1934.
Pecker, J. Cl. and Peytureaux, R.: Ann. d'Astroph. **11**, 90, 1948.
Pecker, J. Cl.: Ann. d'Astroph. **12**, 197, 1949.
Phillips, J. G.: Astroph. J. **96**, 61, 1942.
Plaskett, H. H.: Mon. Not. Roy. Astron. Soc. **91**, 870, 1931.
Rauer, W.: Zeit. Astroph. **37**, 1, 1955.
Righini, G.: Mem. Oss. Astrof. Arcetri **48**, 29, 1931. Zeit. Astroph. **10**, 349, 1935.
Roach, F. E. and Phillips, J. G.: Astroph. J. **96**, 71, 1942.
Shane, C. D.: Bull. Lick Obs. **16**, No. 449, 1932; **19**, No. 507, 1941.
Thackeray, A. D.: Mon. Not. Roy. Astron. Soc. **94**, 99, 1934; **95**, 293, 1935. Astroph. J. **84**, 433, 1936.
Ten Bruggencate, P. and von Klüber, H.: Veröff. Göttingen No. 78; Nach. Akad. Wiss. Göttingen, Math.-Phys. Kl., pp. 165 to 183, 1944.
Ten Bruggencate, P. and Houtgast, J.: Zeit. Astroph. **20**, 149, 1940.
Ten Bruggencate, P.; Golnow, H.; Günther, S.; Strohmeier, W.: Zeit. Astroph. **26**, 51, 1949.
Unsöld, A.: Zeit. Phys. **46**, 765, 1928.
Weidemann, V.: Zeit. Astroph. **36**, 101, 1955.
Woolley, R.v.d.R.: Ann. Solar Phys. Obs. Cambridge **3**, 88, 1933. Mon. Not. Roy. Astron. Soc. **93**, 706, 1933.

2.4 Behavior of Atomic Lines in the Sun-Spot Spectrum: Column Four

The physical conditions prevailing in sun-spots have long attracted the attention of the astrophysicist. The great importance of spot behavior in assigning identifications to the solar lines has been recognized throughout the present work. The most extensive spot data available are those based on the Mount Wilson observations of spot spectra. One of the authors (C.E.M.) used this material for a detailed study of *Atomic Lines in the Sun-Spot Spectrum*, in 1932 [15]. At this time an attempt was made to estimate spot intensities on approximately the same scale as Rowland used for estimating the disk intensities. Although estimated intensities are far from ideal for work on determining abundances of chemical elements in the stars, yet they provide reliable general information as to whether the line is strengthened, unchanged, weakened, or obliterated in the spot spectrum as compared with the disk spectrum.

The spectrograms were made with the 150-foot tower telescope at Mount Wilson with the use of a Nicol prism and quarter-wave plate to reveal the Zeeman effect in the spot spectra. The zigzag effect thus produced enables one to select atomic from molecular lines in the spot spectrum.

For the present it is impossible to include measured equivalent widths for lines in the spot spectrum, such as are contained in columns two and three for the disk lines. The great amount of stray light in most sun-spot spectra vitiates the photometric measurements by an amount often unknown. In place of the equivalent widths the following letters are introduced in column four to indicate the spot behavior as compared with the disk intensity, and thus add weight to the assigned identifications in column five.

S	The line is greatly strengthened in the spot spectrum as compared with the disk spectrum. For atomic lines appearing only in the spot spectrum, the estimated spot spectrum is 0 or greater, on the Rowland scale of intensities. For disk lines, the strengthening is estimated to be 3 or more units on that scale. This letter is used, also, for selected unweakened winged lines, which were labeled "W" in the 1933 publication [16].
s	The line is strengthened in the spot spectrum, probably less than 3 units on the Rowland scale. For atomic lines present only in the spot spectrum the intensity is estimated as "−1" or less, i.e. 00 or less, on Rowland's scale.
u	The line is unchanged in intensity in the spot spectrum.
W	The line is greatly decreased in intensity in the spot spectrum, 3 or more units on the Rowland scale.
w	The line is weakened in the spot spectrum, but the weakening is estimated to be less than 3 units.
o	The line is obliterated in the spot spectrum.
N	The line is diffuse.
NN	The line is very diffuse.
d	The line is double.

The spot spectrum data are taken mostly from the publication entitled *Atomic Lines in the Sun-Spot Spectrum* for the region 3894 Å to 6635 Å [16]. In general, for wavelengths longer than 6635 Å the estimated spot intensities from the 1947 publication [11] have been used. In addition, for a limited number of lines, miscellaneous unpublished notes furnished by H. D. Babcock and some unpublished estimates by C. E. Moore have been used.

It is hoped that the next revision of the solar spectrum will include homogeneous measured equivalent widths for atomic lines in the spot spectrum, derived from high-dispersion spot spectrograms covering the whole range with the *same* spot. This is one of the crying needs in solar spectroscopy today. Difficult as such an observing program is, it would well repay the effort. The spot spectrum contains thousands of lines that have not yet been measured. Many are of molecular origin, but the atomic lines interspersed with these have not yet been fully studied.

2.5 The Identifications: Column Five

The entries in this column consist of both atomic and molecular lines, each of which can be recognized easily from their chemical symbols. The wealth of material collected at The National Bureau of Standards for the program on *Atomic Energy Levels* has been used to revise and extend the identifications of atomic lines. Data were collected for as many atomic spectra as possible, from laboratories engaged in spectroscopy throughout the world. The collaboration of many spectroscopists has made possible the revisions included in this column. For each atomic spectrum, the individual lines arranged by multiplets in order of increasing excitation potential have been examined in making the final identification assignments. The intensity behavior in the spot spectrum as compared with the disk has also been a valuable guide throughout.

For molecular spectra the services of various specialists in molecular spectroscopy have been solicited. These identifications have been made not by coincidence of wavelength alone, but rather by a study of the behavior of the various rotation branches of a given molecular spectrum. The procedure has been similar to that of studying multiplet structure for atomic lines. If the intensities of the solar lines vary consistently with the observed laboratory intensities along the lines of the branch, and the wavelengths are in reasonable agreement, the identifications are considered to be plausible. Further details are discussed in the descriptions of the last three columns of the table. §§ 2.6, 2.7, 2.8.

