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Editorial

Single Molecules and Atoms

The last decade has brought a revolution in the ability of chemists to study and manipulate single molecules and atoms. Single molecules and atoms have been studied in vacuum, liquids, solids, and on surfaces, both with electron tunneling probes and with optical methods. Spectroscopy, shape, and even chemical reactivity have been investigated. Examples range from single enzyme molecules to organic dyes, to single isolated atomic ions in a magnetic bottle. Far from just a scientific curiosity or just an elegant textbook example, studies on single molecules and atoms are offering a new perspective on many important fundamental issues in physics, chemistry, and biology. In particular, the ability to study single members of a chemical ensemble of molecules is leading to some of the first direct information on spectroscopic and chemical heterogeneity. These studies probe individual members of an ensemble, yielding direct information about the distributions of physical quantities rather than just the first moment of the distributions.

At the same time, single molecules offer exquisite probes in biophysics and materials science for the investigation of spatially resolved structure and dynamics, e.g., the local mobility in a phospholipid bilayer or in a muscle fiber. From an analytical chemistry perspective, single-molecule spectroscopy represents the ultimate in sensitivity. That is, research in this area is finding immediate applications ranging from DNA sequencing to biomolecular sorting.

A driving force in the single-molecule field has been the belief that, by simply exploring new regimes, new physical and chemical effects will be discovered and new physical insights will be obtained. The field has been punctuated by a series of discoveries that involved scientists proposing that a novel single-molecule or -atom study might be possible, followed by the hard work to realize these difficult experiments in practice. The continually improving technology of modern experimental methods, ranging from state-of-the-art lasers and detectors, ultrasensitive fluorescence detection methods, and scanning microscopy approaches has been critical in achieving these observations. Many of the central concepts for the entire field were established in the seminal work in the mid-1980s on the spectroscopy of single isolated ions in vacuum. But, the first report of the optical spectroscopy of a single molecule did not appear until 1989, and involved a low-temperature aromatic hydrocarbon present as a diluent in a molecular crystal. In the early 1990s the first reports of single-molecule spectroscopy at room temperature appeared involving samples at surfaces and in liquid solution. When electron rather than optical probes are considered, direct imaging of single molecules and even atoms has been possible for over two decades, through the use of electron microscopy. However, the invention of scanning tunneling microscopy (STM) in the late 1980s allowed for a tremendous improvement in spatial resolution and has produced the ultimate atom images.

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This special issue includes a selection of some of the most exciting recent directions in single-molecule and -atom investigations. However, due to the limited number of articles in an *Accounts of Chemical Research* special issue, it was not possible to thoroughly cover the many important directions in this field. In particular, many recent applications of scanning force microscopy and STM to single biomolecules and to single molecules at metal interfaces are not included (but have been reviewed recently in several places). We hope the reader enjoys this "snapshot" of the exciting and rapidly developing field of the spectroscopy and manipulation of single molecules and atoms.

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