# What Is The Theoretical Maximum Concentration For DLS?

There are a number of issues that need to be considered when attempting dynamic light scattering measurements of concentrated samples, e.g. restricted diffusion effects, particle interactions, and multiple scattering. It is the latter (multiple scattering), that is used to define the "theoretical" maximum concentration for DLS measurements.

In dynamic light scattering experiments, single scattering is the desired experimental situation, where single scattering means that every photon which reaches the detector was scattered by only one particle. As the sample concentration is increased, the probability of the scattered photon being "re-scattered" by a second, third, .... particle increases. This phenomenon is defined as multiple scattering. The presence of multiple scattering during a DLS measurement will lead to error, and an apparent size that is smaller than the physical size of the particle being measured.

In the diffuse, highly concentrated limit, the photons can be considered to undergo a random walk through the sample. According to Pine and Weitz (chapter 16 in "Dynamic Light Scattering: The Method and Some Applications" ed. Wyn Brown, 1993), this diffusive limit of multiple scattering is governed by the photon mean free path ($l^*$). The mean free path is the distance which an average photon travels in a sample before encountering a scattering particle, i.e. it is the average distance between scattering events. Using Mie theory, it is possible to calculate the mean free path when the particle diameter, refractive index of particles and dispersant, laser wavelength, and sample concentration are known. For geometric reasons, the mean free path is inversely proportional to the sample volume fraction $\Phi$.

$$l^* \sim 1/\Phi$$

In a traditional 90 degree optical configuration (such as the Nano ZS90), the scattering volume lies in the center of the sample cuvette, often about 5 mm from the cuvette edge. In order to avoid multiple scattering then, the mean free path must be greater than 5 mm. When coupled with this requirement, the $l^*$ expression shown above can be used to calculate the theoretical maximum sample concentration for multiple scattering free DLS measurements. The same approach can be used to calculate the theoretical maximum concentration for the Zetasizer Nano ZS system, which utilizes the patented NIBS (Non-Invasive Back Scatter) optical configuration, with path length of < 1 mm.

Figure 1 shows the concentration dependence of the multiple scattering limit for dynamic light scattering measurements using the Zetasizer Nano ZS and Nano ZS90 systems. A particle refractive index value of 1.59, typical of polystyrene spheres, was used for the Mie scattering calculations. Notice the approximate V shape of the data. For small particles (left leg of V), the maximum concentration limits are a result of the point-like isotropic Rayleigh scattering, with the concentration limits following a $d^{-3}$ dependence. For larger particles (right leg of V), the limits are controlled by effects from anisotropic Mie scattering, with the upper concentration limit following roughly a $d^{2/3}$ dependence. The "wiggles" in the data, in the 0.2 to 1 um region, are a consequence of internal resonances, which are most significant when the particle size is close to the laser wavelength.

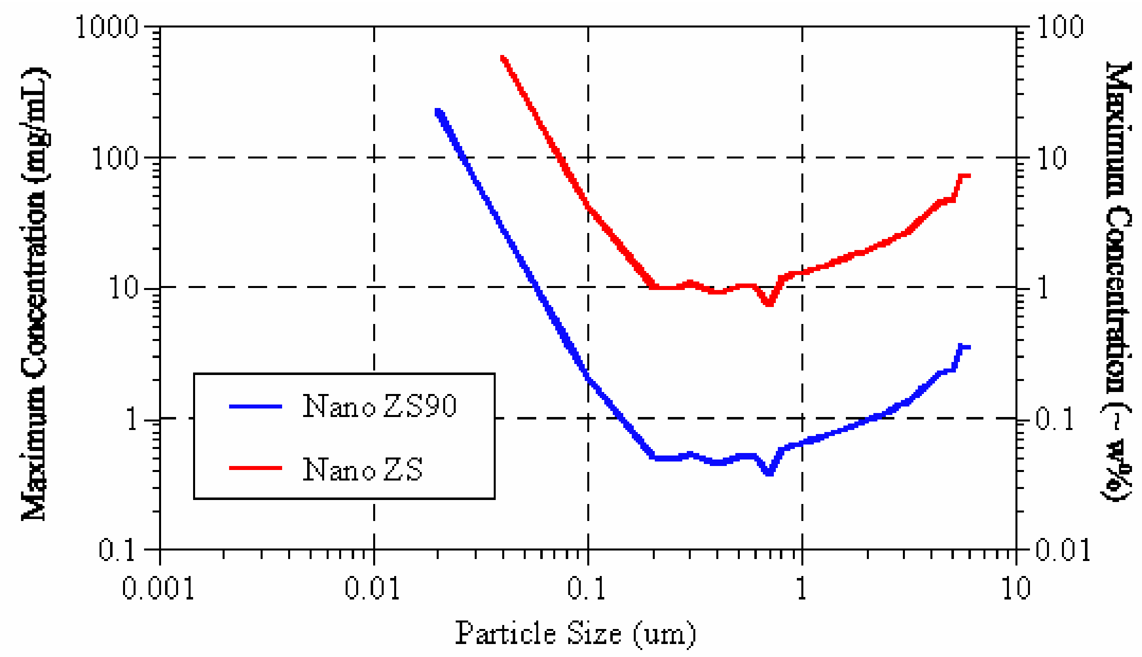


**Figure 1:** Concentration dependence of the multiple scattering limit for dynamic light scattering measurements using the Zetasizer Nano ZS and Nano ZS90 systems, using a particle refractive index value of 1.59.

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