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AN ATTEMPT TO MEASURE THE FREE ELECTRICITY IN THE SUN'S ATMOSPHERE

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We have the strongest of reasons to infer the existence of free electricity in the sun. At high temperatures in the laboratory carbon and other elements emit great numbers of negatively charged particles, while friction, collision and exposure to ultra-violet light may be mentioned among various other agencies capable of producing free electrons under solar conditions. On the other hand, the presence of intense magnetic fields in sun-spots points to a marked preponderance of negative electrons whirling in the spot vortex. Thus, without adducing further evidence, we find that both laboratory results and solar phenomena indicate the presence of free electricity in various parts of the solar atmosphere.[1]

The greater mobility of negative electrons and the influence of light pressure must coöperate to transfer negative electricity toward the upper levels of the atmosphere, thus leaving the body of the sun with a positive charge. However, hot vapors and gases are such good conductors that any considerable potential difference would tend to be compensated by a flow of current. In the presence of complex and uncertain conditions, such as the possible influence of radio-active substances, definite and unimpeachable knowledge of solar electric phenomena must be based upon a direct method of observation, which has recently become available through Stark's capital discovery of the effect of an electric field on radiation. If adequately applied, this method may ultimately furnish as reliable information of solar electricity as the Zeeman effect has already afforded of solar magnetism.

The Stark effect may be briefly described. Positively charged particles (canal rays), emitted from the anode of a vacuum tube, pass through perforations in the kathode into an intense electric field. When viewed across the lines of electric force, the series lines of such an element as hydrogen are split into two sets of components, polarized in planes at right angles to one another. When seen along the lines of force, one set of components disappears, while the others are present but unpolarized.[2] Thus, while the phenomenon resembles the Zeeman effect, a fundamental distinction lies in the fact that the components observed along the lines of force of a spectrum line resolved by a magnetic field are circularly polarized in opposite directions.

Our studies of the magnetic phenomena of sun-spots and of the sun as a whole have been based mainly upon this circular polarization, thus eliminating any possibility of attributing the observed effects to electric rather than magnetic fields. Many other criteria, such as differences in the number of components and the variation of separation with wave-lengths are also available to remove possible doubts, which may enter when the observations are made at right angles to the lines of force.

The $H\alpha$ line of hydrogen, when observed by Stark with moderate dispersion in an electric field of 28,500 volts per centimeter, was resolved into three components. The two outer components are polarized parallel to the field while the central line (which is double under higher dispersion) is polarized in the opposite plane. Hence the total width of the resolved line may be greatly varied by rotating the Nicol prism mounted above the spectroscope slit, since in one position the two outer components will be transmitted, while if the Nicol is turned ninety degrees these will be cut off and the central line transmitted.

In the sun the only known cases of line resolution (other than unpolarized reversals) are those found in the spectra of sun-spots. Immediately after the announcement of Stark's discovery, we examined our photographs of spot spectra to determine whether any anomalous cases of widened or resolved lines might be attributable to an electric rather than a magnetic field. In general, however, it was found that the outer components of spot triplets were sharply and completely cut off by the Nicol and quarter-wave plate under favorable conditions of observation, and are thus circularly polarized. Even in the case of spots near the middle of the sun, the central line of these triplets is usually present, apparently indicating that the lines of magnetic force are not exactly radial. But this component is very narrow, and if the Stark effect, not yet determined for the elements represented by these triplets, even approaches in order of magnitude the values indicated by the hydrogen and helium lines, the electric field at the level in question must be of very low intensity.[8] This point will be followed up as soon as the Stark effect can be observed for iron, chromium, nickel, titanium, manganese, vanadium and other elements whose lines are resolved in sun-spots.

The hydrogen lines are shown by our photographs to be weakened and narrowed in spot spectra. Thus they offer no indication of an electric field, but they will be carefully studied for possible traces of polarization phenomena.

As the magnetic fields in sun-spots seem to point so plainly to the existence of electric fields, the negative evidence of the Stark effect so far found in this quarter is not promising for researches in other parts of the sun. But it must not be forgotten that the establishment of a definite upper limit of intensity for electric fields at many different levels in the solar atmosphere is of the utmost importance, and this can be secured even if no pos'tive evidence of the Stark effect can be detected. In sun-spots the lines of force of the electric field would presumably be tangential to the surface, making the center of the sun the best point for studies of the Stark effect. For the sun as a whole, on the contrary, the lines of electric force would be radial, so that evidence of a general electric field should be sought in the behavior of lines near the limb. These are well known to be unresolved and the only effect to be anticipated is a very slight widening of the lines, which should have plane polarized edges.

