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MEASUREMENT OF ANGULAR SCATTERING FUNCTION AND DEGREE OF LINEAR POLARIZATION OF BENTONITE CLAY PARTICLES EMBEDDED IN CYLINDRICAL EPOXY MATRIX

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ABSTRACT. Scattering properties of bentonite clay particles were investigated at 543.5 nm incident laser wavelength by using a designed and fabricated light scattering setup. The scattering samples were held in front of a laser beam by using a transparent cylindrical thermosetting epoxy matrix.

1. Introduction

Light scattering instruments and systems use different arrangements, e.g. nebulizer to spray dust particles [1], parabolic flights to attain microgravity to float scattering particles [2], pyrex glass cuvette to suspend hydrosols [3, 5], electrodynamic balance to levitate ice-like crystals [4], to present the scattering samples in front of the laser beam. In this work, a different type of sample holding arrangement, i.e., a cylindrical polymer matrix made of cycloaliphatic amine cured epoxy resin was used to embed and present the bentonite clay particles in front of the laser beam. A major advantage of such arrangement was the environment it created where the scatterers (clay particles) were frozen i.e. not moving with respect to time. This situation helped in taking the average of a large number of scattering measurements on the same set of particles to reduce experimental errors. Notably such measurements will give the scattering properties of the scatterers in the embedding medium only. Therefore such arrangements will be applicable not only for investigating the light scattering properties of polymer embedded nanostructures (such as Au, Cu, ZnO, CdS, TiO_2 etc.) but also for measuring scattering properties of other complex shaped non-spherical particles and use the results to improve the performance, usefulness and accuracy of the light scattering theories. The results of the laboratory light scattering measurements on such a system of particles under controlled conditions are presented. A comparative analysis of the results with Mie theory was also conducted to interpret the experimentally observed light scattering patterns.

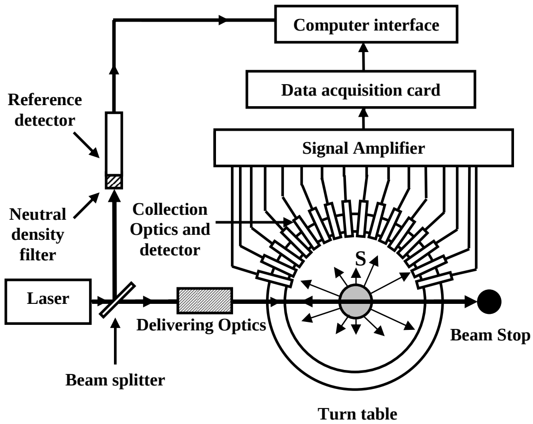

Figure 1. Schematic diagram of the light scattering setup (S: scattering centre).

2. Experimental Section

2.1. Experimental Setup. Figure 1 illustrates the schematic design of the light scattering setup. The present setup is similar to the setup described earlier [5] with a slight modification. In this modified version unpolarized light beam from the laser source is split by a 50:50 beam splitter and the direct beam is allowed to pass through the delivering optics system comprising of a linear polarizer and a circular polarizer which are used to select the state of polarization of the incident light. The polarizer arrangement in the delivering optics unit of the light scattering setup is optional and was not specifically used in this work as the measurement of only scattering function, $\beta(\theta)$ and the degree of linear polarization, $P(\theta) = -F_{12}/F_{11}$ were attempted. The reflected beam after passing through the neutral density filter enters the reference photodetector. The reference detector was used to measure the incident light intensity on the samples which is used for the determination of $\beta(\theta)$. It is noteworthy to mention that for unpolarized incident light $\beta(\theta)$ is equivalent to the first element, F_{11} of the scattering matrix. The present setup is capable of using three types of sample presenting arrangements to put the scattering particles in front of the laser beam, for example, aerosols were sprayed at the scattering centre as a stream of flowing particles by using a nebulizer, hydrosols were placed in a sample cell made of Pyrex glass at the scattering centre by a mechanical arrangement and clay particles were embedded in cylindrical polymer matrix placed at the scattering centre. Measurements were taken in steps of 1° from an angle of 10° to 170° and each detector was separated from the next one by an angle of 10°. The results from the measurements were processed through the data reduction procedure [5] and then plotted.

