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MEASUREMENT OF THE MAGNITUDE AND DIRECTION OF THE MAGNETIC FIELD IN THE REGION OF SUNSPOTS

B. A. Ioshpa and V. N. Obridko

Institute of Terrestrial Magnetism, Academy of Sciences, USSR

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A method for the simultaneous measurement of all quantities which determine the magnitude and direction of the magnetic field on the solar surface is described.

Work to produce a total-vector magnetograph has been going on at the Institute of Terrestrial Magnetism, AN SSSR, since the end of 1961. This magnetograph is designed for the simultaneous measurement of all quantities which determine the magnitude and direction of the magnetic field strength on the surface of the sun. A brief description of the operating principles of the magnetograph is given in the present paper.

It has been shown in [1] that to determine the total magnetic vector it is sufficient to measure the Stokes parameters [2] of the radiation received on the Earth. From the measured Stokes parameters and the theory of absorption-line formation in the solar photosphere it is possible to calculate all the quantities determining the magnitude and direction of the magnetic field. The Stokes parameters are measured in the following way. The radiation received from the sun in the wings of the absorption lines passes through a quarter-wave plate, an electro-optical crystal ADR, and a polaroid, all of which are placed in front of the spectrograph exit slit. The radiation, after passing through the polaroid, falls on a photomultiplier cathode. The quarter-wave plate is placed at an angle of $\pi/8$ to the axes of the crystal. The intensity of the radiation incident on the photomultiplier is given by

$$I=\frac{1}{2}\Big[J-Q\Big(\cos 2\Phi\cdot\sin\frac{\pi}{4}\cos\delta_1-\sin 2\Phi\sin\delta_1\Big)-V\cos\frac{\pi}{4}\cos\delta_1\Big]. \qquad (1)$$

Here J, Q, V are the Stokes parameters, Φ is the angle between the direction of the magnetic field in the image plane and the ordinary axis of the quarter-wave plate, and δ_1 is the phase difference produced by the crystal when a potential difference is applied to it. If the amplitude of the sinusoidal potential is 4.6 kV, then

$$\delta_1=\frac{\pi}{2}\sin\omega t, \qquad (2)$$

$$\cos\delta_1=J_0\left(\frac{\pi}{2}\right)+2J_2\left(\frac{\pi}{2}\right)\cos 2\,\omega t+\ldots, \qquad (3)$$

$$\sin\delta_1=2\,J_1\left(\frac{\pi}{2}\right)\sin\omega t+\ldots, \qquad (4)$$

where J_n is the Bessel function of the first kind of order $\underline{n}$.

Measurements are made on both wings of an absorption line [3]. The dependence of Q and V on wavelength inside the line has been obtained by Unno [4]. Q has the same sign in both wings of the line, while V changes sign. As can be seen from (1), a simultaneous measurement of J, Q, V, and Φ requires the use of four channels: 1) a channel at the basic frequency ω, adding the signals from both wings of the line, 2) a channel at double the basic frequency, also adding the signals from the two wings, 3) a channel at double the basic frequency, subtracting the signals from the two wings, and 4) a channel measuring the constant signal.

The output signals from the four channels will be proportional to

$$I_{=}=0.5\left[J-QJ_0\left(\frac{\pi}{2}\right)\sin\frac{\pi}{4}\cos 2\,\Phi\right]$$
$$=0.5J-0.24\cdot\frac{\sqrt{2}}{2}\,Q\cos 2\,\Phi, \qquad (5)$$

$$I_{\omega+}=J_1\left(\frac{\pi}{2}\right)Q\sin 2\,\Phi=0.55\,Q\sin 2\Phi, \qquad (6)$$

$$I_{2\omega+}=J_2\left(\frac{\pi}{2}\right)\sin\frac{\pi}{4}\,Q\cos 2\,\Phi$$
$$=0.23\cdot\frac{\sqrt{2}}{2}\,Q\cos 2\,\Phi, \qquad (7)$$

$$I_{2\omega-}=J_2\left(\frac{\pi}{2}\right)\cos\frac{\pi}{4}\,V=0.23\cdot\frac{\sqrt{2}}{2}\,V. \qquad (8)$$

The angle Φ can be obtained from expressions (6) and (7) independently of any assumptions concerning the model of the photosphere, the nature of the Zeeman splitting, and the mechanism of reradiation in the line. The absolute magnitude of Φ can be obtained from (6) and (7) to within an additive constant of $\pi/2$. This uncertainty can be eliminated by a supplementary calibration.

In order to determine the projections of the magnetic field strength along the line of sight, $H_{||}$, and in the image plane, $H_{\perp}$, we make use of Unno's calculations [4] for the normal Zeeman effect on the assumption of true absorption for the Milne-Eddington model of the solar photosphere. The dependence of Q and V on H and ψ allowing for the finite width of the slit is of the form

$$V = -B_0\beta_0 \cos\theta f_1(H) \cos\psi, \quad (9)$$

$$Q = -B_0\beta_0 \cos\theta f_2(H) \sin^2\psi, \quad (10)$$

where $f_1(H)$ and $f_2(H)$ are functions of the total magnetic field strength obtained from theory, B_0 is the intensity of the continuous spectrum at the solar limb, θ the position angle on the solar disc, β_0 the coefficient of limb darkening, and ψ the angle between the magnetic vector and the line of sight. The function $f_1(H)$ may be taken to be linear up to $H \sim 900$ Oe; $f_2(H)$ initially increases as H^2 (up to $H \sim 300$ Oe) and then becomes linear with H. At very large field strengths both functions attain a maximum and then decrease.

$I_=$ depends only weakly on H and ψ, so that in the first approximation it can be taken proportional to the intensity of the continuous spectrum B_0.

Thus, a knowledge of the theoretically evaluated functions $f_1(H)$ and $f_2(H)$ and the measured values of $I_=$, $I_{\omega+}$, $I_{2\omega+}$, and Φ allows us to determine the magnitudes of H and ψ or $H_{||}$ and $H_{\perp}$. The sensitivity in $H_{||}$ is about 3 Oe, that in $H_{\perp}$ about 200 Oe.

Maps of the various components of the magnetic field obtained for a sunspot group on June 14, 1963 are given in [6]. The method for the measurement of the total magnetic vector developed in [5] involves three separate scans across a given area of the solar disc. In the case of the method proposed by us, only one scan is required and this makes possible a simultaneous determination of all the parameters of the magnetic field. This is an important advantage, since the pattern of the magnetic field may change during the time required for three successive scans. A disadvantage of our method is the lower sensitivity by comparison with the method developed at the Crimean Astrophysical Observatory. However, the sensitivity of our method can be raised to 70 Oe by the proper choice of the potential applied to the ADR crystal and the angle between the quarter-wave plate and the crystal. A detailed description of the method of measurement and the apparatus will be published in "Geomagnetizm i aeronomiya" [6].

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All abbreviations of periodicals in the above bibliography are letter-by-letter transliterations of the abbreviations as given in the original Russian journal. *Some or all of this periodical literature may well be available in English translation.* A complete list of the cover-to-cover English translations appears at the back of this issue.