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STABINO ZETA

FINGERPRINT METHOD FOR THE COMPREHENSIVE CHARACTERIZATION OF THE PARTICLE CHARGE (ZETA POTENTIAL)

Introduction

Zeta potential (ζ) is the electrical potential at the hydrodynamic shear plane of a particle or droplet. It describes the effective charge environment within the electrical double layer and is directly linked to electrostatic repulsion between dispersed particles. According to classical colloid science and DLVO theory, colloidal stability results from the balance between:

- | Attractive van der Waals forces
- | Repulsive electrostatic interactions

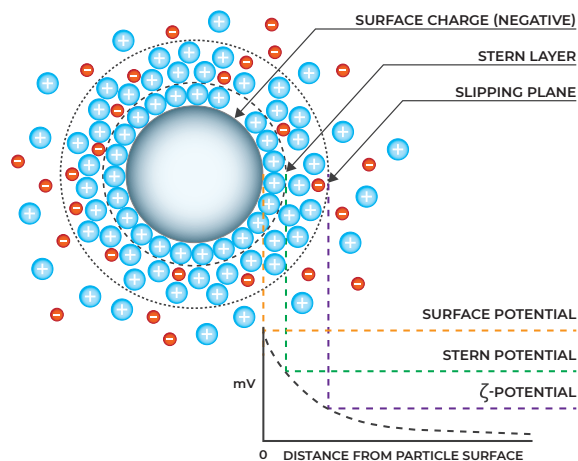


Fig. 1: Schematic representation of zeta potential

The total interaction potential between particles is the sum of these opposing contributions. If the repulsive barrier is reduced—for example by changing pH, adding electrolyte, or modifying surface chemistry—aggregation becomes more likely.

Zeta potential is therefore a key formulation parameter: a sufficiently high absolute ζ -value usually indicates stronger electrostatic repulsion and a lower risk of irreversible aggregation.

This contributes to:

- | Improved dispersion stability
- | Reduced flocculation
- | Better redispersibility after sedimentation
- | More consistent product performance over time

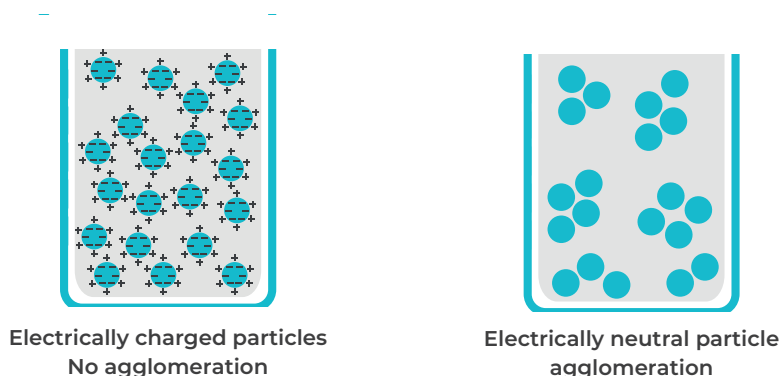


Fig. 2: Influence of zeta potential on dispersion stability

Charge distribution at the interface with the surrounding liquid: the electrical double layer

These principles apply equally to flat, particulate, and molecular interfaces. A charged surface attracts oppositely charged ions from the surrounding liquid and thereby shields its surface charge.

