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# Analysis of light scattering by erythrocyte based on discrete sources method

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**Abstract**

A renewed algorithm of the discrete sources method (DSM) is applied to model light scattering from a human erythrocyte. In contrast to traditional volume-based methods which are widely used for light scattering simulation DSM allows calculation of scattering for all incident angles and polarizations at once. This leads to an essential reduction of the computing time. The renewed DSM algorithm allows using a lower number of elementary sources which results in an increased accuracy of approximation for every harmonic. In this paper, we investigate several erythrocyte shapes such as flat spheroid and disk-sphere, which are usually used to represent the erythrocyte shape in light scattering modeling. Besides conventional mathematical shapes the rigorous biconcave erythrocyte shape was investigated. This is the first attempt to apply a semi-analytical method to model obstacle with concavities. Numerical results for light scattering by different shape models are presented and compared with the rigorous erythrocyte shape. Some practical recommendations in using appropriate models are given.


*Keywords:* Light scattering; Discrete sources method; Erythrocyte

## 1. Introduction

In recent years interest associated with polarized light scattering by different biological objects increased. Because biological structures are complex, it is generally difficult to study light scattering from a single object, however there are important exceptions, the blood cells. For experimental

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studies of blood cells, the scanning flow cytometer (SFC) can be used. SFC is designed to measure the light-scattering pattern of individual particles [1,2]. The interaction of light and blood cells or tissue is important for different applications, e.g., the determination of hemoglobin and volume of red blood cells (erythrocytes), to improve differentiations of blood cells by physical means, the determination of oxygen concentration in tissue and the interpretation of images in optical mammography. The interested reader can obtain more information on the interaction of light and tissue in the papers by Tuchin [3] and Roggan [4]. Among other blood cells the erythrocyte is very important because of its hemoglobin content. In addition, human erythrocytes do not show internal structure, providing an opportunity to apply theoretical models of scattering to these cells. However, theoretical modeling of erythrocytes is still complicated, because of it's shape, size and optical properties. The refractive index of an erythrocyte relative to blood plasma belongs to the range $1.045 \leqslant m \leqslant 1.058$, that means that for a scattering problem, where the incident light is a visible laser beam, an erythrocyte is a low-contrast dielectric scatterer. The size parameter band for blood cells is rather wide: from 26 until 50, the erythrocyte itself has a size parameter of 42, which makes modeling quite time-consuming. Another feature we should take into account is the complex shape of a real erythrocyte [2], which can change from biconcave discoid to a toroidal shape, due to the functions which an erythrocyte has in human blood. Recently, different methods have been applied to model light scattering from a single erythrocyte: Wentzel–Kramer–Brillouin approximation [5], Mie theory, Fraunhofer and anomalous diffraction [6], Rayleigh and Rayleigh–Gans–Debye approximation [7], Fredholm Integral Method, Boundary Integral Equation Method [8], T-matrix [9], Discrete Dipole Approximation (DDA) [10], Boundary Element Method (BEM) [11] and others. To model the erythrocyte shape, one usually uses the model of an oblate spheroid with aspect ratio 1:4 or even an equivolume sphere. The first attempt to solve scattering problem for real erythrocyte shape numerically has been made by Tsinopoulos and Polyzos [11].

In experimental studies SFC allows to measure light scattering from a single particle in angular range over 10–60°. The most interesting are two directions of scattering: forward scattered and side-scattered. The first one depends on particle size and the second on internal particle structure. Results obtained using SFC allow comparison of the results of theoretical modeling with the experimental results [2,10].

In this paper, the Discrete Sources Method [12] is applied to modeling light scattering from the human erythrocyte. In the frame of DSM, the approximate solution is constructed as a finite linear combination of the fields of Discrete Sources (DS): dipoles and multipoles deposited in some supplementary domain (axis of the symmetry of imaginary plane). The representation for the approximate solution satisfies all the conditions of the boundary value scattering problem, except conditions at the obstacle boundary. The unknown amplitudes of DS are to be determined from the transmission conditions at the obstacle boundary. So, the boundary value scattering problem under investigation is reduced to the solution of an approximation problem enforced at an obstacle surface [13]. Unlike volume-based methods like DDA and FDTD, the surface-based methods like DSM or T-matrix allow to compute scattering for all the incident angles and polarizations at once. In DSM only the surface of the scatterer has to be discretized. In addition taking into account of the rotational symmetry of the erythrocyte in DSM gives an essential reduction of calculation time compared with volume discretization methods.

To our knowledge, the paper presents the first attempt to apply a semi-analytical method to model obstacle with concavities. On the base of DSM a rigorous biconcave erythrocyte shape in parallel with such common mathematical shapes, like oblate spheroid and disk-sphere is modeled.

First we will present the mathematical theory of DSM. Next we will give an overview of numerical algorithm realization and present some numerical results for different erythrocyte shapes with detailed discussion. Conclusions and recommendations in using appropriate erythrocyte models are given at the end of the paper.