Kinetics of coagulation of sols

The aim of this practice is to investigate the stability of colloidal systems.

1. Theoretical background

1.1. Basic concepts

Colloidal systems are multicomponent systems that appear to be homogeneous, in which the size of one component is about 10 times, 100 times larger than the size of atoms and ordinary small molecules, but they are not yet distinguishable to the naked eye, they form so-called micro (or nano) phases. It can be gas, liquid or solid phase.
In dispersion colloids, these microphases are uniformly distributed, dispersed in a continuous medium. If the medium is liquid and the dispersed part is solid, the colloid is called a sol.
The solid particles of the sol can collide with each other, form larger and larger clusters, the system becomes a coarse dispersed system, the sol coagulates (precipitates).
External factors that cause coagulation may include:
- Changing the stabilizer or peptizator concentration of the sol, changing the sol concentration, adding additives, coagulators,
- temperature change (thermal coagulation),
- mechanical effect,
- electrical and radiant energy.

The rate of coagulation is determined by the frequency of particle collisions and the interaction of the particles. The repulsion between particles is a function of the charge and thickness of the electrical double layer formed on the surface of the particles. The more diffuse the electrical double layer around the particle, the more stable sol is obtained. For the addition of electrolytes, the initially stable sol coagulates slowly or rapidly, as electrolyte-type coagulators change the potential and thickness of the double layer.

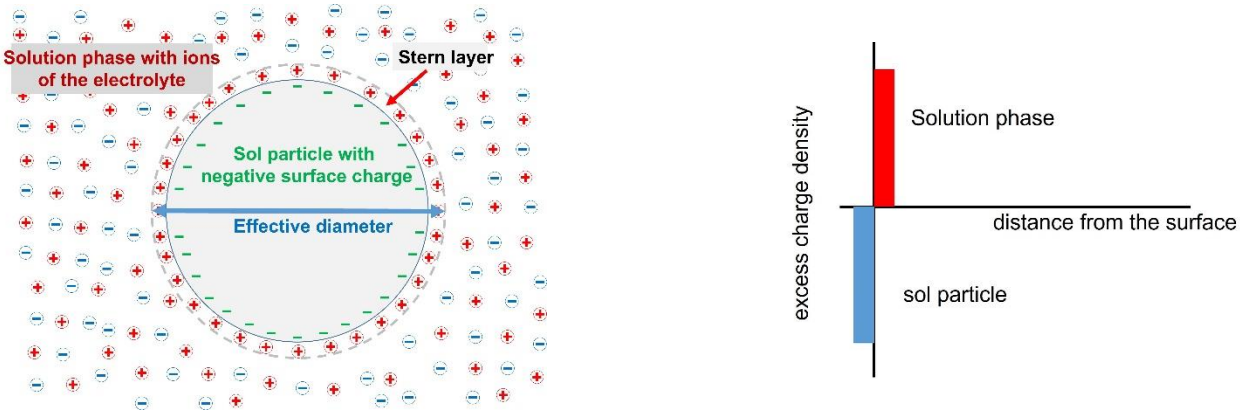


Figure 1 *Schematic of an electrical double layer formed in a concentrated electrolyte solution around a sol particle with a negative surface charge and the distribution of the resulting excess charge density (net charge per unit area). Only a compact (Stern (Helmholtz)) double layer should be considered. (Small circles represent solvated (hydrated) ions.)*

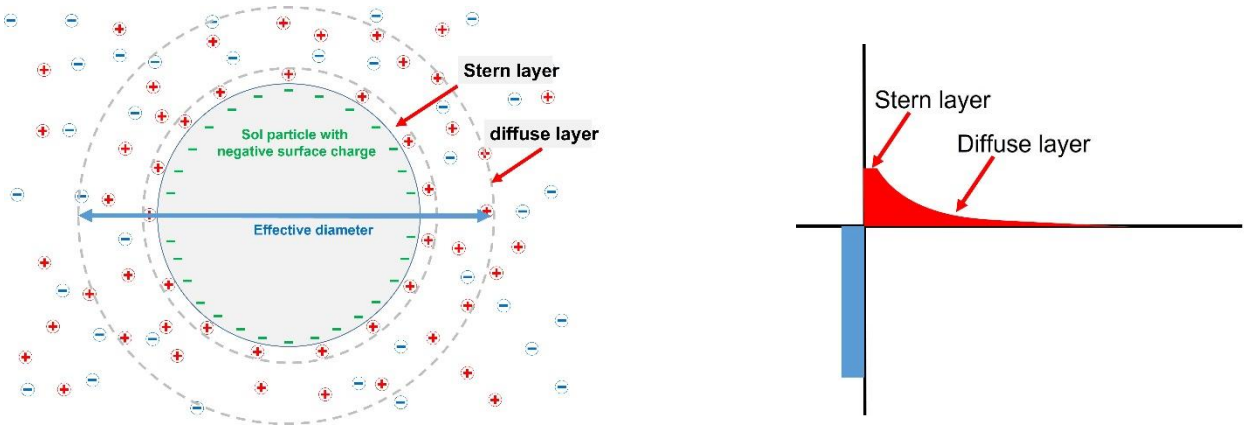


Figure 2 *Schematic of an electrical double layer formed in a dilute electrolyte solution around a sol particle with a negative surface charge and the density distribution of the resulting excess charge. We also have to reckon with a compact (Stern (Helmholtz)) layer and a diffuse charge distribution.*

