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Variations in the Thermodynamic State of the Chromosphere over the Sunspot Cycle

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Introduction

The solar corona undergoes marked systematic changes in brightness and shape during the course of a sunspot cycle. Standard photometric techniques enable us to detect the variations in both the continuous and the line spectra. The flash spectrum observed at eclipse indicates that the chromospheric spectrum also undergoes marked changes in character (Menzel, 1931; Cillié and Menzel, 1935; Athay and Thomas, 1956). The significance of this apparent variation in chromospheric structure is somewhat difficult to assess, in terms of the physical character. The available data concerning chromospheric variability are extremely limited. One may reasonably question the reliability of the indicated changes. The available data refer to the chromosphere in the equatorial regions. To our knowledge, no eclipse observations exist for the polar chromosphere. Existing spicule and prominence structure must produce some variation in the character of the spectrum from point to point on the limb. Thus, we must find the answer to two main questions, in our search for systematic changes in chromospheric structure. Can we determine the properties of an average chromosphere from observations over a narrow sector of the limb at a given eclipse? If we can, does this average change with time? In this paper we shall attempt to answer both questions.

In order to study chromospheric changes, we need reliable emission gradients and reliable absolute and relative intensities of both line and continuous emission. Data from five eclipses are available for study, not uniformly precise as far as photometric standardization is concerned. The 1932 eclipse occurred within a year of sunspot minimum, the 1941 and 1952 eclipses two years before minimum, the 1945 eclipse one year after minimum, and the 1936 eclipse one year before maximum. The available data for the 1945 eclipse are very limited. Thus, evidence for time-variable changes in chromospheric structure must depend heavily on the 1932 and 1936 eclipses. Fortunately, "jumping-film" spectrograms for those two eclipses and the 1952 eclipse are at our disposal. As a result, we shall center our discussion around these data.

We have mentioned three quantities of interest in the character of the chromospheric spectrum: emission gradients, relative intensities, and absolute intensities. Any attempt to set

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the relative intensities on an absolute scale encounters serious difficulties. Since the various emission lines may possess different gradients, any change in the zero point of the height scale will produce systematic differences in both relative and absolute intensities. A shift in zero point by only 300 km leads to apparent changes of a factor two in the ratio of intensities of helium lines to faint metal lines. For this reason, we have redefined the zero point of the height scale for the 1932 and 1936 eclipses to be consistent with that used for 1952.

Although considerable effort has gone into the reduction of the 1936 data, no results have been published in readily available form. Hemmendinger (1939) measured line intensities at several points on the limb and Menzel (unpublished data, 1939) made similar measurements for two points on the limb. The advent of World War II interrupted the analysis and reduction of these data. Since we are looking specifically for evidence of changes in chromospheric structure, it seemed advisable to remeasure some of the data for the 1936 and 1932 eclipses in order to obtain as much homogeneity as possible in the reduction techniques. The techniques used were consistent with those used for 1952.

We have mentioned that reliability of the photometric standardizations is a prime question in all existing eclipse data. In the following section we shall review the standardizing methods used at the three eclipses, and shall discuss an alternative method of standardization which indicates the reliability of the data.

Photometry

Before we discuss the methods of standardization at the three eclipses we shall consider how to check the reliability of the results. One of us (Athay, 1953) has previously pointed out that the coronal spectra superposed on slitless eclipse spectrograms may be used as a secondary standard light source. Here we shall only briefly summarize the method and assumptions used.

The corona as a standard source.—On slitless spectrograms with the dispersion set parallel to the line of contacts, the image of the corona at the upper and lower edges of the spectrum is not affected by the motion of the moon across the solar surface. We assume that the brightness of this coronal image is constant with time and that the color at all heights matches that of the disk. We can determine the absolute brightness of the coronal image as a function of distance from the center of the disk, either from direct measurements made at the eclipse or from van de Hulst's (1953) coronal model for the polar regions. Independent measurements of coronal brightness are available for 1936. For 1932 and 1952 we must rely on the coronal models.

The corona serves as a continuous light source with an intensity variation perpendicular to the direction of dispersion. In this respect it is equivalent to a uniform source exposed through a slit of varying aperture. The intensity distribution with wavelength is accurately known since it corresponds to that of the uneclipsed sun. Although the intensity distribution with distance from the center of the disk and the absolute intensities are less accurately known, we may still employ them as a secondary standard. Since light rays from both corona and chromosphere trace essentially identical paths through the earth's atmosphere and through optical instruments, the corrections for atmospheric extinction, instrumental absorption, and film sensitivity are automatically included. Also, since the coronal standard and chromospheric spectrum receive identical exposures and development, the determined coronal intensity serves as an additional check on the constancy of successive exposures.

In slitless spectrograms each wavelength produces a ring-shaped image of the corona. The continuum intensity at any point in the spectrogram is the sum of the overlapping images. Each image represents a different wavelength and different point in the coronal image. At the limb ±90° to the line of dispersion, the images are displaced along a tangent to the limb. The tangential scale height in the lower corona is about 0.8 solar radii. Thus, most of the intensity at a point beyond the limb at ±90° to the line of dispersion will be built up from images displaced less than a solar radius. On the spectrograms for the three eclipses in question, a solar radius corresponds to about 50–100 A. The average intensity of photospheric continuum over a 100–200 A band is very nearly equal to the intensity at the central wavelength of the band, and we may neglect the change in wavelength in the displaced images.

Let $F_\lambda(R)$ represent the surface brightness of the polar corona at wavelength λ and distance R from the center of the disk, and let y be the coordinate of a point in the coronal image measured along the direction of dispersion; then the intensity in the coronal image at a point beyond the limb ±90° to the line of dispersion is

$$E_\lambda(R)=\int_{-\infty}^{\infty} F_\lambda(R)\,dy. \qquad (1)$$

Fortunately, eclipse observers customarily take one or more long exposures of the coronal spectrum during midtotality, and the three eclipses under discussion were no exception. Within the limits of reciprocity failures, these different exposure times furnish an additional check on the standardization.

Direct standardizations.—The primary standardizations of the 1952 and 1936 spectrograms were based on exposures from tungsten standard lamps. The standardizing exposures gave characteristic curves on an absolute intensity scale as well as the usual corrections for differential apparatus and film functions. Corrections for atmospheric extinction were measured at the eclipse sites. In neither case were the standardizing exposures at the eclipse site completely successful and auxiliary standardizations proved to be necessary.

The auxiliary standards for 1936 received exposures and processing different from those of the eclipse films. These tests agreed reasonably well with results from the original standardizing exposures, except for relatively minor differences in detail.

Each 1952 spectrum possessed as auxiliary standards the filtered image of a step wedge, taken simultaneously with the spectrogram. A beam splitter formed two images of known intensity ratio for each spectrum. In addition, the calibration by means of a standard lamp was repeated after the return of the expedition. The step-wedge exposures were used to construct characteristic curves at the wavelength of the transmission band of the filter. Curves of two wavelengths, one near λ5000 and one near λ7000, were obtained in this way. These curves served to determine coronal brightness, $E_\lambda(R)$, as a function of R. The fact that $E_\lambda(R_1)/E_\lambda(R_2)$ proved to be the same at these two wavelengths furnished a check on the accuracy of the calibration technique. Characteristic curves at other wavelengths were then derived from the measured $E_\lambda(R)$. The shapes of the curves and displacement in intensity with wavelength agreed with those obtained from the standard-lamp exposures repeated after eclipse, except for the very toe of the characteristic curves. The double images of the spectrum also gave results consistent with the standardization from the coronal image. The absolute intensity scale was fixed by the standard-lamp exposures.

