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Still feeling the force

As the impact of the atomic force microscope is felt more and more in nanobiotechnology, physical scientists continue to use and develop this versatile instrument.

When seeking to convey the impact that the atomic force microscope (AFM) has had on science, authors often quote the number of times the original paper[1] by Gerd Binning, Calvin Quate and Christoph Gerber has been cited since it was published in *Physical Review Letters* (*PRL*) in 1986. According to the *Web of Science*, this paper had received more than 5,200 citations at the time of writing. Surprisingly, perhaps, this landmark report — which boasts the very literal title "Atomic force microscope" — is not the most-cited paper to appear in *PRL:* that honour belongs to a report outlining a new way to calculate correlations between electrons in computational physics[2]. However, there is more to impact and influence than number of citations, and what is most impressive about the AFM is the way in which it has been applied to so many areas of science — from the 7×7 surface reconstruction in silicon so beloved by physicists, to the applications in nanobiotechnology described in the review article by Daniel Müller and Yves Dufrêne on page 261.

The AFM has its origins in the invention of the scanning tunnelling microscope (STM) at the IBM Zurich Research Laboratory in 1981. As with so many other important breakthroughs, the paper[3] reporting the STM was rejected at first (by *PRL*) before being published in *Applied Physics Letters* and earning Binning and Heinrich Rohrer a share of the Nobel Prize for Physics in 1986. The STM and the AFM are now the foundations on which a wide range of scanning probe microscopy (SPM) techniques — such as magnetic force microscopy and dynamic force microscopy — have been built[4].

What these SPM techniques all have in common is that a flexible cantilever containing an ultrafine tip is scanned over a surface and the change in some quantity (for example, a tunnelling current or a force) is measured and converted into an image of the surface. The first atomic-resolution images emerged from the STM a year or so after its invention because the signal was an electrical current, which was relatively straightforward to work with. However, it took longer for the AFM because the interaction between the tip and the surface involves several different forces (which is also one of the reasons why it is so versatile) and, moreover, the movement of the cantilever has to be converted into an electrical signal before the image can be produced[5].

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In their review article, Müller and Dufrêne report how the ability of the AFM to measure the interactions between and within single biomolecules is important for understanding a range of topics including "tissue development, tumour metastasis, bacterial infection and an almost uncountable number of medical and biotechnological questions". In addition to spatial resolution, the AFM can study biological systems without fixing or staining them, as is required by many other bioimaging techniques. (This same advantage is shared by a variety of label-free cantilever-based sensors, such as that reported on page 301.) Time-lapse AFM also allows researchers to observe biological specimens at work, although there is scope to improve the time resolution of this approach.

While biologists grasp the opportunities offered by the AFM with both hands, various groups at the spiritual home of the instrument — IBM Research — continue to work on both the fundamentals and applications. Earlier this year, for instance, Markus Ternes and co-workers[6] used an AFM to measure the force needed to move an atom on a surface for the first time, whereas researchers on the IBM millipede project[7] are attempting to overcome the speed limitations of the instrument by using arrays of AFMs (4,096 at the last count) for data storage applications. In the millipede project the AFMs are used to write/read data to/from a polymer-coated silicon substrate. An alternative approach to information technology in which the data are stored as different oscillation states of the nanomechanical element itself is reported by researchers from NTT on page 275.

An outstanding challenge in SPM is to chemically identify the elements on a surface[8]. However, this is an area where electron microscopy techniques have an advantage (page 255), which is why this community is now looking to move into a third dimension — but that is a completely separate story.

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