

## On the effect of polarization for scattering in spectral lines

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In recent years essential progress has been achieved in studying spectral line formation with partial frequency redistribution (for reviews, see Mihalas, 1978, and Hubeny, 1985). It has been revealed that photon correlations may be important for many applications in non-LTE line formation theory. This has led to efforts to reconsider the conceptions of redistribution and to seek for appropriate formulations as well as for methods of numerical calculations for redistribution functions which could be applied for treating non-LTE line formation problems. Much work in this direction has been performed by Heintel (1981) and Heintel and Hubeny (1982, 1983). These authors have appropriately reformulated and extensively analyzed the redistribution functions which have been derived by Omont, Smith and Cooper (OSC) (1972) for the quantum theory of light scattering with collisional redistribution in resonance and subordinate lines. Polarization effects, however, have been generally neglected so far.

A first analysis of the results of OSC for scattering of polarized light has been performed by Ballagh and Cooper (1977), who have derived explicit formulae for specific assumptions on polarization of incident and scattered light. For radiative transfer theory, however, we need the complete redistribution phase matrix  $\bar{F}(\omega_1 \mathbf{n}_1; \omega_2 \mathbf{n}_2)$  referred to the laboratory rest frame.

Starting with the formulae of OSC, we obtained the complete redistribution matrix describing light scattering in the atomic rest frame,  $F$ , in the form

$$(1) \quad F(\omega_1, \mathbf{n}_1; \omega_2, \mathbf{n}_2) = \sum_{J=0}^2 \mathbf{p}^J(\theta) F_J(\omega_1, \omega_2)$$

as a linear combination of three partial phase matrices  $\mathbf{p}^J$  depending on the scattering angle  $\theta$  ( $\cos \theta = \mathbf{n}_1 \cdot \mathbf{n}_2$ ) with three scalar functions  $F_J(\omega_1, \omega_2)$  as coefficients, depending on the frequencies  $\omega_1$  and  $\omega_2$  of incident and scattering light, respectively. The frequency redistribution functions are simple combinations of the func-

tions  $f_1^{(K)}$  and  $f_{23}^{(K)}$  defined in the paper of OSC (Ballagh and Cooper, 1977). Using the Stokes parameters  $I, Q, U, V$  and referring them to the scattering plane, we obtain the partial phase matrices  $p^J$  in the form

$$(2) \quad p^0 = \frac{2}{3} \begin{pmatrix} 1 \\ 0 \\ 0 \\ 0 \end{pmatrix} (1, 0, 0, 0), \quad p^1 = c \begin{pmatrix} 0 \\ 0 \\ 0 \\ 1 \end{pmatrix} (0, 0, 0, 1),$$

$$p^2 = \frac{1}{2} \begin{pmatrix} c^2 - 1/3 & -s^2 & 0 & 0 \\ -s^2 & (1 + c^2) & 0 & 0 \\ 0 & 0 & 2c & 0 \\ 0 & 0 & 0 & 0 \end{pmatrix}$$

with  $c = \cos\theta$ ,  $s = \sin\theta$ .

If we have a sharp lower atomic level not influenced by collisions, the redistribution matrix would have a simple structure revealing three different effects: (i) coherent scattering with maximum correlation in angular distribution and polarization, (ii) complete frequency redistribution due to collisions with depolarization and isotropization, and (iii) complete collisional frequency redistribution without depolarization.

In order to get the redistribution matrix in the laboratory rest frame, one has to account for Doppler shift of frequencies. Therefore, the scalar redistribution functions  $F_J(\omega_1, \omega_2)$  in Eq. (1) have to be convoluted appropriately with the velocity distribution of the atoms. This implies an angular dependence  $\bar{F}_J(\omega_1, \omega_2, \theta)$ .

As revealed by numerical analysis, the dependence on the scattering angle  $\theta$  may be rather steep. Expanding the transformed redistribution functions in Legendre polynomials,

$$(3) \quad \bar{F}_J(\omega_1, \omega_2, \theta) = \sum_{l=0}^{l_{\max}} \bar{F}_J^l(\omega_1, \omega_2) P_l(\cos\theta),$$

we would have generally to retain a large number of terms. Nevertheless, for practical transfer calculations it might be sufficient to confine the expansion to a small number ( $l_{\max} + 1$ ) of terms without distorting essentially the significance of polarization effects. However, this has to be carefully examined by numerical calculations.

## References

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