

Dynamic Light Scattering (DLS)

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Abstract: Dynamic Light Scattering (DLS) is a technique aiming to determine the size of particles using their diffusion coefficient. Experimentally, a laser beam enters a cuvette containing the analyzed sample, and the intensity of the scattered light is measured to determine the diffusion coefficient. In this experiment, polystyrene and silica beads of variable sizes will be used to investigate different regimes of the DLS.

Learning Objectives:

- Sample preparation
- Experimental implementation of a DLS measurement
- Data evaluation
- Investigation of the different DLS regimes
- Effect of interparticle interactions
- Theory: Physical principle of light scattering
- Theory: Brownian motion, intensity fluctuations, and correlation function
- Theory: self-diffusion coefficient vs. collective diffusion coefficient

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1 Theoretical Background

1.1 Static Light Scattering

1.1.1 Scattering of Single Gas Molecules in the Gas Phase

Light, as an electromagnetic wave, interacts with molecules by periodically shifting the electrons versus the nuclei and thereby inducing an oscillating electric dipole m (Hertz dipole), which serves as a source for secondary electromagnetic radiation of the same wavelength as the incident light (scattering). The amplitude (= electric field) of the scattered light in this case depends on the polarizability of the molecules α , whereas the oscillating electric field of the incident light is given as:

$$E(x, t) = E_0 \cos\left(\frac{2\pi x}{\lambda} - \frac{2\pi t}{\lambda/c}\right) \quad (1)$$

Here, $\omega = 2\pi\nu = 2\pi\frac{c}{\lambda}$ is the frequency of the incident light of wavelength λ , and $|\vec{k}| = \frac{2\pi}{\lambda}$ is the wave vector. Note that in Eq.1 for simplification we have assumed linearly polarized light spreading in x -direction. Figure 1 shows the corresponding scattered light which is spreading isotropic and perpendicular to the oscillation axis of the Hertz dipole.

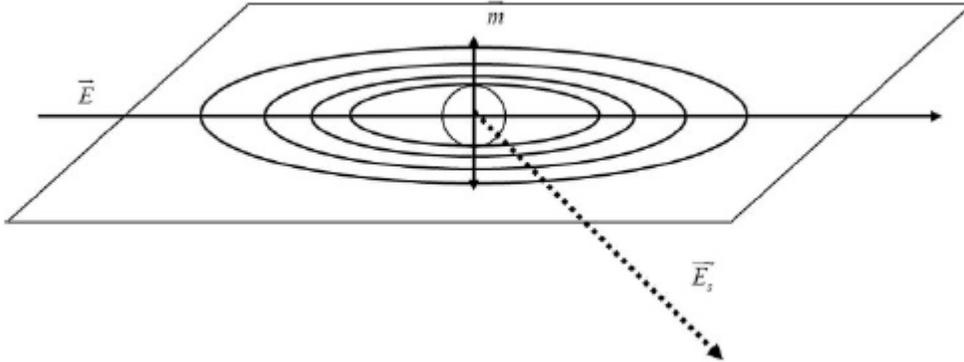


Figure 1: Isotropic spreading of light scattered by a single molecule.

The amplitude of the scattered light is given as:

$$E_s = \left(\frac{\partial^2 m}{\partial t^2}\right) \frac{1}{r_D c^2} = \frac{-4\pi^2 \nu^2 \alpha E_0}{r_D c^2} e^{i(2\pi\nu t - \vec{k} \cdot \vec{r}_D)} \quad (2)$$

Note that, according to the complex exponential function given in Eq.2, the scattered amplitude is both periodic in time and space. In a static light scattering experiment, not the amplitude (= electric field, see above), but the intensity of the scattered light is detected: $I_s = \vec{E}_s \vec{E}_s^* = |\vec{E}_s|^2$. The so-called Rayleigh scattering intensity of N molecules in the gas phase then is given as:

$$I = \frac{I_s}{I_0} = \frac{1}{r^2} \frac{16\pi^4}{\lambda^4} \alpha^2 N \quad (3)$$

with I_0 the intensity of the incident light, and r_D the distance between the scattering sample and the detector.

1.1.2 Scattering of small particles in solution

Pure solvents weakly scatter light due to thermal density fluctuations. For solutions, in contrast, the concentration fluctuations of the solute molecules are the main source of scattering. Therefore, the scattered light intensity is approximately given by these concentration fluctuations and the scattering contrast of an individual solute molecule, b :

$$I_s \propto b^2 kT \frac{c}{\left(\frac{d\pi}{dc}\right)_T} \quad (4)$$

In Eq.4, we have used that the concentration fluctuations are directly related to the thermal energy kT and the variation of the osmotic pressure with solute concentration $d\pi$ at given temperature, $\left(\frac{d\pi}{dc}\right)_T$.

According to van't Hoff, we find for ideally dilute solutions and for real solutions of finite concentrations, respectively:

$$\left(\frac{d\pi}{dc}\right)_T = \begin{cases} \frac{kT}{M} & \text{ideally dilute} \\ kT \cdot \left(\frac{1}{M} + 2A_2c + \dots\right) & \text{real (dilute but finite concentration)} \end{cases} \quad (5)$$

(M is the molar mass of solute molecules, A_2 the second virial coefficient of osmotic pressure).

We therefore get for ideal (= highly dilute) solutions of small molecules the following simple expression for the intensity of scattered light:

$$I_s \propto b^2 cM \quad (6)$$

In this case, the scattering contrast b^2 does not depend, as in case of molecules in the gas phase, on the absolute polarizability, but on the difference of the polarizabilities of solute and solvent molecules $\Delta\alpha$.