In 1932, the photospheric spectrum and a step-wedge sensitometer provided the standards. The sensitometer exposures gave the shapes of the characteristic curves, and the photospheric spectrum was used to obtain absolute and relative intensities. The absolute intensities were based on the assumption that the extreme edges of the photospheric disk radiate as a black-body of temperature 4700°. The relative intensity corrections were based on the assumption that the continuous spectrum of the chromosphere and corona corresponds to a black-body at 5700°. As mentioned above, this procedure automatically corrects for all differential effects in the observing equipment and for atmospheric extinction.

We turn now to an attempted check of the direct standardizations by using the coronal images as secondary standards.

Coronal standards versus direct standards.—At the 1952 and 1936 eclipses the atmosphere was clear, and we have little reason to expect trouble if we use the corona as a standard source. However, in 1932 the eclipse was observed through thin clouds, and we cannot hope for completely reliable measures of intensities in the coronal continuum. The original standardization matched the color of the combined chromospheric and coronal continuum near the line of contacts to the photospheric curve. This same standardization, however, does not match the polar corona to the photospheric curve. Similarly, when we use the polar corona as the standard, the equatorial regions do not match. The discrepancy undoubtedly arises from the cloud cover, and raises serious doubts about the justification of using the continuum in either the original standardization or the proposed standardization against the corona. This doubt does not necessarily imply that line intensities are similarly affected since they are obtained by integration above the continuous background.

In spite of the doubts about using the corona as a standard in 1932 it is of interest to carry through the reduction to see its effect on the data.

Figure 1 contains plots of $E_\lambda(R)$ at λ4700 for various representations of the polar corona normalized to give a common value at $R=1.05$. The curves for sunspot maximum and minimum were derived from van de Hulst's (1953) coronal model. The curves labeled 1932, 1936, and 1952 are those obtained from the flash spectrograms. The observations of the corona in 1936, by Bugoslavskaya (1941), Vsessviatsky and Dombrovsky (1941), and Zonn (1937), when averaged together, agree well with the 1936 curve from the flash spectrograms. The 1936 and 1952 curves agree satisfactorily with the maximum and minimum coronal models, respectively. However, the 1932 curve diverges widely from any of the accepted models.

Absolute intensities of $E_\lambda(R)$ at λ 4700 and $R=1.1$ are given in table 1. Two values are given for 1932. The higher value corresponds to the short exposures of the flash spectrum and the lower values to the long exposure during midtotality. Both the 1936 and 1952 results are independent of exposure time. Again, the

TABLE 1.—*Absolute intensities* (Log $E\lambda$ (R)* for λ4700 and $R=1.1$)

Max.	Min.	1932		1936	1952
12.72	12.18	12.05	12.75	12.60	12.48

*Intensity units are erg sec⁻¹ dλ=1 Å for the radiation in all directions from a 1 cm slice of atmosphere.

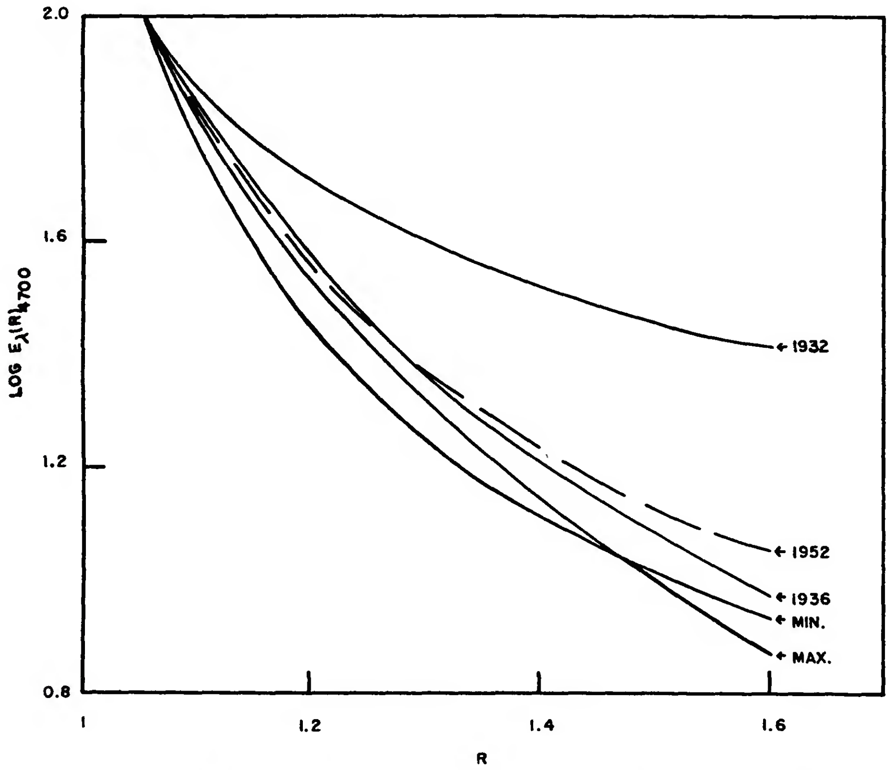

FIGURE 1.—Radial brightness distribution for polar corona on slitless spectrograms.

1936 and 1952 results are reasonably consistent with the coronal models, whereas the 1932 results lead to inconsistencies on different exposures.

Since the 1952 eclipse occurred two years before sunspot minimum, the absolute intensities seem to be too high by 0.2 to 0.3 relative to the coronal models. The 1936 values appear to be within 0.1 of the expected values.

The 1952 spectrograms show essentially the same intensity distribution with wavelength in the coronal continuum as the continuous spectrum of the integrated photospheric disk. Both the 1932 and 1936 spectrograms show a slight ultraviolet deficiency.

From the above discussion it is evident that the calibrations of the 1952 and 1936 eclipse spectrograms are reasonably consistent with the coronal models, whereas the 1932 calibrations are inconsistent. It is not clear how much of the difficulty in 1932 to attribute to interference by clouds and how much to the original calibrations. Thus, the 1952 and 1936 results can be compared with some confidence, but any discrepancies that appear in the 1932 data of Cillié and Menzel (1935) must be regarded with suspicion.

The 1936 and 1932 spectrograms were restandardized against the 1936 and the sunspot minimum coronal models. For the 1936 spectrograms this restandardization required only slight modifications of the intensities in the ultraviolet. For the 1932 spectrograms, however, a complete revision of the standardization was necessary. New microdensitometer tracings were made at regions of the limb selected as having no signs of abnormal activity. The 1936 data are tabulated in the following section. However, in view of the uncertainty in the 1932 standardization we have not tabulated the data. As we have pointed out above, the standardization of the 1932 spectrograms against the corona is not necessarily better than the original standardization. Indeed, in view of the variable cloud cover, the reverse is more likely to be true. Nevertheless, the standardization against the corona eliminates most of the differences between the 1932 data and the data from the other eclipses. In the subsequent discussions, unless otherwise stated, all references to 1932 data refer to the standardization against the corona.

Data

Definition of $h=0$.—The zero point of the height scale in 1952 was defined as the height where $\tau_{4700}=1$ for a tangential ray. If the solar atmosphere near the limb is assumed to be isothermal and of constant scale height, $\tau_{4700}=1$ for a tangential ray when $d^3E/dh^3=0$. Hence, on a plot of E versus height, $h=0$ at the point of inflection. To a good approximation, the same is true on a plot of log E versus height.