Several symbols have been used in column five to explain the identifications in some detail. These symbols have the following meanings:

|| Parallel lines preceding the chemical symbol indicate the predominant contributor in the case of a blend.

Example: 4844.022 Å ||Fe I
Ti I

Fe I is the predominant contributor, but Ti I is not completely masked.

| A single vertical line preceding the chemical symbol denotes one of the principal contributors to a blend.

Example: 5247.923 Å |Co I
Cr I

Here Co I is a stronger contributor than Cr I.

In cases where more than one identification is given and no such symbols are used, no choice has been possible as to the leading or predominant contributor.

— A dash is used for blends of three types:

Example: 5041.450 Å —C I

Here it is felt that C I does not account fully for the solar intensity. The dash indicates that the line is probably a blend. It precedes the "C I" because the laboratory wavelength is longer than the solar wavelength. The other unknown contributor(s) may well be a line (or lines) having shorter wavelengths.

Example: 5092.309 Å C_2—

This blend is similar to the one described above, except that the C_2 laboratory wavelength is shorter than the solar wavelength. Other contributors may be on the long-wave side or to the red of the solar line.

Example: 4466.165 Å Cr I—
Fe I

In the case of this blend, the Cr I is on the short-wave side of the solar line and Fe I is to longer waves.

( ) Parentheses indicate masked lines. Only more important masked lines are entered throughout the solar table. Usually the multiplet evidence indicates that the masked line should be present. The most conspicuous examples occur in the wings of very strong solar lines.

Example: 3933.682 Å Ca II (*K*)
(Sc I) (V I) (Co I)

? A question mark denotes that the identification is somewhat dubious.

p Chemical symbols followed by "p" indicate identifications based on wavelengths "predicted" from known atomic energy levels. Such lines have mostly not yet been observed in the laboratory, but the multiplet behavior confirms the suggested solar identification.

Example: 4481.031 Å Fe I p

The method of identifying solar lines by prediction is particularly fruitful for a spectrum like Fe I. The solar spectrum still provides more Fe I lines than have as yet been observed in the laboratory. This situation indicates the need for reobserving this complex spectrum with a modern laboratory source, such as an electrodeless discharge. Still more solar identifications of Fe I could be made if the analysis were extended by means of a new homogeneous line list.

2.6 The Low Excitation Potential or Rotation Line: Column Six

This column contains two types of data. For atomic lines, the lower excitation potential of the individual line is tabulated. This excitation potential is that of the lower level involved in the transition giving rise to the laboratory line, expressed in eV. The multiplication factor used to convert cm^{-1} to eV is 0.00012395. This conversion factor has been used throughout to obtain all the ionization potentials listed in the volumes on *Atomic Energy Levels* [27]. The excitation energies listed in this solar table appear slightly larger than those in the 1928 edition, because of the revision in the conversion factor.

For molecular lines, this column has been used to enter the rotation branch and quantum number. For example, the solar line at 4084.327 Å is identified as CH. This line in the laboratory spectrum of CH occurs in the "P" branch and has the quantum number 7, denoted as "P 7" in column six.

2.7 The Multiplet Number or Vibration Band: Column Seven

This is arranged similarly to column six. It contains the multiplet numbers taken from the published Multiplet Tables. These are old multiplet numbers, but since they are well established in the literature, every effort has been made to retain them. In cases where lines have been added to the multiplet, if the multiplet has been assigned a number, that same number is now used for the additional lines. For lines longer than 3000 Å the Multiplet Numbers are from the Princeton University Observatory Contribution No. 20, 1945 [28]. For lines short of 3000 Å, the *Ultraviolet Multiplet Table* has been used, as indicated by "UV" preceding the listed multiplet number [29].

For molecular spectra the vibration bands are indicated in this column. For example, the solar line at 4096.941 Å is identified as CN. This line of CN belongs to the vibration band (1, 2); which is entered in column seven.

2.8 Notes to the Solar-Spectrum Ledger: Column Eight

The numbers in the last column refer to notes that follow the solar ledger (pp. 344 to 349). Most of these are self-explanatory.

Molecular Spectra—Solar Lines

A large number of the notes contain information regarding the molecular lines present in the solar spectrum. Each classified molecular line has a note number. For each molecule all lines having the same electronic transition have the same note number. The note gives the transition, the vibration bands, the spectral range of the individual bands from laboratory spectra, and references used for the material on analysis. Only the bands represented in the present solar ledger are included in the notes.

Molecular Spectra—Atmospheric Lines

For Atm O_2 the limiting range of wavelength is quoted from the paper on analysis by H. D. Babcock and L. Herzberg [14]. A different note number is used for each isotope of O, the electronic transition being the same.

For the classified lines of atmospheric water vapor, Atm H_2O, the limiting spectral range quoted in the notes is taken from the solar table itself. No attempt has been made to include a detailed picture of this complex molecule. In general, the identifications of atmospheric lines have been taken from the 1928 [3] and 1947 [11] tables. This has been supplemented by unpublished data from W. S. Benedict, who has made a most exhaustive study of the bands and has kindly furnished his analysis for use here.

Unclassified atmospheric lines are entered as "Atm", although they are probably due to the water vapor molecule.

A summary of the notes referring to molecular lines is given in Table 7:

Table 7. Notes on Molecular Lines in the Solar-Spectrum Ledger

Note Number	Molecule	Note Number	Molecule	Note Number	Molecule
1	OH	11	CN (blue)	22	Atm O_2 $O^{16}O^{16}$
2	CH	12	CN (red)	23	Atm O_2 $O^{16}O^{17}$
3	CH	19	C_2	24	Atm O_2 $O^{16}O^{18}$
4	CH	20	MgH	26	Atm H_2O
6	NH				

Selected Lists of Solar Lines

Six notes give solar wavelengths of lines that are in special categories (notes 5, 7, 8, 15, 18, 27). Three refer to pairs of lines: (1) formerly listed as double, but recorded here as single (note 7); (2) lines that may be double but are still unresolved (notes 15 and 18).