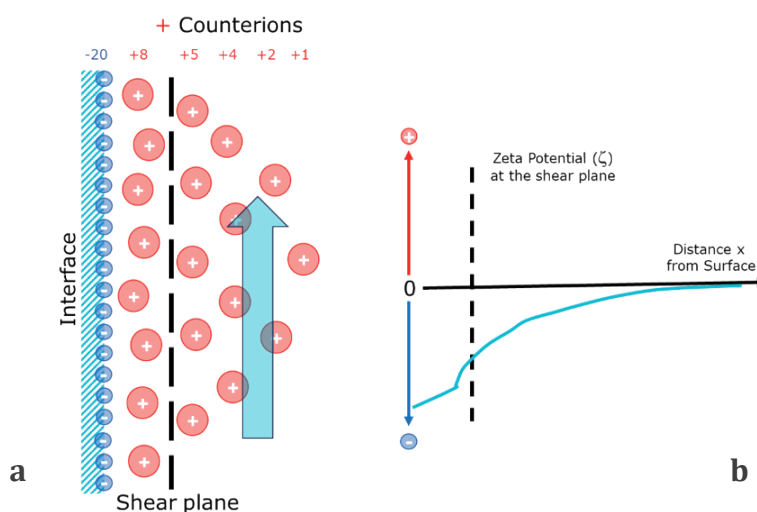


Fig. 3a: Anionic interface with cationic charge cloud, which balances the charge outwardly. At the shear plane, the outer loosely bound excess ions can be sheared off.

Fig. 3b: Simplified potential profile at the interface. For practical purposes, only the potential measurable at the shear plane is important: the zeta potential ζ .

In an aqueous medium, cations and anions, such as Na^+ and Cl^- , are initially distributed uniformly. At a charged interface, oppositely charged ions accumulate near the surface and form an ion cloud that compensates for the interfacial charge (Fig. 3a).

Ions closest to the surface are strongly bound, whereas those further away are weakly associated. Together they form the electrical double layer which is typically between 0.5 and 20 nm. The loosely bound ions can be displaced by an electric field or by mechanical forces such as flow or ultrasound. The resulting net-charge distribution can be represented as a potential profile (Fig. 3b). Of practical relevance is the potential at the shear plane: the zeta potential.

The principle of Oscillating Flow Potential (OFP)

When liquid flows through a narrow capillary, the mobile part of the charge cloud is displaced in the flow direction (Fig. 4). This displaced charge depends on the zeta potential, which in turn depends on the ionic strength of the surrounding solvent. The resulting electrical potential difference, the oscillating flow potential U_r , is measured by electrodes **E1** and **E2** positioned along the flow path. According to the Helmholtz-Smoluchowski relationship, the oscillating flow potential is proportional to the zeta potential ζ and the dielectric permittivity $\epsilon\epsilon_0$, and inversely proportional to the viscosity η . A higher applied pressure difference generates a higher oscillating flow potential; since the **STABINO ZETA** induces always at the same pressure we do not need to measure it, it can be considered as cell constant which is part of calibration factor. The conductivity of the medium κ_m counteracts the generated oscillating flow potential. Measuring the pH dependence of the zeta potential and determining the surface charge provide important information about the type and number of functional groups on carbon-based materials.

$$U_r = \frac{\epsilon\epsilon_0}{\eta * K_m} \text{ (Helmholtz Smoluchowski) (1)}$$

This enables the determination of the zeta potential of surfaces.

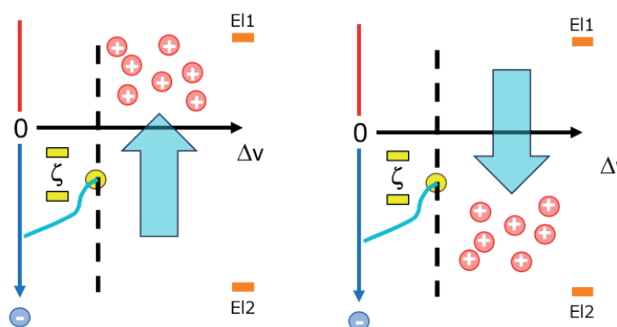


Fig. 4: By applying a streaming pressure in a narrow gap, the medium flows past the interface and shears off the counterions. The flow potential is tapped between the electrodes E1 and E2.

The main elements of the setup are a measurement cell (**C**), a piston (**P**) that defines the gap, and two electrodes (Fig. 5).

When an aqueous sample is introduced into the measurement cell and the piston is driven into oscillation by the motor (**M**), strong fluid flow is generated in the narrow gap between the piston and the inner wall. Because the gap width is small relative to both the piston radius R_i and the axial gap length S ($h \ll R_i$ and $h \ll S$), the flow channel can be approximated as a planar slit. The characteristic flow velocity in the gap is about one order of magnitude higher than the piston velocity, so particles near the piston and cell wall can be treated as quasi-stationary. As a first approximation, the velocity profile is therefore parabolic.