The continuum data at λ4700 for the three eclipses are plotted in figure 2. The solid curve below 200 km is the curve obtained for a black-body at λ4700 and $\tau_{4700}=e^{-h/80}$, where h is measured in km. The 1932 and 1936 curves were adjusted horizontally to place the point of inflection at $h=0$. The uncertainty in this assignment of $h=0$ does not appear to be more than ±50 km.

Tabulations of 1936 data.—Tables 2–6 contain the measured intensities of chromospheric lines from three separate spectrographs. The intensity units are ergs sec^{-1} for the radiation in all directions from a slice of atmosphere 1 cm wide, bounded radially by the moon on one side and extending to ∞ on the other. In general, the blended lines are listed under the element that comes earliest in the alphabet. Thus, most of the blends with Ti lines are listed under preceding elements in the tables. We have made exception of lines occurring in close multiplets, e. g., the blended line of Fe and Mg at λ5167 is listed with the other two lines of the Mg triplet. Lines measured on the spectrograms from the three spectrographs are tabulated separately because the mean heights of the exposures were not the same.

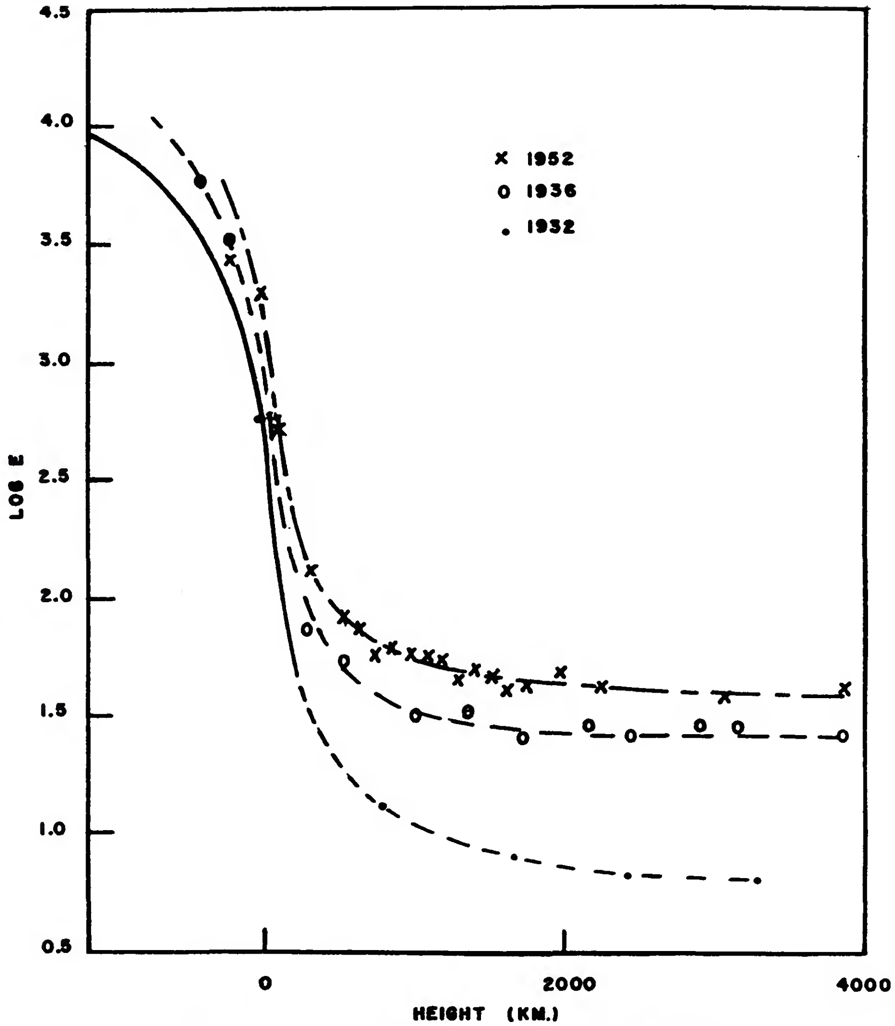

FIGURE 2.—Continuum intensity near solar limb at λ4700.

With few exceptions the line intensities can be adequately represented by an exponential emission gradient of the form,

$$E=E_0\,e^{-\beta h}. \qquad (2)$$

The last columns of the tables contain the observed values of β. Whenever there are consistent data for three or more heights, the values of β are given to three significant figures, otherwise only two figures are given.

It is of interest to compare our results with those obtained from the earlier reductions of the 1936 spectrograms. In figure 3 we plot our intensities against Hemmendinger's (1939) for the same region on the limb. The plotted points define a straight line of slope 0.85, and the two scales give equal intensities at log E=12.0. For the strong lines, our intensities are stronger than Hemmendinger's by about 0.2 in the logarithm. The scattering of points is surprisingly small.

Figure 4 exhibits our intensities plotted against Menzel's (unpublished data, 1939) for a different region of the limb. The scatter is somewhat greater, but the best straight line through the points has a slope 0.97, which is an

TABLE 2.—*Hydrogen, helium, strontium, and calcium spectrograph No. 3*

Wave-length λ	Line identity	Height													$\beta \times 10^8$ cm^{-1}
		290	1000	1720	2440	3140	3850	4550	5250	5950	6660	7370	8060	8800	
4340	Hγ			4.77	4.57	4.16	3.63	3.39	2.77	2.25					1.41
4101	Hδ		4.86	4.47	4.12	3.72	3.22	3.09	2.70	2.27					1.17
3889	H8	4.96	4.66	4.16	3.76	3.30	2.87	2.62							1.38
3835	H9	4.69	4.29	3.68	3.16	2.84	2.58								1.52
3798	H10	4.54	4.14	3.53	2.94	2.67									1.79
3771	H11	4.51	4.02	3.35	2.72										1.82
3750	H12	4.47	3.96	3.27	2.71										1.82
3734	H13	4.43	3.92	3.25	2.59										1.97
3722	H14	4.36	3.76	3.17											1.88
3712	H15	4.13	3.64	2.97											1.82
3704	H16	4.06	3.45	2.83											1.93
3697	H17	3.97	3.36												2.0
3692	H18	3.88	3.28												2.0
3687	H19	3.87	3.18												2.2
3683	H20	3.76	3.16												2.0
3679	H21	3.88	3.15												2.4
3676	H22	3.80	3.06												2.4
3674	H23	3.65	2.96												2.2
3671	H24	3.62	2.87												2.4
3669	H25	3.63	2.97												2.1
3668	H26	3.38	2.78												2.0
3666	H27	3.35	2.78												1.9
4713	He I		2.61	2.48	2.14										0.8
4472	He I	4.18	4.00	3.72	3.43	3.09	2.76	2.67		1.90					0.99
4026	He I	3.47	3.05	2.86	2.51	2.46	2.24								0.90
4388	He I		2.12												
4686	He II		2.10		1.68										0.7
4078	Sr II	4.52	4.05	3.35	2.77	2.53	2.31								1.57
4215	Sr II	4.39	3.89	3.05	2.43	2.14	2.09								1.75
3969	Ca II				4.85	4.65	4.46	3.98	3.68	3.47	3.02	2.73	2.54	2.28	0.99
3934	Ca II				4.91	4.76	4.62	4.13	3.90	3.75	3.30	2.91	2.75	2.40	0.97
4227	Ca I	4.10	3.43	2.54											2.44
3701	Ca I-Ti II	3.97	3.18												2.6

improvement over the value 0.85 obtained from comparison of our data with Hemmendinger's.