There are 223 atomic lines appearing only in the sun-spot spectrum. These are included in the main ledger and listed separately in note 13. They can be detected readily by the absence of equivalent width data in columns two and three. Numerous spot lines recorded in the 1932 survey [15, 16] have since been detected on the Atlas spectrograms as present, also, in the disk spectrum, which explains their absence from the listing in note 13 as compared with the 1932 listing [16].

In selecting the atomic lines in the sun-spot spectrum from the appearance of the Zeeman effect, many cases were noted in which it was difficult to separate atomic from molecular lines with certainty. In cases where the spot line is possibly a molecular line, note 16 is entered. Definite blends of atomic and molecular lines in the spot spectrum are indicated by note 17.

Laboratory Wavelengths in the Table

Laboratory wavelengths have been used for higher members of the Balmer and Paschen series of hydrogen, because of the diffuseness of these lines in the solar spectrum. The Balmer lines from H_8 through H_{17} are listed in note 10; and the Paschen lines from n equals 12 through 18, in note 31.

Seven notes contain special comments concerning the data on widths of lines: (notes 9, 14, 21, 28, 29, 30, 32).

The only "forbidden" lines entered in the table are those of [O I] reported by Bowen in 1948 (note 25).

3. General Results

In August 1963 an International Symposium on the Solar Spectrum was held in Utrecht. One paper on this program dealt with the present revision of the solar spectrum, and gave a general account of this solar program [30]. Since that date a new summary of the data included in the table, has been prepared.

3.1 Number of Lines

It is interesting to compare the approximate counts of lines in the present revision with similar counts from the 1928 edition. The 1963 summary [30] has been revised and extended in Table 8. Short of 3061 Å and long of 6600 Å, new observations replace those of Rowland. The counts have been made by regions in order to emphasize the comparison over the long interval from 3061 Å to 6600 Å, where the Rowland Table has not yet been superseded.

Separate counts have not been made for the 223 atomic spot lines in the various categories: unblended, blended, and unidentified. They are included in the overall counts of lines recorded in Table 8. With the aid of note 13 the spot lines can be easily segregated and counted.

The last three columns of Table 8 answer a question that has been persistent over the years, namely, the reality of the faintest Rowland lines. Rowland's Table started at 2975 Å; consequently the counts of new lines short of this wavelength are handled separately. A glance at the last column of this Table indicates an important trend. It seems extremely evident that many more faint solar lines remain to be found and that the rejections of those now recorded will be on the decrease.

Table 8. Counts of Lines in the Solar Ledger

Range (Å)	Unblended	Blended	Unidentified	Total	Percentage Identified	Range (Å)	New Lines Added	Rowland Lines Rejected	Difference
1966 Edition									
2935 to 3061	389	114	153	656	77	2935 to 2975 2975 to 3061	142 80	37	+43
3061 to 4000	4509	1138	1786	7433	76		165	50	+115
4000 to 5000	3327	697	2143	6157	65		430	76	+354
5000 to 6600	3372	380	1830	5582	67		604	346	+258
6600 to 7330	1306	163	356	1825	80				
7330 to 8770	1699	303	312	2314	87				
2935 to 8770	14602	2795	6580	23977	73				
3061 to 6600	11208	2215	5759	19182	70		1199	472	+727
1928 Edition									
2975 to 3061	186	49	236	471	50				
3061 to 4000	3527	933	2868	7328	61				
4000 to 5000	2440	533	2764	5737	52				
5000 to 6600	2725	235	2280	5240	56				
6600 to 7330	695	48	504	1247	60				
2975 to 7330	9573	1798	8652	20023	57				
3061 to 6600	8692	1701	7912	18305	57				

The strongest unidentified lines are listed in Table 9. The limiting intensities are 2 on the scale of eye estimates (<3061 Å). To longer waves the selection is quite arbitrary, since both the measured equivalent width in column two and the reduced width in column three have been used as guides. The total number listed is 241.

3.2 Atoms and Ions in the Sun

In 1941, W. F. Meggers published tables of leading lines in first and second spectra [31]. These tables have been invaluable for astrophysicists. They have been quoted for the *Ultimate Lines* of individual spectra in both the Princeton and the Ultraviolet Multiplet Tables [28], [29]. Since 1941 our knowledge of atomic spectra has increased steadily, and some of the material in these tables has been superseded. Pending the publication of a complete revision containing the designations and a current bibliography for the "Raies Ultimes", the leading lines from his tables, with some revisions and extensions, are given in Table 10 with the low excitation potential of the transition giving rise to the line. Wavelengths in vacuo are denoted by "v" in columns three and nine. All other wavelengths are in air. Laboratory data are in columns three and four for first spectra, and nine and ten for second spectra. The laboratory lines are observed in emission. These are followed by solar data. Some *raies ultimes* short of 3000 Å are strong solar lines, as, for example, Lyman α of H I at 1215 Å. In Table 10, however, the solar material is limited to the range of the present volume, 2935 Å to 8770 Å, all of which is an absorption spectrum. Special notes refer to spectra whose lines are known in solar, spot, or chromospheric spectra, particularly in cases where the lines occur beyond the above ranges.

Many absences can be explained from a glance at Table 10. For the less abundant elements having their ultimate lines in the far ultraviolet, the search for the element should be made in the ultraviolet solar spectrum. The accessible lines have high excitation potentials, which is unfavorable for their appearance. This was pointed out by H. N. Russell in 1929 [32], as was, also, the greater abundance of elements having even atomic numbers.

3.3 Molecules in the Sun

A general survey of this subject was presented by H. P. Broida and C. E. Moore at a symposium in Liège in 1957 [33]. They prepared tables giving counts of the lines of the various bands of CH, OH, and CN present in the sun [34]. Two subsequent papers give the detailed identifications of CH [34] and OH [35] in the solar ledger. A later summary of the solar lines of molecular origin, in the range of the present ledger, was given in Utrecht in 1963 [30]. In 1964 the general question of *Molecules in the Sun*, including spot spectra and the infrared solar spectrum was discussed at the Florence symposium honoring Galileo [36]. To this should be added the recent identification by L. Goldberg and his associates [37] of CO in the solar spectrum near 1600 Å. The molecules identified to date from a detailed study of the laboratory observations and analysis are listed briefly in Table 11 [36].

The present identifications of C_2 can be extended when the Berkeley Monograph on this molecule has been completed. Further study is also needed on SiH; this molecule may be present in the disk spectrum.

