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PrimeView
Scanning probe microscopy

Scanning probe microscopy (SPM) uses a sharp tip to physically scan the surface of samples to obtain information at the atomic level. Scanning tunnelling microscopy (STM) and atomic force microscopy (AFM) are the two most established forms of SPM, with a number of variants derived from these two methods.

Experimentation

STM and AFM provide avenues for obtaining high spatial resolution images of sample surfaces. Both techniques use a tip sharpened to a single atom to raster scan the sample. STM uses a conductive tip to measure the tunnelling current between the tip and the surface when a bias voltage is applied, with information acquired by monitoring the tunnelling current as the tip scans the surface. AFM uses conductive and non-conductive tips, measuring local force. Information is acquired by measuring deflections of the tip and using a force-feedback loop. Tips are produced by mechanical cutting, electrochemical etching or more complicated nanofabrication techniques. When fabricating the tip for experiments in ultra-high vacuum and low-temperature conditions, the best way to ensure an atomically sharp tip is to functionalize the tip by picking up a single atom on the sample surface.

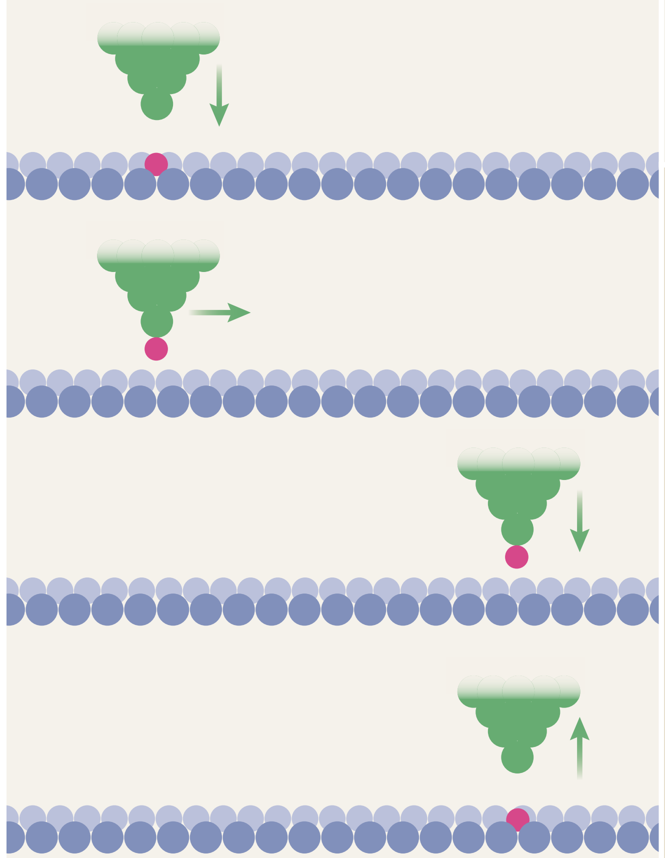
● There are currently no standards for the representation of SPM data in publications, and sometimes misleading filters are used on images.

Results

The steps involved in data processing include image inspection, noise analysis, filtering and image reconstruction. Images are pseudo-3D; the data about the surface are presented on an X–Y plane, and for each point a Z-height is shown as a false colour scale. Presenting SPM data in 3D is visually appealing but scientifically inaccurate, as the technique is surface-probing and not intended to measure the internal volume of the sample. Image visualization is made difficult by the lack of common SPM file formats and proprietary microscope-associated software for image analysis. Gwyddion and WSxM are free, open-source software used for analysis and have the benefit of being compatible with most file formats acquired by commercial microscopes.

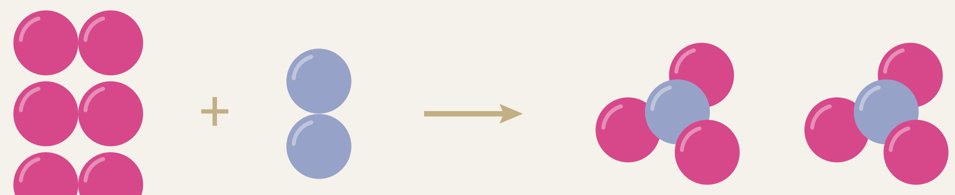
Applications

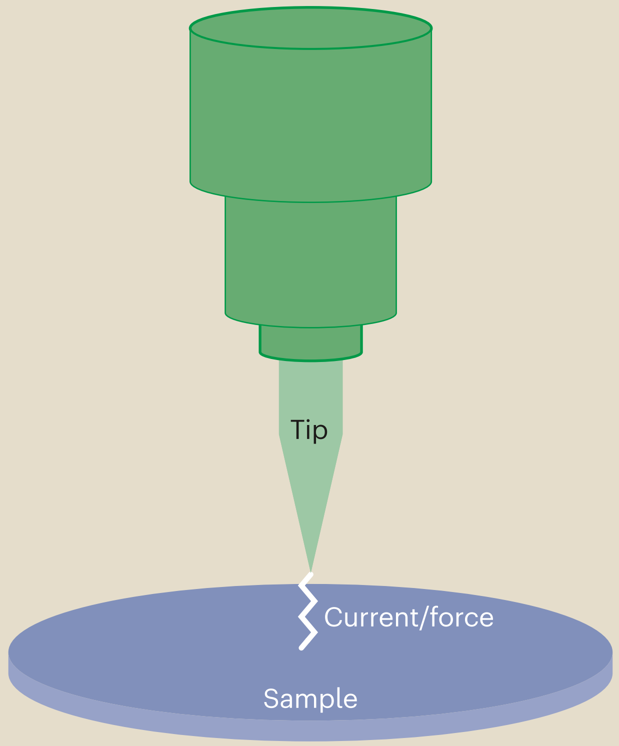
SPM is used in many research areas, including physics, chemistry, materials science and biology.



