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Scattering by interstellar graphite dust analog

Gazi A. Ahmed [a,*], Ankur Gogoi [b]

[a] Department of Physics, Tezpur University, Tezpur 784028, Assam, India
[b] Department of Physics, Jagannath Barooah College, Jorhat 785001, Assam, India

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ABSTRACT

The analysis of optical scattering data of interstellar carbonaceous graphite dust analog at 543.5 nm, 594.5 nm and 632.8 nm laser wavelengths by using an original laboratory light scattering setup is presented. The setup primarily consisted of a laser source, optical units, aerosol sprayer, data acquisition system and associated instrumentation. The instrument measured scattered light signals from 10° to 170° in steps of 1°. The results of the measurements of the volume scattering function $\beta(\theta)$ and degree of linear polarization $P(\theta)$ of the carbonaceous graphite dust particles that were sprayed in front of the laser beam by using an aerosol sprayer were subsequently compared with theoretically generated Mie plots with estimated parameters.

1. Introduction

The light scattering patterns of small particulate matter contains characteristic information about their physical and optical properties. These particles are normally found as aerosols, suspended particles in solutions (hydrosols) or as embedded particles, especially nanoparticles in optically transparent media. The intensity of light scattered by a particle (or ensemble of particles) is a function of the angle between the incident and scattered radiation. This angular dependence is also a function of size (and dispersion of sizes) of particles, shape (and dispersion of shapes) of particles, optical properties of particles (refractive index, permittivity, absorption), particle orientation, wavelength of the incident light, polarization of the incident light, density, structure of aggregates (fluffy, fractal, dense, etc.), and quality of particle surfaces (roughness, buffing, etc.) [1–5]. These results contain information by which the particle may often be classified or even identified [6] and helps for better understanding of radiation transfer through a medium containing the scatterer. Different types of dust particles, with different shapes, composition and size dispersions, are present everywhere in the solar system, interstellar dust clouds, intergalactic dust clouds, circum-planetary dust rings, cometary comae and tail, asteroidal atmospheres and aerosols of other planetary atmospheres. Knowledge of the absorption and scattering properties of interstellar dust particles is essential for deducing physical properties of the constituent particles, which in turn is essential for understanding earlier events like formation of comets, planets, planetary systems, etc. In-situ investigation on the composition of the cometary dust particles, conducted by the Cometary and Interstellar Dust Analyzer (CIDA) onboard the NASA spacecraft STARDUST, provided evidence that interstellar dust is a mixture of irregularly shaped silicate and carbonaceous materials that are also highly porous in nature (fluffy) [7,8]. These particles act as a heterogeneous media to scatter solar or stellar light which is unpolarized in nature. The volume scattering function (VSF), that is $\beta(\theta)$, and degree of linear polarization (DLP), that is $P(\theta)$, is measured to estimate parameters like size, porosity and roughness of the dust particles. In this context experimental laboratory research on the properties of terrestrial interstellar dust analogs are of great astronomical importance as their properties are found

* Corresponding author. Tel.: +91 943 501 4377; fax: +91 371 226 7006.
E-mail addresses: gazi@tezu.ernet.in, gaziaahmed@yahoo.com (G.A. Ahmed).

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to be similar to the properties of planetary regolith, cometary dust etc. [9,10]. The interstellar extinction curve was found to fit very well with the dust grains comprising silicate and graphite spheres with power law grain size distribution [11–14].

A number of experiments have been performed in the recent past to measure the light scattering properties of irregular mineral dust particles having astrophysical importance. A sophisticated and fully computerized setup was built successfully to investigate laser light scattering from particulate matter in the 1980s and subsequently improved and extended by P. Stammes, F. Kuik, H. Volten, J.W. Hovenier and Olga Muñoz at the Department of Physics and Astronomy, Free University, Amsterdam [4,9,20]. Recently an improved version of this experimental setup has been constructed at the Instituto de Astrofísica de Andalucía (IAA) in Granada, Spain [30], to measure the scattering matrices of dust particles having astrophysical importance. Another instrument for scattering measurements, with a unique way of particle levitation technique, that is, using microgravity obtained during parabolic flights to produce the actual environment experienced by the dust particles in space [27,31], is used in the Propriétés Optiques des Grains Astronomiques et Atmosphériques (PROGRA2) or Optical Properties of Astronomical and Atmospheric Grains project which is mainly dedicated for polarization measurements of dust particles. Notably, to explain such experimentally observed light scattering patterns, various theoretical approaches which involve computational techniques have been developed. Some of these techniques are the Mie theory, Waterman′s T-matrix method, finite difference time domain (FDTD) method, discrete dipole approximation (DDA) etc. [4,5]. Despite the availability of such advanced numerical techniques, the results of laboratory and in situ experiments still do not agree with the theories exactly. This is because of limitations of these numerical methods to model the light scattering properties of natural particles having too complicated structures with sufficient accuracy as well as due to inaccuracies in the instruments used in the experiments.