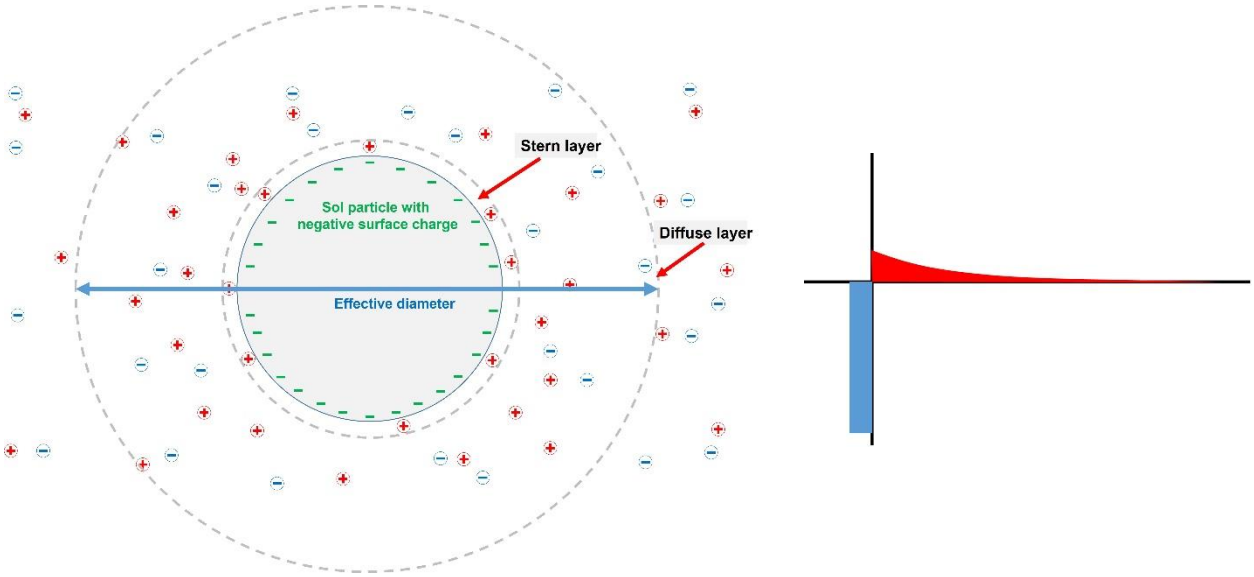


Figure 3 *Schematic of an electrical double layer formed in a very dilute electrolyte solution around a sol particle with a negative surface charge and the distribution of the resulting excess charge density. We only have to reckon with a diffuse double layer.*

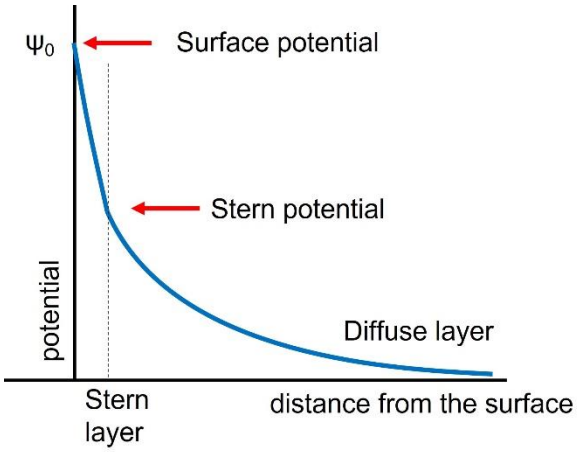


Figure 4 *Distribution of the double layer potential formed in a dilute electrolyte solution around a sol particle with a negative surface charge. There is a linear potential drop in the Stern (Helmholtz) layer and an exponential potential drop in the diffuse layer.*

1.2. DLVO-theory

DLVO theory named after Boris Derjaguin and Lev Landau, Evert Verwey and Theodoor Overbeek.
The theory takes into account that there is always an electrostatic repulsion between colloidal particles of the same charge, which is inversely proportional to the square of the distance between the particles, and an attraction due to the dispersion forces, which is inversely proportional to the sixth power of the distance between the particles.
DLVO theory describes the combined effect of van der Waals attraction forces and electrostatic repulsive forces resulting from identical charges through a thin layer of liquid (the dispersion medium).