The difference in reduction methods probably accounts for the fact that our data show better agreement with Menzel's results than with Hemmendinger's. In our reduction and in that of Menzel, the density profiles were replotted as intensity profiles on an enlarged scale before the areas under the profiles were measured. Hemmendinger used a mechanical device to measure the intensities directly from an integration of the density profiles. The integrating device he used introduced a possible additional source of systematic errors in the results. The differences that are present in our characteristic curves appear to be both too small and in the wrong direction to explain the differences in the data. It seems unlikely that the integrating device used by Hemmendinger would lead to errors as large as those indicated. Thus, it appears that a combination of the reduction techniques and photometric standardizations rather than a single phase of either operation accounts for the differences in the two sets of data.

1932 data.—The restandardization of the 1932 spectrograms, as we indicated in the previous section, leads to results considerably different from the data published by Cillié and Menzel (1935). Table 6 contains the new β's for a limited number of lines. They are systematically greater than Cillié and Menzel's values for the same lines by about a factor 1.5.

Discussion

The 1952 data are more complete with regard to wavelength coverage and height resolution than are those of 1936 or 1932. However, the 1936 and 1932 data are of great value for indicating possible variations during the sunspot cycle and in indicating the uncertainties in the 1952 data. In the introduction to this paper we posed two problems: Do observations of the chromospheric spectrum over a narrow sector of the limb at a given eclipse suffice to determine the properties of the average chromosphere at the time of the eclipse? If so, does this average change with time? Abundant evidence suggests an affirmative answer to the first question. Hemmendinger measured line intensities and emission gradients at 14 regions

TABLE 3.—*Metals spectrograph No. 3*

Wavelength λ	Line identity	Height				$\beta\times10^{8}$
		290	1000	1720	2440	
3962	Al I	3.77	3.08			2.2
3944	Al I	3.76				
4554	Ba II	4.22	3.42	2.22		3.2
4565	Cr I	2.62				
4344	Cr I-Ti II	3.49				
4290	Cr I-Ti II-Ca I	4.19	2.99			3.9
4275	Cr I-Ti I	3.82	2.61			3.1
4254	Cr I	3.78	2.88			2.9
4588	Cr II	3.14				
4581	Fe I-Ca I	2.97				
4556	“	3.70				
4534	“ -Ti II	4.19	3.19	2.59		3.1
4415	“ -Sc II	3.79	2.24			5.0
4408	“ -Ti II	3.29				
4405	“	3.66	2.55			3.6
4384	“	3.92	2.98			3.0
4375	“ -Sc II-Y II	4.10	2.74			4.4
4326	“ -Ni I	3.91	2.79			3.6
4294	“ -Ti II	3.83	2.78			3.4
4272	“	3.66	2.35			4.3
4260	“	3.20	2.00			3.2
4250	“	3.52	2.09			4.6
4072	“	3.60	2.45			3.7
4064	“	3.66	2.57			3.6
4045	“	3.75	2.81			3.0
3914	“ -Ti II	3.86	3.03			2.7
3886	“ -La II	3.67				
3879	“ -V II	3.65	2.74			3.0
3860	“	3.83	3.16			2.2
3856	“ -Si II	3.48	2.77			2.3
3840	“ -CN		2.67			
3826	“	3.40	2.82			1.9
3824	Fe I	3.41	2.66			2.4
3820	Fe I-He I	3.57	3.05			1.7
3816	Fe I		2.66			
3795	“	3.24				
3767	“	3.47	2.51			3.1
3764	“	3.35	2.78			1.9
3746	“	3.78	3.11			2.2
3720	“		3.21			
3737	“ -Ca II-Ni I	3.94	3.45			1.6
3728	“ -Zr II	3.74				
4629	Fe II-Ti I	3.81				
4584	“	4.03	2.69			4.3
4576	“	2.88				
4559	“ -Cr II	3.38	2.13			4.1
4550	“ -Ti II	4.28	3.25	2.32		3.2
4523	“ -Ti I	3.69				
4520	“	3.55				
4515	“	3.31				
4417	“	3.56				
4385	“	3.57				
4352	“ -Cr I	3.89	2.36			5.0
4302	“ -Ti II	3.98	2.40			5.2
4233	“	3.97	2.66			4.3
4334	La II	3.03				
3838	Mg I	4.03	3.67	3.02	2.52	1.66
3832	“	3.95	3.52	2.86	2.24	1.75
3829	“	3.70	3.14			2.1
4034	Mn I	3.29	2.25			3.4
4033	“	3.45	2.36			3.5
4031	“	3.53	2.41			3.6
4247	Sc II	4.16	3.33	2.39		2.9
4400	Sc II-Ti II-V I	3.92				
4590	Ti II	3.11				
4572	“	4.17	3.20	2.37		2.9
4564	“	4.05	3.02	2.20		3.0
4501	“	4.07	3.13	2.27		2.9
4468	“	4.10	3.25			2.8
4444	“	4.17	3.21	2.29		3.0
4418	“	3.56	2.47			3.5
4395	Ti II-V I	4.13	3.29	2.45		2.7
4338	“	4.08				
4331	“	2.95				
4321	“ -Sc II	3.87	2.43			4.7
4300	“	4.07	2.98			3.5
4028	“	2.84				
3900	“	3.91	3.08			2.7
3761	“	4.32	3.96	3.43	2.87	1.55
3759	“	4.42	4.01	3.25	2.81	1.72
3742	“	3.75	2.92			2.7
3685	“	4.42	4.01	3.40	2.89	1.64
3774	V II	3.55				
3710	Y II	3.78				

on the solar limb at the 1936 eclipse. Nine of these regions were essentially the same in both line intensities and emission gradients. All of the remaining regions showed visible prominences extending above the chromosphere. At the 1952 eclipse, Athay, Billings, et al. (1954), measured line intensities and emission gradients at two regions on the limb and found no discernible differences. Houtgast (1953) determined emission gradients at the 1952 eclipse by combining data from several points on the limb to obtain the necessary dispersion in height. His results agree quite well with those of Athay, Billings, et al. (1954).

At most eclipses there are outstanding regions of peculiar emission characteristics. Such regions have been variously referred to as "hot spots," "excited regions," and "active regions." However, in all reported cases of this type the anomalous characteristics are concentrated in regions 1°–2° wide located over sunspot and plage areas. At any one eclipse, they make up only a very small percentage of the chromosphere. Thus, we conclude that measurements of the chromospheric spectrum at one region of the limb are capable of giving a fair picture of the chromospheric spectrum. It should be pointed out that physical limitations on the size of microdensitometer slits and on the resolving power of observing instruments have required that chromospheric data be averaged over about a 1° sector on the solar limbs. Such a strip of chromosphere includes several of the fine structural features observed with the 15-inch chromosphere camera at Sacramento Peak (Dunn, 1956).

