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Analytical nanoscience

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What is analytical nanoscience?

"Nanoscience" refers to research and development related to materials with dimensions between *ca.* 1–100 nm and to systems with important processes that occur over similar dimensions. Properties, structural organization, and behaviors distinct from those observed at the bulk and molecular levels are often found at the nanoscale. The breadth of nanoscience spans physics, chemistry, engineering, biology, and medicine. In this sense, nanoscience is a nexus between traditional scientific disciplines; however, nanoscience is also a field in its own right, with specialized jargon and technical knowledge—for example, a scientist with years of experience working with molecular materials often does not intuitively know the nuances of working with nanoparticles.

"Analytical nanoscience" likewise encompasses many different aspects of research and development. On one hand, nanomaterials and nanotechnology are tools that can be used to enhance existing analytical methods. For example, in assays and sensors, nanomaterials enable the generation of bigger and better signals, whether through their special properties or through size and surface area that support novel architectures and formats. On the other hand, nanomaterials are themselves important samples for analysis. A detailed physical and chemical characterization of nanomaterials is important for understanding their fundamental behaviours, how they can be selected and tailored and manufactured for downstream applications, and how they can impact human health and the environment. However, the unique combination of small size, heterogeneity, and physicochemical complexity makes such characterization challenging. Yet another aspect is the nanoscale resolution of a system that does not necessarily include a nanomaterial, but nevertheless has organization, interactions, transport, or other important processes that occur at that dimensionality. Although some methods and technologies that provide such resolution are available, there remains a need for a larger toolbox for nanoscale characterization.

All of the conventional sub-disciplines of analytical chemistry contribute to the vibrancy and great utility of analytical nanoscience: electronic and vibrational spectroscopies and imaging, electrochemistry, chromatography and separations, mass spectrometry, and more. In many cases, the contributions are reciprocal, with nanomaterials potentially enhancing these analysis methods and with these methods contributing to the characterization of nanomaterials or nanoscale systems.

Given the importance of analytical nanoscience, *Analyst* commissioned a themed collection on this research. The collection includes 10 reviews and 19 original papers from research groups around the world, covering a diverse range of topics in the field.

The role of metallic nanostructures in enabling surface enhanced Raman spectroscopy (SERS) is well represented, with reviews on the development of SERS and surface enhanced resonance Raman spectroscopy (SERRS) for therapeutic drug monitoring (DOI: 10.1039/D0AN00891E) and for cellular and tissue imaging (DOI: 10.1039/D0AN01274B). Original papers address multifunctional gold nanomaterials designed for a magnetic pull-down SERS assay format (DOI: 10.1039/D0AN00711K), SERS paired with plasmon-enhanced fluorescence (DOI: 10.1039/D0AN00538J) or colorimetric (DOI: 10.1039/C9AN01748H) measurements of microRNA, and gold nanomaterials for the in-solution SERS detection of a pharmaceutical (DOI: 10.1039/C9AN02439E). Other original papers demonstrate exciting applications of SERS: the detection of tetrahydrocannabinol and its secondary metabolite (DOI: 10.1039/C9AN02173F), the detection of synthetic cannabinoids (DOI: 10.1039/C9AN01512D), differentiation of mutants of *Campylobacter jejuni* (DOI: 10.1039/C9AN02026H), and the tracking of changes in pH during intracellular transport (DOI: 10.1039/D0AN00986E).

Of course, the plasmonic properties of metallic nanoparticles have utility in analytical science beyond SERS, as represented by reviews on nanoparticles with plasmon-enhanced fluorescence for

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chemical sensing (DOI: 10.1039/D0AN01092H) and metal nanoparticles for colorimetric and fluorimetric chemical and biological analyses (DOI: 10.1039/D0AN00609B). An original paper also shows how plasmonic assemblies of gold nanoparticles are able to map cellular metabolism (DOI: 10.1039/C9AN02262G), while another paper reports on the use of gold nanoparticles in a lateral flow assay for screening the binding activity of aptamers (DOI: 10.1039/D0AN00634C).

Other contributions to this themed collection more broadly address how nanomaterials may contribute to analyses with enhanced analytical performance, simpler technical requirements, and new strategies of detection. Reviews cover various modalities of multiplexed detection supported by nanomaterials (DOI: 10.1039/D0AN00392A), the roles for nanomaterials in amplified immunosorbent assays (DOI: 10.1039/D0AN00597E), how stimuli-responsive polymers can be formulated as nanoparticles or integrated with other nanomaterials for sensing applications (DOI: 10.1039/D0AN00686F), and luminescent nanoparticle probes for hypochlorous acid (DOI: 10.1039/D0AN00645A). Original papers explore energy transfer between quantum dots for detection based on visible changes in the fluorescence colour (DOI: 10.1039/D0AN00746C), the naked-eye detection of sulfur dioxide using mesoporous silica nanoparticles loaded with colorimetric reagents (DOI: 10.1039/D0AN00621A), gold nanoparticles and quantum dots as signalling labels for a lateral flow immunochromatographic assay (DOI: 10.1039/C9AN01996K), and Prussian blue nanoparticle-loaded liposomes as signalling labels for a photothermal immunoassay (DOI: 10.1039/D0AN00417K). Other original papers describe an adaptation of the DNA-templated synthesis of fluorescent metal nanoclusters for the detection of a DNA-modifying enzyme (DOI: 10.1039/D0AN00928H), and the rapid detection of prions *via* nanopores (DOI: 10.1039/D0AN00063A). An original paper in this themed collection also presents an application of metal–organic framework nanoparticles for hydrophilic interaction liquid chromatography (HILIC) (DOI: 10.1039/D0AN00304B).

Additional original papers in this themed collection address nanoparticle surface chemistry and reactivity, which are complex and often challenging to characterize, but essential for function. One review paper focuses on the topic of light responsive nanozymes (DOI: 10.1039/D0AN00389A), an original paper re-examines the mechanism by which arsenic(III) ions aggregate gold nanoparticles in colorimetric assays (DOI: 10.1039/D0AN00946F), and another original paper examines the impact of a shell architecture on energy transfer from lanthanide-based upconverting nanoparticles to dye-labeled DNA (DOI: 10.1039/C9AN02532D). A review also explores how natural or selectively guided protein adsorption on nanoparticles can be strategically exploited for *in vivo* applications (DOI: 10.1039/D0AN00633E).

The above papers are but a small snapshot of the field of analytical nanoscience. Year after year, there are exciting explorations and engineering of nanomaterials for detection and imaging, nanomaterial-driven advancements in analytical methods, and new approaches to nanoscale characterization. The strategically targeted pairing of nanomaterials with analysis and imaging applications, in-depth understanding of the physicochemical properties of nanomaterials, and improved and more accessible methods for nanomaterial quality control will continue to maximize the return on research investment. Such efforts will ultimately lead to new benchmarks for analytical performance, and to manufacturing and commercialization of technologies from analytical nanoscience. The scientific and societal impacts have the potential to span health, energy, the environment, and more.

We hope you enjoy reading about the research in this themed collection.