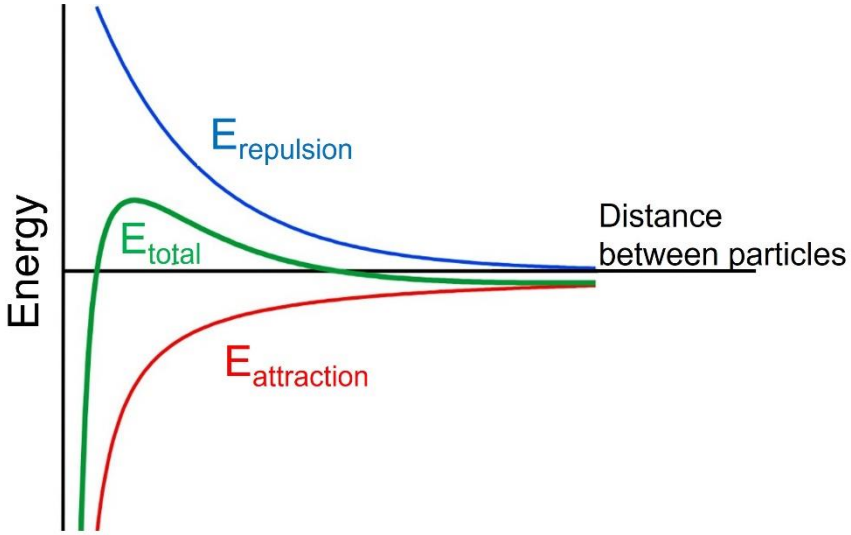
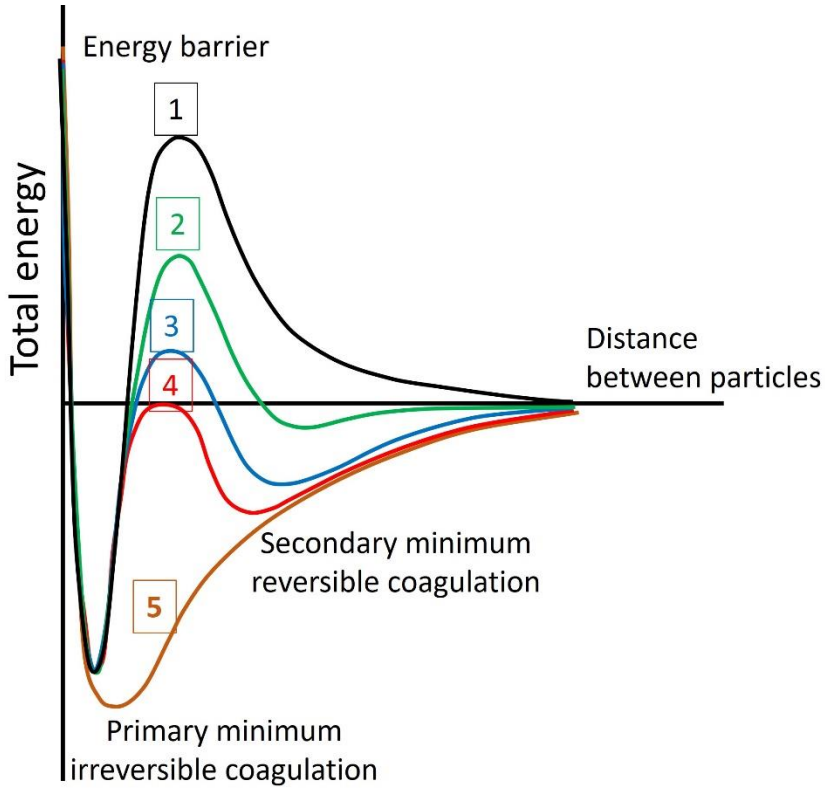


Figure 5 *Potential energy change resulting from the approach of colloidal particles as a result of repulsive and attractive interactions.*

Both the attractive forces and the repulsive forces depend on several factors (particle size, electrolyte concentration, dispersion medium, etc.) hence the resulting curve is different. A colloidal system is considered stable if a maximum is formed in the total energy (potential energy barrier) and its value is ≥ 10 $k_B \cdot T$ (k_B - Boltzmann constant, T- thermodynamic temperature).
As the electrolyte concentration of the dispersing medium changes, the ratio of repulsive and attractive forces changes, so the distance dependence of the total energy also changes.

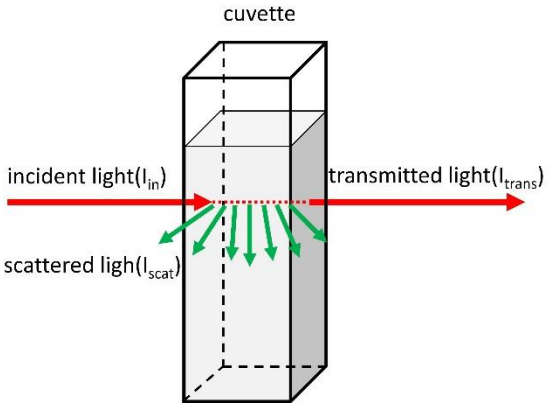


1. Very dilute electrolyte. The surface charge density remains high in the outer layer of the particle. High potential barrier, stable colloid.
2. Secondary minimum may appear (x > 3 nm). The potential barrier is still quite high. Kinetically stable colloid (particle collisions do not lead to coagulation).
3. Small potential barrier, slow coagulation (only a fraction of particle collisions leads to particle association).
4. The potential barrier reaches zero. Critical coagulation concentration (c.c.c.). In the curves below, rapid coagulation (any particle collision leads to coagulation) occurs, unstable colloid.
5. No energy barrier, repulsive forces are negligible, coagulation rate is no longer changes above c.c.c. (diffusion-controlled coagulation).

