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Study of Phase Function of the Biological Cell

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Abstract. In order to settle the influence of measuring results of cells with its shape-variety in the examination of biological cell, MCEM (modify co-central ellipse model) is adopted based on the theories of Rayleigh- Debye- Gans, and the changing tendency of scattering phase function of nucleated cells with different body factor, nuclear size and shooting angle are studied. These provide a useful theory foundation for improving the measurement and distinguishing of biological cell.

Introduction

Scattering is one of the most important radiation characteristics of biological cell when light transferring in the cells. Scattering phase function containing size and shape information of scattering body could describe the light scattering properties and space distribution of scattering intensity [1]. Scattering phase function plays an important role in the transport computation; it is one of major way to study the interaction of particles and beam [2]. Mie scattering theory is a useful applied theory of solving scattering phase function of ball cell. But, measure result would be influenced in the actual measurement because of biological cell having various kinds and shape. In fact, ellipsoid is more near to true cell in its shape than ball because of cell's internal structure, surface tension and growth mechanism. So, MCEM based on the theories of Rayleigh- Debye- Gans can be adopted. In this paper, changing tendency of scattering phase function of nucleated cells with different body factor, nuclear size and shooting angle are studied after match proceeding. These provide a useful theory foundation for the further research.

Rayleigh-Debye-Gans theory and MCEM

According to the Rayleigh- Debye- Gans theory (or the Born theory), only single scattering and elastic scattering are studied. The angular intensity of the scattered radiation is given by[3]

$$I(\theta) = I_0 \frac{i_1(\theta) + i_2(\theta)}{2k_0^2 R^2} \quad , \qquad (1)$$

Where $i_n(\theta) = \left|S_n(\theta)\right|^2$ and θ means angle of detection. The scatter functions $S_n(\theta)$ result from perpendicular (n=1) or parallel (n=2) polarized incident light relative to the plane of scattering. I_0 represents the intensity of the incident light. The distance from the particle to the point of observation is given by R, and k_0 is the propagation constant of the applied field outside the particle and is defined by $k_0 = (2\pi / \lambda_0)$, where λ_0 is the wavelength of incident light in vacuum. The form factor $P(\theta)$ contains all the information on cellular size, shape, and refractive index [$m(r)$] and is defined by[3]

$$\left.\begin{matrix} S_1(\theta) \\ S_2(\theta) \end{matrix}\right\} = ik_0^3 \alpha(r) P(\theta) \begin{cases} 1 \\ \cos\theta \end{cases} \quad , \qquad (2)$$

Where $\alpha(r) = \int_v \alpha'(r) dv$ and $\alpha'(r)$ means volume polarizability.

CEM is a model presented to calculate the light scatter properties of nucleated cells that are mimicked by two concentric ellipsoids [4]. The MCEM is modify co-central ellipse model .CEM

model can availably express the scattering situation of the shape cells when light shoot along with the stalk axis and shows the affecting relation between the scattering distribution and varying shape of cells in mathematics. But, for the shape cells (no spheroid ball cells), while passing scattering area, there is a varying incidence angle β (shooting angle) between the stalk axis and shooting direction, that will made a affecting up on the scattering area, scattering factor and polarization rate in this case. Therefore, a correction must be done as follows: The volume polarizability of ellipsoid is defined by

$$\frac{(m^2-1)n_n}{1+(m^2-1)n_n} \quad , \tag{3}$$

Where: $n_x=\frac{1-e^2}{2e^3}(\ln\frac{1+e}{1-e}-2e)$, $n_y=n_z=\frac{1}{2}(1-n_x)$, $e=\sqrt{1-(\frac{1}{\eta})^2}$. Considering the non-axial incident situation. The model is rotational symmetric, it is proposed to modify the volume polarizability of ellipsoid and can be expressed as

$$N(m,\beta)=\sqrt{[\frac{(m^2-1)n_x}{1+(m^2-1)n_x}\cos\beta]^2+[\frac{(m^2-1)n_y}{1+(m^2-1)n_y}\sin\beta]^2} \quad , \tag{4}$$

Therefore the volume polarizability of the cytoplasm and the nucleus can be given

$$\alpha_{a\beta}^{'}=\frac{3}{4\pi}M_{a\beta},\ \alpha_{b\beta}^{'}=\frac{\eta b^3M_{0\beta}-\eta a^3M_{a\beta}}{V_b-V_a} \quad , \tag{5}$$