This velocity gradient shears the ion cloud within the electrical double layer. Shear is greatest near the wall and weakest in the center of the gap. The superposition of these local charge separations produces a measurable oscillating flow potential (U_r).

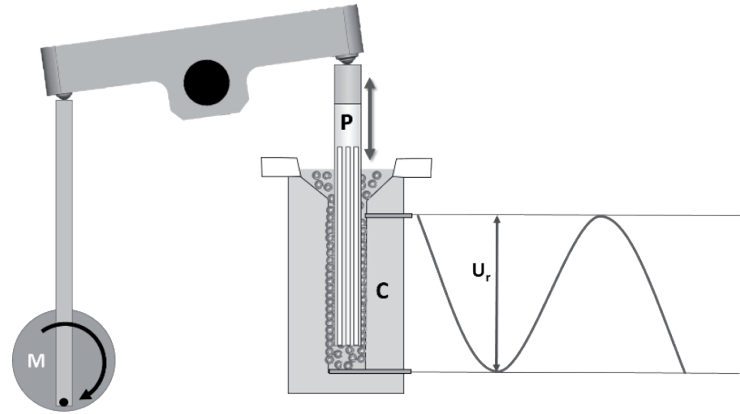


Fig. 5: Setup to measure the Oscillating Flow Potential

The raw Oscillating Flow Potential is detected by the electrodes in the measurement cell and evaluated by the software. After calibration, the measured signal U_r is converted into zeta potential and streaming potential.

$$\zeta = U_r * k_{zeta} \quad (2)$$

$$\Phi_{streaming} = U_r * k_{streaming} \quad (3)$$

with:

U_r : Oscillating Flow Potential,

k_{zeta} : Zeta cell constant,

$k_{streaming}$: Streaming cell constant,

ζ : zeta potential,

Φ streaming: streaming potential

Because the inner surfaces of the measuring cell must be sufficiently covered by quasi-stationary particles, the method becomes less reliable at low particle concentrations.

Measurement setup of STABINO ZETA

The vertical movement of a PTFE plunger inside a PTFE measuring cylinder causes a strong liquid flow in the narrow gap between plunger and cylinder (Fig. 5/6), thereby generating the oscillating flow potential described above.

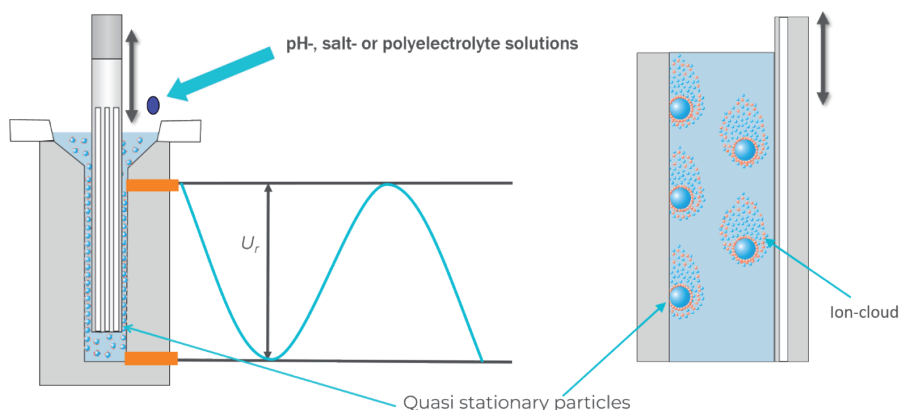


Fig. 6: Measurement cell with sample volumes of 10 mL, 3 mL, 1 mL, or 500 μ L, including piston and electrodes for detecting the raw oscillating potential U_r . Titrant solutions for pH, polyelectrolyte, or salt titration can be added from above in minimum steps of 10 μ L.