Figure 6 *Potential energy change as colloidal particles approach each other at various electrolyte concentrations as the result of attractive and repulsive forces.*

1.3. Rate of coagulation

The rate of coagulation can be measured by the change in the number (concentration) of independent particles over time. The process can be followed by measuring turbidity (turbidimetry, nephelometry) or (apparent) light absorption.



In the case of a light intensity detector (180 °) against incident light:

Transmittance: $T = \frac{I_{trans}}{I_{in}}$

Absorbance: $A = -lgT = lg\frac{I_{in}}{I_{trans}}$

In the case of a light intensity detector not opposed to the direction of the incident light (e.g., 90 °):

Turbidity: $\tau \propto \frac{I_{scat}}{I_{in}}$

Turbidity can also be considered an “apparent” transmittance (often measured in this way).

Figure 7 *Absorbance, transmittance, turbidity.*

Light scattering varies depending on the size of the scattering particles. Large particles (larger than the wavelength of the scattered light, e.g., raindrops, air bubbles in a solution) have so-called Mie scattering, on particles of a size comparable to the wavelength of the scattered light (e.g., on colloids with a larger particle size), the so-called Tyndall scattering, on particles much smaller than the wavelength of the scattered light, the

so-called Rayleigh scattering is observed. For small sol particles (diameters < wavelength/10), Rayleigh scattering measurements can be used.
The degree of Rayleigh scattering (turbidity (τ)) is proportional to the number of the scattering particles (concentration (c)), the sixth power of the radius of the particles, i.e., the square of the volume of the particle. However, the Rayleigh equation for light scattering is valid only up to a limited particle size and in the case of solid clusters. Under simplified conditions - the same sol, identical coagulation structure - the rate of coagulation can be examined by photometric method, but quantitative evaluation is only possible to a limited extent. Under the same experimental conditions, the **ratio** of coagulation rates can be determined by monitoring the change in turbidity of the dispersion over time. The rate constants are proportional to the rate of turbidity change in the initial stage of coagulation until only dimers (still small enough particles) are formed from the primary sol particles, i.e.,
primer + primer → dimer

Measured in the Rayleigh range, the turbidity (τ) at time t = 0:

$$\tau_0 = Const_1 \cdot c_{primer,0} \cdot V_{primer}^2 \qquad \textbf{1.3.1}.$$

where $Const_1$ is the optical constant for the detection of light scattering (efficiency depending on the wavelength of the light, the angle of detection, etc.), $c_{primer,0}$ is the initial concentration of the primer sol particles and V_{primer} is the volume of the primer particle.

Initial coagulation can be described by second-order kinetics.

$$\frac{dc_{dimer}}{dt} = -\frac{1}{2} \cdot \frac{dc_{primer}}{dt} = k_{coag} \cdot c_{primer}^2 \qquad \textbf{1.3.2}.$$

where c_{dimer} is the concentration of dimer formed, k_{coag} is the rate coefficient of coagulation depending on the electrolyte concentration, t is the time.
The integrated rate equations:

$$c_{primer}(t) = \frac{c_{primer,0}}{1 + 2 \cdot k_{coag} \cdot c_{primer,0} \cdot t}$$

$$c_{dimer}(t) = \frac{c_{primer,0} - c_{primer}(t)}{2}$$

Thus, after time t, the turbidity (the combined light scattering of the remaining primer and the dimer sol particles formed)

$$\tau(t) = \tau_{primer}(t) + \tau_{dimer}(t)$$

Because the volume of the dimer is twice that of the primer: $V_{dimer} = 2 \cdot V_{primer}$

$$\tau_{dimer}(t) = Const_1 \cdot c_{dimer}(t) \cdot \left(2 \cdot V_{primer}\right)^2$$

If there were only primer + primer → dimer coagulation process, the turbidity for infinite time without any other process:

$$\tau_\infty = \tau_{max} = Const_1 \cdot \frac{c_{primer,0}}{2} \cdot \left(2 \cdot V_{primer}\right)^2 = 2 \cdot \tau_0$$

Using this and using the integrated rate equations, the so-called reduced turbidity:

$$\tau_{red}(t) = \frac{\tau(t) - \tau_0}{\tau_\infty - \tau(t)} = \frac{\tau(t) - \tau_0}{2\tau_0 - \tau(t)} = 2 \cdot c_{primer,0} \cdot k_{coag} \cdot t = Const_2 \cdot k_{coag} \cdot t \qquad \textbf{1.3.3}.$$

That is, $\tau_{red}(t)$ changes linearly with coagulation time, and the slope of the change is proportional to the rate coefficient of coagulation.
With the significant increase of the concentration of dimer particles, other collision and coagulation processes can also start and become significant:

dimer + primer → trimer
dimer + dimer → tetramer
trimer + primer → tetramer
⋮
etc.

