Guide to Selecting Refractive Index

Refractive index is a physical property of a material that can have a significant effect on light scattering particle size measurements. As such it is important to have an understanding of what refractive index is and how to make the correct selection for the material to be analyzed.

Introduction

Refractive Index is defined by two components - real and imaginary:
RI = n – *i*k, where:
n = the real component, which is the ratio of the velocity of light in a vacuum to the velocity of light in the material
k = the extinction coefficient of the material
$i = \sqrt{-1}$

The real component can be determined from published tables or it can be measured using Snell's Law:
n sin θ = n′ θ sin ′, where:
n = refractive index (RI) of first substance (usually air)
θ = angle of incidence
n′ = refractive index of second substance (usually measured substance)
θ′ = angle of refraction (deviation from original direction

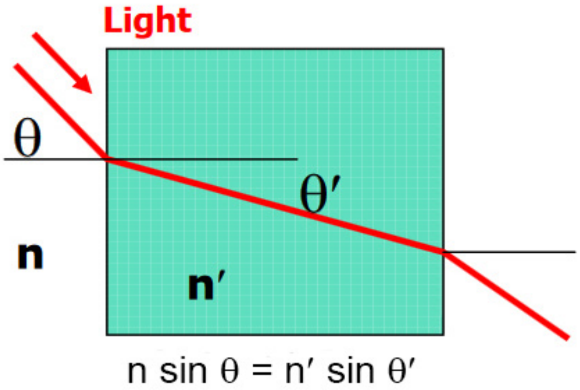

Figure 1. Refraction

The imaginary component (k) of the refractive index is the extinction of the material, defined as the reduction of transmission of optical radiation caused by absorption and scattering of light $k = (\lambda/4\pi)\,\alpha$, where:

k = the extinction coefficient
α = the absorption coefficient
λ = the wavelength of light used

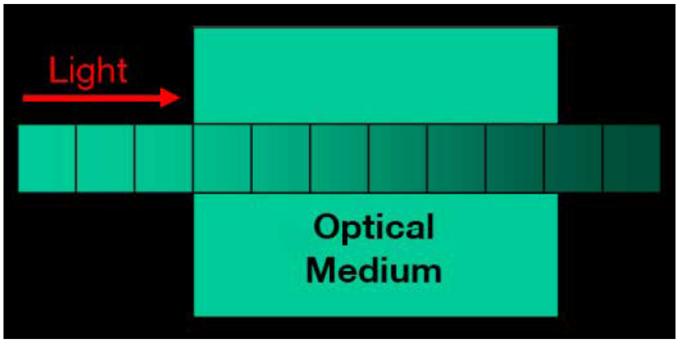

Figure 2. Absorption

The absorption coefficient (α) is the reciprocal of the distance light will penetrate the surface and be attenuated to 1/e of its original intensity, about 37%. Opaque materials will have a higher absorption coefficient than transparent materials.

The effects of refractive index (RI) selection on reported particle size results are most pronounced when particles are spherical, particles are transparent, when the RI of the particle is close to the RI of the fluid, or when the particle size is close to the wavelength of the incident light.

If particle characteristics deviate from any or all of these conditions, the refractive index value selected will have a smaller effect on the calculated particle size results.

Calculating Relative Refractive Index

The calculation of relative refractive index is included to help users transition from older to more modern instruments. Modern HORIBA instruments do not require Relative Refractive Index. Users enter the refractive index of the medium (typically air or water) and the refractive index of the particle. This is simply the refractive index of the particle divided by the refractive index of the dispersion medium. If n = 1.33 (water) and n' = 1.60 (particle), then the relative refractive index is 1.60/1.33 = 1.203.

If the particles are totally transparent, then k = 0 and the selected kernel function would be 120-000. However, if the particles are somewhat opaque, then k > 0 and the selected kernel function would be 120-010.

If the sample is being analyzed dry, then the relative index is as follows: If n = 1.0 (air) and n' = 1.60 (particle), then the relative refractive index is 1.60/1.0 = 1.60. The selected kernel function would 160-000 or 160-020 depending on the degree of transparency of the particles.

Practical Approach To Selecting The Refractive Index (RI) Values

There are scores of RI values stored in the LA-series programs. Values can be obtained from reference texts. In some cases, a single material may have several values of index of refraction depending upon its crystal structure. Alumina exists in alpha (a), beta (b), and gamma (g) crystalline forms. If the type is not known, use the average - the values usually are similar.

The most difficult decision to be faced in selecting a refractive index value is that in which a mixture of materials is involved, each with a different RI value.

If the particles are all roughly the same size, use a weighted average of the different RI values. If there is one component that is smaller in size, then it will be more sensitive to changes in refractive index. It would be more important to use the correct value for this smaller component. In any case,any potential errors from differing refractive index materials should cancel each other out.

There are situations in which a value for refractive index is not known and is not readily available. Remembering that RI compensation is much less important for non-spherical particles, the best approach is to use a default value. Choose a relatively large number such as 1.8 for the real index.

In the case of truly spherical particles, it is important to determine an accepted value for RI unless the particles are very large. Large particles fall into the realm of Fraunhofer Diffraction and are affected less by refractive index.

Important Variables to Consider

Opaque particles
If material is absorbing, it does not transmit light—such as a metal powder, carbon black, coke, coal or other similar material. If it is not transparent, a high imaginary component should be inserted.

Non-spherical particles
If the particles are not perfectly spherical, index correction is generally not critical. Very few industrial materials are truly spherical. Even latex particles made on earth are not absolutely spherical, but may be sufficiently so as to be considered spherical for index correction purposes. Unless an estimated 80% or greater amount of the sample is spherical, the sample should be considered non-spherical.

Very large particles
Measurement of particles that are larger than several microns is influenced very little by the refractive index of the material. Particles that are very large compared to wavelength of light can be measured using Fraunhofer Diffraction which is the deflection of light at an edge. High, default real index and large imaginary component should be selected.

Imaginary value
The imaginary component is the Extinction Coefficient (k), which is a direct function of the absorption coefficient (α). If the particles are completely transparent, the value approaches zero (0). If they are opaque, the value can be very large. Corrections for the imaginary component are less critical for very large values of k.

Effect on results
Higher refractive index gives a higher angle of scatter for the same particle size. Changing to a higher refractive index for the same sample material would yield results showing an increased size; the instrument is getting a higher angle of scatter than it expects for that size of particle.

Changing the imaginary component should not change the median size of the distribution significantly, but it will change the shape of the distribution. The main difference will be observed when changing between 0.00 (transparent, spherical) and any other value.

Using «chemistry» to estimate RI: Refractive index is the ratio of the velocity of light in a vacuum to the velocity of light in the material. This difference in speed is related to the interaction of the light wave with the electrons in the material. A material with a looser hold on its electrons will interact with the light wave more, giving a higher refractive index. This applies to electrons in a bond as well.

Examples
RI will increase as you proceed down or to the right in the periodic table. Use this to approximate RI from other known materials (SiO_2 - 1.46, GeO_2 - 1.65). In an organic molecule, the more functional groups, the higher the RI (Hexane 1.37, Bromohexane 1.45).