Optical properties of turbid colloids

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Light refraction is used to characterize complex systems

A rigorous theoretical framework for the propagation of light in turbid colloids assures that the use of light refraction is probably the safest way to determine its “effective” index of refraction.

Blood, milk, paint or clouds, all these systems may be called colloids. What they have in common is that they consist of a dispersed phase (colloidal inclusions) embedded in a continuous one. For example, milk is made of micelles and saturated-fat globules dispersed in water while clouds are made of small water droplets dispersed in air. If the colloidal inclusions are big enough, when light goes through these systems it gets scattered in all different directions and this scattered light is what gives the turbid appearance. Milk looks like a white opaque liquid.

Besides the light scattered in all different directions, also called the diffuse field, there is a beam that follows the direction of the incident beam, and is usually called the coherent beam. This beam decreases in intensity as light goes through the colloid, either because it gets absorbed or because the scattering process transforms it into the diffuse field. If the sample is thick enough the coherent beam will eventually disappear and all the light will be diffuse. For a long time, there have been efforts to describe properly the behavior of the diffuse field, although it is a difficult task several theoretical frameworks have been developed.

On the contrary the behavior of the coherent beam looks simpler because, for example, when light coming from air gets into a colloid with a flat interface, the coherent beam gets refracted and reflected as if the colloid could be described with an “effective” index of refraction. So it is tempting to look for what is called: an effective-medium approach, which could regard the highly inhomogeneous colloidal system as if it were a fictitious homogeneous medium with “effective” optical parameters.

Also one could use the results of these effective-medium theories to interpret measurements of refraction and reflection of the coherent beam at different frequencies (coherent beam spectroscopy) in order to obtain information about the size, shape and composition of the colloidal inclusions. This has been done already, and has turned out to be very useful in the case of non-turbid colloids, where the scattering is negligible and where the effective-medium approach is well established. But the extension of a concept like the “effective” index of refraction to turbid colloids is not straightforward.

Recently we have proved that it is actually possible to define an “effective” medium in turbid colloids but we have also shown that it turns out to be non-local. This means, for example, that the average of the induced current density
at point $\vec{r}$ is not proportional to the average of the electric field at $\vec{r}$ but it depends also on the integrated value of the electric field in the neighborhood of $\vec{r}$ (non-local Ohm’s law). This result is important because it implies that the usual treatment for the calculation of the reflection amplitudes from a plane interface (Fresnel’s relations) is no longer valid. Also a valid general treatment for the calculations of these amplitudes, within an effective medium approach, has not been developed yet, essentially because the result depends not only on the “effective” index of refraction but also on the specific structure of the interface.

We propose that a safe way to go around this difficulty is to use refraction instead of reflection. Light refraction is less demanding and it requires the determination of only the direction of the refracted beam and its relative intensity. We have proposed that it is possible to use these two measurements for the determination of the size and the index of refraction of non-absorbing colloidal particles within a turbid colloid\textsuperscript{4}. Actually, we are now extending earlier refraction measurements\textsuperscript{5} using a hollow prism (see Fig. 1) to develop a coherent-beam spectroscopy based only on light refraction, for the more general case of absorbing colloids.

![Figure 1. Schematic view of the experimental set up for the measurement of the angle of refraction of the coherent beam in turbid colloids using a hollow prism.](image)

Since photonic crystals and metamaterials could be regarded as “ordered colloids” some of our conclusions on turbid colloids might also be applied to the determination of their effective optical properties when the size of the unit cell is not so small and scattering is present.
References