On the other hand, $\Delta\alpha$ depends on the respective dielectric constants ϵ (solute) and ϵ_0 (solvent), and therefore on the refractive indices, as:

$$\Delta\alpha = \alpha - \alpha_0 = \frac{\epsilon - \epsilon_0}{4\pi N/V} = \frac{n_D^2 - n_{D,0}^2}{4\pi N/V} \quad (7)$$

with n_D the refractive index of the solute, $n_{D,0}$ the refractive index of the solvent, and N/V the number of solute scattering particles within the illuminated and observed detection volume (= scattering volume).

To measure an absolute scattering intensity independent of the respective experimental setup (= sensitivity of the detector, size of the scattering volume, distance of the detector from the sample, etc.), we define the absolute scattering intensity or Rayleigh ratio as:

$$R = (I_s - I_{LM}) \cdot \frac{r_d^2}{V} = \frac{4\pi^2}{\lambda_0^4} \cdot n_{D,0}^2 \cdot \left(\frac{dn_D}{dc}\right) \cdot \frac{cM}{N_L} \quad (8)$$

with the so-called refractive index increment given as:

$$\left(\frac{dn_D}{dc}\right) \sim \frac{n_D - n_{D,0}}{c} \quad (9)$$

In experimental practice, one determines this Rayleigh ratio by calibration, typically using toluene as a scattering standard. In this case, first, the scattering intensity of the pure solvent I_{LM} is subtracted from the scattering intensity of the solution I_s , and then this difference is renormalized with the ratio of the absolute intensity of the standard $I_{std,abs}$ to the intensity measured for the standard I_{std} with a given setup:

$$R = (I_s - I_{LM}) \cdot \frac{I_{std,abs}}{I_{std}} \quad (10)$$

Comparing Eq. 6 and 8 yields for the scattering contrast (b_2 or K):

$$b^2 = \frac{4\pi^2}{\lambda_0^4 N_A} \cdot n_{D,0}^2 \cdot \left(\frac{dn_D}{dc} \right)^2 = K \quad (11)$$

Finally, in case of non-ideally dilute real solutions, interparticle interactions between solute and solvent molecules also have to be taken into account via the 2nd virial coefficient A_2 (see Eq.5), and we finally get for the Rayleigh ratio R in case of scattering particles of size $\gg 10$ nm in solution:

$$\frac{Kc}{R} = \frac{1}{M} + 2A_2c + \dots \quad (12)$$

1.1.3 Scattering of solutions of nanoparticles of size > 10 nm

For very small scattering particles or molecules of size < 10 nm, the secondary light waves emitted from all Hertz dipoles within one particle (= intraparticle) all show perfect constructive interference, and therefore the detected Rayleigh ratio is isotropic and not depending on the scattering angle. R in this case only depends on the number concentration of scattering particles N and on the number of Hertz dipoles Z (= scattering centers) within a single particle squared ($R \propto N \cdot Z^2$). On the other hand, Z should be proportional to the mass of a scattering particle m , and therefore we find:

$$R \propto N \cdot m^2 = nN_A \cdot \left(\frac{M}{N_A} \right)^2 = \frac{1}{N_A} \cdot c \cdot M \quad (13)$$

with N_A the Avogadro number, M the molar mass of the solute particles, n the molar concentration, and c the mass concentration. Note here that in Eq.11, we added the term $1/N_A$ to the contrast factor, and therefore got $R = K \cdot c \cdot M$.

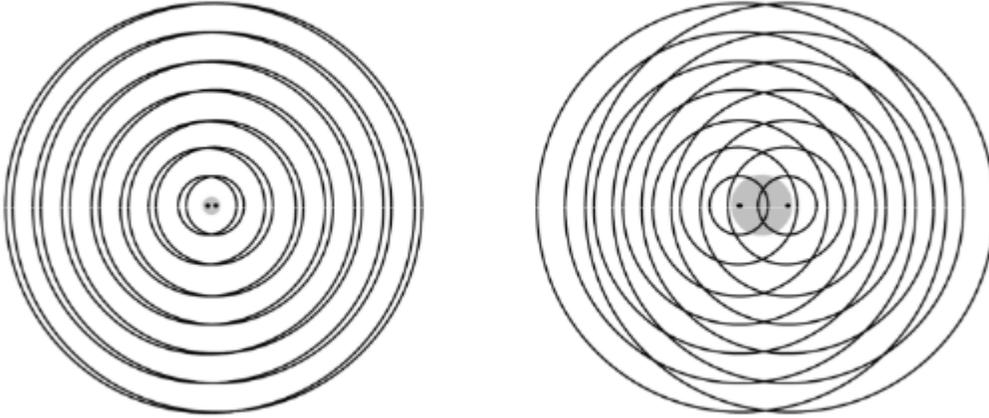


Figure 2: Intraparticle interference of secondary waves with point scatterers (left) and particles $\gg 10$ nm (right)

For solute scattering particles larger than 10 nm, on the other hand, the secondary light waves emitted from a single particle also may show partially destructive interference. Therefore, in this case, the Rayleigh ratio R is no longer isotropic but becomes dependent on the scattering angle. This important difference in the scattered intensity from small particles of size < 10 nm (also called point scatterers) and that from larger particles is also sketched in Figure 2.

As described, the absolute scattered intensity for particles larger than 10 nm depends on the scattering angle. Therefore, we introduce the so-called scattering vector \vec{q} , which defines the optical resolution and length scale of the light scattering experiment (see Figure 3).