Advantages of the STABINO ZETA:

- | Due to the oscillating plunger movement:
 - the measurement signal is generated within one second.
 - the sample remains homogeneous.
 - the sample is mixed immediately.
 - convection-related effects are minimized.
- | the method is up to 30 times faster than optical methods.
- | The electrical signal is independent of color or transparency.
- | The gap depth can be adapted using four pistons with different gap sizes:
 - For high viscosities (50–100 mPa·s), a wide gap is used.
 - For high conductivities (5–50 mS/cm), a narrow gap increases signal sensitivity.
- | Calibration in Zeta potential

These properties make the system particularly suitable for efficient charge titrations. To reduce vessel changes, it includes two titration lines and pumps. Overall, it is highly suitable as a charge-mapping tool for real-world samples.



STABINO ZETA

The STABINO ZETA



Fig. 7: Stabino Zeta

The **STABINO ZETA** is an oscillating-flow zeta potential analyzer designed for efficient charge characterization of dispersions. It covers a broad particle size range from **0.3 nm to 300 µm** and can measure most samples with little or no dilution. This helps users obtain results that are more representative of the original formulation. In one measurement, the system records zeta potential, streaming potential, conductivity, pH, and temperature. The concentration range of **0.01 to 40 vol.%** also makes the instrument suitable for concentrated or conductive samples that are often difficult to analyze with classical optical methods. Integrated pH, salt, and polyelectrolyte titration functions support systematic charge mapping and help identify formulation conditions that improve stability.

Automated titration enables controlled adjustment of pH, salt concentration, or dispersant dosage in a controlled way. This supports typical formulation and quality-control tasks such as:

- | Zeta potential measurement at high concentrations
 - Real-world samples can be **measured directly without dilution or alteration.**
- | Titrations can be used for:
 - pH adjustment
 - Polyelectrolyte adsorption (Charge Titration)
 - Salt sensitivity studies
 - Determination of isoelectric point (IEP)
 - Mapping of electrostatic stability windows

General applications

Typical application areas include proteins, beverages, nano- and microcoatings, algae, chitosan, carbon products, battery materials, and geological samples. For many of these materials, the method helps users understand how formulation conditions affect charge, stability, and process behavior.

pH Titration

As an example, Fig. 8 shows pH titration of alumina in both directions. The forward and reverse titrations do not follow the same path, which indicates that the surface charge depends on the titration history. This information is useful when selecting a stable pH range for a formulation. Each continuous titration direction typically takes only 5 to 10 minutes.

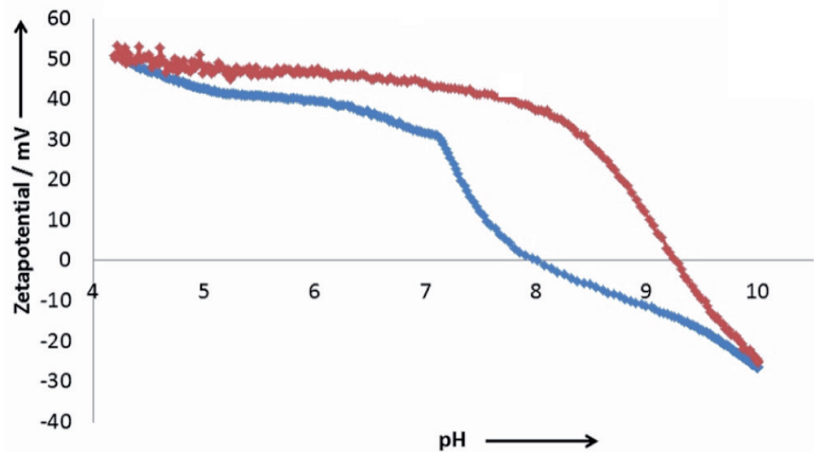


Fig. 8: pH titration of Al_2O_3 from pH 4 to 10 (blue) and from pH 10 to 4 (red).