The marked widening and displacement of solar lines near the limb, found here some years ago to be a general phenomenon of much importance, is not due to the Stark effect, if we may judge from the fact that the lines cannot be reduced by a Nicol prism to their normal width at the center of the sun. We must determine, however, whether there may remain a very minute effect of widening, such as can be detected only with the most refined methods of observation. Three requirements must be met:

1. High resolving power and linear dispersion in the spectrograph, supplied in our experiments by a large Michelson grating, giving theoretically perfect resolution. As used in the 75-foot spectrograph of the 150-foot tower telescope the linear dispersion in the second order is about 3 mm. to the angstrom unit, or slightly greater than in Rowland's map of the solar spectrum, which was enlarged from negatives of

about one-quarter this scale. The third order, where the linear dispersion is nearly 5 mm. to the angstrom, has been used in some of our work.

2. A strictly differential method of observation, involving the determination of the width of the same line on contiguous strips of spectra photographed in a single exposure with apparatus transmitting light polarized in planes at right angles to one another. A long Nicol prism mounted over the slit, with a compound half-wave plate above it, made of mica strips 2 mm. in width, fully met this requirement. In order to eliminate possible absorption effects in individual strips, the half-wave plate was made by combining the compound quarter-wave plate used in our investigations of the general magnetic field of the sun with a long piece of quarter-wave mica. By inverting this between exposures, a given strip can be made to transmit light polarized in either plane.

3. A measuring machine capable of exhibiting the smallest variations in the width of the lines on the odd and even strips. A Koch registering micro-photometer, recently constructed in our instrument shop, served admirably for this purpose.

A series of photographs of the $H\alpha$ and $H\beta$ lines of hydrogen, made with the slit set about 3 mm. within the limb (parallel to a tangent) of the large solar image of the 150-foot tower telescope, furnished the required observational material. As employed for this work, the Koch machine gave photographic curves (reducible to intensity curves) of the $H\alpha$ and $H\beta$ lines on a scale fifty times that of the original negatives. Combining measures of curves made for several sets of odd and even strips, the probable error of the average width of one group of curves is $\pm$ 2.7 mm. Thus a difference in mean width of 5 mm., corresponding in the second order to 0.034 angstrom, should certainly be discernible by our method. Assuming this least appreciable difference in width to be of the same order of magnitude as the Stark separation of the components, we may at once determine the maximum electric field present from Stark's published results for $H\alpha$. For a field of 28,500 volts per centimeter he obtained a difference in separation of 6.4 angstroms between the outer and inner components (polarized parallel and normal to the field). As the total separation is directly proportional to the field-strength, and as the $H\alpha$ line shows no appreciable difference in width on the odd and even strips, it follows that the intensity of the solar electric field at the point of observation cannot exceed 150 volts per centimeter. A similar determination for the $H\beta$ line in the third order gives a corresponding value of 100 volts per centimeter. It therefore seems safe to say that the electric field-strength at the level in question is less than 200 volts per centimeter.[4]

Salet and Millochau, using lower dispersion, had previously found a maximum value of 7000 volts per centimeter for $H\gamma$ in the chromosphere.[5] Our much lower value indicates that in order of magnitude the electrical potential differences in the solar atmosphere may not greatly exceed those in the lower atmosphere of the earth, where they average about 1 volt per centimeter. In thunderstorms, of course, enormously greater differences occur, and it remains to be seen whether appreciable electric fields can be detected in solar eruptions, where the conditions for their production appear to be more favorable than in the quiet regions of the atmosphere.

[1] For a summary of the views of Goldstein, Bigelow, Deslandres, Arrhenius, and others on the electrical condition of the solar atmosphere see Bosler, *Les théories modern du soleil;* also recent papers in the *Comptes Rendus Paris Acad. Sci.*

[2] See Stark, *Elektrische Spectralanalyse chemischer Atome*, Hirzel, Leipzig, 1914.

[3] Hale, Solar Magnetic Phenomena, *Proc. Amer. Phil. Soc.*, April 24, 1914, p. 254.

[4] Under high dispersion, Stark has resolved $H\delta$ into many components (loc. cit., Plate III). A variation in the relative intensities of these components under solar conditions, which is not improbable, might introduce an error into a determination of the maximum intensity of the electric field. It is likely, however, that the results here given are of the true order of magnitude.

[5] Salet and Millochau, *C. R. Paris Acad. Sci.*, **158**, 1000 (1914).

RESULTS OF AN INVESTIGATION OF THE FLASH SPECTRUM WITHOUT AN ECLIPSE

REGION λ 4800 TO λ 6600

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The study of the bright line spectrum given by the comparatively thin layer of gases which constitutes the sun's atmosphere has usually been limited to the brief periods of total solar eclipses. During the few minutes that the dark body of the moon covers the sun's image the spectrum of the shell of radiating gases surrounding the sun may be observed without difficulty, and photographs of this spectrum, known to astronomers as the spectrum of the flash, have formed one of the most important products of recent eclipse expeditions.

Although admirable results have been secured in this way the