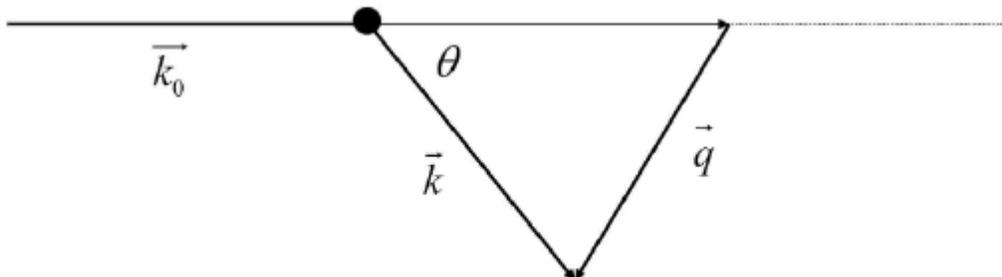


Figure 3: Geometric interpretation of the scattering vector \vec{q}

As seen in Figure 3, \vec{q} is given by the difference of the wave vectors of the detected scattered light and the incident light, i.e. $\vec{q} = \vec{k} - \vec{k}_0$. Since both wave vectors have the same magnitude $|\vec{k}| = |\vec{k}_0| = 2\pi n_D/\lambda$ (elastic scattering), the magnitude of the scattering vector is given as:

$$q = \frac{4\pi n_D \cdot \sin(\theta/2)}{\lambda} \quad (14)$$

θ is the scattering angle, λ is the wavelength of our light source, and n_D is the refractive index of the solvent. Therefore, λ/n_D is the wavelength within the sample. Practically speaking, the light scattering experiment resolves more details of the scattering particles at higher q values, since q directly corresponds to the reciprocal length scale of our experiment. This is illustrated for polymer coils in solution as an example in Figure 4 and Table 1:

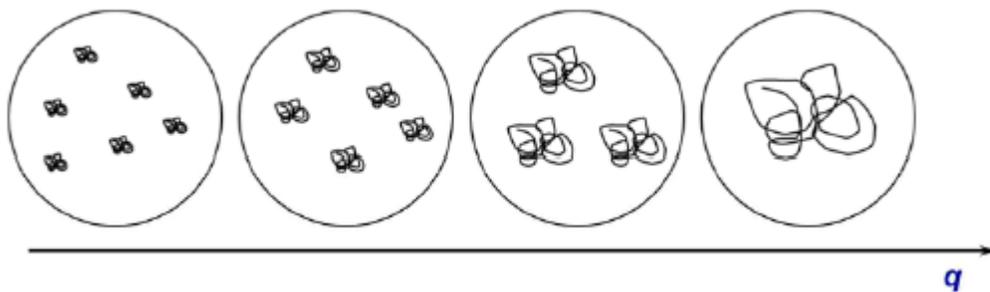


Figure 4: Scattering vector q as magnification factor (inverse length scale)

Range	Sample Resolution	Sample Characteristics	Data Evaluation
$qR \ll 1$	overall size	Mass, radius of gyration	Zimm plot
$qR < 1$	Particle shape	crude topology	
$qR \approx 1$	details of particle shape	elongation of anisotropic particles etc.	
$qR > 1$	inner structure of coil	chain structure (helix, coil, rod etc.)	
$qR \gg 1$	chain segments	conformation, tacticity	

Table 1: q -range and length scales (= sample characteristics) for polymer coils; here R is the radius of gyration of a polymer chain.

Adding up all possible interferences of light waves originating from a pair of scattering centers within a single solute particle, we obtain the q -dependence of the absolute scattered intensity:

$$R(q) = Nb^2 \cdot \left| \sum_{i=1}^Z \sum_{j=1}^Z e^{-i\vec{q} \cdot (\vec{r}_i - \vec{r}_j)} \right| = Nb^2 \cdot \left| \sum_{i=1}^Z \sum_{j=1}^Z e^{-i\vec{q} \cdot \vec{r}_{ij}} \right| \quad (15)$$

If we consider that the scattering particles are randomly oriented in space, we can replace the distance vectors $(\vec{r}_i - \vec{r}_j)$ with the absolute values r_{ij} (= spatial averaging). Also, we define the so-called particle form factor $P(q)$ as $R(q)$ normalized by particle number N number of scattering centers per particle Z^2 , and contrast factor b^2 . Spatial averaging and subsequent series expansion then lead to:

$$P(q) = \frac{1}{NZ^2b^2} R(q) = \frac{1}{Z^2} \sum_{i=1}^Z \sum_{j=1}^Z \frac{\sin(qr_{ij})}{qr_{ij}} = \frac{1}{Z^2} \sum_{i=1}^Z \sum_{j=1}^Z \left(1 - \frac{1}{6} q^2 r_{ij}^2 + \dots \right) \quad (16)$$

Finally, we can replace the Cartesian coordinates r_{ij} with coordinates based on the center of mass as the spatial center, and truncate the Taylor series expansion of $P(q)$ at the 2nd order term:

$$P(q) = 1 - \frac{1}{3} \cdot q^2 \cdot s^2, \quad (17)$$

with the radius of gyration s (or R_g) given as:

$$\frac{1}{Z^2} \sum_{i=1}^Z \sum_{j=1}^Z r_{ij}^2 = 2Z^2 s^2 \quad (18)$$

Note that for particles larger than 50 nm it is not allowed to truncate the Taylor series at the 2nd order term due to the comparably higher spatial resolution of the structure of the scattering particles in this case. For homogeneous spheres of radius R , for example, the particle form factor is given as:

$$P(q) = \frac{9}{(qR)^6} \cdot (\sin(qR) - qR \cdot \cos(qR))^2 \quad (19)$$

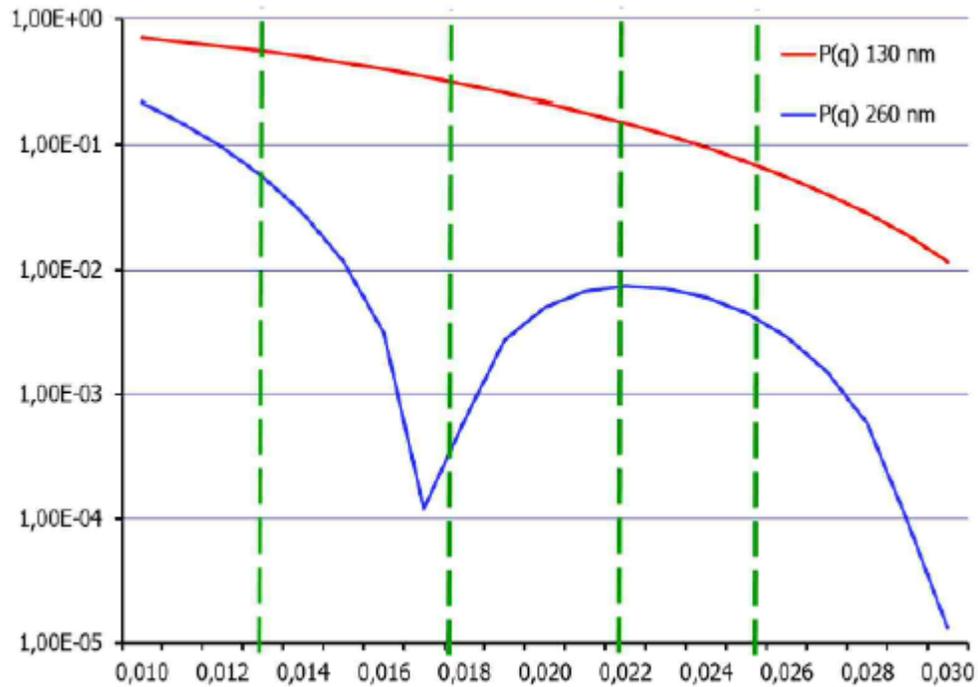


Figure 5: Particle shape factor $P(q)$ for 2 spheres of different sizes ($R = 130nm$ and $260nm$ respectively) versus q (in nm^{-1}) in logarithmic plot. Green lines = angles of 50° , 70° , 90° and 110°

1.2 Dynamic light scattering

Particles in solution undergo Brownian motion, causing in a light scattering experiment temporal fluctuations of the interparticle interferences, and therefore leading to a fluctuating scattered intensity $I(q, t)$, as sketched in Figure 6.

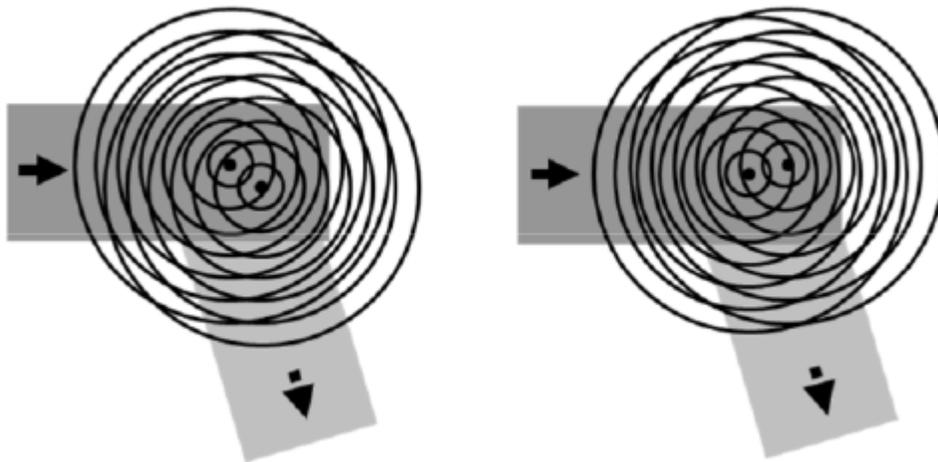


Figure 6: Sketch of temporal change of interparticle interferences and resulting changes in scattered intensity at given scattering angle.

In real space, the van-Hove-autocorrelation function describes the changes in particle position with time, whereas

the signal detected in dynamic light scattering is given by its Fourier transform:

$$G_s(\vec{r}, \tau) = \langle n(\vec{0}, t) \cdot n(\vec{r}, t + \tau) \rangle_{V,T} \Leftrightarrow F_s(\vec{q}, \tau) = \int G_s(\vec{r}, \vec{r}) \cdot e^{i\vec{q} \cdot \vec{r}} d\vec{r} \quad (20)$$

Here, the local particle number density $n(\vec{0}, t)$ or $n(\vec{r}, t + \tau)$ either assumes the value 0 or 1, depending if a particle is found at a certain time at a given position vector within the sample. \vec{r} is the distance vector between the two positions that are correlated in time. The Brownian motion of a single particle (= "random walk") can be described quantitatively by its mean squared displacement $\langle \Delta R(\tau)^2 \rangle$ and its self-diffusion coefficient D_s according to the Einstein-Smoluchowski- and the Stokes-Einstein- equation:

$$\langle \Delta R(\tau)^2 \rangle = 6D_s\tau \quad D_s = \frac{kT}{f} = \frac{kT}{6\pi\eta R_H} \quad (21)$$