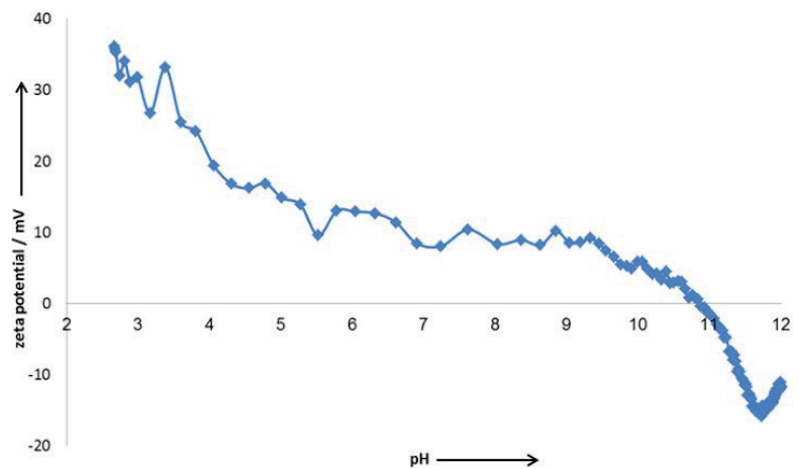
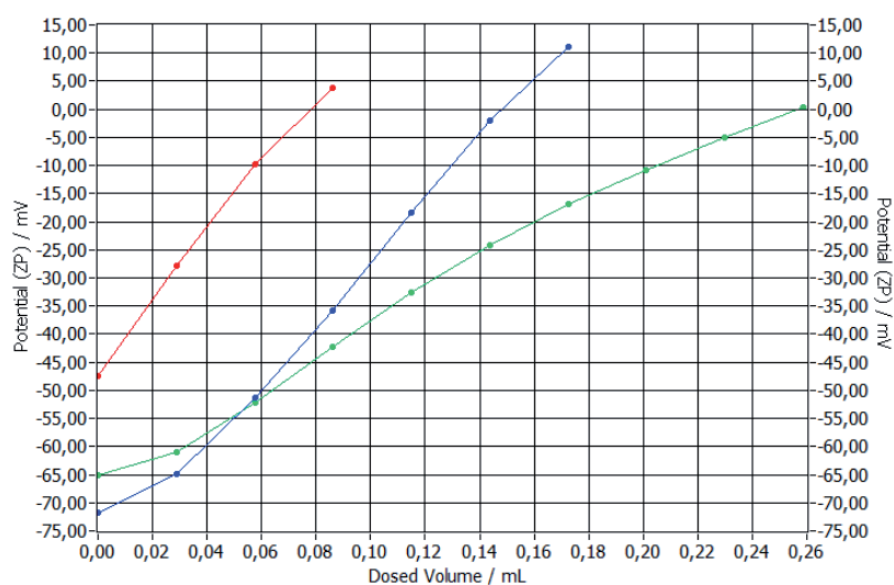


Fig. 9: pH titration for determining the isoelectric point (IEP) of lysozyme, yielding a value of approximately pH 11, in good agreement with literature values

Polyelectrolyte titration

Polyelectrolyte titration helps quantify surface charge density and adsorption behavior. It is especially useful when users need to understand how additives interact with particle surfaces, how much charge must be neutralized, or how a formulation may respond during processing.

During titration, Poly-DADMAC adsorbs onto the particle surface and compensates the surface charge. The required titrant amount can be used to estimate available adsorption or coordination sites. This makes polyelectrolyte titration a practical tool for product development and routine quality control. By comparing measurements with different pH values, users can also distinguish functional surface groups according to their acid strength (Fig. 10).



Sample	Titrant	Volume (mL)	Charge / C g ⁻¹	Charge / µeq g ⁻¹
Graphite pH 11	P-DADMAC	0.257	0.155	1607
Graphite pH 9	P-DADMAC	0.148	0.089	966
Graphite pH 7	P-DADMAC	0.078	0.047	488

Fig. 10: Charge determination of graphite at different pH values

In practice, this means that charge differences at different pH values can be linked to functional groups on the particle surface. This helps explain why a formulation behaves differently under acidic, neutral, or alkaline conditions.

