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STUDY ON THE POLARIZATION DEGREE OF RADIATION SIDE-SCATTERED BY THE MULTIPLE PARTICLES DISTRIBUTED RANDOMLY

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Abstract: The suspending liquid consists of various concentrations of particles which are either 0.22μm or 0.494μm in diameter and were mixed into filtered, distilled water, and serve as the scattering medium for studying the polarization property of radiation side-scattered by the particles. The experiment results show that the de-polarization of radiation side-scattered by the particles is very sensitive to the variation of the particles' diameters: the horizontal polarization degree of the side-scattered radiation of the particles with smaller diameters is much higher than that with larger diameters, but the vertical polarization degree of the side-scattered radiation of smaller particles is much lower than that of larger particles.

Key words: multiple scattering; polarization degree; laser

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随机分布群体粒子场侧向散射光偏振度研究

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摘要:由直径0.22μm或0.494μm的粒子与过滤的蒸馏水混合构成不同浓度的悬浮液,作为研究粒子侧向散射光偏振特性的散射介质。实验结果表明,粒子侧向散射光的退偏振对粒子直径的变化非常敏感:直径小的粒子其侧向散射光水平方向偏振度远大于直径大的粒子,而其侧向散射光垂直方向的偏振度却远小于直径大的粒子.

关 键 词:复合散射;偏振度;激光

Introduction

The researches on the properties of a laser radiation side-scattered by the multiple particles distributed randomly have extensive applications in modern science and engineering[1~5]. The scattering mediums in the experiments consist of various proportion concentrations of spherical particles which are either 0.22μm or 0.494μm in diameter and which were mixed into filtered, distilled water. The horizontal and vertical polarization degrees of the radiation side-scattered by the particles were discussed. It was found that the horizontal polarization degree of the side-scattered radiation of the smaller particles is much higher than that of the larger particles, and the vertical polarization degree of which is much lower than that of the larger particles. The results can be practically applied to detect the diameter distribution of the particles in a multiple scattering field (especially for the particles which are less than 1μm in diameter).

1 Basic Theory

The classical scattering effects for small particles (diameter $d < \lambda$) is showed in Fig. 1, a polarized beam of radiation incident upon a very small particle which is positioned at O, and the incident light is po-

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larized in the x-z plane where +z axis is the direction of light propagation.

As is well known, according to the Mie Theory, the intensity of radiation scattered to point P from a spherical particle at point O (in Figure. 1) and which is subject to un-polarized incident radiation is:

$$I_\mu = \frac{\lambda^2}{4\pi^2 R^2}|S|^2 \quad , \tag{1}$$

where $|S|^2 = |S_1|^2 + |S_2|^2$, S_1、S_2 are the amplitude functions of the scattered light at x-z plane and x-y plane respectively. The polarization degree is defined as:

$$P = \frac{|S_1|^2 - |S_2|^2}{|S_1|^2 + |S_2|^2} \quad . \tag{2}$$

The particle field in the experiment discussed in this report is of multiple particles, not of single particle. The effect of the multiple particle scattering must lead to the variations of the intensity and the polarization for the scattered radiation in the x-y plane, and these variations are the function of the particle size, the concentration, and the space size in the scattering field.

For this report, incident radiation is linearly polarized, the intensity of the scattered radiation in the plane perpendicular to propagation direction is:

$$I_i = \frac{\lambda^2}{4\pi^2 R^2}\{|S_1|^2\sin^2\phi + |S_2|^2\cos^2\phi\} \quad . \tag{3}$$

Note that the plane x-y is studied, $\theta = \frac{\pi}{2}$, thus:

$$I_i = PI_\mu\sin^2\phi + \frac{\lambda^2}{4\pi^2 R^2}|S_2|^2 \quad , \tag{4}$$

then:

$$\frac{I_i(\phi)}{I_i(\phi=0)} = 1 + \left[\frac{|S_1|^2}{|S_2|^2} - 1\right]\sin^2\phi = A(\phi) \quad , \tag{5}$$

