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Light scattering by single erythrocyte: Comparison of different methods

Thomas Wriedt[a,*], Jens Hellmers[b], Elena Eremina[b], Roman Schuh[a]

[a]Institut für Werkstofftechnik, Badgasteiner Str. 3, 28359 Bremen, Germany
[b]Universität Bremen, Badgasteiner Str. 3, 28359 Bremen, Germany

Abstract

In this paper we investigate the capabilities of different light scattering programs for light scattering simulation of the single human red blood cell, also known as erythrocyte. Knowledge of the scattering properties can help to solve the inverse problem of classifying erythrocytes according to size and shape using measured scattering diagrams. We compare the different programs by presenting the corresponding scattering diagrams. Then we give an overview of computation times and point out the different characteristics of the methods.

Keywords: Erythrocyte; Electromagnetic scattering; Discrete sources method; Discrete dipole approximation; Multiple multipole program; Finite integration technique; T-matrix

1. Introduction

In recent years there has been an increased interest in light scattering by the human red blood cell, also known as erythrocyte. For experimental studies the scanning flow cytometer (SFC) can be used to measure the light scattering pattern of individual cells [1]. Knowledge about the theoretical light scattering behavior promises to enable advanced analysis of human blood, e.g. to detect abnormal mutated erythrocytes caused by disease. For this fast theoretical light scattering simulations are needed. Because of the special shape of the red blood cell and its size there are not many light scattering programs which are suitable.

In literature so far one can find several publications regarding to light scattering by the erythrocyte.

Lu et al. [2] for example used the finite difference time domain (FDTD), which is a time domain method like the finite integration technique (FIT) presented in this paper. Investigations using the discrete dipole approximation (DDA) were done by Karlsson et al. [3] and Yurkin et al. [4]. Eremina et al. [5] simulated light scattering by the erythrocyte using the discrete sources method (DSM). Nilsson et al. [6] used the T-matrix method. A boundary element method (BEM) approach can be found in Tsinopoulos et al. [7].

Although there is a number of publications about light scattering by erythrocyte they usually concentrate on one simulation method only. So the question for the most suitable method is still open.

*Corresponding author. Tel.: +49 421 2182507; fax: +49 421 2185378.
E-mail address: thw@iwt.uni-bremen.de (T. Wriedt).

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In this paper we would like to give an overview of several theories and algorithms which we will compare than presenting computational results. As these methods for simulating light scattering are always strongly connected with the way how the shape of the cell is described, we start with a presentation of different approaches to model the human red blood cell. Then we give a short introduction into the following light scattering theories: DDA, FIT, DSM and Multiple Multipole Program (MMP). Additionally, we have a look at the latest developments of the Nullfield Method with Discrete Sources (NFM-DS). For the comparison we will present the corresponding light scattering diagrams for a single erythrocyte and also computation times. As every scattering theory has its own advantages and disadvantages, we will point out this in more detail. Finally, we would like to summarize our findings about accuracy, computational speed and characteristics of each method.

2. Erythrocyte

The erythrocyte is composed of hemoglobin, water and membrane components. As it does not contain any nucleus and thus no internal structure it provides a good opportunity to apply different computational light scattering methods. Nevertheless, the calculation of light scattering by the erythrocyte is not a trivial task, mostly due to the special cell characteristics: size, aspect ratio and a biconcave form.

In general, it can be described as a biconcave oblate disc with an average diameter between 6 and 8 μm while the average aspect ratio is up to 4 : 1 [1,8]—see also Fig. 1.

The refractive index also varies, depending on the incident wavelength and the surrounding media. For an incident wavelength of $\lambda = 632.8\,\text{nm}$, the absolute index of refraction falls between 1.40 and 1.42, the imaginary part is usually neglected for this wavelength. For the relative refractive index 1.058 is usually used [8].

The main characteristic of the erythrocytes' shape is the presence of concavities on its sides. This makes an exact light scattering calculation especially difficult. To overcome this problem some studies use simplified shape models like flat cylinders with a rounded edge or oblate spheroids. Such approximations for example are

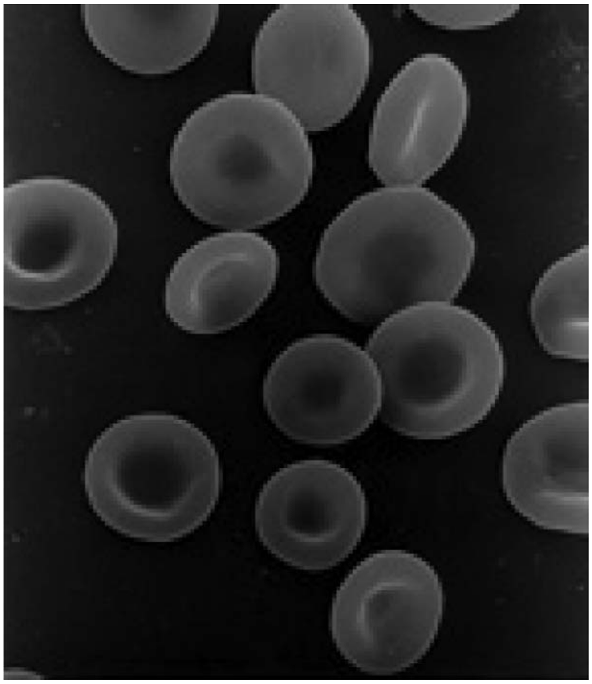

Fig. 1. Erythrocytes. Photo is courtesy of Drs. Noguchi, Rodgers, and Schechter of NIDDK. Public domain, taken from Wikipedia [9].