Polarimetry in the Mg II h and k Lines

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Abstract. The Ultraviolet Spectrometer and Polarimeter (UVSP) on the SMM satellite has been used to record the linear polarization profile across the Mg II h and k lines, including its center-to-limb variation. Linear polarization with an orientation of the electric vector parallel to the solar limb is detected in the line wings on the short wavelength side of the k line and on the long wavelength side of the h line, in agreement with theoretical predictions of Auer et al. (1980). The predicted negative polarization (electric vector perpendicular to the limb) between the h and k lines is however not confirmed by the observations. Instead values close to zero are indicated there, although the statistical significance of the results is marginal.

We have examined possible explanations of such a discrepancy between theory and observations. After having rejected other alternatives (e.g., opacity effects, different continuum polarization, or deviations from a plane-parallel stratification), it is suggested that the solution may be found in a treatment of partial redistribution of the polarized radiation with the quantum-mechanical interference between the two scattering transitions being included as an integral part of the redistribution problem.

1. Introduction

In the solar ultraviolet spectrum the largest polarization amplitudes are expected to be due to coherent scattering in spectral lines, a basically non-magnetic phenomenon that may be observed in quiet regions with low spatial resolution. This makes the scattering polarization more accessible to polarimetric observations than the Zeeman effect, which is quite small in the UV since it scales with the square of the wavelength, and the field strengths decrease with height in the solar atmosphere. The degree of circular polarization due to the Zeeman effect reaches a magnitude of the order of one percent only above major sunspots.

Using the Ultraviolet Spectrometer and Polarimeter (UVSP) on the Solar Maximum Mission (SMM) satellite, Henze et al. (1982) succeeded in determining the magnetic field in the transition region above a sunspot through recordings of the circular polarization in the C IV 1548.19 Å line. In the present paper this unique instrument is employed to investigate the scattering polarization in the Mg II h and k lines around 2800 Å.

In a theoretical analysis of linear polarization due to coherent scattering in solar lines in the vacuum ultraviolet (VUV) Stenflo and Stenholm (1976) showed how the polarization could be used to diagnose the structure of the chromosphere-corona transition zone. With an experiment in 1976 on the Soviet Intercosmos 16 satellite Stenflo et al. (1976, 1980b) tried to measure the scattering polarization in the
H Lα 1216 Å line, but only an upper limit of 1% for the limb polarization with low spatial resolution could be determined. This low polarization is explainable in terms of the small anisotropy of the Lα radiation field (as expressed by the insignificant limb darkening or brightening). In other VUV lines the anisotropy and polarization are expected to be much larger. Nevertheless these observations established the feasibility of accurate solar polarimetry in this portion of the spectrum.

Another physical process to be discussed in the present paper in connection with the MgII h and k polarization is the quantum-mechanical interference between widely separated fine structure components of a scattering transition. This remarkable phenomenon was unexpectedly discovered in a solar context through polarimetric observations with the HAO Stokesmeter at the Sacramento Peak Observatory in the CaII H and K and the NaI D1 and D2 lines (Stenflo et al., 1980a). Using the subsequently developed quantum-mechanical theory (Stenflo, 1980) for this interference, Auer et al. (1980) incorporated the interference effect in a non-LTE radiative transfer formalism to compute the expected polarization profiles and their center-to-limb variations for a number of lines, including the MgII h and k lines.

A survey of the linear scattering polarization near the solar limb has been performed with the vertical grating spectrometer and the Fourier transform spectrometer at the Kitt Peak McMath telescope over the whole visible spectrum, from 3165 to 9950 Å (Stenflo et al., 1983a, b). Thereby a number of new cases of quantum-mechanical interference were revealed, in addition to fluorescent effects as well as several anomalies or unexplained spectral polarized features. The survey also showed that the largest scattering polarization of all lines in the visible spectrum is exhibited by the CaI 4226 Å line. The radiative-transfer theory of Auer et al. (1980) could reproduce astonishingly well the observed polarization and its center-to-limb variation not only in this line, but in particular also in the CaII H and K lines, for which the interference effect plays a decisive role. This agreement has provided confidence in the validity of the theory.

The calculations of Auer et al. (1980) however predicted that the linear polarization of the MgII h and k lines should be about three times larger than that of the CaII H and K lines, and larger than that of the CaI 4227 Å line as well. The MgII polarization amplitude is thus expected to exceed that of any line in the whole visible spectrum. The quantum-mechanical interference effects are also predicted to be extremely pronounced, which makes this line pair most useful for tests of the theory.

The diagnostic use of the non-magnetic scattering polarization is to provide information on the anisotropy of the radiation field, the rates of atomic collisions, atmospheric inhomogeneities (departures from plane parallel stratification), the optical thickness of the line-forming region, etc. A longer-term goal is however to use the modification of the scattering polarization by magnetic fields via the Hanle effect, to diagnose the strength and geometry of the magnetic field (cf. the review by Leroy, 1985). This approach is particularly promising for the diagnostics of the magnetic fields in the chromosphere and transition region (cf. Stenflo, 1977), due to the low collision rates and relative weakness of the magnetic fields there, the availability of useful resonance lines in the vacuum ultraviolet with large radiation anisotropies, and in view of the small