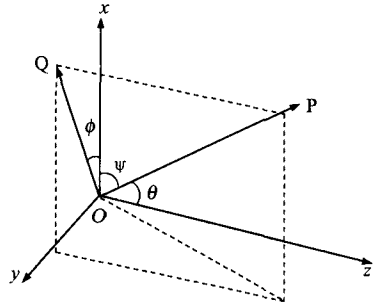

Fig. 1 Geometry of classical scattering
图1 经典散射几何关系

so, reduced from the equation (2), the polarization degree of the scattered light with respect to the linearly polarized incident light is defined as[6~9]

$$P = \frac{A(\phi) - 1}{A(\phi) - 1 + 2\sin^2\phi} \quad . \tag{6}$$

2 Experiment

The experimental apparatus (Fig. 2) were placed on vibration isolation pads. The structure was leveled so that the level of the liquid in the container and the beam from the laser were orthogonal. To detect different depths, the vertical locator can be adjusted along the vertical axis of the structure.

The linearly polarized light (wavelength λ as 0.632 8μm) radiated from the laser was not only perpendicular to the liquid surface but collinear with the axis of rotation of the detector. Thus the fiber optics bundle was positioned so as to view the beam at all angular positions.

The scattering medium consists of three types of liquid concentrations, 0.002 5%, 0.005% and 0.012 5% of spherical polymer granules which are either 0.22μm or 0.494μm in diameter and which were suspended in the twice-filtered distilled water;

The aperture is attached to the end of an optical fiber bundle. The other end of the fiber optic bundle is connected to the photoelectric multiplier. A polarizer (i. e., a Polaroid sheet) could be set in front of the aperture. The detecting spot of the aperture was taken

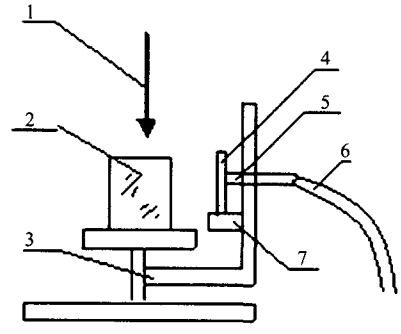

Fig. 2 Experimental apparatus
1. laser beam 2. container of liquid and particles
3. rotating plate 4. polaroid sheet 5. accepting aperture
6. fiber optics bundle 7. vertical locator
图2 实验装置
1. 激光束 2. 散射场(粒子和水混合液) 3. 转盘
4. 检偏器件 5. 接收窗 6. 光纤 7. 垂直支架

at every 5° in the plane parallel to the liquid surface in the experiment, At each spot three intensities of the side-scattered radiation were detected: first, the intensity of the total scattered radiation, acquired with no polarizer; second, the horizontal polarization intensity, acquired with the pass direction of the polarizer parallel to the liquid surface; third, the vertical polarization intensity, acquired with the pass direction of the polarizer perpendicular to the liquid surface.

3 Results and Discussion

The polarization degrees in table 1 are estimated according to the equation (6), i. e., for the particle field consisting of particles in diameter 0.22μm and having a concentration of 0.002 5%, the de-polarization relative values estimated for the total scattered radiation intensity. The 8 group values in the table are the results obtained at variable depths from every observing angle ϕ. The values vary slightly, and it indicates that the degree of the total radiation intensity descends a little with the depth increasing but changes gently, all at 0.8 or so. This shows that the total effect of multiple scattering approximates to the theoretical calculation of the single-particle scattering.

Table 2, 3, 4, 5 illustrate the comparison of the horizontal polarization degree and the vertical polarization degree of side-scattered radiations of the two types of particles in three concentrations (all of these data are acquired at the surface of the liquid). Included with these data points is that for the horizontal polarization, the polarization degrees of the smaller particles (0.22μm) are all higher than that of the bigger particles (0.494μm); but for the vertical polarization, the polarization degrees of the smaller particles are all lower than that of the bigger particles. Moreover, the polarization degree of vertical polarization varies greatly with the angle φchanging, this cannot be acquired from the theoretical analysis for the single particle scattering and it

Table 1 Polarization degree of the detected total radiation scattering intensity (for 0.22μm particles with a concentration of 0.002 5%)

表 1 散射总光强的偏振度 (粒子直径 0.22μm,浓度 0.002 5%)