3.4 Summary of Identifications

It is well known that some spectra, like Fe I, are well represented in the sun. This laboratory spectrum can be matched line for line in both position and relative intensity with a solar line. Other less abundant elements have only their leading lines present in the sun, as, for example Ag I. In order to summarize the present identifications, counts have been made of the number of lines of each spectrum contained in this compendium. These are recorded in Table 12. The spectra are in order of increasing atomic number. The counts are by regions, and the blended and unblended lines in the solar spectrum have been counted separately. Blended lines are solar lines having more than one contributor to the identification, as, for example:

4046.341 Å Ce II
V II

4043.768 Å —Ti I

Masked lines, entered in parentheses in the ledger, are not included in the counts. Lines whose identifications are subject to question are counted in with the others. Counts for spot lines are included.

Finally, a condensed summary of all elements present in the sun is contained in Table 13. The results given here are based on material over the entire spectral range, i.e. from the far ultraviolet solar spectrum to the infrared. In preparing Table 13 one of the authors (C.E.M.) has had the benefit of communication with R. Tousey regarding identifications in the short-wave region. The notes to Tables 10 and 13 indicate cases where the evidence rests upon observations beyond the range of the present work.

There are 63 elements proven as present without doubt in the sun. Of these, the spectroscopic evidence is least certain for Os and Ir, but the data from the accessible region are more favorable for these elements than for the two elements (Tb and Er) listed as dubiously present. Both Au and Cd were formerly identified from one line each, in the accessible region. R. Tousey [38] reports additional confirmation for these elements from the presence of the *raies ultimes* in the short-wave region. The *raie ultime* of Pt I is also present [38]. One element, Ne, was first detected from the ultraviolet rocket solar spectrum, where the resonance lines of Ne VIII near 780 Å, were identified [38]. The element Ar was first found

Table 9. The Strongest Unidentified Solar Lines

Wavelength	Estimated Intensity
2942.85	[5*d*?]
2975.038	[2]
2984.574	[2]
2987.052	[2]
2990.876	[2]
2991.774	[4]
2993.798	[4]
2995.494	[2]
2996.849	[2]
2997.222	[2*N*]
2998.152	[2]
2998.966	[2]
3000.339	[2]
3001.791	[3]
3006.573	[4*d*]
3007.96	[3*NN*]
3008.470	[3]
3016.872	[3]
3017.418	[3]
3017.854	[2]
3023.068	[3]
3024.242	[2]
3024.802	[3]
3027.016	[2]
3027.699	[2]
3028.869	[2]
3029.000	[2*N*]
3029.990	[3]
3034.60	[3]
3037.23	[3]
3040.761	[2]
3041.038	[2]
3044.228	[2*N*]
3051.04	[3]
3053.744	[2]
3057.963	[3]
3058.706	[3]
3060.773	[2]

Wavelength	Equivalent Width	Reduced Width
3062.83	55	21.5
3064.015	147	48.0
3064.515	65	21.2
3064.829	80	26.2
3068.476	75	24.6
3069.334	57	20.4
3074.07	82	30.3
3075.035	50	24.7
3075.455	39	22.6
3075.595	78	49.0
3078.915	52	21.4
3079.105	78	25.5
3080.877	65	27.8
3081.725	120	39.0
3082.38	64	24.5
3083.850	40	24.0
3085.043	64	20.7
3085.395	58	23.5
3085.720	79	25.6
3086.988	161	52.2
3087.693	58	25.3
3088.188	64	34.0
3088.355	101	32.7
3088.752	105	54.2
3089.505	66	21.5
3091.693	45	32.0
3091.876	96	31.2
3092.473	63	29.2
3097.785	66	23.5
3099.790	44	47.2
3101.417	88	47.4
3101.694	97	77.4
3101.974	45	26.2
3113.838	66	21.1
3119.198	77	24.8
3130.631	63	32.7
3148.900	67	21.4
3152.000	75	23.8
3179.166	73	45.4
3183.05	47	22.6
3186.86	98	43.0
3186.964	64	28.7
3196.195	33	21.3
3196.835	48	30.4
3199.662	55	21.4
3205.223	66	25.2
3211.634	73	40.6
3215.844	69	21.5
3222.944	24	25.3
3225.712	33	57.7
3227.631	46	38.3
3281.716	70	21.5
3286.628	41	31.0
3289.027	48	33.8
3305.864	44	24.5
3306.093	65	27.3
3315.420	74	34.3
3335.923	50	21.6
3336.831	32	41.3
3344.936	70	21.1
3349.266	19	27.7
3360.351	36	22.9
3369.665	33	77.1
3380.313	76	43.4
3391.107	36	31.9
3392.894	17	26.2
3414.511	53	34.2
3414.918	49	157
3415.098	15	24.9
3440.099	25	22.1
3440.192	26	31.0
3442.148	34	20.5
3458.594	32	37.6
3461.796	32	30.9
3466.002	24	22.5
3475.519	22	74.0
3492.369	60	21.5
3492.815	23	20.2
3504.684	70	20.0
3505.294	92	26.2
3524.358	16	24.6
3610.508	250**	42.6
3618.523	12	20.2
3618.999	31	43.2
3619.114	12	21.8
3621.105	84	25.3
3631.265	35	45.4
3631.586	10	31.2
3634.412	36	22.8
3638.104	78**	21.1
3648.082	24	34.5
3649.837	75	26.7
3688.804	72	24.6
3730.308	38	21.7
3735.118	6.5	42.8
3735.244	14	56.0
3736.712	12	29.2
3737.032	10	67.0
3737.299	4.5	31.6
3743.218	25	22.2
3745.349	(68)#	(72.5)#
3749.244	46	103
3749.365	4	31.2
3749.740	15	33.4
3749.850	7.5	22.7
3757.959	29	37.2
3758.437	15	38.6
3763.008	53	21.2
3763.979	16	33.8
3766.968	24	27.5
3767.081	7	23.9
3767.356	18	34.5
3780.706	110	36.2
3792.686	121**	36.0
3794.887	14	24.0
3795.155	547**	20.6
3796.803	33	26.0
3815.328	27	21.7
3815.617	38	58.7
3820.056	27	41.6
3820.196	13	43.7
3824.573	84	97.5
3826.026	7	26.9
3827.692	6.5	21.9
3828.019	24	33.9
3829.250	10	32.4
3832.510	9.5	27.6
3834.10	20	43.1
3836.920	34	20.8
3838.208	3	23.5
3840.303	12	25.0
3840.583	26	40.4
3841.190	14	25.5
3859.400	39	32.6
3859.741	20	45.8
3881.980	56	31.2
3884.292	66**	23.4
3903.854	224**	25.0
3911.989	76	25.6
3921.187	59	24.0
3927.797	42	41.7
3929.357	24	27.7
3930.150	26	40.8
3935.216	6	22.4
3937.974	28	28.8
3947.693	45	21.6
3965.930	25	30.2
3967.636	7	26.4
3967.859	7.5	29.5
3968.715	3	20.6
3968.936	6	37.2
4001.163	127**	27.2
4004.915	72.5	24.1
4005.072	52	26.5
4007.926	68	17.0
4009.146	53	13.2
4015.611	88	21.9
4017.573	74	18.4
4020.272	107**	18.2
4025.823	64	15.2
4033.588	46	11.4
4045.715	7.5	13.3
4045.968	14	23.0
4063.789	19	18.7
4066.120	48	10.8
4132.711	40	10.2
4146.990	45	10.8
4167.722	44	10.6
4181.974	93	22.2
4219.199	42	10.0
4226.970	45	55.8
4227.321	44	28.9
4231.954	45	10.6
4299.831	93	21.6
4300.744	33	11.8
4302.65	43	19.5
4308.289	31	12.8
4337.252	46	12.2
4393.284	46	10.5
4401.022	58	13.2
4403.187	62	14.5
4518.342	40	*10.0*
4599.843	56	12.2
4672.334	56	12.0
4678.172	62	13.2
4699.340	64	13.6
4748.141	78	16.4
4771.472	70	14.7
4971.351	55	11.1
5053.577	50	9.9
5271.054	31	5.9
5298.497	65**	11.9
5341.151	180**	10.2
5390.527	30	5.6
5418.775	49	*8.7*
5421.178	44	8.1
5654.501	75	13.3
6020.016	49	8.1
6299.588	36	5.7
6449.127	34	5.3
7032.319	33	*4.1*
7375.251	45	6.1
7435.584	32	4.3