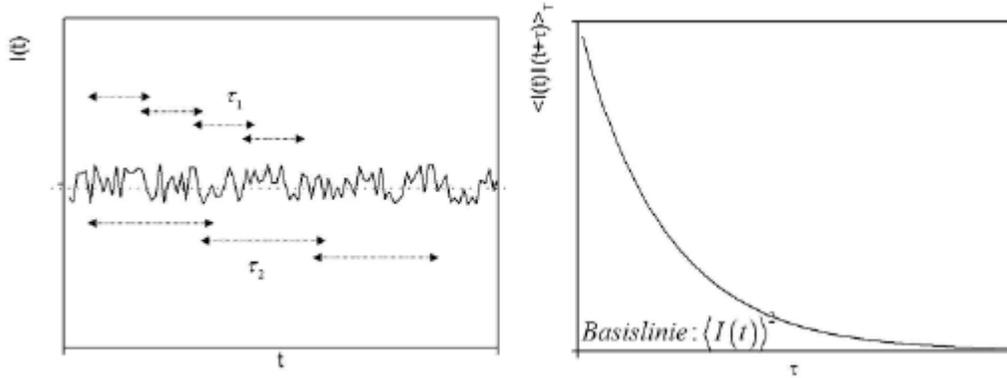


Figure 7: Principle of DLS - determination of the intensity autocorrelation function from the temporal fluctuations of the scattering intensity $I(t)$ by correlating (= pairwise multiplication).

D_s is given by the balance between thermal energy kT which drives the Brownian motion, and a friction coefficient f , which slows down the moving particles. f depends on the hydrodynamic particle radius R_H and on the solvent viscosity η . In a dynamic light scattering experiment, one determines the amplitude correlation function $F_s(q, \tau)$ from the measured time-dependent scattered intensity $I(q, t)$ and its time autocorrelations function $\langle I(q, t) \cdot I(q, t + \tau) \rangle$ as following:

Using the Siegert relation (Eq.22), the amplitude correlation can be calculated from the intensity correlation:

$$F_s(q, \tau) = e^{-D_s q^2 \tau} = \langle E_s(q, t) \cdot E_s^*(q, t + \tau) \rangle = \sqrt{\frac{\langle I(q, t) \cdot I(q, t + \tau) \rangle^2}{\langle I(q, t) \rangle^2}} - 1 \quad (22)$$

For samples with monodisperse solute particles at very low concentration, according to Eq.22 $\ln F_s(q, \tau)$ plotted versus correlation time τ corresponds to a straight line. From the slope, one determines the self-diffusion coefficient D_s , which then is used to calculate the hydrodynamic particle radius by the Stokes-Einstein eq. (Eq.21).

1.2.1 DLS data analysis for polydisperse samples

For polydisperse samples, $F_s(q, \tau)$ corresponds to a superposition of several exponentials:

$$F_s(q, \tau) = \frac{\sum_i n_i M_i^2 P_i(q) \cdot e^{-D_i q^2 \tau}}{\sum_i n_i M_i^2 P_i(q)} \quad (23)$$

Note that the amplitude of a given exponential in Eq.23 corresponds to $n_i M_i^2 P_i(q)$, which besides the missing contrast factor K_i is exactly the average absolute scattered intensity R_i of particles of species i . Here, the contrast factor cancels since the considered particles only differ in size but not in chemical composition, and therefore all species should have identical contrast factors $K_i = K$.

Applying a Taylor series expansion to Eq.23 we get the so-called cumulant expression for $\ln F_s(q, \tau)$:

$$\ln F_s(q, \tau) = -\kappa_1 \tau + \frac{1}{2!} \kappa_2 \tau^2 - \frac{1}{3!} \kappa_3 \tau^3 \quad (24)$$

The first cumulant $\kappa_1 = \langle D_s \rangle q^2$ directly yields the average self-diffusion coefficient $\langle D_s \rangle$ and therefore a corresponding average hydrodynamic radius. Note, however, that this average only is well-defined for particles of size ≤ 10 nm, whereas it becomes q -dependent for larger particles, as will be explained in more detail below. The 2nd cumulant κ_2 here provides a quantitative measure of sample polydispersity if the principle shape (e.g. Gaussian) of the size-distribution function is known.

Important: For samples of polydisperse particles which, on average, are larger than 10 nm in hydrodynamic radius, the diffusion coefficient depends on the scattering angle because of the q -dependent contributions of the particle form factors $P_i(q)$ to the amplitudes of the exponentials (see Eq.23). Therefore, this diffusion coefficient is also called apparent self-diffusion coefficient $D_{app}(q)$.

$$D_{app}(q) = \frac{\sum_i n_i M_i^2 P_i(q) \cdot D_i}{\sum_i n_i M_i^2 P_i(q)} = \langle D_s \rangle_z \cdot (1 + k_1 + \langle s^2 \rangle_z \cdot q^2) \quad (25)$$

The series expansion shown in Eq.25 explains how, by interpolation of $D_{app}(q)$ versus $q \rightarrow 0$, the z -average is obtained as the intercept. This is to be expected, since irrespective of particle size all particle form factors $P_i(q \rightarrow 0) = 1$!

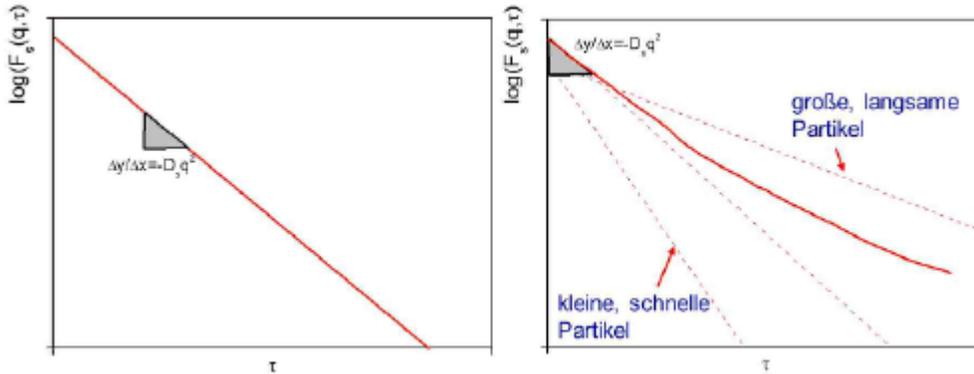


Figure 8: Log-lin representation of the normalized amplitude-decorrelation function for monodisperse (left) and polydisperse (right) samples.