As far as the optical constants are concerned, the materials with astrophysical importance can be broadly divided into two broad classes: non-absorbing particles and absorbing particles with a large value of real and imaginary part of the refractive index [27,29]. In this work, graphite was chosen as the scattering sample to simulate the real absorbing astrophysical dust particles. The results of the laboratory measurements of the VSF and DLP of graphite particles as a function of scattering angle at 543.5 nm, 594.5 nm and 632.8 nm He–Ne laser wavelengths are presented in this paper. The measurements were taken in differential mode to ensure that the scattering results are independent of the background noise. A comparison of the experimental results with the theoretical Mie calculations was also conducted to interpret the experimentally observed light scattering patterns.

2. Experimental technique

2.1. Light scattering setup

The laboratory light scattering setup [15–18] is shown schematically in Fig. 1. It primarily consists of a laser source, photo-detectors, data acquisition system and associated instrumentation. The sample, which in this case is carbonaceous interstellar dust analog, is introduced in front of the beam at position S in Fig. 1 by using controlled dust particle spraying arrangement. Light beam from the laser source passes through a 50:50 beam splitter for sending the reflected part of the beam to a reference detector, while the transmitted beam gets scattered at the scattering center S. The scattered intensity as a function of scattering angle was measured from 10° to 170° by using a radial photodetector array of 16 static silicon PIN photodetectors, mounted on a circular disc and connected to a high gain, low noise amplifier circuit. The angular separation of the detectors was 10° and the array could be rotated in steps of 1° about an axis passing through the center and perpendicular to the plane of the circular disc. The amplified signals were collected, digitized and stored by using a dedicated data acquisition system for further analysis. The data from the measurements were processed by a data reduction procedure and then plotted. The reliability of the measurements was ensured by taking 100 readings per angle. The whole set-up was covered by a black polished metallic enclosure to cutoff electromagnetic noise and to minimize the intensity of stray reflections.

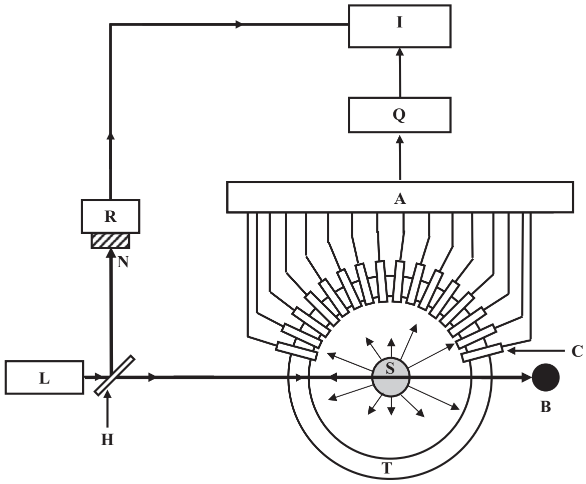

Fig. 1. Light scattering setup. L-laser source; H-beam splitter; N-neutral density filter; R-reference detector; C-detector coupled with changeable analyzer; S-sample; T-rotatable circular disc; B-beam stopper; A-amplifier; Q-data acquisition system; I-computer.

2.2. Measurements

The basic parameters measured in this work were the variations of light intensity due to scattering at different scattering angles and which, after being converted to electrical signals, were obtained in units of voltage. The data analysis gave the (i) volume scattering function, $\beta(\theta)$ and (ii) degree of linear polarization, $P(\theta)$. The sample density was controlled so as to have measurements in a single scattering regime on randomly oriented multiparticle systems. The scattering matrix elements also depend on the azimuth angle ϕ when the particles are aligned in a particular orientation as shown in Fig. 2(a). But for randomly oriented axially symmetric particles as