MUTUAL SHIELDING OF PARTICLES IN THE NEAR FIELD. V. P. Tishkovets, Institute of Radio Astronomy of NASU, 4 Chervonopraporna St., Kharkiv, 61002, Ukraine, tishkovets@ri.kharkov.ua

The classical radiative transfer equation (RTE), which is widely used in many areas of science, may be inapplicable to densely packed random media since the derivation of this equation from the Maxwell equations is explicitly based on the assumption that the scatterers are located in the far-field zones of each other [1]. In this assumption, a number of important peculiarities of light scattering by densely packed scatterers are ignored. In particular, the RTE does not take into account the near field. (In the literature the near field is associated with a field, which amplitude decreases more rapidly than r^{-1}, where r is a distance to a scatterer [2].) Up to now, the influence of the near field on the scattering properties of densely packed media has not been studied adequately. In this paper, mutual shielding of particles as a phenomenon related to the near field is considered.

Fig.1a and 1b show the intensity I of light scattered by bispheres with touching components as a function of the scattering angle. The axis of the bispheres is perpendicular to the propagation direction of the incident unpolarized light indicated by the wave vector $\mathbf{k}_0$. The size parameter of the particles composing the bispheres is $x = 4.0$, and their refractive index is $m = 1.32 + i0.05$.

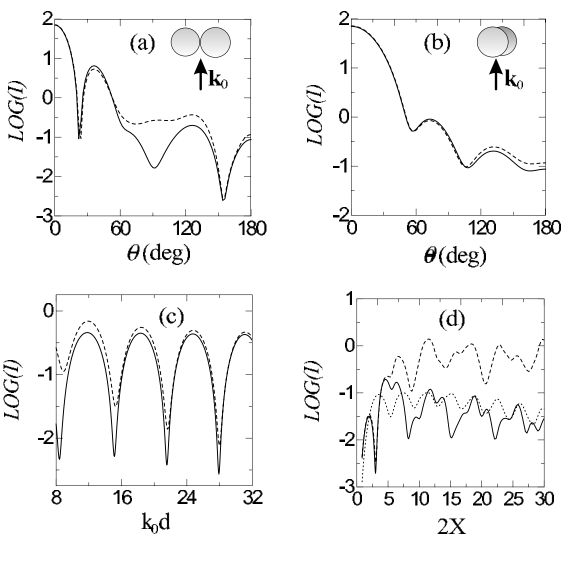

Fig.1 The intensity of light scattered by bispheres versus scattering angle ϑ (a, b). The models with the near field (continuous curves) and without it (dashed curves) are presented. (c) The intensity of light scattered in the direction of a bisphere axis versus distance d between the particles. (d) Dependence of the intensity of light scattered along the axis of a bisphere with touching components versus size of components.

The scattering plane coincides with the picture plane. Orientation of bispheres is shown in the right upper corners of Figs.1a and 1b. The intensity of scattered light is divided by a quantity $2x^2$.

As seen from a comparison of the curves in Fig.1a, the intensity of light in the scattering direction along the axis of the bisphere, calculated with the near field components, is significantly lower than that calculated without the near field. In the scattering direction perpendicular to the bisphere axis (Fig.1b), the intensity is practically the same in both models. The differences between models are caused by shielding of particles. With the near field taken into account all peculiarities of the electromagnetic field between particles are completely described. These peculiarities are manifest themselves, in particular, in the mutual shielding of particles, because the sizes of particles and the distances between them are comparable. If the field components decreasing more rapidly than r^{-1} are ignored, only spherical waves propagate between particles. This means that in describing the electromagnetic field between the particles, the sizes of particles are neglected in comparison with the distances between them. In this approach there is no shielding of particles by each other and, therefore, the intensity of light scattered along the bisphere axis is larger than in the case when the near field is taken into account.

The dependence of the intensity of light scattered in the direction of the bisphere axis on the distance between the particles is shown in Fig.1c. As can be seen from the plot, the difference between the models is noticeable up to the distances of about several diameters of the particles. The minima of intensity are caused by the interference of waves coming from the particles to the observation point and having the phase difference πn with n odd integers.