The size of the particles formed in them is already too large, resulting in a Tyndall scattering for which the above simple equations do not apply. **That is, Eq. 1.3.3. is valid only for the initial stage of coagulation for a limited time.**

When large amounts of electrolyte are added, the interparticle attraction is predominant, in which case all collisions are accompanied by coagulation. This is called rapid coagulation after Smoluchowski. This obviously means the maximum coagulation rate, which is determined only by the number of collisions of the particles, i.e., the movement of the particles (e.g., diffusion). Let this maximum speed coefficient be k_{fast}. When a small amount of electrolyte is added, repulsive forces still occur between the particles, the magnitude of the potential barrier is comparable to the kinetic energy of the particles, only a fraction of the particle collisions lead to coagulation, in which case we speak of slow coagulation (k_{slow}).

The rate of slow coagulation can be characterized by the so-called deceleration factor W, which can be expressed as the ratio of the rate of fast and slow coagulation
:

$$W = \frac{k_{fast}}{k_{slow}} \qquad \textbf{1.3.4}.$$

As the repulsive potential increases (the electrolyte concentration decreases), the value of W increases, so it can be considered a characteristic of sol stability and is therefore also called a stability factor (stability ratio). Under the same experimental conditions ($c_{primer,0}$ and τ_0), the ratio of fast to slow coagulation rates can be determined by monitoring the change in turbidity over time. In this case, the rate constants are proportional to the rate of turbidity change in the initial stage of coagulation until only dimers are formed. Thus, the deceleration factor (stability factor) can be given by the time changes of the reduced turbidities:

$$W = \frac{k_{fast}}{k_{slow}} = \frac{\left(\frac{d\tau_{red}}{dt}\right)_{fast}}{\left(\frac{d\tau_{red}}{dt}\right)_{slow}} \qquad \textbf{1.3.5}.$$

The logarithm of the stability ratios calculated for typical surface potential and diffuse layer potential values shows a linear decrease with the logarithm of the electrolyte concentration over a wide range of lg W values. (9> lg W> 0.5), and empirically the following correlation was found:

$$\lg W = tm - m \cdot \lg c_{electrolyte} \qquad \textbf{1.3.6}.$$

where tm is the intercept of the function, m is the slope. The DLVO theory can be used to prove the relationship, and, e.g., the value of m can be given by the particle size and the surface potential of the particle. Between the stability ratios determined at different coagulant electrolyte concentrations and the electrolyte concentration there is a relationship according to equation 1.3.6., so the slope of the experimental lg W - lg c function gives the value of m in the range of slow coagulation, and the critical coagulant electrolyte concentration (c.c.c.) can be determined from the intersection of the lines interpolated to the slow and fast coagulation range. c.c.c. is inversely proportional to the sixth power of the counterion valence according to the SCHULZE – HARDY rule. This empirical relationship is jointly supported and successfully explained by counterion adsorption and DLVO theory.

2. Measurements

2.1. Preparing dilute sol

Prepare a dilute solution from the concentrated polyacrylate-based aqueous latex dispersion in a 100 cm^3 flask so that its turbidity is approx. 100 NTU (Nephelometric Turbidity Unit). Currently about 0.03 cm^3 of concentrated solution diluted to 100 cm^3). Hereinafter, this is the "sol" stock solution.

2.2. Calibration

2.2.1. Calibration of the ADDA converter

Adjust the turbidimeter as described in the "Instructions for Use" (Sections 9-11) and set the turbidity of the sol to 100.0. Make sure that the cuvette is clean and that the solution (as well as the wall of the cuvette) does not contain air bubbles (cavities).
After closing the light path, start the data acquisition program, "Logger". Then the voltage (V (τ = 0) belonging to zero turbidity is measured, the so-called offset of the Analog-Digital converter connected to the computer, relative to the zero-input signal (V (τ = 0) = V_{offset}).
Open the light path during registration. If the turbidity value does not return to 100.0, this is not a problem, but record the value read from the turbidimeter (e.g., $\tau_{initial}$)! This is required to calibrate the registration. The measured signal, V ($\tau_{initial}$). Here the data collection can be stopped, a two - point calibration is enough, because the function V - τ is absolutely linear compared to the uncertainties of the measurements!)
For further measurements, the following relationship can be given between the registered voltage values (V (τ)) and the measured turbidity ($\tau_{measured}$) using the offset and $\tau_{initial}$:
τ=0, V= V(τ = 0) =V_{offset}
$\tau_{initial}$, V= V($\tau_{initial}$)

$$\tau_{measured} = \frac{V(\tau) - V_{offset}}{V(\tau_{initial}) - V_{offset}} \cdot \tau_{initial} \qquad \textbf{2.2.1.}$$

2.2.2. Calibration of the turbidimeter

In the previous cuvette containing 4.00 ml of sol, dilute to half the concentration of sol, i.e., take 2.00 ml of sol and add 2.00 ml of water. (Make sure that there are no air bubbles in the solution, or on the wall of the cuvette!) Homogenize the solution and measure the turbidity ($\tau_{measured,0}$). No need to register, just read / write from the display panel. This will be the initial measured turbidity, because in each further measurement the stock solution will be diluted twice with the electrolyte solutions.