According to the cumulant series expansion Eq.24, the apparent self-diffusion coefficient $D_{app}(q)$ is given by the initial slope of the curves shown in Figure 8. Again, please note that $D_{app}(q)$ has to be plotted versus q^2 and interpolated towards $q \rightarrow 0$ to obtain a meaningful z -average value $\langle D_s \rangle_z$, if the particles are larger than 10 nm (see figure 9). Here, it also should be noted that $D_{app}(q)$ only gives a straight line if the particles are smaller than

100 nm, since in this case the particle form factor can be approximated by a Taylor series expansion truncated after the 2nd term.

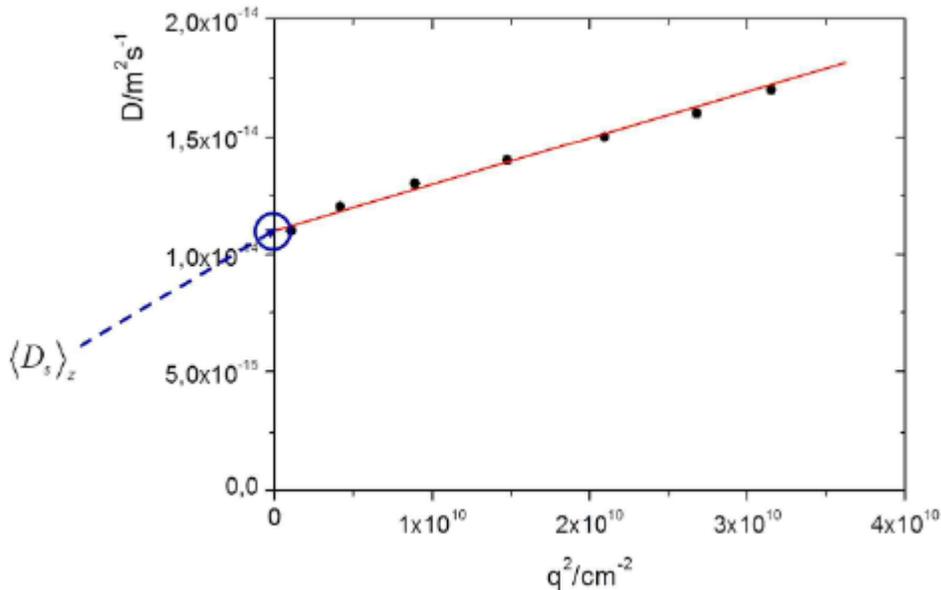


Figure 9: Determination of the z average of the diffusion coefficient by interpolation of D_{app} for $q \rightarrow 0$. This is only valid if $10 \text{ nm} < R < 100 \text{ nm}$!

1.2.2 DLS on concentrated samples

For concentrated samples, interparticle interactions of the scattering solute particles lead to the structural ordering of particle positions as well as to a correlation of particle diffusion. Consequently, the particle trajectories can no longer be described as an independent random walk of individual solute particles, and the self-diffusion coefficient has to be replaced by a so-called cooperative diffusion coefficient. The structural ordering leads to additional interferences, wherefore the normalized time-averaged scattered intensity due to interparticle interferences (= static structure factor $S(q)$) is no longer constant (= 1), but becomes dependent on scattering angle, as shown in figure 10:

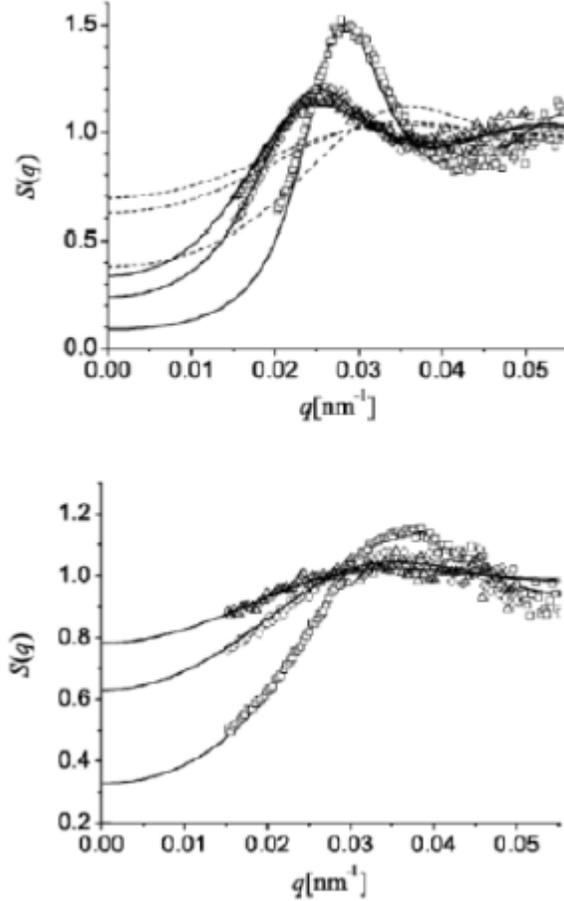


Figure 10: $S(q)$ from SAXS measurements, particle radius approx. 80nm, $c = 200, 97$ and $75g/L$, in water: top: $c(\text{salt}) = 0.5mM$; bottom: $c(\text{salt}) = 50mM$ [taken from: Gapinsky et al, J.Chem.Phys. 126, 104905 (2007)].

