

Depolarization of multiply scattered light in transmission through a turbid medium with large particles

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Received 5 January 2005; received in revised form 30 August 2005; accepted 17 October 2005

Abstract

An approximate analytical method for solving the vector radiative transfer equation is proposed. The method is based on the assumption that single scattering of light by large-scale inhomogeneities occurs predominantly through small angles. The method is applied to calculate the polarization state of multiply scattered light. The results obtained are discussed for various turbid media.

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PACS: 42.25.Dd; 42.25.Ja; 42.68.Ay

Keywords: Multiple light scattering; Polarization

1. Introduction

In the recent years, explaining the polarization effects in multiply scattering media with large-scale (size a is larger than wavelength λ) inhomogeneities have been of special interest in connection with many applications. A large number of experimental and theoretical studies have been devoted to this problem [1–23]. New effects were revealed, in particular, the difference in the depolarization rates between linearly and circularly polarized beams of light [6–9,21–23].

In most theoretical studies dealing with multiple scattering of polarized light in turbid media, methods of numerical calculations are generally discussed [13–18,21]. Simple analytical results that could explain basic experimentally observed effects were not available until recently. Within the framework of simplifying assumptions, the first results along this line were obtained in [12,16,24–28].

In this study, we consider the depolarization of multiply scattered light in optically isotropic turbid media with large inhomogeneities. Two different mechanisms of depolarization, viz, the “geometrical” mechanism and the “dynamical” one, can be distinguished [26]. The “geometrical” mechanism is due to the Rytov rotation [29,30]. The plane of polarization turns simultaneously with the ray of light. The wave remains linearly polarized along the overall path of propagation. The depolarization observed in multiple scattering of linearly polarized light results from superposition of randomly oriented polarizations of the different rays. The “dynamical” mechanism [31] is due to the difference in amplitudes between two cross-polarized components of the single-scattered wave. By this mechanism, multiply scattered light depolarizes as the spread in amplitudes increases. Single scattering of light by large-scale inhomogeneities occurs predominantly through small angles ($1 - \langle \cos \gamma \rangle \ll 1$, where $\langle \cos \gamma \rangle$ is the mean cosine of single-scattering angle γ) [32,33]. In this case, the “geometrical” mechanism of depolarization is dominant as compared with the “dynamical” one [6–8,25]. This permits us to

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develop a procedure for decoupling the vector radiative transfer equation. This procedure is based on the selection of basic and additional modes. In the case of single scattering through small angles the interaction between the basic polarization modes appears to be weak. To a first approximation we can neglect this interaction. In the succeeding approximation, the interaction between the basic modes results in the excitation of the additional modes (overtone). Allowance for the overtones makes it possible to describe in detail the polarization state of multiply scattered light deep in the medium. With the method proposed, the polarization state of multiply scattered polarized light is calculated. The influence of the scatterer parameters on the depolarization process is discussed.

2. General relations

Let a wide polarized beam of light be incident on a medium normally to its surface. The medium is assumed to be a statistically isotropic disordered ensemble of large-scale scatterers. The polarization state of scattered light is generally described by the four Stokes parameters [1,32–34]

$$\hat{S} = \begin{pmatrix} I \\ Q \\ U \\ V \end{pmatrix}, \quad (1)$$

where

$$\begin{aligned} I &= \langle E_{\parallel} E_{\parallel}^* + E_{\perp} E_{\perp}^* \rangle, \\ Q &= \langle E_{\parallel} E_{\parallel}^* - E_{\perp} E_{\perp}^* \rangle, \\ U &= \langle E_{\parallel} E_{\perp}^* + E_{\perp} E_{\parallel}^* \rangle, \\ V &= i \langle E_{\parallel} E_{\perp}^* - E_{\perp} E_{\parallel}^* \rangle. \end{aligned} \quad (2)$$

The Stokes parameters and the components $E_{\parallel}$ and $E_{\perp}$ of the electric field appearing in Eq. (2) are defined in the system of unit vectors $\{\mathbf{e}_{\parallel} = \partial \mathbf{n} / \partial \theta, \mathbf{e}_{\perp} = [\mathbf{e}_{\parallel}, \mathbf{n}], \mathbf{n}\}$ [34]. The unit vector $\mathbf{n} = (\sin \theta \cos \varphi, \sin \theta \sin \varphi, \cos \theta)$ is the direction of propagation of the transverse electromagnetic wave, the vector $\mathbf{e}_{\parallel}$ lies in the plane formed by the vectors $\mathbf{n}_0$ and $\mathbf{n}$ ($\mathbf{n}_0$ is the internal normal to the surface), the vector $\mathbf{e}_{\perp}$ is perpendicular to this plane (Fig. 1). The brackets $\langle \dots \rangle$ denote statistical averaging.

The Stokes parameters are always defined with respect to a reference frame, in our case the system of unit vectors $\{\mathbf{e}_{\parallel}, \mathbf{e}_{\perp}, \mathbf{n}\}$ or the plane $\{\mathbf{n}, \mathbf{n}_0\}$. If the reference frame is rotated through angle α around the direction $\mathbf{n}$, the transformation of the old Stokes vector $\hat{S}$ into the new Stokes vector $\hat{S}'$ is given by rotation matrix $\hat{L}$

$$\hat{S}' = \hat{L}(\alpha) \hat{S}, \quad (3)$$

where

$$\hat{L}(\alpha) = \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & \cos \alpha & \sin \alpha & 0 \\ 0 & -\sin \alpha & \cos \alpha & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix}. \quad (4)$$

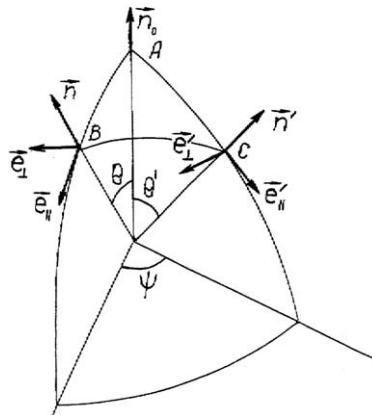


Fig. 1. Coordinate system used to describe the direction of propagation and polarization state of the incident and scattered light.

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