Wash the cuvette and add 4.00 ml of water. Measure the turbidity (τ_{back}). No need to register, just read from the display panel. This will henceforth be the background turbidity measured without the sol, which has nothing to do with the light scattering on the sol particles, i.e., only background scattering ("stray light", scattering on the lamp, lens, mirrors, cuvette wall, solvent). This can sometimes be a surprisingly high value (20-40%), depending on the sol concentration and the gain set by the CORSE, FINE buttons.
Its determination is important because later all measured turbidities must be corrected in order to obtain a turbidity that is really proportional to the sol concentration.

$$\tau_{sol} = \tau_{measured} - \tau_{back} = Const_1 \cdot c_{sol} \cdot V_{sol}^2 \qquad \textbf{2.2.2}.$$

2.3. Measurement of coagulation

Measure 2.00 ml of electrolyte solution into the cuvette according to the tables below. (As the type of sol changes, the measured quantities may change! Ask the instructor for help / advice!)
The easiest way to do this is to use an automatic pipette (using different tips to add the electrolyte solution and water!). But if this is not available, it can also be done with weight measurement and injection syringes. For example, place the cuvette on the balance, and add enough electrolyte solution with a syringe until 0.40 g is in the cuvette. Using another syringe, add as much water as the balance shows 2.00 g. (As dilute aqueous solutions, we can assume that their density is 1.00 g/ml, and the volumes are additive!)
Do not forget to homogenize the solution!
Insert the cuvette into the cuvette holder of the turbidimeter as measured so far and push it into the light path.
In each case, also record the value of τ_{back}, which must be in a good agreement with the value of τ_{back} defined in 2.2.2. Small deviations may result from different positions of the cuvette, but if the deviation is large (e.g., more than 10%), one of the ZERO, COARSE, FINE buttons may have been set and will need to be recalibrated. Adjust the turbidimeter as described in the "Instructions for Use" (Sections 9-11) and set the turbidity of the test sol to 100.0.
Measure 2.00 ml (2.00 g) of sol stock solution into a 5 cm^3 long needle syringe (washed with water and rinse with sol solution). For example, the beaker containing the sol solution is weighted on the balance and so much is drawn into the syringe that the given weight is missing from the beaker!
Start the data logger on your computer. (The voltage corresponding to τ_{back} is then recorded.)
The needle of the syringe containing the sol is inserted into the cuvette through the septum on top of the turbidimetric part of the photometer completely. Withdrawing 1 cm, add the sol solution to the electrolyte solution in a firm motion and pull the needle out of the light path. The two solutions are then mixed.
The change in turbidity from the value of τ_{back} to the value of $\tau_{measured,0} = \tau_0 - \tau_{back}$ is the indication of good (and fast) mixing, and then the coagulation starts.
The value of τ_0 can be estimated as half the turbidity of the sol stock solution (due to dilution 2 ml of electrolyte solution + 2 ml of sol stock solution), i.e., $\tau_0 = (100 - \tau_{back})/2$, so $\tau_{measured,0} = (100 + \tau_{back})/2$ should be.

The change in turbidity is recorded for dilute electrolyte solutions up to a change of 10-30% of $\tau_{measured,0}$, for more concentrated electrolyte solutions up to 100.
Perform experiments on all given compositions.

Measurement	V (2 M NaCl)/ml	V(water)/ml	τ_{back}
1.	0.30	1.70	
2.	0.35	1.65	
3.	0.40	1.60	
4.	0.45	1.55	
5.	0.50	1.50	
6.	0.55	1.45	
7.	0.60	1.40	
8.	0.80	1.20	

Measurement	V (0.1 M $CaCl_2$)/ml	V(water)/ml	τ_{back}
1.	0.40	1.60	
2.	0.50	1.50	
3.	0.60	1.40	
4.	0.70	1.30	
5.	0.80	1.20	
6.	1.00	1.00	
7.	1.50	0.50	
8.	2.00	0.00	

Measurement	V (1 mM $LaCl_3$)/ml	V(water)/ml	τ_{back}
1.	0.40	1.60	
2.	0.50	1.50	
3.	0.60	1.40	
4.	0.70	1.30	
5.	0.80	1.20	
6.	1.00	1.00	
7.	1.50	0.50	
8.	2.00	0.00	

3. Evaluation

3.1.

Prepare the sol turbidity-time diagrams based on the registered (turbidity-proportional) voltage values. (see Eqs. 2.2.1 and 2.2.2) In the case of one cation (series of measurements), there may be on one figure. Then scale the measurement times so that the mixing time of the solutions is t = 0. (E.g., when $\tau_{sol} = \tau_0$ or $\tau_{measured} = \tau_{measured,0}$)

The registered data before can be deleted.

Reduced turbidities are also calculated (Eq. 1.3.3).

t/s	V(t)/V	$\tau_{measured}(t)$	$\tau_{sol} = \tau_{measured}(t) - \tau_{back}$	$\tau_{red}(t)$

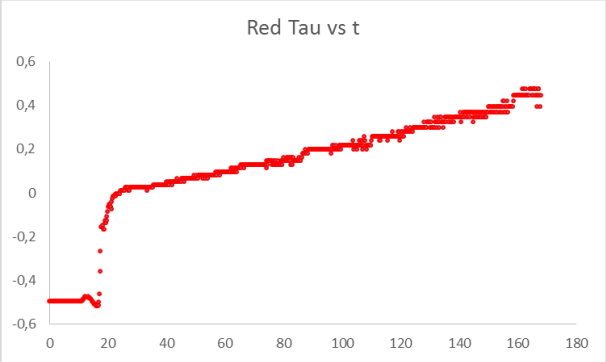
3.2.