If we ignore the hydrodynamic coupling of interparticle motion, the q -dependence of the cooperative diffusion coefficient is given by the static structure factor as:

$$D_{app}(q) = \frac{D_0}{S(q)}, \quad (26)$$

with D_0 the self-diffusion coefficient for very dilute samples, in which case interparticle interactions can be neglected ($S(q) = 1$).

Figure 11 shows the corresponding results for $D_{app}(q)$ in the case of the lower salt concentration. Please note the following differences between the results shown in Figure 11 (and Figure 10) and the data obtained for the concentrated dispersions of charged Ludox particles to be investigated in the practical course of $D_{app}(q)$:

1. the q range of SAXS (= small-angle X-ray scattering) or XPCS (= X-ray photon correlation spectroscopy) is, since these are scattering methods with radiation of very short wavelengths is significantly greater than in light scattering (in the practical course: $0.013nm^{-1} < q < 0.026nm^{-1}$)!
2. the Ludox particles examined are significantly smaller at approx. 25nm, i.e. the maximum in $S(q)$ lies further

to the right $q(S(q)_{max}) > 0.1 \text{ nm}^{-1}$! It is therefore expected that $D(q)/D_0$ for the highly concentrated salt-free sample 5 investigated in the practical course is almost constant at is almost constant at all 4 scattering angles and assumes values around 2.

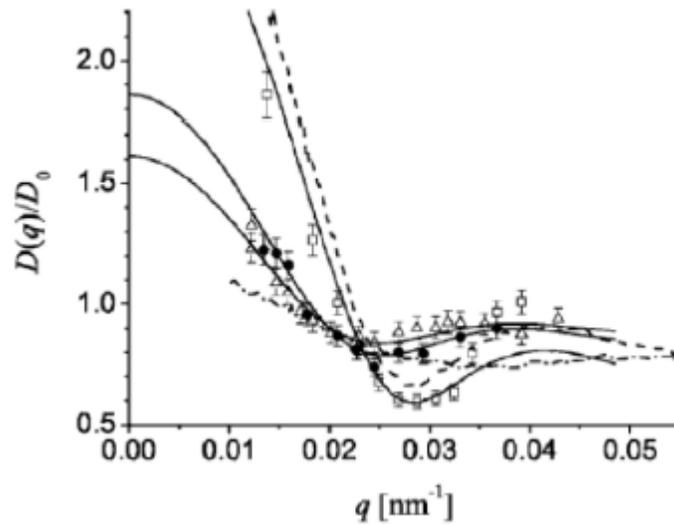


Figure 11: $D(q)$ from XPCS measurements, particle radius approx. 80nm, $c = 200, 97$ and 75 g/L , in water: $c(\text{salt}) = 0.5 \text{ mM}$ [taken from: Gapinsky et al, J.Chem.Phys. 126, 104905 (2007)].

2 Experimental setup

Pictures of the DLS apparatus used in the practical course are shown below.