Influence of salts in the surrounding solution

Because the streaming potential is detected electrically, the method provides a strong signal even at elevated salt concentrations. This enables users to study how increasing ionic strength affects zeta potential and dispersion stability (Fig. 11).

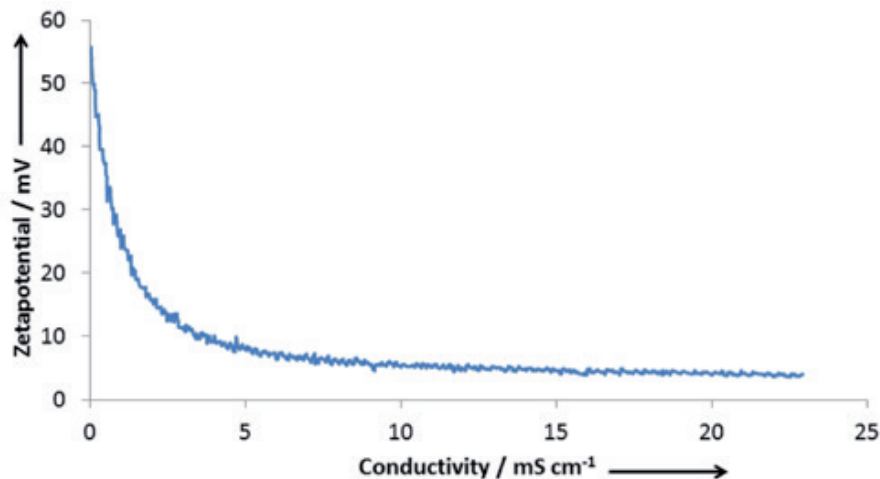


Fig. 11: Salt titration of Al_2O_3 at pH 4 with KCl to increase conductivity. As conductivity increases, the zeta potential decreases strongly and approaches zero asymptotically.

Repeatability and reproducibility

In typical use, repeatability and reproducibility are approximately 10% at the potential level, mainly depending on the accuracy of the calibration standard. The electronic signal acquisition itself is more precise, with deviations of about 2%. For titrations, reproducibility based on titrant consumption is typically around 6%, provided that more than 3 mL of titrant are used. Reliable results also depend on consistent cleaning of the measurement cell and piston. The piston frequency remains constant during operation. Although the measured raw potential depends on the selected piston gap depth, the titrant consumption required to reach the endpoint remains unaffected.

Concentration and viscosity

The recommended concentration range is approximately 0.1 to 40%. For titration experiments, concentrations up to about 20% are recommended. At higher concentrations, viscosity may increase strongly near charge neutralization, which can make sample mixing less efficient.



Additional particle size measurement with **NANOTRAC FLEX** as **DUO**



Fig 12a: Combination of **STABINO ZETA** and **NANOTRAC FLEX**.

The **DUO** configuration combines **NANOTRAC FLEX** particle size analysis with **STABINO ZETA** charge characterization. This allows users to monitor particle size and zeta potential on the same sample and directly see how changes in charge affect aggregation, stability, and formulation behavior.

The **NANOTRAC FLEX** is an 180° heterodyne Dynamic Light Scattering (DLS) system for particle size analysis. The combination of **STABINO ZETA** and **NANOTRAC FLEX** is shown in Fig. 12a. Thanks to its external probe design,

measurements can be performed in a wide range of vessels (including the **STABINO ZETA** measurement cell) and over a broad concentration range. This gives users flexibility when working with monomodal, multimodal, concentrated, or application-relevant samples.