The answer to our second question is not so readily obtained. Because absolute photometry is difficult, and errors in relative and absolute intensities may result from changes in the zero point of the height scale, the emission gradients appear to be the most reliable indicator of variations in chromospheric structure. However, the corona, which exhibits easily recognized changes during the solar cycle, displays only relatively small changes in the emission gradients. On the other hand, absolute and relative intensities of spectrum features at a given latitude, and differences in brightness

Table 4.—*Spectrograph No. 6*

Wave-length λ	Line identity	Height										$\beta \times 10^8$
		560	1360	2140	2900	3700	4480	5220	6060	6800	7600	
6563	Hα			5.34	5.14	4.76	4.24	3.96				1.20
4861	Hβ	5.52	5.24	4.93	4.75	4.41	3.97	3.35	2.96	2.66	2.07	1.37
5876	He I	5.19	4.86	4.44	4.19	3.91	3.60	3.13	2.78	2.43	2.17	0.99
5016	"	2.71	2.69	2.26	1.91							0.88
4922	"	2.68	2.46									0.6
4713	"	2.40	2.37	2.14	2.16							0.4
4686	He II	1.85	1.76	1.62								0.4
4934	Ba II	3.55	2.96									1.7
5328	Cr I-Fe I	3.40	1.89									4.3
5208	Cr I	3.37	2.02									3.9
5206	"	3.58	2.04									4.3
5204	"	3.12	1.72									4.0
5169	Fe I-Fe II	3.92	2.89	2.42	1.97							2.1
4921	Fe I	2.70	1.46									3.5
4919	"	2.26										
5317	Fe II	3.54	1.97									4.5
5018	Fe II	3.97	2.78	1.93								2.9
4924	"	3.78	2.55									3.5
5184	Mg I	4.24	3.65	2.92	2.42	2.00						1.75
5173	"	3.97	3.44	2.55	2.30	1.66						1.89
5167	" -Fe I	3.87	2.95	2.03	1.01							3.04
5896	Na I	4.01	3.13	2.22	1.59							2.34
5889	Na I	4.08	3.33	2.43	2.00							2.25

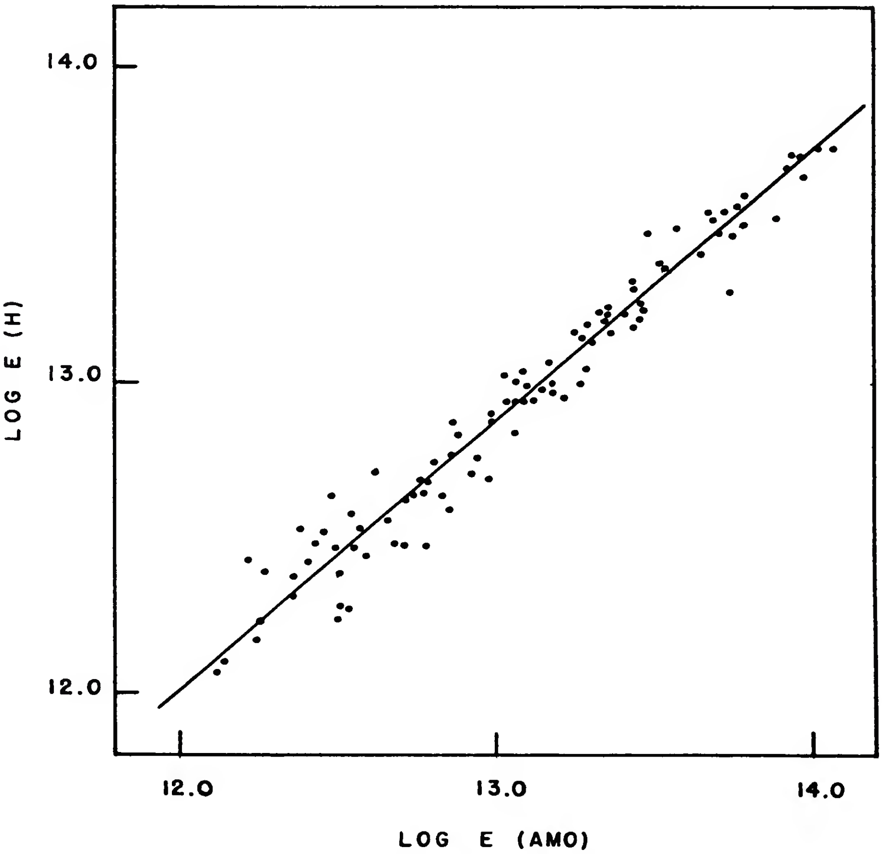

Figure 3.—Correlation diagram for our measures of line intensities versus Hemmendinger's.

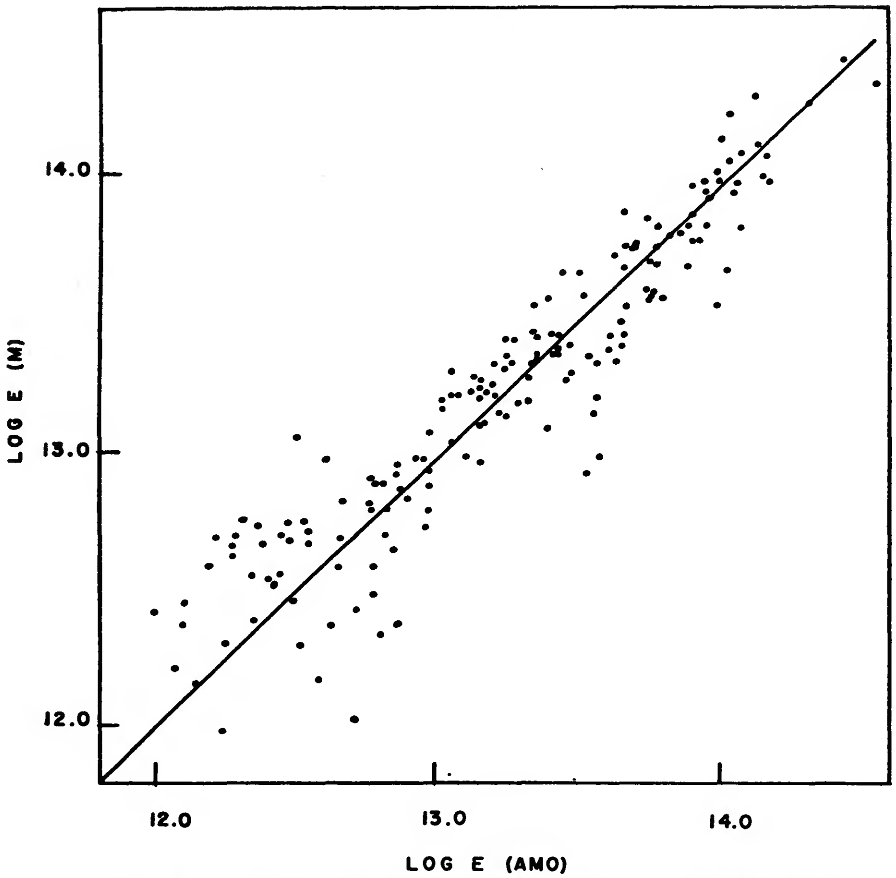

FIGURE 4.—Correlation diagram for our measures of line intensities versus Menzel's.

between polar and equatorial regions, give marked indication of variations. In the chromosphere we do not have sufficient data in the polar regions to compare the polar and equatorial regions. Hence, though we may use the emission gradients as possible indicators of variability, we must also compare absolute and relative intensities.

TABLE 5.—*Spectrograph No. 5*

Wavelength λ	Line identity	Height					$\beta \times 10^{8}$
		380	1060	1780	2520	3220	
7065	He I	4.29	4.06	3.82	3.51	3.27	0.85
6678	He I	3.75	3.47	3.09			1.06

Emission gradients.—We obtain the most satisfactory comparison of emission gradients by comparing the 1936 and 1932 gradients with those of 1952, since they have more lines in

TABLE 6.—*Emission gradients, 1932*

Wavelength λ	Line identity	$\beta \times 10^{8}$
3722	H14	1.8
3712	H15	1.6
3704	H16	1.9
3697	H17	2.0
3692	H18	1.9
3687	H19	1.9
3683	H20	2.0
3679	H21	2.1
3676	H22	2.2
3674	H23	2.3
3671	H24	2.3
3669	H25	2.7
3668	H26	2.2
3666	H27	2.2
3640	H∞	2.3
4713	He I	1.3
4026	He I	1.4
4686	He II	0.9
4072	Fe I	2.6
4064	"	3.0
4045	"	2.8
3764	"	3.1
3746	"	2.2
3720	"	2.1
4078	Sr II	1.7
3759	Ti II	2.0
3761	"	2.0
3714	V II	3.8
3710	Y II	4.3

common. The emission gradients for the metal lines at the 1952 eclipse are not yet available in the literature, but will soon be published by J. B. Zirker. Figures 5 and 6 exhibit the indicated comparisons. In both cases straight lines passing through the origin with slope 1.0 are adequate representations of the plots. The faint metal lines have the largest β's. Because of the faintness of these lines, the probable errors in the β's are relatively large, as evidenced by the increased scatter for large β's in figure 5.