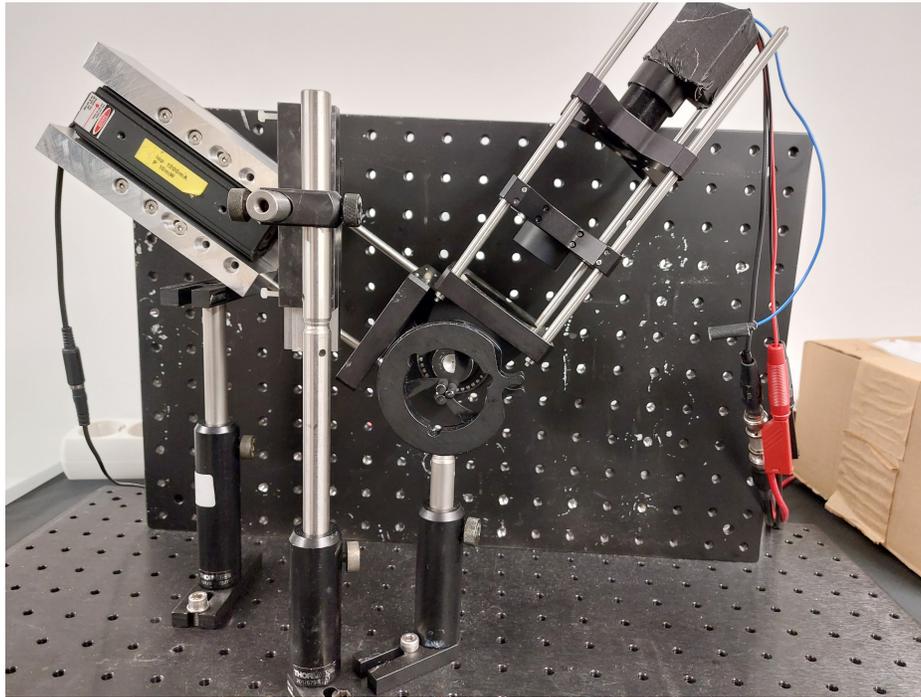


Figure 12: Front view of the DLS setup

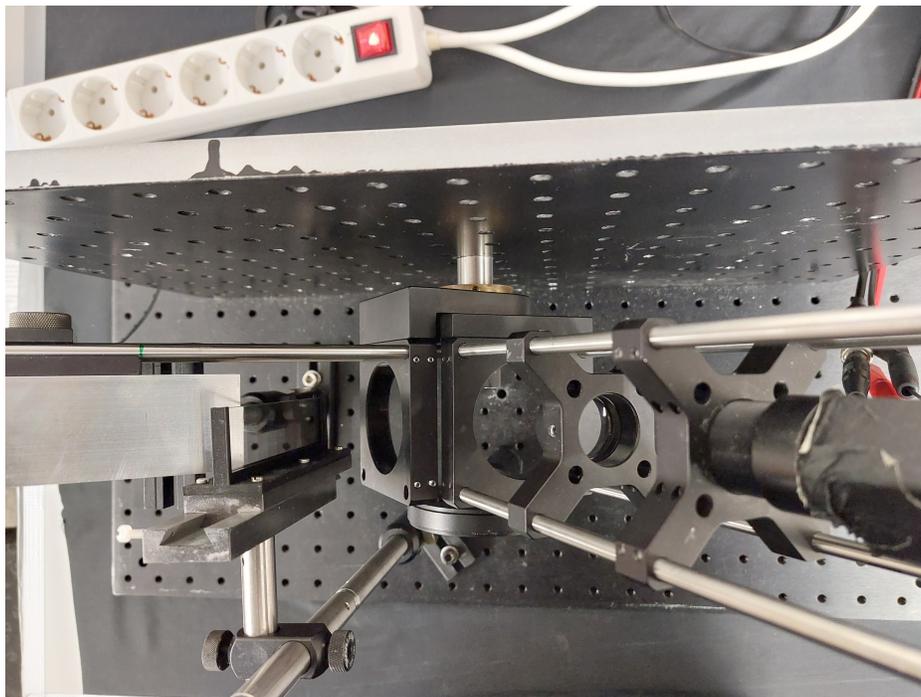


Figure 13: Top view of the DLS setup

3 Test execution

3.1 Sample preparation

The samples analyzed are polystyrene latex particles or Ludox particles with different radii dispersed in water. For the latex particles, the water is filtered using a syringe with a membrane filter ($0.2\mu\text{m}$) before it is pipetted together with the scattering particles into a light scattering cuvette. pipetted together with the scattering particles. The diluted Ludox sample is filtered together with the particles. The filtering is important to remove dust from the solution. The cuvette is filled carefully rinsed with filtered water before filling to remove dust. dust. Before the measurement, the cuvette, which is sealed with a Teflon stopper is carefully inserted into the sample holder of the light-scattering apparatus (see Figure 12, 13).

3.2 DLS measurement

The measurements for dynamic light scattering are carried out using a multi-angle apparatus. The correlator (measurement duration: 2 minutes per sample) determines the amplitude correlation functions, which can be saved in a Txt file for further evaluation with Origin. txt file for further evaluation with Origin or any suitable code. All measurements need to attenuate the intensity of the laser with suitable filters so as not to damage the detector! In the first part of the practical course, the correlation functions of the following three samples at scattering angles 45° , 60° , 75° , and 90° using DLS:

- Sample 1: Latex I, approx. 100 nm radius, concentration: $1\mu\text{L}$ in 5mL H_2O .
- Sample 2: Latex II, approx. 460 nm radius, concentration: $1\mu\text{L}$ in 5mL H_2O .
- Sample 3: Ludox, approx. 10 nm particle size, concentration: $580\mu\text{L}$ in 5mL H_2O .

Samples 1 and 2 are fitted with a fit function for one particle size, sample 3 with the fit function for one and two particle sizes. Determine in each case from the particle size from the diffusion constants. Explain your results. Where do deviations from the actual particle size come from?

In the second part, the change in the correlation curve as a function of the sample concentration is investigated. For this measurement, the latex I particles are measured in the following dilution series at an angle of 90° :

- Sample 4: Latex I, approx. 100 nm radius, concentration: $1\mu\text{L}$ in 5mL H_2O .
- Sample 5: $200\mu\text{L}$ of sample 4 in 3mL H_2O .
- Sample 6: $200\mu\text{L}$ of sample 5 in 3mL H_2O .

Determine the particle size here too and explain your results. In the third part, a mixture of Latex I and Latex II beads is prepared. The recorded correlation function is compared with the functions of sample 1 and sample 2. Explain the differences.

- Sample 7: $0.5\mu\text{L}$ Latex I + $0.5\mu\text{L}$ Latex II in 5mL H_2O .

4 Evaluation

The data from the correlation functions is saved as a txt file and can be further processed in further processed in Origin, for example. Enter the exported data in a semi-log plot, whereby the time is displayed logarithmically. The fit function for particle size has the form:

$$f(t) = A + Be^{-2\Gamma t} \quad (27)$$

Accordingly, the fit function for two particle sizes takes the following form:

$$f(t) = A + Be^{-2\Gamma_1 t} + Ce^{-2\Gamma_2 t} \quad (28)$$

What does the parameter A in both equations indicate? The fit parameter Γ is proportional to the diffusion constant:

$$D = \frac{\Gamma}{q^2} \quad (29)$$

where q^2 is the magnitude squared of the wave vector. The magnitude of the wave vector is made up of the refractive index of the solvent n_0 , the wavelength of the laser $\lambda = 638nm$ and the set angle.

$$q = \frac{4\pi n_0}{\lambda_0} \sin \frac{\theta}{2} \quad (30)$$

The particle size is derived from the diffusion constant according to the Stokes-Einstein equation. Process your measurement data with the help of these instructions according to the of the experiment.

5 Questions

- On what does the mean absolute scattering intensity R (also: Rayleigh ratio) depends on a solution of particles of any size?
- State the Stokes-Einstein equation.
- What is the mean squared displacement?
- How is the intensity correlation function measured in dynamic light scattering measured in dynamic light scattering ((i) mathematically, (ii) graphically)?
- How is the normalized amplitude correlation function obtained from this intensity correlation function $F_s(q, \tau)$?
- What is the apparent diffusion coefficient?
- What is meant by collective diffusion coefficients?
- How does the static structure factor depend on the strength of the interparticle interaction?

6 Literature

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