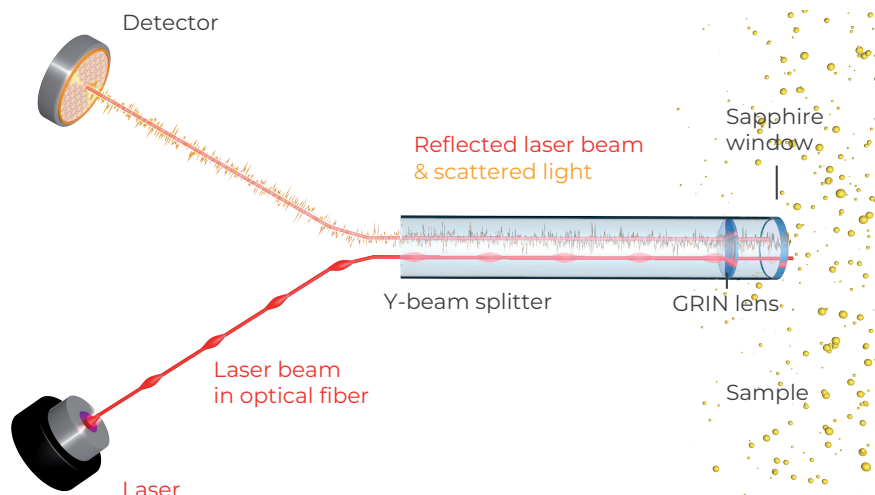


Fig 12b: Optical setup of the **NANOTRAC FLEX**

The optical bench of the **NANOTRAC FLEX** is a probe containing an optical fiber coupler with a Y splitter. Laser light is focused close to the interface of the probe window and the dispersion. The sapphire window at the probe tip reflects a portion of the laser beam back to a photodiode detector. The laser light enters the dispersion and the particles' backscattered light (180 degrees) reaches the same detector via the probe (Fig. 12b).

For example, an Al_2O_3 suspension shows a particle size of 165 nm at pH 4 and remains stable under these conditions. During titration with NaOH, coagulation starts around pH 7, even though the isoelectric point is reached later at pH 8.4. This shows the value of measuring both zeta potential and particle size at the same time: the zeta potential indicates electrostatic stability, while the particle size measurement shows when aggregation begins (Fig. 13).

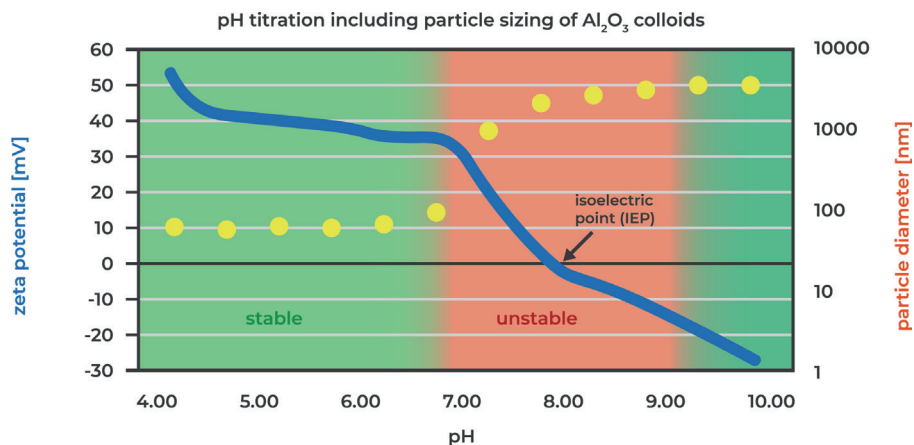


Fig. 13: pH titration with NaOH from pH 4 to 10 combined with particle size measurement.

Controlling particle charge and additive dosage is important for optimizing particle coatings and keeping dispersions stable. By measuring particle size together with additive consumption, users can directly follow how charge compensation influences aggregation. During polyelectrolyte titration of a pigment toward the point of zero charge (ZPC), for example, the particle size increases as electrostatic stabilization decreases (Fig. 14). This provides practical guidance for selecting suitable additive concentrations.

