DYNAMIC LIGHT SCATTERING AS A PROBE OF NANOSIZED ENTITIES: APPLICATIONS IN MATERIALS AND LIFE SCIENCES

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Abstract. The ability of dynamic light scattering (DLS) to probe dynamics in non-crystalline media and to provide by virtue of this rather accurate estimations of dimensions of nanosized entities is discussed in this contribution. Selected applications of DLS in materials science (supercooled liquids) and life sciences (use of DLS as a diagnostic tool for early cataract detection in the ocular lens) are briefly discussed.

Keywords: dynamic light scattering; supercooled liquids; diagnosis of cataract

1. Introductory Remarks: Structure vs. Dynamics

A great body of experimental work in materials and life science is driven nowadays by the imperative need to characterize fast and accurately nanosized entities. Electron microscopies offer a convenient way to directly visualize the size and morphology of objects in immobile environments at the nanoscale. However, several important aspects in physics, materials and life sciences occur in liquid-like environments where the mobility of particles is important. In most cases an in situ study of the properties of such systems is desirable because “drying” procedures to isolate the nanoscale objects onto a substrate usually alter their morphological properties. A powerful method that can be used to determine non-invasively particle sizes in mobile environments is dynamic light scattering.

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By definition, DLS can provide information on the dynamics of a medium. This has to be contrasted to structure-probing techniques dealing with static properties. In solids, atoms are situated at rather fixed positions executing small periodic oscillations around their equilibrium positions. Structural probes such as Raman scattering, X-ray and neutron diffraction, etc. can furnish information on static (time independent) parameters such as bond lengths, bond angles, force constants, short range order (i.e. local bonding geometry), etc. On the contrary, in liquids atoms undergo diffusive motion in combination with periodic oscillations around their equilibrium positions. In this case time is important and dynamical properties must be determined.

To understand dynamics in liquids one has to introduce the concept of fluctuations. When an external perturbation is applied to a fluid, the disturbance will be damped by so-called relaxation processes in the medium. In a macroscopic description, dissipation phenomena include diffusion, viscous flow and thermal conduction. However, even in the absence of an external perturbation, spontaneous microscopic fluctuations always occur in the medium at any finite temperature above absolute zero. These fluctuations are dissipated by the same mechanism as those induced by external perturbations. The determination of the time scale of these fluctuations is important for understanding the dynamics of a fluid.\(^1\) The theory of Fluctuation was devised mainly by Einstein and Smoluchowski almost a 100 years ago.\(^1,2\) It was suggested that thermal fluctuations are an infinite Fourier series with a distribution of wavevectors (\(q\)) and frequencies (\(\omega\)) propagating along all directions in the medium. These fluctuations induce local inhomogeneities in the local density or equivalently in the refractive index of the medium. Light is scattered by these local inhomogeneities or density fluctuations.

2. Dynamic Light Scattering: Particle Sizing Issues

DLS (or equivalently Photon Correlation Spectroscopy or Quasi-Elastic Scattering) is a technique used to measure dynamics in liquids over a broad time scale spanning almost 10 decades in time, i.e. \(10^{-7}\) to \(10^3\) s. In the simple case of illuminating a particle suspension using laser light (i.e. monochromatic and coherent), light is scattered to all directions (Rayleigh scattering) if the particles are small enough compared to the light wavelength (\(\lambda \approx 500\) nm in the visible spectrum). The light scattered by the surrounding particles undergoes either constructive or destructive interference giving rise to the speckle pattern shown in Figure 1. This is due to the fluctuations occurring in the fluid medium as a result of the Brownian motion executed by the suspended particles. The scattered intensity measured by a detector placed