BASIC PRINCIPLES OF DYNAMIC LIGHT SCATTERING

The Horiba LB-550 analyzer use the principle of dynamic light scattering to measure the size of particles in the range of .001 – 6 microns. Brownian Motion causes a Doppler Shift in the frequency of the incident light, which can be related to the size of the particles

Microscopic particles exhibit Brownian motion. While dispersed in a solvent, very small particles are pushed in random motion by the liquid molecules due to thermal motion. Smaller particles move faster and travel longer distances, while larger particles move slower and travel shorter distances. Higher temperatures or lower fluid viscosity will result in a higher frequency vibration.

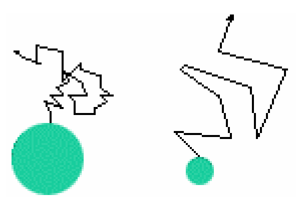

Figure 1. Comparison of Brownian motion

The rate of movement of a particle is closely related to the diffusion coefficient D, which is calculated by Stoke's and Einstein's equation: $D = kT / 3\pi\eta Dv$, which is determined by Boltzmann's constant k, solvent viscosity η, temperature T and particle diameter Dv.

When light strikes these moving or "vibrating" particles, the frequency of the light exhibits a Doppler shift. The frequency is shifted when reflected off a moving surface (of the particle). It increases when the particle is moving towards the incident light and decreases when the particle is moving away.

The resultant interference of scattered light beams from various particles produces interference waves or a "temporal wobble." These interference waves are measured by the detector of the LB-550.

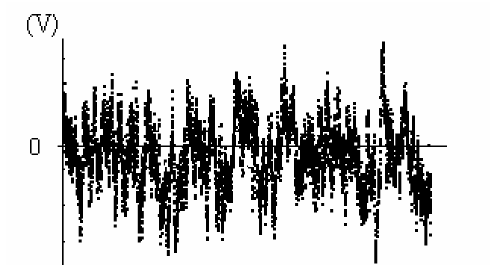

Fig. 2 Temporal wobble signal

Thus, the light intensity detected by the detector fluctuates over time. This shifted signal is Fourier-transformed to determine a frequency vs. intensity distribution (power spectrum), based upon which a particle size distribution can be calculated. Fourier transform is a mathematical operation that can determine the relative intensity of each frequency contained in the temporal wobble signal.

This power spectrum takes the form of a Lorentz distribution, whose half-value width can be expressed as $2Dq^2$.

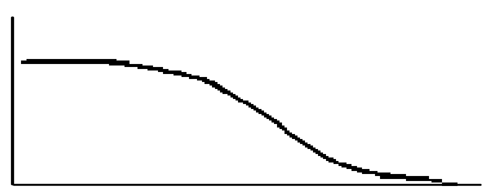

Fig. 3: Power spectrum

In the case of a monodisperse sample, this half-value width is known, so its particle size distribution can be determined.

Calculating Ideal Power Spectra
A series of frequency-intensity distributions for a wide range of particle sizes are prepared in advance. When the measured power spectrum is compared to the previously calculated power spectrums, the particle size distribution of the particles contained in the sample can be obtained.

The algorithm for calculating these ideal power spectrums is based on the principle in which f(a) is determined from any measured frequency/intensity distribution $S(\omega)$ by solving the following general Fredholm's integration of the first kind:

$S(\omega) = \int K(\omega,a) f(a)\, da$ (Eq. 1)

where ω is the angular frequency and a is the particle size. This solution (elucidation) must solve very difficult non-linear problems called inverse operations.

In order to accomplish this, the LB-550 employs a uniquely optimized iterative method for particle sizing. $K(\omega,a)$ is an intermediate function referred to as a response function, which is calculated as follows. Let k be the Boltzmann constant, T the absolute temperature, η the viscosity coefficient of the solvent, a the particle size, and D the diffusion coefficient. Then the diffusion coefficient D can be expressed from the Stokes-Einstein equation as follows:

$D = kT / (3\pi\eta a)$ (Eq. 2)

In addition, suppose that λ is the wavelength of a laser beam in the full vacuum, n is the refractive index of a solvent and α is the angle through which the laser beam is scattered. Then, the scatter vector K can be described as:

$K = 4\pi(n/\lambda)\cdot\sin(\alpha/2)$ (Eq. 3)

Since it has been proven that for any spherical particle, its power spectrum is in agreement with any distribution obtained using the Lorentzian function, the calculated power spectrum, $S_0(\omega)$, for each particle size is given by:

$S_0(\omega) = 2DK^2 / \{(2DK^2)^2+\omega^2\}$ (Eq. 4)

Determining the Size Distribution
The diameter of the particles is dependent on the half band width discussed above. For example, if the half band width of the measured frequency/intensity distribution (power spectrum) is identical to the half band width of that calculated for a 50nm particle, the diameter of the particle in the sample would also be 50nm.