$P'(\theta)$ can be defined as fellow $P'(\theta)=\alpha(r)\cdot P(\theta)$

To sum up, the distribution of scattering could be given

$$P^{'}(\theta,\beta)=\int_v\alpha_\beta^{'}(r)\left|m^2(r)-1\right|e^{i2k_0m(r)r\sin(\frac{\theta}{2})}dv \quad , \tag{6}$$

and $$I(\theta,\beta)=I_0\frac{i_1(\theta,\beta)+i_2(\theta,\beta)}{2k_0^2R^2} \quad , \tag{7}$$

The equation (6) is called as the function of form factor distribution with shooting angle βand the equation (7) is called as the function of scattering intensity distribution with shooting angle β . It has been given that the theory of MCEM and Raleigh- Debye- Gans has a same result under uniformity ball model.

The scattering phase function under MCEM

Van de Hulst define scattering phase function as: the ratio of the scattering energy in unit solid angle in a given direction and the scattering energy in the average unit solid angle in all direction (light is scattered single)[3]. Where θ is scattering angle. If the particle to be studied is rotational symmetry structure , scattering phase function have nothing to do with azimuth angle. It can be seen from definition of scattering phase function that: scattering phase function is proportional to the scattering intensity along the direction when the incident light intensity is constant. If particles system with uniform size, scattering phase function could be given as following

$$S(\theta)=I(\theta)/\int_0^{2\pi}I(\theta)d\theta \quad , \tag{8}$$

Where: $I(\theta)$ is function of scattering intensity distribution expressed by equation(7)when adopting MCEM .The numerical value simulation calculation will be proceeded here because of there is no analytical solution for equation(8).The wavelength of incident light is $0.6328\mu m$， refractive index of suspension medium is1.345.

First, a typical model is chosen for $a=2\mu m, b=5\mu m, m_a=1.10, m_b=1.08$, $\eta=1.5,2.5,5$, light irradiate along the short axis. The scattering phase function is shown as in fig.1, it is shows that: scattering intensity basically focus on forward;forward scattering more concentrated with the increase

of the form factor;which conform to the Mie scattering theory. But, lateral scattering and back scattering that reflect cell inside information change significantly; number and position of maximum and minimum change obviously; position of minimum increase gradually with the increase of form factor.

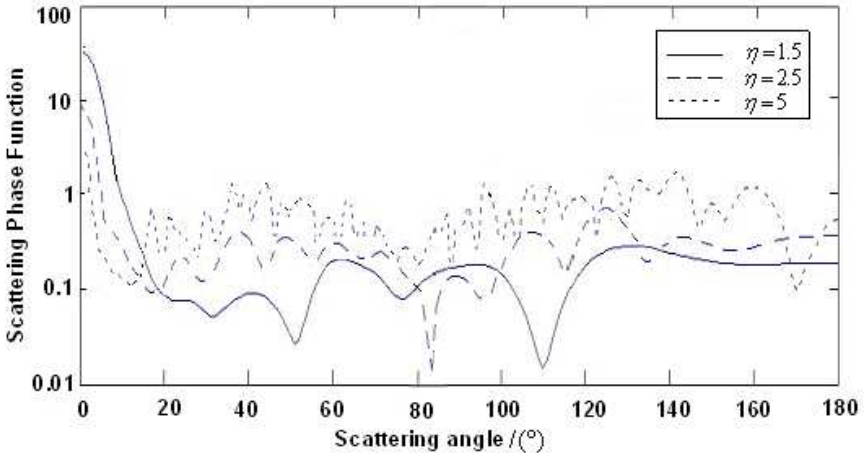

Fig. 1. Scattering phase function with different body factor

Second, the model is chosen for $b=5\mu m,\eta=2,m_a=1.10,m_b=1.08$, $a=1,2,4\mu m$, light irradiate along the short axis. The scattering phase function is shown as in fig.2, it is shows that: for the same body size of cells, the distribution of forward scattering intensity dose not changes. Nuclear size changes have slightly influenced for forward scattering peak. But, lateral scattering and back scattering change significantly; number and position of maximum and minimum change obviously; position of maximum and minimum increase gradually with the increase of the nucleus.