ϕ(degree) Depth(cm)	90	75	60	45	30	15
0.0	0.886 8	0.891 4	0.895 3	0.896 5	0.900 0	0.897 2
0.5	0.877 5	0.881 1	0.890 2	0.898 2	0.911 8	0.925 7
1.0	0.858 5	0.865 4	0.874 2	0.872 7	0.888 8	0.894 8
1.5	0.835 1	0.834 0	0.850 0	0.862 1	0.878 9	0.881 8
2.0	0.828 0	0.819 9	0.844 2	0.839 7	0.866 6	0.881 6
2.5	0.818 1	0.822 2	0.840 0	0.857 1	0.866 6	0.881 8
3.0	0.800 0	0.803 4	0.828 5	0.836 9	0.852 1	0.881 5
3.5	0.794 9	0.795 3	0.821 0	0.843 2	0.842 5	0.867 8

Table 2 Polarization degree of horizontal polarization scattering radiation (for 0.22μm particles with three concentrations)

表 2 水平偏振散射光的偏振度 (粒子直径 0.22μm,三种浓度)

ϕ(degree) C%	90	75	60	45	30	15
0.012 5	0.827 4	0.830 8	0.835 2	0.852 3	0.846 6	0.861 0
0.005	0.891 8	0.888 2	0.894 7	0.911 1	0.916 1	0.927 3
0.002 5	0.927 2	0.927 8	0.928 5	0.931 0	0.933 3	0.937 2

Table 3 Polarization degree of horizontal polarization scattering radiation (for 0.494μm particles with three concentrations)

表 3 水平偏振散射光的偏振度 (粒子直径 0.494μm,三种浓度)

ϕ(degree) C%	90	75	60	45	30	15
0.012 5	0.520 4	0.507 1	0.526 8	0.519 2	0.537 0	0.572 8
0.005	0.672 7	0.675 8	0.682 2	0.735 4	0.743 2	0.792 0
0.002 5	0.739 2	0.752 4	0.758 5	0.809 2	0.832 2	0.898 8

Table 4 Polarization degree of vertical polarization scattering radiation (for 0.22μm particles with three concentrations)

表 4 垂直偏振散射光的偏振度 (粒子直径 0.22μm,三种浓度)

ϕ(degree) C%	90	75	60	45	30	15
0.012 5	0.010 0	0.015 8	0.03 84	0.082 5	0.218 7	0.563 0
0.005	0.011 0	0.015 8	0.032 2	0.137 9	0.305 5	0.641 7
0.002 5	0.025 0	0.036 1	0.079 5	0.166 6	0.350 6	0.711 2

Table 5 Polarization degree of vertical polarization scattering radiation (for 0.494μm particles with three concentrations)

表 5 垂直偏振散射光的偏振度 (粒子直径 0.494μm,三种浓度)

ϕ(degree) C%	90	75	60	45	30	15
0.012 5	0.032 0	0.046 0	0.162 0	0.324 2	0.652 7	0.895 6
0.005	0.091 0	0.101 1	0.261 0	0.487 1	0.743 3	0.930 3
0.002 5	0.120 0	0.325 3	0.482 7	0.696 9	0.868 4	0.969 0

exhibits the characteristics of the multiple scattering. This is very useful to detect the particle diameter in a multiple scattering field. Besides, within the range of experimental concentrations (0.012 5% ~0.002 5%), as the concentration gets lower, the intensity of each scattered radiation and its polarization degree all get higher.

4 Conclusions

The polarization degree of the radiation side-scattered by the multiple particles distributed randomly is studied, and the following results are obtained:

(1) In a multiple scattering field with particles of any diameter, the polarization degree of the total side-scattered radiation intensity decreases with the detecting depth increasing.

(2) The vertical polarization degree and the horizontal polarization degree of the side-scattered radiation show an absolutely reverse phenomenon, i. e., the vertical polarization degree decreases with the diameter of the particles decreasing, on the contrary, the horizontal polarization degree increases with the diameter of the particles decreasing.

(3) Such characteristics of the side-scattered radiation in the multiple particle scattering field are all the same as shown in (1) and (2) for variable concentrations adopted in the experiment.

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