Determine the slope of the reduced turbidity – time functions which are proportional to the rate constants of coagulation (the initial, linear part):

$$\frac{d\tau_{red}}{dt} = 2 \cdot c_{primer,0} \cdot k_{koag}$$

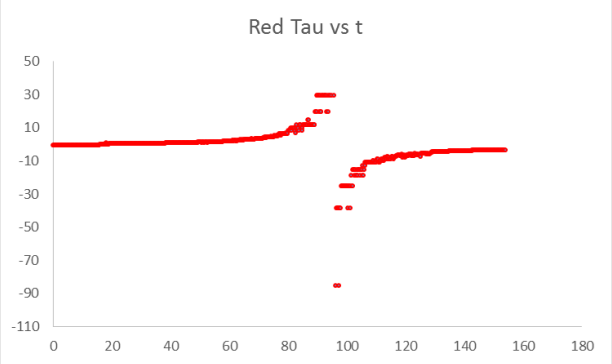
The time of addition of the sol may be different in each measurement, the initial time of coagulation is different, but it is not necessary to adjust the time scale. In the case of a linear fit, this appears only in a non-zero intercept, the slope does not change, and we only need it later.

In case of slow coagulation approx. such a τ_{red} –time diagram can be expected.



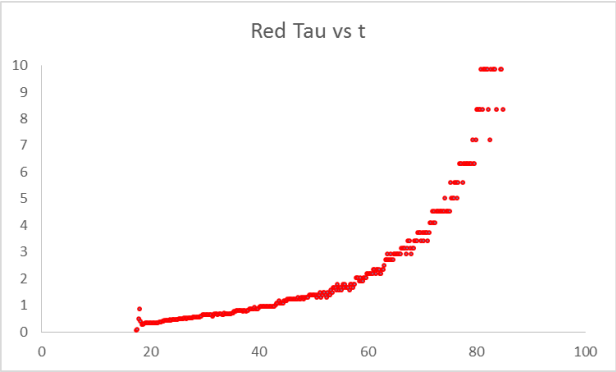
Points where τ_{red} (t) is negative can be omitted because this is still the time before the sol is added and mixed. Fit a straight line to the residue for as long time as possible.

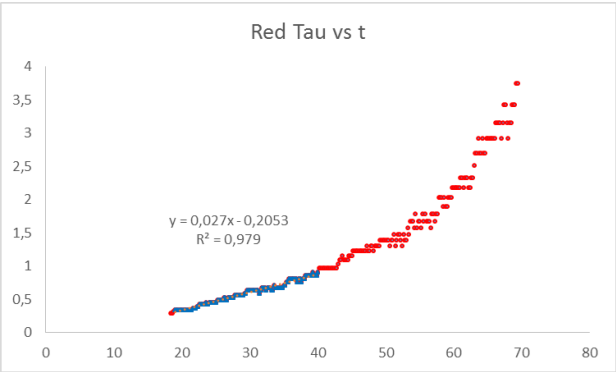
For faster coagulation approx. such a τ_{red} –time diagram can be expected.



Here, too, it is true that from the beginning, where τ_{red} (t) is negative, the points can be omitted because this is still the time before the sol is added and mixed. Where τ_{red} (t) has a discontinuity, changes sign, i.e., $\tau_{sol} > 2\tau_0$ (see Eq. 1.3.3), the initial conditions are certainly no longer valid, we do not see the process primer + primer = dimer, so these points are also can be omitted.

By enlarging the remainder, it is possible to find the part that can be considered linear and to determine the slope.





With very fast coagulation, this range may only be a few seconds!

3.3.

Knowing these slopes (proportional to coagulation rate constants), the deceleration (stability) factor W is determined, the maximum value(s) of which is considered to be k_{fast} according to Eq. 1.3.5.
Calculate the electrolyte concentration in the cuvette, considering the dilutions for each measurement. (E.g., 0.40 ml 0.1 M $CaCl_2$ + 1.60 ml water + 2.00 ml sol → 0.01 M $CaCl_2$.)

Make the following table.

Number of the measurement	Electrolyte	Concentration in the cuvette (c/M)	Red τ slope (1/s)	W	lg(c/M)	lgW

3.4.

Plot the lgW - lg c functions for each electrolyte and determine c.c.c. and the value of the slope.

3.5.