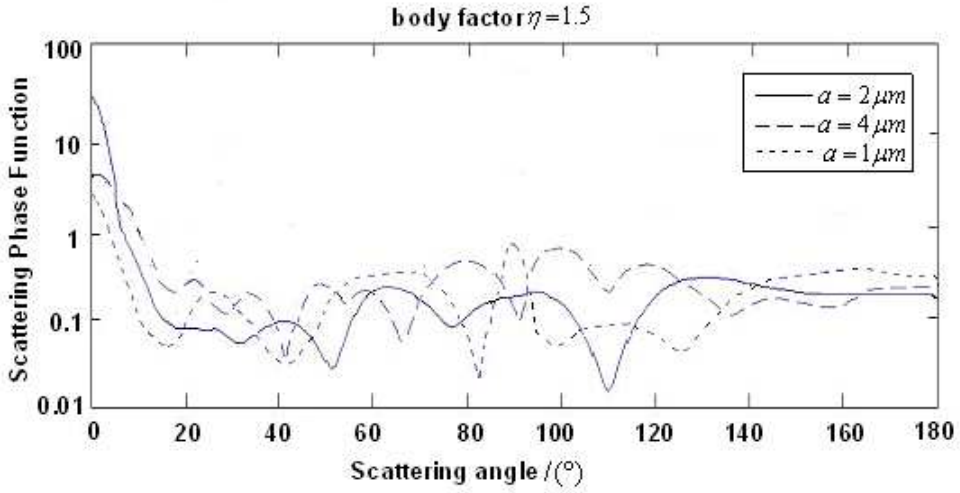

Fig. 2. Scattering phase function with different nuclear size

The last, the model is chosen for $a=2\mu m,b=5\mu m,\eta=2,m_a=1.10,m_b=1.08$， shooting angle as $\beta=0°,30°,60°$ are chosen respectively. The scattering phase function is shown as in fig.3, it is shows that: for the same structure of cells, the distribution of scattering phase function has few change for these three different shooting angle case.

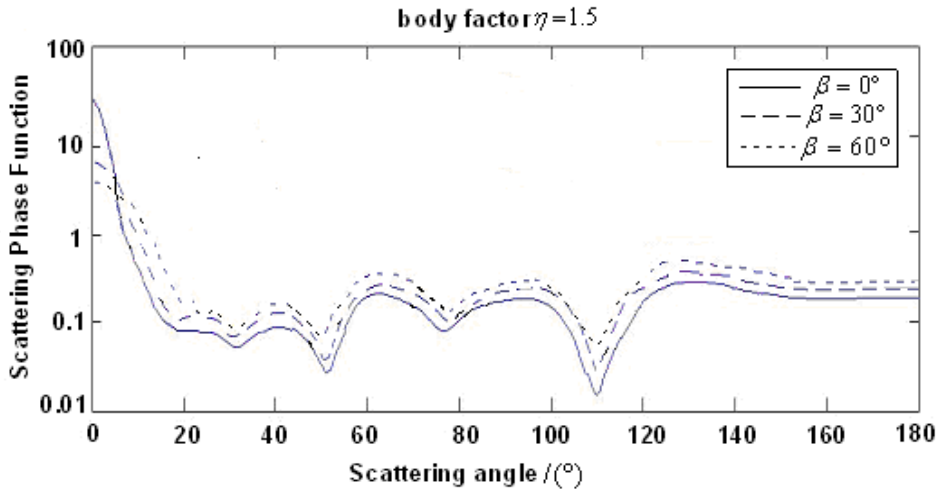

Fig. 3. Scattering phase function with different shooting angle

Conclusions

In this paper, the theory of MCEM is adopted to study the scattering of nonspherical nucleated cell. The changing tendency of scattering phase function of nucleated cells is discussed with different body factor, nuclear size and shooting angle. The main conclusions from the present numerical study are the following: In the application of light scattering theory, the influence of cells' shape doesn't be considered when measuring cell's size based on the forward scattering theory, but the varying of cells' body factor and nuclear size must be considered when measuring its shape based on the side scattering theory. Therefore, the accuracy of measurement and distinguishing of shape biological cell is improved effectively.

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