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Determination of Optical Properties of a Turbid Medium using Fiber Optic Transmission Experiment

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A new method is described for estimation of the intrinsic optical properties *viz.*, the scattering coefficient, the absorption coefficient and the anisotropy factor of a turbid medium. Two different experimental set ups for measuring the collimated- and the diffused transmission light have been developed. At the green He-Ne laser wavelength of 543 nm, the anisotropy factor for milk was observed to be 0.91 ± 2%, which compares well with the reported values in literature.

Key Words: Scattering coefficient, Absorption coefficient Anisotropy factor, Monte Carlo simulation.

INTRODUCTION

A lot of research efforts are focused on the study of light propagation in biological tissues for biomedical diagnostics and therapeutic use. Other applications, like estimation of concentration of fluorophores in a given turbid medium, also require accurate measurements of the optical properties characterized through the total interaction coefficient μ_t, the anisotropy factor (g) and the albedo (b). In the case of biological tissues, estimation of the optical properties is generally made using the Integrating-sphere technique[1], spatially resolved[2] and time resolved[3] methods. In this paper, a novel and a simple method is presented to determine the above optical properties for light propagation in a given turbid (liquid) medium.

Parameter defination

Light propagation in a turbid medium can be characterized by radiative transport theory[4,5] with three optical properties – absorption coefficient, scattering coefficient and the phase function. The absorption (scattering) coefficient is defined as the probability of photon absorption (scattering) per unit infinitesimal path length. The sum of the absorption coefficient (μ_a) and the scattering coefficient (μ_s) is termed as the total interaction coefficient μ_t. The mean free path of the photon is given by $1/\mu_t$. Also a term albedo (b) is introduced which is defined as the fraction of light getting scattered and is expressed as μ_s/μ_t. The phase function, p(s,s′) describes the fraction of light scattered from the direction s into the direction s′. It is characterized by a parameter g, which is usually referred to as the anisotropy factor and defined through[4]

$$g = \int_{4\pi} p(\mathbf{s},\mathbf{s}')(\mathbf{s}.\mathbf{s}')d\omega'$$

The anisotropy factor varies between isotropic scattering ($g = 0$) and complete forward scattering ($g = 1$). For light propagation through turbid medium, we have used the Henyey-Greenstein phase function[6] for obtaining the distribution of the scattering angle θ.

EXPERIMENTAL

Two different experimental setups were arranged to determine the optical properties of a turbid medium. The first setup shown in Fig. 1,