2.2. Embedding samples in the cylindrical polymer matrix. Bentonite clay particles have their origin at volcanic rocks and its main meneral constituent is montmorillonite [6]. In this work, we began with the study of light scattering properties of bentonite clay particles by embedding them in a suitable polymer matrix. Diglycidyl based epoxy resin

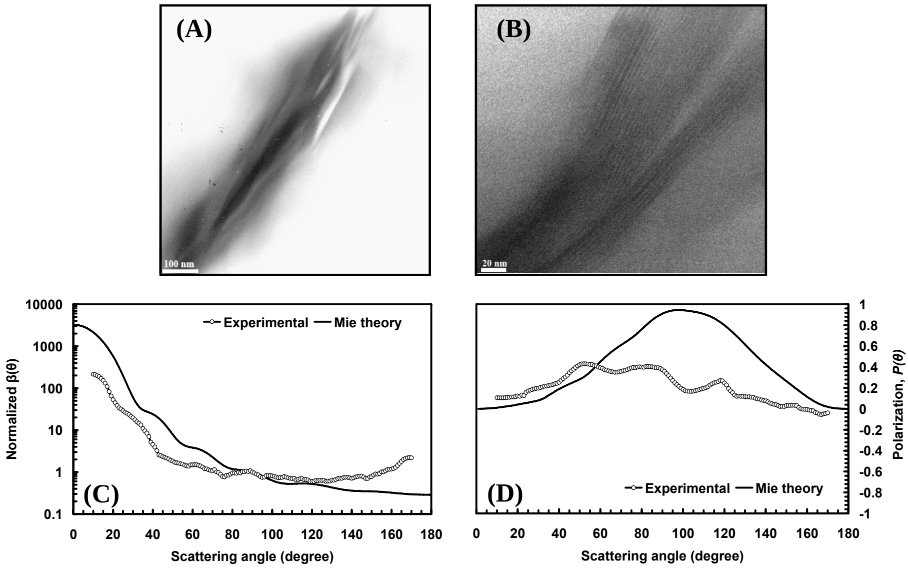

Figure 2. (A) TEM image of bentonite clay particle dispersed in the polymer matrix. (B) High resolution TEM image showing the typical layered structure (appearing as dark lines) of the bentonite clay particles. (C) Measured $\beta(\theta)$ (dotted line) and (D) $P(\theta)$ (dotted line) are compared with Mie calculations (bold line).

(CY-250, Ciba Geigy, Mumbai) was selected as the host polymer matrix as it is an optically transparent polymer having refractive index of approximately 1.55 at the visible wavelengths. For the preparation of the polymer embedded clay particles ex-situ technique was adopted [7]. The measurements were performed in differential mode [5] and hence cylindrical matrices with and without the clay particles were prepared in the specially designed cylindrical glass tubes of diameter 5 mm having flat entrance and exit window for the laser beam. To perform the experiments in single scattering regime, the method described by Hovenier et al [1] was used where the intensity of scattered light was measured for unpolarized incident light as a function of increasing sample concentration for a fixed position of the detector (10° in this case). The sample concentration up to which the graph is linear indicated the experiment to be in the single scattering regime.

3. Results

Transmission electron microscopy (TEM) techniques were employed to observe the physical morphology of the clay particles and are shown in figure 2(A) and figure 2(B). It was observed from the TEM image in figure 2(A) that the shape of the clay particles embedded in the polymer matrix was highly nonspherical. Figure 2(B) shows the typical layered structure [6] of the individual clay particles appearing as dark lines.

The plot for the measured scattering function, $\beta(\theta)$ is presented in figure 2(C). It was observed that $\beta(\theta)$ contains sharp forward scattering peaks followed by an almost flat back scattering response. The degree of linear polarization, $P(\theta)$ was found to be positive over most of the scattering angles while it went slightly towards negative over 160° as shown in figure 2(D). For comparison purpose the measurements were correlated with Mie calculations by considering Gaussian distribution (minimum, maximum and modal radius of the particles were 0.2 μm, 0.5 μm, and 0.3 μm respectively and the standard deviation, σ^2 was 2) for the particles in the scattering volume. The particle and medium refractive indices were taken to be 1.65 + i0.00 and 1.55 + i0.00. In case of $\beta(\theta)$ both the measured and calculated values were normalized to 1 at 90°. Although the theoretical results calculated by assuming equivalent sphere radii could not mimic the experimental results as can be observed from the figures, the deviation of $\beta(\theta)$ was within acceptable limits as compared to that of $P(\theta)$. The presence of clay particles of shapes and sizes different from the estimated values in the scattering volume was one of the reasons for the observed discrepency. Therefore it is important to understand the morphology of the scattering particles to a greater extent for accurate prediction of their scattering properties.

4. Conclusion

In this paper we report the use of a transparent cylindrical polymer matrix to embed the bentonite clay particles in front of the laser beam. The simplicity and the ease of fabrication of this type of polymer matrix make itself a promising sample holding arrangement for light scattering studies. After successful determination of the scattering properties of bentonite clay particles at 543.5 nm incident wavelength, the setup will be used for further measurements at 594.5 nm and 632.8 nm incident laser wavelengths.

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