**Blend.

#Parentheses indicate that the equivalent width could not be measured directly. See p. XVI.

as [Ar x] in the coronal spectrum. The only radioactive element known to be present is Th; here the *raie ultime* of Th II provides the only evidence.

Two elements, Tb and Er, are listed as questionably present. For both Tb II and Er II, the behavior of the lines in the flash spectrum as having the rare-earth characteristic described by Menzel [40], has been a guiding factor in assigning identifications.

No positive statement can be made about the four elements in the category "Further study needed". The presence of BH has been reported, but further data are needed [33]. The strongest lines of B I lie near 2500 Å. Because of blending they can neither be clearly identified nor ruled out as definitely absent [38].

Sixteen elements are listed as absent on the basis of spectroscopic study. Two, Tc and Ta, have been added to this group as a result of additional solar observations. R. Tousey finds no evidence of the presence of the leading Tc II multiplet near 2600 Å. The strong Ta I line at 2714 Å is masked and other strong lines are absent [38].

Further laboratory work on the lanthanon group of rare earths may add to line identifications in spectra of elements known to be present, and may increase the number of rare-earth elements present. The third spectra of these elements extend into the infrared and may well be of astrophysical importance. Only one third spectrum is mentioned in the present table, namely Ce III. In this spectrum the strongest accessible line is at 3055.589 Å, and it may explain the chemical origin of the faint solar line observed at 3055.594 Å.

Table 10. Leading Lines in First and Second Spectra

Z	Laboratory			Sun-Present Volume			Laboratory			Sun-Present Volume		
	Sp	λ (Å)	Low E P	λ (Å)	Reduced Width	Low E P	Sp	λ (Å)	Low E P	λ (Å)	Reduced Width	Low E P
1	^{1}H I	1215. 668v△	0. 00	6562. 808	649	10. 20						
2	He I	584. 334v△	0. 00				^{4}He II	303. 780v_△	0. 00			
3	Li I	6707. 761	0. 00	6707. 76▲	0. 2	0. 00	Li II	199. 282v	0. 00			
4	Be I	2348. 610	0. 00	3321. 352	2. 7	2. 72	Be II	3130. 420	0. 00	3130. 414	27. 3	0. 00
5	B I	2497. 725	0. 00				B II	1362. 460v	0. 00			
6	C I	1657. 008v	0. 01	8335. 150	13. 7	7. 68	C II	1335. 708v	0. 01			
7	N I	1134. 979v	0. 00	8683. 384	0. 9	10. 33	N II	1085. 701v	0. 02			
8	O I	1302. 169v	0. 00	7771. 954	*9. 4*	9. 14	O II	834. 467v	0. 00			
9	F I	924. 825v	0. 00				F II	606. 81 v	0. 00			
10	Ne I	735. 892v	0. 00				Ne II	460. 725v	0. 00			
11	Na I	5889. 953	0. 00	5889. 973	120	0. 00	Na II	372. 069v	0. 00			
12	Mg I	2852. 127	0. 00	3838. 302	641	{2. 72 {2. 72	Mg II	2795. 528	0. 00	4481. 140	*14. 5*	8. 86
13	Al I	3961. 520	0. 01	3961. 535	220	0. 01	Al II	1670. 786v	0. 00	3900. 660?	7. 1	7. 42
14	Si I	2516. 112	0. 03	3905. 532	*219*	1. 91	Si II	1533. 445v	0. 04	3856. 026	26. 0	6. 86
15	P I	1774. 942v □	0. 00				P II	1542. 321v	0. 06			
16	S I	1807. 341v	0. 00	8694. 641	3. 9	7. 87	S II	1259. 53 v	0. 00			
17	Cl I	1347. 238v	0. 00				Cl II	1071. 036v	0. 00			
18	Ar I	1048. 219v	0. 00				Ar II	919. 782v	0. 00			
19	K I	7664. 899	0. 00	7698. 977	*19. 4*	0. 00	K II	600. 765v	0. 00			
20	Ca I	4226. 728	0. 00	4226. 740	*342*	0. 00	Ca II	3933. 663	0. 00	3933. 682	(4874)	0. 00
21	Sc I	3911. 810	0. 02	3911. 825	18. 2	0. 02	Sc II	3613. 836	0. 02	} 3613. 809 } 3613. 881	29. 6 } 29. 6 }	0. 02
22	Ti I	3653. 497	0. 05	3729. 813	39. 4	0. 00	Ti II	3349. 399	0. 05	3349. 447	163	0. 05
23	V I	3185. 396	0. 07	3185. 388	38. 8	0. 07	V II	3093. 108	0. 39	3556. 803	55. 7	1. 13
24	Cr I	3578. 682	0. 00	3578. 693	142	0. 00	Cr II	2055. 59	0. 00	3368. 058	56. 3	2. 48
25	Mn I	4030. 755	0. 00	4030. 763	75. 2	0. 00	Mn II	2576. 106	0. 00	3441. 982	107	1. 78