Figures 5 and 6 show no indication of change in the emission gradients through the sunspot cycle. This is contrary to the results reported by Athay and Thomas (1956), who found that the emission gradients, relative to 1952, were systematically high in 1936 and low in 1932. Their results represented accurately the available data at that time. The differences between our measures of the emission gradients in 1936 and Hemmendinger's, which were used by Athay and Thomas, arise from the greater height range in our data. A given spectrogram usually shows systematic errors in intensities resulting from such effects as instrumental vibrations, seeing, focus, exposure time, etc. Hemmendinger's reduction was restricted to optical densities below about 1.3. By using a more sensitive microdensitometer we extended the reductions to densities of about 2.5 and were thus able to measure lines at lower heights. The increased height range in our data gives a corresponding increase in the accuracy of the

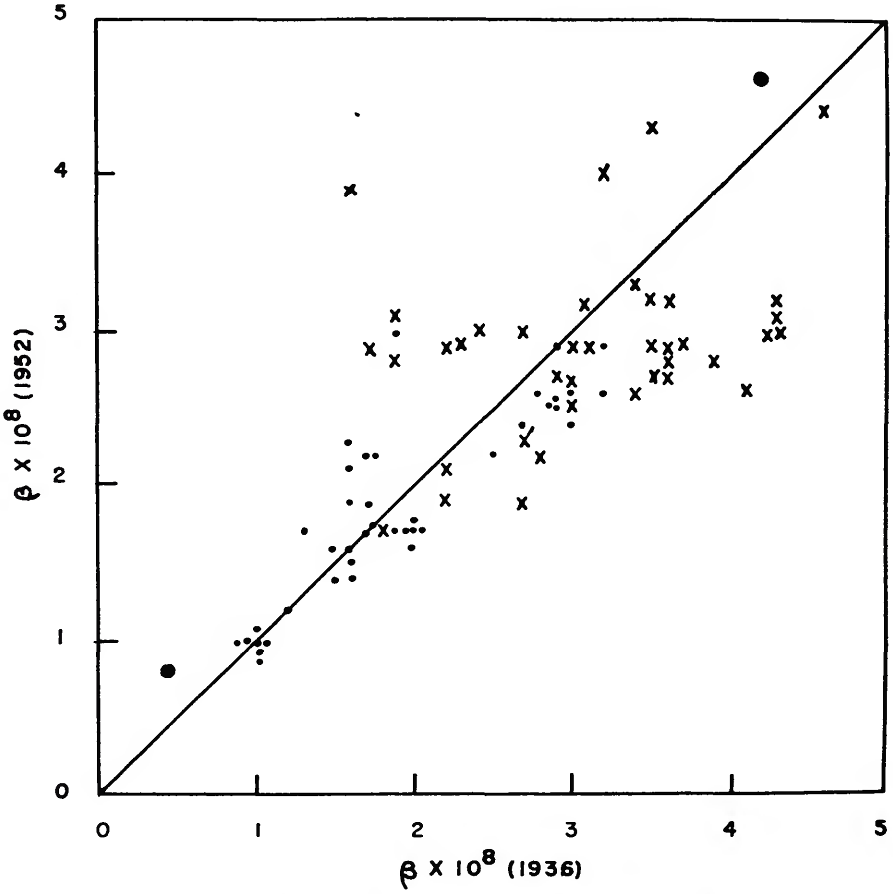

FIGURE 5.—Correlation diagram for 1936 β's versus 1952 β's.

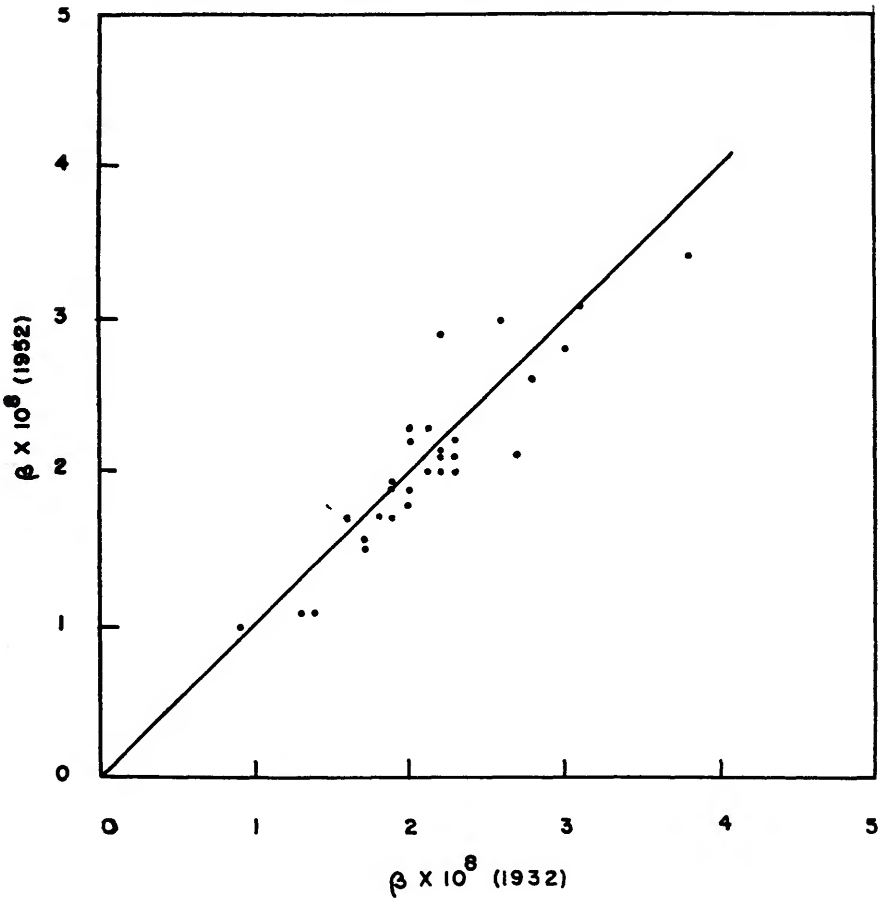

FIGURE 6.—Correlation diagram for 1932 β's versus 1952 β's.

emission gradients. The 1932 emission gradients used by Athay and Thomas were those given by Cillié and Menzel, which are, as we have noted, systematically low.

