REMARKS ON THE LIMITATIONS OF OPTICAL METHODS FOR MEASURING ELECTRON DENSITIES IN THE CORONIA AND INTERPLANETARY SPACE*

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The electron density in the part of the solar corona which is very close to the sun (1.2 > R/R⊙ > 1) can be measured at a time of a total solar eclipse with reasonable ease and accuracy because in this region most of the coronal light is sunlight which has been scattered by free electrons. The difficulties of measurement increase with increasing distance from the sun partly because at greater distances some of the light of the corona is due to scattering by interplanetary dust, and a separation of the dust (F) and electron (K) components must be made before electron densities can be deduced.

Two methods of separating the two components have been tried so far. In one method the polarization of the coronal light is measured and the separation of F and K is based on the assumption that the polarization of the F component is zero. The brightness of the corona is sufficient for this method to be applied with ease, but there are doubts about its validity at larger distances from the sun (R/R⊙ > 6) because it is now known that the dust component of the zodiacal light, which is an outer extension of the solar corona, shows a high polarization (BLACKWELL et al., 1961a), and the polarization of the F component of the corona at distances greater than 6 R⊙ from the sun may not therefore be negligible. For example, the polarization of the solar corona at a distance of 5° from the sun is only 2.8 per cent (BLACKWELL, 1955), while the polarization of the zodiacal light at elongation 30°, which is largely attributable to the dust component, is 21 per cent.

In the second method of separation, the depth of a Fraunhofer line in the coronal spectrum is measured and a separation made by assuming that the F component has a pure Fraunhofer spectrum, while the K component, because the electron temperature is high, has a pure continuous spectrum. This method is reliable in principle, but it is not easily applied because it requires a spectrograph which combines speed and fairly high resolving power. Because of this limitation, it has so far been used only out to a distance of 2.6 R⊙ from the centre of the sun (ALLEN, 1946). The difficulties of applying this method increase very rapidly with increasing distance from the sun, partly because the K component is becoming fainter, but also because it is being increasingly diluted by the F component and the sky background, which shows a Fraunhofer spectrum. Probably the use of photoelectric techniques in high altitude aircraft will greatly extend this limiting distance, perhaps to as far as 10 R⊙.

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Attempts have been made to apply the second method described above to the zodiacal light region in the neighbourhood of 1 A.U. One such attempt made in 1958 using photographic techniques (Blackwell et al., 1961b) gave an upper limit only to the electron density at 1 A.U. of 120 cm$^{-3}$. A second series of observations was made by Dr. Dewhirst and the author in 1961 using photoelectric techniques; the accuracy of measurement was considerably increased on this occasion but it is not yet known whether free electrons were detected in the course of these experiments.

No experiments using other techniques have so far yielded electron densities far from the sun, and we conclude that there is no direct quantitative knowledge of electron densities in the quiet corona and in interplanetary space at distances from the sun of greater than about 6 $R_\odot$, although radio observations (Hewish, 1958 and Vinko, 1958) have shown that free electrons certainly exist at much greater distances than this. Furthermore, we now show that if zodiacal light observations fail to detect free electrons in interplanetary space, we have with present eclipse techniques little hope of measuring electron densities beyond the limit of about 10 $R_\odot$ already mentioned. In this demonstration, having suggested that polarization methods are inadequate, we suppose that measurements are made with an idealised spectrometer, which is specified later, and we use as a basis the model of the outer corona developed by Ingham (1961) which gives the following brightness values for the K of F components at elongation 15°, where $B_\odot$ is the mean surface brightness of the solar disk.

$$ K + F = 5.25 \times 10^{-12} B_\odot $$

$$ K = 0.01 \times 10^{-12} B_\odot $$

$$ F = 5.24 \times 10^{-12} B_\odot $$

This model corresponds to an electron density of about 2 cm$^{-3}$ at a distance of 1 A.U. from the sun.

During a total solar eclipse the sky brightness at the wavelength of 5200 A which may be expected at the height of 30 000 ft is $500 \times 10^{-12} B_\odot$, (c.f. Blackwell, 1955).

The idealised spectrometer is supposed, arbitrarily, to have an aperture of 10 cm, to take in an area of the corona of diameter 1°, to have a transmission of 50 per cent, and to measure within a wavelength range of 10A near 5200A. The following table gives (a) the contribution to the expected photon flux through the apparatus from the electron scattered component, the total corona, and the sky background, (b) the flux of photo-electrons, $n$, assuming a quantum efficiency of 10 per cent, and (c) the fluctuations of these quantities, represented approximately by $\sqrt{n}$. A time interval of one minute has been chosen because this is the order of magnitude of the duration of a total solar eclipse.

<table>
<thead>
<tr>
<th>Contributor</th>
<th>Photon flux $\text{min}^{-1}$</th>
<th>Photo-electron flux $n \text{min}^{-1}$</th>
<th>Fluctuation $\sqrt{n}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>K</td>
<td>$4.8 \times 10^4$</td>
<td>$4.8 \times 10^3$</td>
<td>—</td>
</tr>
<tr>
<td>K + F</td>
<td>$2.4 \times 10^7$</td>
<td>$2.4 \times 10^6$</td>
<td>$1.6 \times 10^5$</td>
</tr>
<tr>
<td>sky background</td>
<td>$2.3 \times 10^6$</td>
<td>$2.3 \times 10^5$</td>
<td>$1.5 \times 10^4$</td>
</tr>
</tbody>
</table>

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The important feature of this table is that it shows that, for this model, the fluctuation in the photo-electron stream derived from the sky background is several times greater than the photo-electron flux due to the K component alone; so that, using a spectroscopic technique, we cannot hope to detect the K component in a time interval of 1 minute. But if the observations are made from a space vehicle the sky background becomes negligible, and it is now possible to detect the K component against the fluctuations in the F component. The situation is improved if the electron density is greater than has been assumed in the model, but the density must be almost unreasonably great before the K component can be detected with ease in a terrestrial experiment of this kind. We conclude that investigation of the interplanetary plasma by optical means can be conducted from the earth's surface at a time of total solar eclipse only with great difficulty and recourse should be made to observations from satellites.

References