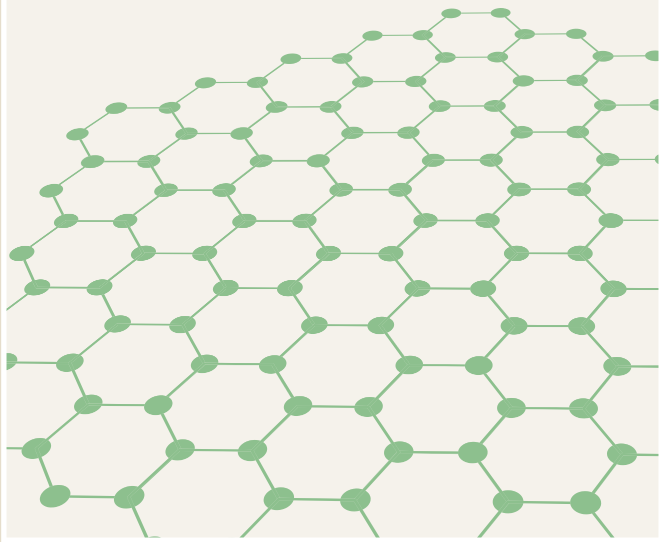
SPM can be used to move individual atoms. AFM is able to measure the atomic forces involved in these manipulations.

SPM is used to probe and control chemical reactions at the single-molecule level.

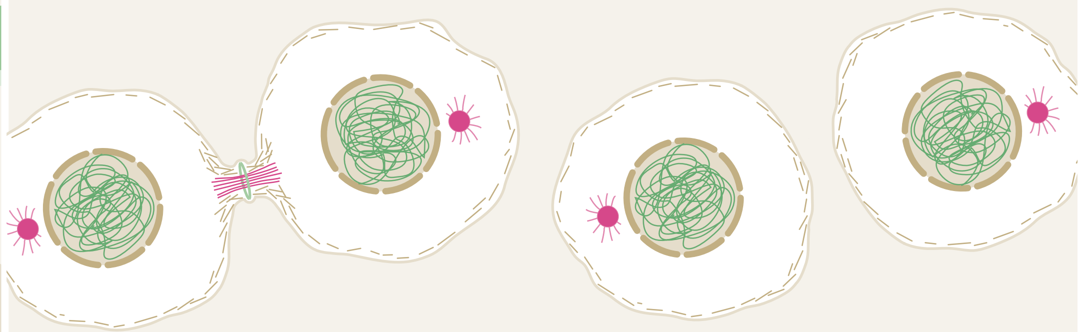




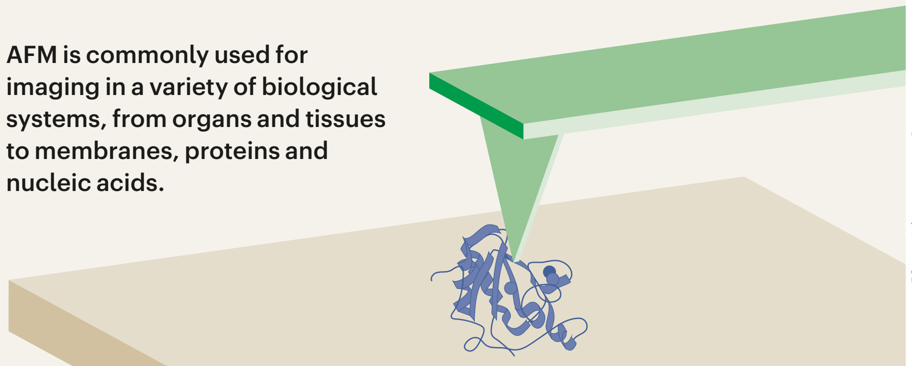
Both STM and AFM are useful for probing the electronic, vibrational, optical and magnetic properties of 2D materials like graphene.



Time-lapse AFM has been used to measure real-time biological processes like cell division.



AFM is commonly used for imaging in a variety of biological systems, from organs and tissues to membranes, proteins and nucleic acids.



Limitations and optimizations

SPM is limited by its impact on the sample, its limited temporal resolution and its inability to measure buried surfaces. The SPM tip inherently disturbs the surface and any adsorbates, deforming the sample surface. This tip disturbance can be reduced by enhancing detection sensitivity and using only small current or force for imaging. The temporal resolution of SPM is limited by the bandwidth of the electronics used for signal acquisition and the resonance frequency of the scanner head. Temporal resolution can be improved by combining SPM with ultra-fast pump–probe technology. Buried interfaces are inaccessible to SPM because it is a surface-sensitive tool. Furthermore, high spatial resolution relies on short-range tip–surface interactions. Breaking the sample apart for cross-sectional SPM is a possible solution to this, although lateral information cannot be obtained this way.

Reproducibility and data deposition

SPM is a young field, with many laboratories operating prototype and/or customized equipment. Operation, data acquisition, tip fabrication and treatment, as well as data processing and analysis, vary between groups, resulting in limited reproducibility for general users. Establishing general reporting standards for data format, data processing and image reconstruction are needed to promote both reproducibility and data sharing.

Outlook

Future directions include integrating machine learning with SPM to enable 3D imaging, developing SPM for extreme conditions like ultra-low and ultra-high temperatures and using AFM to simultaneously image, quantify, map and manipulate specific interactions in living systems.

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