Quantifying the Total and Accessible Amount of Surface Functionalities and Ligands on Nanomaterials

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Engineered nanomaterials (NMs) of various chemical composition and surface functionalization are routinely fabricated for industrial applications such as medical diagnostics, drug delivery, sensing, catalysis, energy conversion and storage, opto-electronics, and information storage. NM dispersibility, stability, processability, and function as well as the interaction with biological species and environmental fate are largely determined by NM surface functionalities, i.e., functional groups (FGs) and ligands. Therefore, reliable, reproducible, and eventually standardized surface characterization methods are vital for quality control of NMs, and mandatory to meet increasing concerns regarding their safety.

Suitable methods for determining surface functionalities on ligand-stabilized core and core/shell NPs include advanced techniques such as traceable quantitative nuclear magnetic resonance (qNMR) as well as X-ray electron spectroscopy (XPS) and time of flight secondary ion mass spectrometry (ToF-SIMS), and simpler optical and electrochemical methods.[1] The latter less costly and fast methods, which can be automated, are often used by NM producers for process and quality control.[1,2] To validate methods, establish measurement uncertainties, test reference materials, and produce reference data, multi-method characterization studies are needed.[3,4] as well as interlaboratory comparisons (ILC) on determining NM surface chemistry and well characterized test and reference NMs providing benchmark values.[5,6] Here, we present examples for quantifying common surface FGs such as amino and carboxyl groups on functional NMs of different chemical composition such as silica, polymer, iron oxide, and lanthanide-based upconversion nanoparticles with optical assays, electrochemical titration methods, qNMR, and chromatographic separation techniques. In addition, ongoing interlaboratory comparisons will be presented.

[1] D. Geissler et al., *Microchim. Acta* **2021**, *188*, 321-349.
[2] I. Tavernaro et al., *Nano Research* **2024**, *17*, 10119–10126.
[3] J. Deumer et al., *Anal. Chem*. **2024**, *93*, 15271-15278.
[4] I. Tavernaro et al., *Anal. Chem.* **2025**, to be submitted.
[5] F. Kunc et al., *Anal. Chem*. **2021**, *96*, 19004-19011.
[6] S. L. Abram et al., *Anal. Bioanal. Chem*. **2025** (10.1007/s00216-024-05719-6)