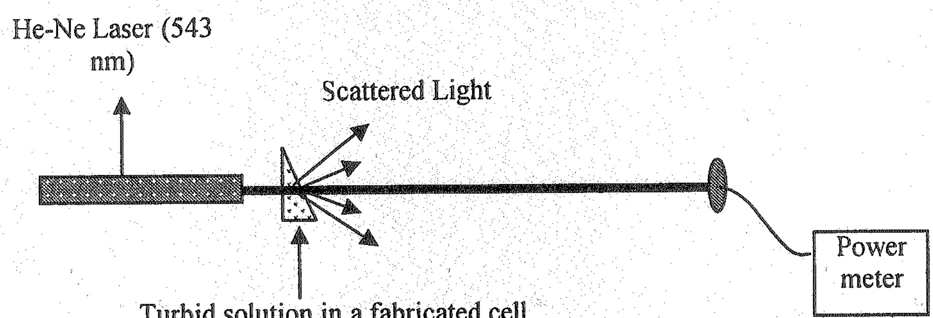

Fig. 1: Set-up for collimated transmission experiment

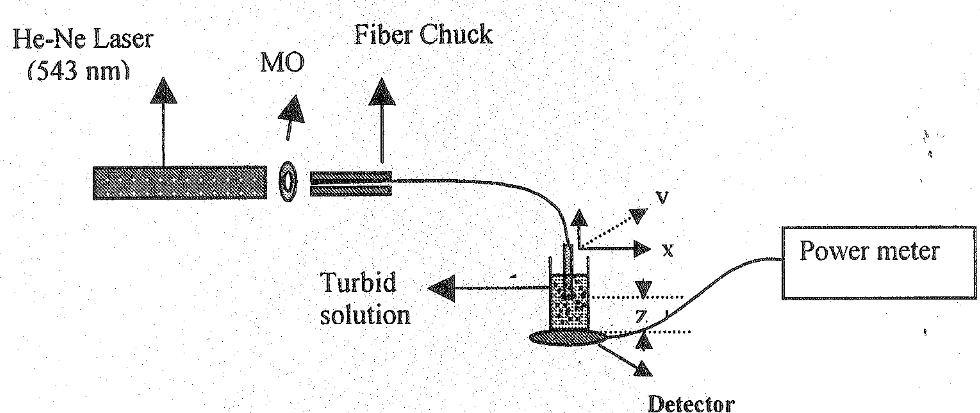

Fig. 2. Set-up for diffused-transmission experiment

involved the determination of μ_t by measuring the collimated-transmission power. The measured power was normalized with respect to a reference liquid, usually water or the solvent in which the turbid solution was prepared. The experiment was performed for different sample lengths by moving the cell across the laser beam and the average value of μ_t was calculated.

A second experimental setup shown in Fig. 2 was designed to collect the light due to diffused-transmission through a certain distance z inside the liquid. The turbid medium was placed in a cylindrical glass cell with a flat glass bottom. The detector was placed right below the cell to collect the transmitted power for different values of z (Fig.2). Optical alignment and positioning of the fiber tip with the detector was achieved through X-Y translation.

Monte Carlo simulation

Monte Carlo simulation tools has been used to determine the optical properties by matching the experimental and the simulation results for diffused transmission. The parameter μ_t, determined from the collimated transmission experiment, was used as an input to the simulation model. The remaining two parameters *viz.*, b and g are obtained by parametric optimization of the simulation results using a novel approach that is discussed in the following section.

The recipe for the Monte Carlo model involves the approach described by Wang *et al.*[6]. The termination conditions incorporated in our simulation are: a) either the photon packet is collected within the circular aperture of radius R (corresponding to the active area of the detector) at a distance z from the fiber tip, or b) the packet leaves a certain field of view that is defined by computational domain, or c) the weight of the photon packet becomes negligible.

RESULTS AND DISCUSSION

The diffused-transmission power collected by the detector is measured for three different values of z, and is normalized with respect to the corresponding power when the turbid liquid was replaced by the

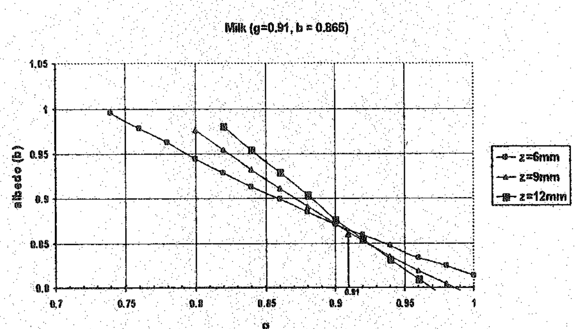

Fig. 3: Plot of (g,b) for different values of z (6, 9 and 12 mm)

reference sample (*i.e.* DI water or the solvent with which the turbid medium was prepared). Using the Monte Carlo simulation, we determine the corresponding power collected within the aperture of radius R. For each value of z, the experimentally measured normalized power is matched with the simulation result for several possible combinations of b and *g*. Fig. 3 shows the three curves, corresponding to three different values of *z*, representing the possible combinations (*g*, b). For a given turbid medium, since the optical properties are constant and are independent of the choice of *z*, the common point of intersection yields us the values of b and *g* for that liquid (Fig. 3).

Experiments were performed on milk (1 mL milk in 40 mL water) and the results were compared with the simulation. The possible pairs of (*g*, b) for each *z* are identified and plotted in Fig. 3. The curves intersect at a common point with $g = 0.93$, $b = 0.87$. The results for *g* were verified with those reported by Yaroslavsky *et al.*[7], which validates our method. The experiment was performed for different concentrations of the turbid medium and the accuracy in the measurement of the anisotropy factor was estimated to be ± 2%. The accuracy is limited by possible misalignments in the experimental setup.

Conclusion

We have presented a simple and novel method to determine the optical properties b and *g* of a turbid solution. One of the advantages of this method is that the model can be used to calculate the effective anisotropy coefficient *g* of a turbid medium containing more than one kind of scattering particles. This effective value of *g* can then be used to study the light propagation in the given medium.

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