Table 10. Leading Lines in First and Second Spectra—Continued

Z	Laboratory			Sun-Present Volume			Laboratory			Sun-Present Volume		
	Sp	λ (Å)	Low E P	λ (Å)	Reduced Width	Low E.P	Sp	λ (Å)	Low E P	λ (Å)	Reduced Width	Low E P
26	Fe I	3719.934	0.00	3734.874	945	0.86	Fe II	2382.034	0.00	3196.106	76.7	1.67
27	Co I	3453.516	0.43	3453.512	87.9	0.43	Co II	2286.165	0.42	3387.718	15.2	2.27
28	Ni I	3414.764	0.03	3524.536	363	0.03	Ni II	1751.914v	0.00	3407.314	26.0	3.08
29	Cu I	3247.538	0.00	3247.569	76.0	0.00	Cu II	1358.764v	0.00			
30	Zn I	2138.56	0.00	3345.024	21.4	4.08	Zn II	2025.512	0.00			
31	Ga I	4172.056	0.10	4172.053	13.9	0.10	Ga II	1414.44 v	0.00			
32	Ge I	2094.258	0.17	4226.568	53.2	2.03	Ge II	1649.192v	0.22			
33	As I	1890.42v	0.00				As II	1266.36 v	0.31			
34	Se I	1960.901v	0.00				Se II	1192.29 v	0.00			
35	Br I	1488.452v	0.00				Br II	1036.983v	0.00			
36	Kr I	1164.868v	0.00				Kr II	917.434v	0.00			
37	Rb I	7800.227	0.00	7800.29▲	0.6	0.00	Rb II	697.04 v	0.00			
38	Sr I	4607.331	0.00	4607.338	7.8	0.00	Sr II	4077.714	0.00	4077.724	100	0.00
39	Y I	4102.38	0.07	3620.971	8.2	0.07	Y II	3710.30	0.18	3664.623	31.4	0.18
40	Zr I	3601.18	0.15	3575.765	9.5	0.07	Zr II	3391.96	0.16	3165.958	26.7	0.16
41	Nb I	4058.933	0.13	3802.959	7.1?	0.09	Nb II	3094.172	0.51	3619.536	17.0	0.98
42	Mo I	3798.249	0.00	5533.039	1.3	1.33	Mo II	2020.32	0.00	3320.915	2.6	3.11
43	Tc I	3636.070	0.32				Tc II	2543.227	0.00			
44	Ru I	3498.944	0.00	3728.042	20.0	0.00	Ru II	1574.337v	0.00	3177.080	4.6	2.40
45	Rh I	3434.893	0.00	3434.896	3.6	0.00	Rh II	1607.86 v	0.00	3187.899	4.2	3.45
46	Pd I	3404.580	0.81	3404.584	10.6	0.81	Pd II	1363.76 v	0.00			
47	Ag I	3280.682	0.00	3280.681	15.3	0.00	Ag II	1112.46 v	0.00			
48	Cd I	2288.018	0.00	3261.065	7.0	0.00	Cd II	2144.408	0.00			
49	In I	4511.323	0.27	4511.31▲	0.4	0.27	In II	1586.37 v	0.00			
50	Sn I	2839.99	0.42	3801.025	2.5	1.07	Sn II	1899.890v	0.53			
51	Sb I	2068.33	0.00	3267.539	3.5	2.03	Sb II	1438.11 v	0.00			
52	Te I	2142.75	0.00				Te II	1404.65 v	0.00			
53	I I	1782.758v	0.00				I II	1220.887v	0.00			
54	Xe I	1295.587v	0.00				Xe II	1100.432v	0.00			
55	Cs I	8521.133	0.00				Cs II	813.85 v	0.00			
56	Ba I	5535.484	0.00	5535.51 ⊠		0.00	Ba II	4554.033	0.00	4554.036	*36.7*	0.00
57	La I	6249.929	0.51	6249.91	0.1	0.51	La II	3949.10	0.40	3794.773	34.3	0.24
58	Ce I	5699.226					Ce II	4186.599	0.86	3560.802	13.7	0.68
59	Pr I	4951.355	0.00				Pr II	4100.746	0.55	3994.810	3.9	0.05
60	Nd I	4924.516	0.00				Nd II	4303.573	0.00	4303.595	15.1	0.00
61	Pm I	4781.291	0.00				Pm II	3998.961				
62	Sm I	4296.743	0.50				Sm II	3568.271	0.48	3735.964	18.0	0.28