The c.c.c. for each ion and m are used to calculate the surface potential (ψ_0) and Stern potential (ψ_{Stern}) values that can be determined using DLVO theory.

$$c.c.c.\left[\frac{mol}{dm^3}\right] = \frac{0{,}107\,\frac{m^3}{dm^3}\cdot(4\pi\cdot\varepsilon_0\cdot\varepsilon_r)^3\cdot(RT)^5}{A^2\cdot(zF)^6}\cdot\xi^4$$

Where ξ is the so-called reduced surface potential:

$$\xi = \tanh\left(\frac{zF\cdot\Psi_0}{4RT}\right)$$

Respectively from the slope of the lgW –lgc function:

$$m = \frac{2{,}15\ nm^{-1}\cdot a}{z^2}\cdot\gamma^2$$

Where γ is the so-called reduced Stern potential:

$$\gamma = \tanh\left(\frac{zF\cdot\Psi_{Stern}}{4RT}\right)$$

c.c.c. is the measured critical coagulation concentration (must be given in mol/dm^3 in the expression!)
A - is the so called effektive HAMAKER-constant, $3 \cdot 10^{-20}$ J
z – is the charge number of the coagulating ion
F – is the Faraday constant, 96485 C/mol
ε_0 – is the permittivity of vacuum, $8.85 \cdot 10^{-12}$ (A s)/(V m)
ε_r – is the relative permittivity (under usual conditions, at room temperature, dilute aqueous solutions) can be taken as 80
R – is the gas constant 8.314 J/(mol·K)
T – is the thermodynamic temperature
m – is the slope of the lgW – lgc function
a – is the diameter of the sol particles (in this case, 50 nm, enter in nm to the expression!)
tanh - is hyperbolic tangent: $\tanh x = \frac{e^x - e^{-x}}{e^x + e^{-x}}$ (in Excel TANH)
its inverse function is area hyperbolic tangent: $\operatorname{artanh} x = \frac{1}{2} \ln \frac{1+x}{1-x}$ (in Excel, ATANH)

3.6.
Interpret the c.c.c. dependence on the type of the cation. To what power of the cation charge is proportional to the critical coagulation concentration in this series of experiments?

3.7.
Dicuss the results!

Controll questions

1. According to DLVO theory, what interactions should be expected between dispersed colloidal particles?
2. What is slow coagulation, what is fast coagulation, and what is the stability factor?
3. What is the critical coagulation concentration?
3. What is the differential and integrated rate equation of 2 A → B kinetically second order processes.
4. What are absorbance, transmittance and turbidity? How does turbidity depend on the concentration and size of light scattering particles in the Rayleigh range?
5. How to determine the reduced turbidity from the registered voltage - time data?
6. Why is it necessary to calibrate the turbidimeter?
7. How do you determine the stability (deceleration) factor based on the time dependence of the reduced turbidities?

Measurements

Instructions for use for the current system

1. A spectrophotometer equipped with a turbidimeter (hereinafter referred to as a turbidimeter) and a computer collecting the measurement data are switched on. (The latter currently charges in 5 to 10 minutes, and you may need to set the computer time after you log in.) The turbidimeter lamp needs to warm up for at least 20 minutes to keep its light stable.

2. Connect the front half of a wire with a BNC connector and banana plugs to the turbidimeter (right, rear) and then the end of the banana plugs to an NIUSB-6008 ADDA converter (red with red, black with black). Finally, the USB connector of the converter is plugged into a USB port on your computer.

3. Verify that the computer can see the converter. On the one hand, the LED on the converter should light up / flash green. On the other hand, if the “NI-DAQmx Base List Devices” program is started, it should indicate a device connected to one of the USB ports. If you have this, you can exit this program with the QUIT button.

4. Start the “NI-DAQmx Base Data Logger” program. Set “Dev1 / ai1” to measure the signal, “Samples per Channel” to 10, “Sample Rate” to 5.0 Hz (5 measured data per second), and “Chart History” to 500 . In the lower left part of the program window, you can see in which directory and under what name the program stores the measured data, the saves are made automatically when the measurement is stopped. Enter a file name here to recognize your measurement data. This will be the name of each measurement; they can only distinguish the data based on the date and time values attached to the files. Therefore, it is important that the order of the measurements is recorded in your reports.

5. The recording of the measurement data can be started by pressing the ARROW in the upper left of the "NI-DAQmx Base Data Logger" program window or can be stopped (and saved) by pressing STOP next to the former.

6. The measured data can be copied at the end of the experiments, e.g., on a flash drive, and they can be opened e.g., in Excel as a data file. You can see such a table after a header in the file:

X_Value	Untitled
0	-1,05042
0,2	-1,05042
0,4	-1,05042
0,6	-1,05552
….	….

Where X_Value is the time (in seconds), Untitled is the converted voltage proportional to the turbidity (in volts).

7. Adjust the wavelength of the measurements on the turbidimeter (currently 500 nm) with the wavelength selector next to the turbidimetric tip (and cuvette holder) protruding on the photometer.

8. Set the measurement mode to Transmittance% and the gain to 100x (turbidity measurement as if it were a 100x amplified apparent transmittance measurement).

9. Close the light path with the toggle switch under the turbidimetric protrusion on the photometer and use the ZERO control (below the display panel) to set 0.0 “apparent transmittance”, i.e., 0.0 turbidity.

10. Weigh 4.00 ml of sol into a clean, dry cuvette and place in the cuvette holder. Contact the entire surface of one side of the cuvette with the side wall of the cuvette holder so that the position of the cuvette can be reproduced. From now on, always use the same cuvette and always place it in the right holder with the labeled side facing forward. Push the cuvette into the light path.

11. With the toggle switch open, set the light path to 100.0 “apparent transmittance” (100.0 turbidity) using the gain buttons (COARSE and FINE buttons) on the right side of the photometer.