Relative intensities.—The relative intensities of the high-order Balmer lines provide a useful indicator of changes in chromospheric structure. The observed intensities are controlled to a large extent by the optical thickness of the chromosphere resulting from absorption by the second quantum level of hydrogen. In the chromospheric regions where the hydrogen emission is concentrated, the kinetic temperature is near 6000° (Athay, Menzel, Pecker, and Thomas, 1955). At this temperature the population of the second quantum level varies rapidly with temperature and density, and we may expect changes in the model to be reflected in the Balmer decrement. The observed decrements at the three eclipses are shown in figure 7 at as nearly a common height as the data allow. For comparison, we have also plotted the decrement given by Cillié and Menzel. Although their decrement is markedly flatter than either of those for 1936 and 1952, the restandardization of the 1932 spectrograms gives a decrement in fairly good agreement with those of 1936 and 1952. The lines H11 to H14 appear to be stronger, relative to the higher order lines in 1932, than in either 1952 or 1936. However, all of these lines are blended with metal lines with steeper emission gradients, and the apparent strengthening of the hydrogen lines probably arises from the metal lines because of the somewhat lower height. As far as relative intensities are concerned, the Balmer decrements are considered to be in satisfactory agreement at the three eclipses. We shall postpone discussion of the absolute intensities until the following section of this paper.

A still more sensitive indicator of changes in chromospheric structure is given by the relative intensities of helium, hydrogen, and metal lines. Since the line at λ4686 from He II differs widely in excitation energy from some of the metal lines, even slight changes in excitation temperatures would produce marked changes in relative line intensities. Figure 8 is a plot of such lines selected from the data for the three eclipses. Figure 9 exhibits some of the stronger lines from the 1936 and 1952 eclipses, which extend to greater heights. There is no evidence that line intensity changes significantly with excitation potential from one eclipse to another.

Absolute intensities.—The data in figures 7, 8, and 9 indicate that the absolute intensities in 1952 are systematically higher in 1936 and 1932, by as much as 0.5 to 0.6 in the logarithm. The continuum data in figure 2, however, show the 1952 continuum intensities near $h=0$ to be about 0.25 above the 1936 intensities, and about 0.5 above the 1932 intensities. The continuum intensities above 1,000 km show still different effects. At these heights, however, the corona and stray light in the spectrographs contribute strongly to the observed emission,

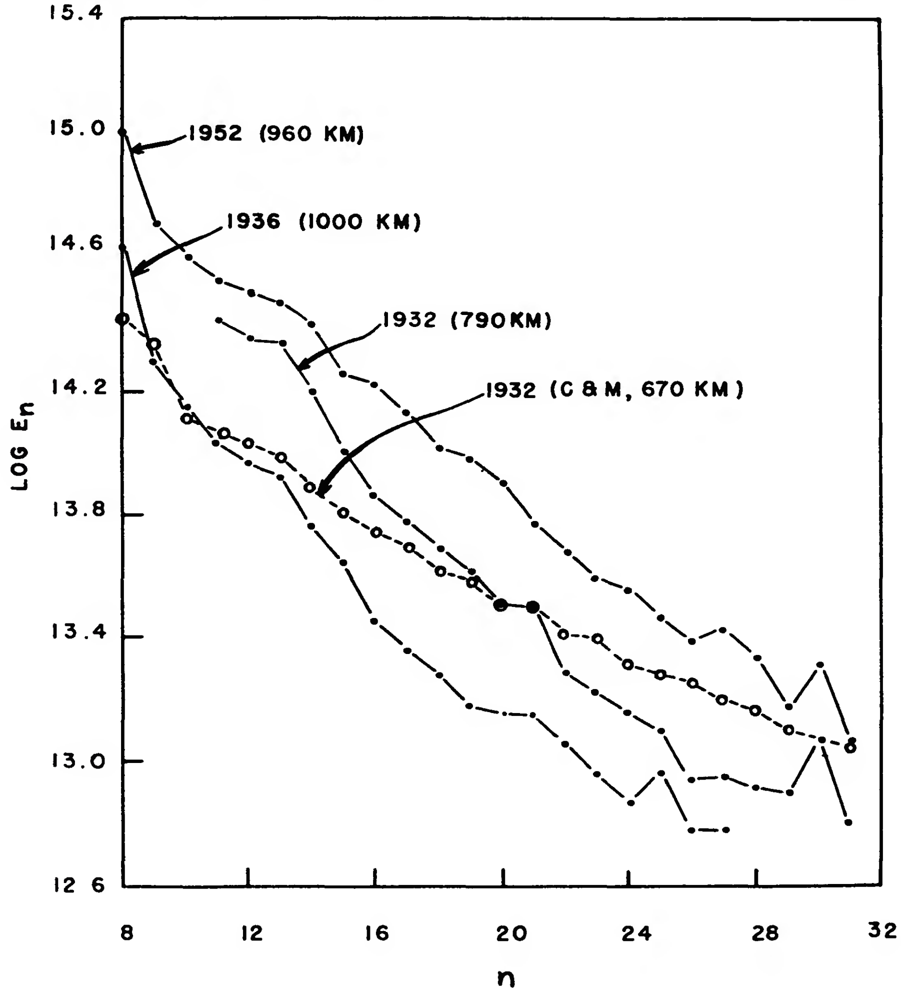

FIGURE 7.—Balmer decrements for 1952, 1936 and 1932 eclipses.

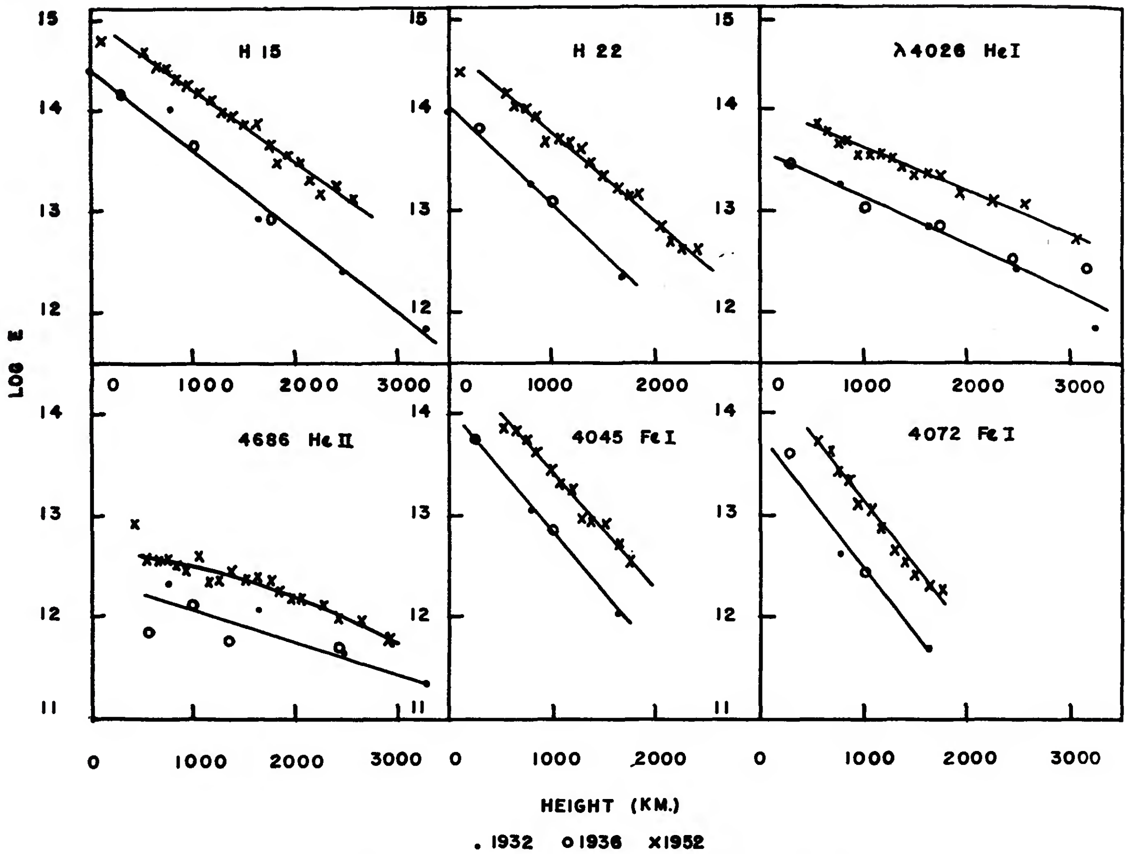

Figure 8.—Plots of log *E* versus height for lines of intermediate strength.

and we cannot expect agreement at the three eclipses. If we force the continuum intensities to agree at $h=0$, the line intensities for the 1952 and 1932 eclipses are also in good agreement, but the line intensities for the 1936 eclipse are relatively weak by about 0.3. The 1952 and 1932 eclipses both occurred near sunspot minimum, and it is reasonable to suppose that the chromosphere would be relatively unchanged. The fact that both lines and continuum can be brought into agreement for the 1932 and 1952 eclipses suggests strongly that the observed differences in absolute intensity result from photometric difficulties rather than from real differences in the chromospheric emission.