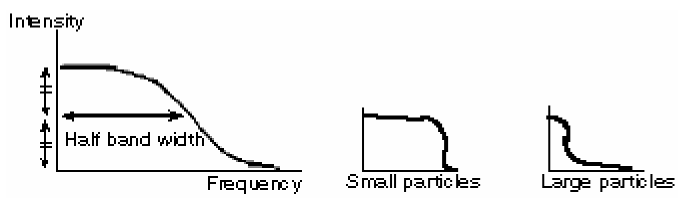

Figure 4: Power spectrum half band width vs. particle size

Basically, the algorithm searches in the previously prepared power spectrums for one that matches the measured spectrum of the sample. Of course, an exact match will not be found except in the case of monodisperse samples. Therefore a process of repeated searching is followed to find the closest possible combination of power spectrums that match the measured spectrum. This combination is then used to determine the particle size distribution.

More specifically, the group of calculated power spectrums, $S_0(\omega)$, for all particle sizes are employed to calculate the response function $K(\omega,a)$, which is required to characterize the particle size distribution f(a) by an iterative operation. Suppose that the particle size distribution $f_0(a)$ is an initial hypothetical distribution. For example, consider a particle size distribution which occurs for all particle sizes with the same frequency. Then, the difference between this and the observed power spectrum is determined, the hypothetical power spectrum is modified so as to decrease the difference, and the modified distribution is re-defined as $f_0(a)$.This loop is operated repeatedly.

When equation (1) is established, that is, the measured power spectrum coincides with the distribution determined from the hypothetical particle size distribution $f_0(a)$ using the response function, the particle size distribution operation is completed by regarding this $f_0(a)$ as the true particle size distribution.

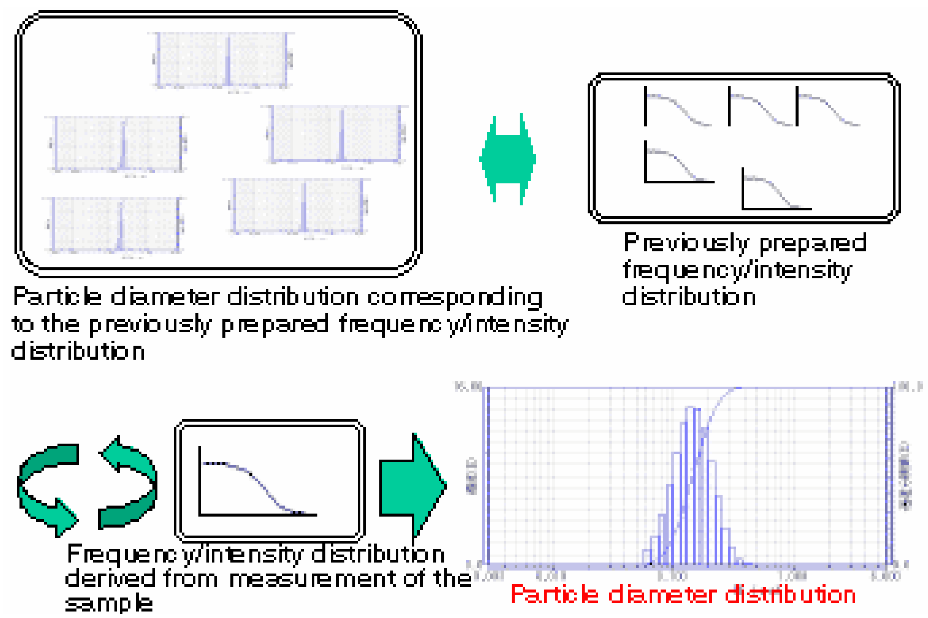

Fig. 5: Particle size distribution calculation

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