Fig.1d demonstrates the dependence of the intensity of light scattered along the axis of the bisphere with touching components versus size of the components. The dotted line corresponds to the intensity of light scattered at $\vartheta = 90^0$ by a single sphere in this picture. As seen from a comparison of the curves, the great difference in the intensities of two models is caused by a contribution of the multiple scattering in the model without the near field.

The shielding phenomenon for more complex randomly oriented clusters of spherical particles is shown in Fig.2. The characteristics of light scattered by such clusters can be calculated with the computer codes available in the Internet [3]. These codes naturally take into account the near field between the particles composing the clusters. For our specific purpose, to neglect the near-field components, we had to adapt these codes. Clusters of identical particles were generated according to the procedure described in [4]. The generated clusters consisting of 50, 100 and 200 particles are shown in Fig.2. The size parameter of the constituent particles of the clusters is $x = 1.5$, and the refractive index of particles is $1.5 + i0.001$. The packing density of the clusters is $\xi = N(x/x_0)^3 \approx 0.2$, where N is the number of particles in the cluster, $x_0 = k_0 a_0$, and a_0 is the radius of the smallest circumscribing sphere of the cluster. The intensities of the scattered light are divided by a quantity x_0^2.

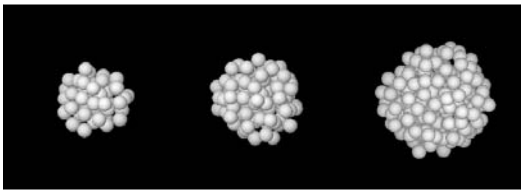

Fig.2. Clusters consisting of 50, 100 and 200 identical spherical particles. For $x = 1.5$, the size parameters x_0 of the smallest circumscribing spheres of these clusters are approximately equal to 9.25, 11.9 and 14.7, respectively.

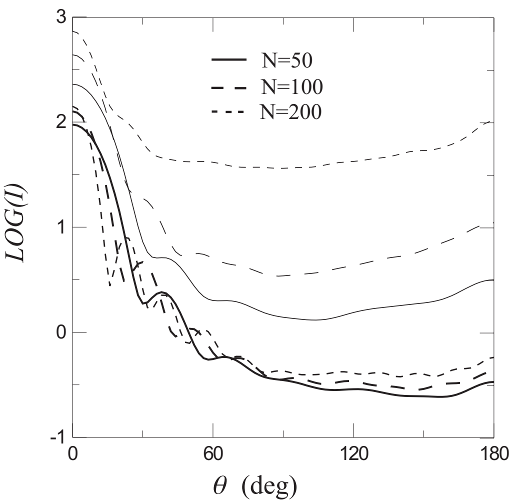

Fig.3. Intensity of light scattered by randomly oriented clusters. The models ignoring the near field (thin lines) produce substantially larger intensity than those taking the near field into account (thick lines). The numbers of particles in the clusters corresponding to the curve types are indicated in the plot.

As seen from Fig.3, ignoring of the near field results in a significant increase of the intensity of light scattered by the clusters at all scattering angles. A behavior of the intensity at $\vartheta > 60^0$ attracts a particular attention. For this angle range, the intensity weakly depends on the number of particles N in the models containing the near field. Since the intensity is normalized to the unit of the cross section area of the clusters (more precisely, it is divided by a quantity x_0^2), this behavior of the intensity implies that in this range of scattering angles the intensity is determined mainly by the particles of the upper layer of the clusters. Other particles of the clusters are shielded by particles of the upper layer. If the near field is ignored, the particles do not shield each other and a large number of particles is involved into multiple scattering. This results in the increase of the multiple scattering contribution, which, in turn, leads to the much higher intensity of the scattered light in comparison with the models considering the interaction of particles in the near field. For the same reason, in the models ignoring the near field, the intensity depends on the number of particles more significantly.

References: [1] Mishchenko, M.I., et al. (2006) Multiple Scattering of Light by Particles. Radiative Transfer and Coherent Backscattering – Cambridge.: Cambridge University Press, 478 p. [2] Greffet, J.-J., and Carminati, R. (1998) Progr. Surface. Sci. 56, 133-237. [3] Mackowski D. W., et al. ftp://ftp.eng.auburn.edu/pub/dmckwski/scatcodes/index.html. [4] Mackowski D.W. (1995) Appl. Opt. 34. 3535-3545.