Table 10. Leading Lines in First and Second Spectra—Continued

Z	Laboratory			Sun-Present Volume			Laboratory			Sun-Present Volume		
	Sp	λ (Å)	Low E P	λ (Å)	Reduced Width	Low E P	Sp	λ (Å)	Low E P	λ (Å)	Reduced Width	Low E P
63	Eu I	4594. 03	0. 00	4627. 221▲	0. 9	0. 00	Eu II	3819. 67	0. 00	3819. 688	28. 2	0. 00
64	Gd I	4225. 850	0. 21				Gd II	3422. 466	0. 24	3100. 524	69. 6 ?	0. 24
65	Tb I						Tb II			3568. 55 ?∧	1. 8	
66	Dy I						Dy II			3407. 805	18. 8	0. 00
67	Ho I						Ho II					
68	Er I	4007. 97	0. 00				Er II			3896. 248 ?	8. 7	0. 05
69	Tm I	4094. 188	0. 00	4094. 20 ?	0. 9	0. 00	Tm II	3848. 02	0. 00	3462. 213	4. 0	0. 00
70	Yb I	3987. 98	0. 00	3987. 966▲	5. 0	0. 00	Yb II	3694. 19	0. 00	3694. 199	25. 6	0. 00
71	Lu I	3359. 56	0. 25				Lu II	2615. 42	0. 00	3397. 062	12. 1	1. 46
72	Hf I	2916. 48	0. 57	3616. 878	0. 1	0. 29	Hf II	3399. 793	0. 00	3505. 232	8. 3	1. 04
73	Ta I	2714. 66	0. 00				Ta II	2400. 62	0. 77			
74	W I	4008. 753	0. 37	3207. 248	4. 0	0. 37	W II	2204. 482	0. 76			
75	Re I	3460. 465	0. 00				Re II	1973. 13 v	0. 00			
76	Os I	2909. 061	0. 00	3232. 076	5. 8	0. 52	Os II					
77	Ir I	2543. 971	0. 35	3220. 775	10. 5	0. 35	Ir II					
78	Pt I	2659. 454	0. 00	3064. 713	53. 6 ?	0. 00	Pt II	1777. 086v	0. 59			
79	Au I	2427. 95	0. 00	3122. 784 ?	1. 6	1. 14	Au II	1224. 57 v	0. 00			
80	Hg I	1849. 499v	0. 00				Hg II	1649. 939v	0. 00			
81	Tl I	3519. 24	0. 97				Tl II	1321. 71 v	0. 00			
82	Pb I	2833. 067	0. 00	3683. 480	3. 9	0. 97	Pb II	1682. 15 v	0. 00			
83	Bi I	3067. 732	0. 00				Bi II	1436. 83 v	0. 00			
84	Po I	2450. 11	0. 00				Po II					
85	At I	2244. 01	0. 00				At II					
86	Rn I	1786. 07 v	0. 00				Rn II					
87	Fr I						Fr II					
88	Ra I	4825. 91	0. 00				Ra II	3814. 42	0. 00			
89	Ac I	4179. 98	0. 00				Ac II	4507. 20	0. 00			
90	Th I	3719. 435	0. 00				Th II	4019. 129	0. 00	4019. 136	2. 1	0. 00
91	Pa I						Pa II					
92	U I	3584. 88	0. 00				U II	3859. 580	0. 04			

△Prominent in the ultraviolet region of the solar spectrum. Lines of He I and He II conspicuous in the spectrum of the chromosphere.

▲Prominent in the sun-spot spectrum.

□First identified in the sun from strong lines near λ10500.

⊠Present only in the spot spectrum.

∧Identification doubtful; Tb II lines may account for some lines observed in the spectrum of the chromosphere.

Table 11. Molecules in the Sun—Summary

Spectrum	Molecule											Number
Disk	OH	CH	NH	C_2	CN	CO	MgH					7
Spot		CH		C_2	CN		MgH	CaH	SiH	TiO	ZrO	8
Disk and Spot		CH		C_2	CN		MgH					4
Total No.	represented from detailed study of lines											11
Total No.	reported prior to 1964											28

Table 12. Counts of Lines of Individual Spectra in the Solar Ledger

Range (Å) →	2935 to 3061		3061 to 4000		4000 to 5000		5000 to 6600		6600 to 7330		7330 to 8770		2935 to 8770	
Sp. ↓	Unblended	Blended	Unblended	Blended	Unblended	Blended	Unblended	Blended	Unblended	Blended	Unblended	Blended	Unblended	Blended
H			11		3		1				4		19	
Li I									2				2	
Be I			1	2									1	2
Be II			2										2	
C I	1	1	1		9	2	16	3	15	5	10	5	52	16
N I											9	4	9	4
O I			2				5	1	1	1	4	2	12	4
Na I			2		12	3	8				2		24	3
Mg I		2	17	2	12		9	1	5	1	24	4	67	10
Mg II	1		2		2						2	1	7	1
Al I	2	1	5	3			1	1	4	1	5	2	17	8
Al II			1										1	
Si I	4		1		24	4	50	13	33	6	64	25	176	48
Si II			2	1		1	3						5	2
P I									1	1		1	1	2
S I					4		5	4	5	2	13	5	27	11
K I				1	2		6	1	1		1	1	10	3
Ca I	4	1	39	17	34	5	47	3	6	1	6	5	136	32
Ca II			7		2	1	5	1			5	1	19	3
Sc I	1	3	4	2	13	6	33	7					51	18
Sc II	2	1	18	12	14	5	19	2	1				54	20
Ti I	6	9	141	84	275	98	231	31	23	10	61	27	737	259
Ti II	9	10	140	72	70	24	16	4	2			1	237	111
V I	18	7	71	65	128	57	99	14	9	1	7	5	332	149
V II	30	21	110	78	29	21	14	7					183	127
Cr I	32	8	211	115	346	126	180	39	25	5	15	9	809	302
Cr II	37	11	125	83	38	16	27	5					227	115
Mn I	16	7	94	42	79	20	31	11	3	1	8		231	81
Mn II	10	7	18	2	3	2							31	11
Fe I	114	50	1517	394	1075	241	869	135	237	54	214	63	4026	937
Fe II	33	25	150	79	76	16	73	23	5	3	7	5	344	151
Co I	14	7	277	127	91	32	95	23	12	3	19	10	508	202
Co II			15	7	2								17	7
Ni I	19	3	220	72	167	60	172	25	40	9	42	6	660	175
Ni II	1	1	10	6	3								14	7