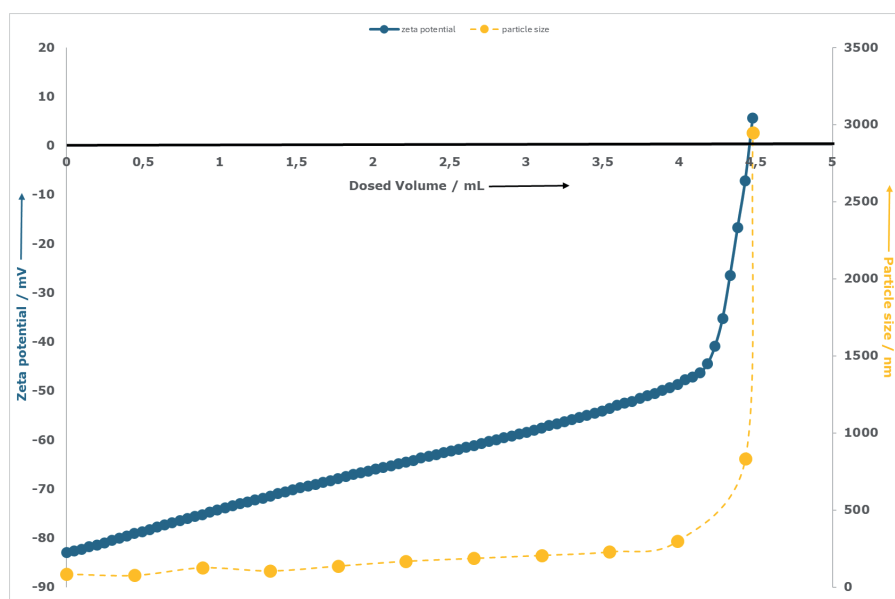


Fig. 14: PE titration with P-DADMAC to the point of zero charge combined with size measurement during the titration.

Conclusion

The broad size range of the **STABINO ZETA** makes zeta potential analysis accessible for many sample types that are difficult to measure with classical optical methods. The oscillating-flow principle enables fast titration experiments and helps users compare dispersion stability under realistic and well-defined chemical conditions.

In addition to zeta potential, charge density measurements provide valuable insight into the surface functionality of particles. Together with pH, salt, and polyelectrolyte titration, the method helps users identify stable formulation windows, determine isoelectric points and points of zero charge, and better understand how surface charge influences product performance.

- | **Five parameters** simultaneously within seconds - **zeta potential**, streaming potential, **conductivity**, **pH**, and temperature; the conductivity is measured at every measurement point.
- | **High-concentration** and high-conductivity performance - measures **0.01–40 vol.%** suspensions and operates reliably even at high conductivity levels and low zeta potential.
- | **No dilution** required for most samples - ensures realistic zeta potential values and enables accurate stability assessment under true application conditions.
- | **Integrated auto-titrator** - **automatically determines** the isoelectric point (**IEP**), the point of zero charge (**PZC**), and the **surface charge density**. It also offers **potentiometric acid–base titrations**, providing valuable insights into the surface properties of the particles examined.
- | **“Mix & Measure” principle** – axial piston motion provides **continuous sample homogenization**, **prevents particle sedimentation**, and allows fast equilibration in titrimetric measurements.
- | **Broad size** range for charge analysis (**0.3 nm – 300 µm**) - from macromolecules to **large particles**, ideal for complex or sedimenting dispersions.
- | Optional **temperature control** from **0 to 90 °C** - enables temperature-dependent analyses to understand the influence of thermal effects on surface properties and to optimize formulations accordingly.
- | **Low maintenance** technology without consumable cuvettes reduces operating costs, decreases material consumption, and minimizes waste.

Additionally with the DUO

- | **Synchronous size and charge analysis** — combines DLS particle sizing with five-parameter zeta measurement within seconds.
- | The combination of **dynamic light scattering (DLS)** for sizing and **electrokinetic analysis** for surface and stability parameters enables **complete particle characterization** in an end-to-end workflow.
- | The **simultaneous recording and correlation** of parameters such as zeta potential, streaming potential, hydrodynamic diameter, particle concentration, pH, temperature, and conductivity in real time provide a **complete picture** of dispersion properties and create a solid basis for decision-making in development, process optimization, and quality control.
- | The combined use of both devices offers a **high degree of versatility**: each system can be operated **stand-alone** or **in combination**, depending on the analytical question and requirements, enabling **maximum flexibility** in research, development, and quality control.



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