From the above discussions it seems evident that the only possible indication of significant changes in chromospheric emission over the sunspot cycle is the apparent discrepancy of a factor two between the line and continuum intensities in 1936. This discrepancy, of course, may be simply a photometric difficulty. If it is real, it represents a change of about the same magnitude, but in the opposite sense to the changes in the corona. Much more reliable absolute intensities are needed before definite conclusions can be drawn. However, it seems clear from the above data that chromospheric changes in brightness are of no greater magnitude than coronal changes, and there is no evidence for significant changes either in excitation conditions or in emission gradients.

If we grant that the absolute intensity scales in 1932 and 1952 should be adjusted by a relative amount of 0.5, it is still not clear just how this adjustment should be made. The data in table 1 indicate that the 1952 intensities are too high by 0.2 to 0.3. In the photograph of the 1932 corona published by Moore (1932), the

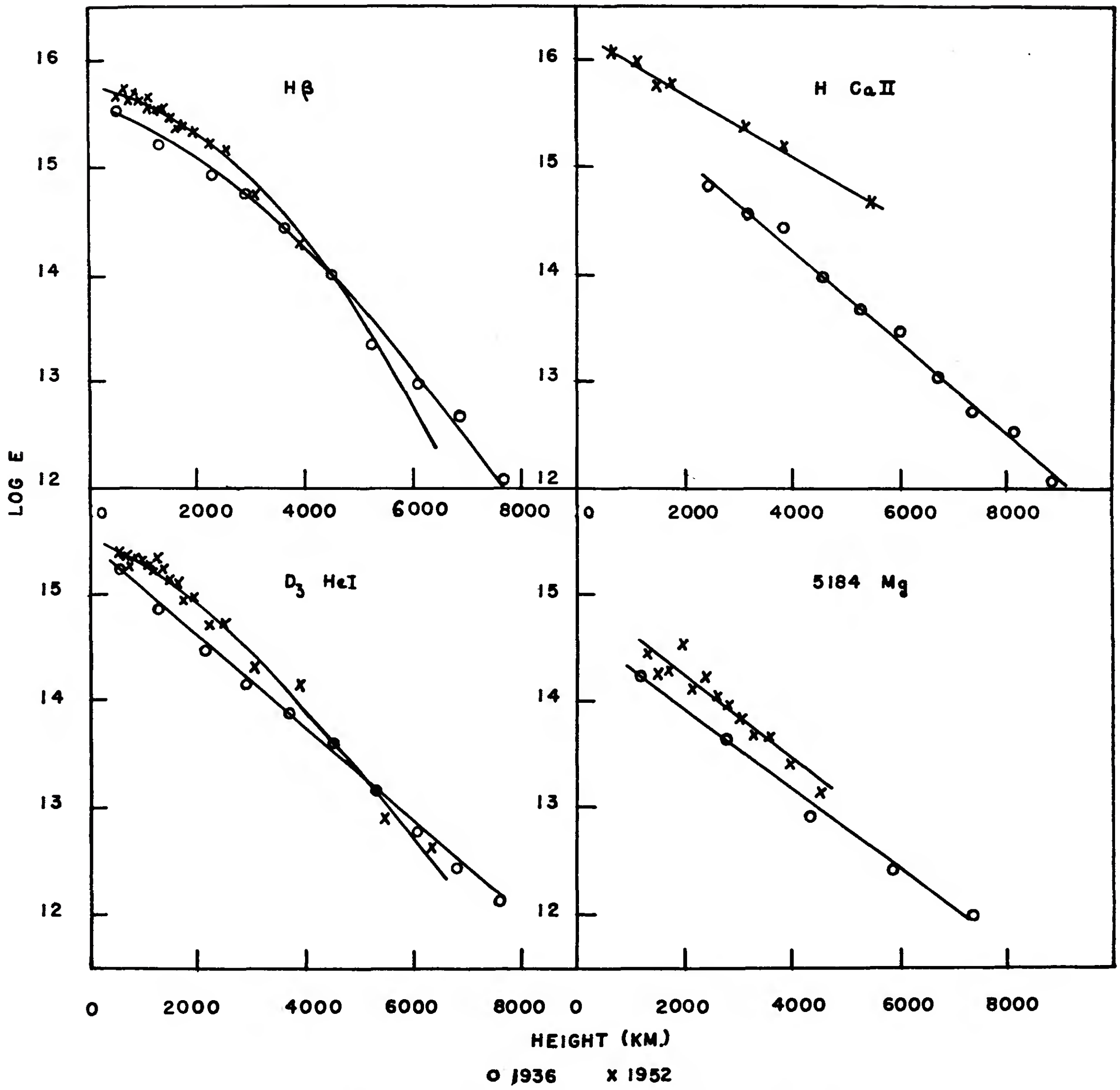

Figure 9.—Plots of log *E* versus height for strong lines.

polar corona at the pole that we used in standardizing the spectrograms is much brighter than the corona over the opposite pole. Thus, the most reasonable adjustment of intensity scales seems to be an average of the 1932 and 1952 absolute intensities. On this basis, no adjustment is necessary for the 1936 intensities if we use the photospheric continuum near the limb as reference.

The possibility remains that the original 1932 data of Cillié and Menzel are more reliable than the data we have used, in which case we must admit strong variations in both emission gradients and relative intensities. The absence of such effects between the 1936 and 1952 data suggests that the 1932 data obtained from the restandardization are the more reliable.

The authors are indebted to J. B. Zirker for providing the metal line data from the 1952 eclipse prior to publication, and to Dr. R. N. Thomas for stimulating interest in the problem.

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Abstract

Chromospheric line and continuum intensities obtained from jumping-film observations of the 1952, 1936, and 1932 eclipses are compared for the purpose of indicating changes in chromospheric structure during the sunspot cycle. The 1936 and 1932 spectrograms are restandardized against the corona as a standard source, and the zero-points of the height scales are redefined to be consistent with the 1952 height scale. For the 1936 spectrograms, the restandardization requires only slight modification of the original standards, but for the 1932 spectrograms a complete revision is required. The tabulated data include chromospheric line intensities and emission gradients for the 1936 eclipse and emission gradients of a few selected lines for the 1932 eclipse. No evidence is found for significant changes in emission gradients and relative line intensities during the sunspot cycle. Absolute intensities of chromospheric lines in 1936 appear to be weaker, relative to 1952 and 1932, by a factor two. This apparent change in emission may result from photometric uncertainties; however, more accurate absolute intensity measurements are necessary before definite conclusions can be stated.

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