Table 12. Counts of Lines of Individual Spectra in the Solar Ledger—Continued

Range (Å) →	2935 to 3061		3061 to 4000		4000 to 5000		5000 to 6600		6600 to 7330		7330 to 8770		2935 to 8770	
Sp. ↓	Unblended	Blended	Unblended	Blended	Unblended	Blended	Unblended	Blended	Unblended	Blended	Unblended	Blended	Unblended	Blended
Cu I	2	2	4	1	5		6				2		19	3
Zn I			4	2	5		1						10	2
Ga I					1	1							1	1
Ge I	1		1	1	1	1							3	2
Rb I											2		2	
Sr I			2	2	9		6		2				19	2
Sr II			1	2	3	1							4	3
Y I			1	1	19	3	7	6	1	2			28	12
Y II	2		25	15	12	4	11	6	4	1	1		55	26
Zr I	1	3	16	20	35	14	27	4	6	1	7	5	92	47
Zr II	12	9	109	54	30	24	5	3	1	1		1	157	92
Nb I			4	1	6	2	1					1	11	4
Nb II	3		13	8		1							16	9
Mo I			2	4	8	2	5	1					15	7
Mo II	1		7	2	1	1							9	3
Ru I			12	5	10	3	1	1					23	9
Ru II			2	8	1	1							3	9
Rh I	1		13	2		3	1						15	5
Rh II	1		2	2									3	2
Pd I		1	7	6	1								8	7
Ag I			2										2	
Cd I			1										1	
In I					1								1	
Sn I	1		1	1									2	1
Sb I			2										2	
Ba I							2						2	
Ba II			1		4		2	1					7	1
La I							1						1	
La II			12	6	16	15	10	3	1				39	24
Ce II	2		36	32	49	32	13	2					100	66
Ce III	1												1	
Pr II			3	3	4	3	6						13	6
Nd II			18	14	26	14	24	6					68	34
Sm II			39	31	44	16	1		1			1	85	48
Eu I					2								2	
Eu II		1	6	4	3		1	1	1				11	6
Gd II	4	1	25	11	9	8	1					1	39	21
Tb II			3	1	1								4	1
Dy II			31	13	4	3	3			1	1		39	17
Er II			1										1	
Tm I					2								2	
Tm II			6	3		1	1						7	4
Yb I			1					1					1	1
Yb II			1	1									1	1

Table 12. Counts of Lines of Individual Spectra in the Solar Ledger—Continued

Range (Å) →	2935 to 3061		3061 to 4000		4000 to 5000		5000 to 6600		6600 to 7330		7330 to 8770		2935 to 8770	
Sp. ↓	Unblended	Blended	Unblended	Blended	Unblended	Blended	Unblended	Blended	Unblended	Blended	Unblended	Blended	Unblended	Blended
Lu II			1	2									1	2
Hf I			2							2			2	2
Hf II			11	4	2		1						14	4
W I		2	4	3	2	2	2						8	7
Os I		1	3	1	1	1							4	3
Ir I			4	2	3	1							7	3
Pt I	1		1	3							1		3	3
Au I			1										1	
Pb I			1			1							1	1
Th II					1								1	
CH			100	102	304	214							404	316
CN			428	207	88	62	18	12	105	35	396	221	1035	537
C_2					99	18	348	90					447	108
NH			159	106									159	106
MgH					2		81	31					83	31
OH	4		164	127									168	127
Atm							283	53	186	45	106	46	575	144
Atm H_2O							407	44	410	84	439	93	1256	221
Atm O_2							81	8	158	11	222	3	461	22
Total	391	195	4507	2079	3327	1192	3372	627	1306	287	1699	554	14602	4934
Total	586		6586		4519		3999		1593		2253		19536	

Table 13. Chemical Elements in the Sun

Classification	Element															No.
Present	H	He	Li	Be	C	N	O	Ne[1]	Na	Mg	Al	Si	P	S	Ar[2]	
	K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	Rb	
	Sr	Y	Zr	Nb	Mo	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Ba	La	
	Ce	Pr	Nd	Sm	Eu	Gd	Dy	Tm	Yb	Lu	Hf	W	Os	Ir	Pt	
	Au	Pb	Th													63
Present ?	Tb	Er														2
Further study needed	B[3]	As	Ho	Hg												4
Absent	F[4]	Cl	Se	Br	Kr	Tc	Te	I								
	Xe	Cs	Ta	Re	Tl	Bi	Ra	U								16
Not to be expected	Remaining radioactive elements															

[1] Evidence based on discovery of Ne VIII and Ne VII in the UV spectrum [38].

[2] Evidence based on discovery of [Ar X] in the coronal spectrum [39].

[3] BH has been reported as present, but further evidence is needed [33].

[4] No atomic lines present. MgF has been reported as present but further evidence is needed [33].

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5. The Solar Spectrum Ledger

5.1 Letters, Symbols, and Special Signs

For ready reference the letters and symbols used in this ledger are listed below with brief descriptions. They are explained fully in the text.

Wavelengths: Column one (see Table 5, p. VIII)

S	**Standard Wavelength**
m	Measured lines; not taken from Rowland's Table.
r	Wavelength from Rowland's Table (corrected to 1928 scale).
a	Wavelengths from Atlas Recordings and Atlas Spectrograms.

Equivalent and Reduced Widths: Columns two and three (see p. XVI)

——— ------	Horizontal separation indicating overlap between successive plates in region where telluric lines occur.
$\widehat{5}$	Unresolved blend; equivalent width refers to the total blend.
|5|	Partial blend with adjacent faint lines; equivalent width refers to the line alone.
}	Lines not analyzed in column two. Equivalent width relates to the blend as a whole.
5	The reduced width, when entered in italics, is the weighted mean of Utrecht measurements and of those by other observers.
( )	Equivalent width not directly measured; derived by interpolation, from multiplets, or from Rowland's estimated intensities.

═══	On page 78 the discontinuity in the Balmer continuum near 3646 Å is thus indicated.

Behavior in Sunspots: Column four (see p. XVII)

S	The line is greatly strengthened.
s	The line is strengthened.
u	The line is unchanged in intensity.
W	The line is greatly weakened.
w	The line is weakened.
o	The line is obliterated.
N	The line is diffuse.
NN	The line is very diffuse.
d	The line is double.

The Identifications: Column five (see p. XVIII)

‖	Predominant contributor to a blend.
|	Principal contributor to a blend.
—	In case of blends the dash indicates whether the contributor is on the short- or the long-wave side of the solar line; or whether the solar line has been completely identified.
( )	Masked lines.
p	Identification based on predicted laboratory wavelength.

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