New ways with microscopes

The range of the phenomena usable in the construction of microscopes continues to increase. Neutrons, for example, are now being used in place of photons.

IF you have a particle or a field of some kind whose interaction with material objects varies with their constitution, the chances are that you will be able to fashion a microscope from the phenomenon. That truth is nicely illustrated by the versatility of microscopy based on the electromagnetic fields corresponding to optically visible radiation. Contrast between different elements of an object can depend on reflectance, on absorption during transmittance through a thin section, on rotation of the plane of polarization or on variations of refractive index, as in phase-contrast microscopy. The texture of an image is determined by the contrast, but a useful microscope also requires a means of magnification equivalent to the lenses of the familiar microscope. Two new developments this week suggest that people's ingenuity is far from exhausted.

The report by a group of Spanish molecular biologists and Switzerland-based IBM researchers on p. 253 of this issue is an application to a biological problem of a technique of microscopy previously used for the measurement of the surface structure of semiconductor materials and others used in the construction of electronic devices, and which may itself be the only application to microscopy of a strictly quantum phenomenon. Electrons, the textbooks say, will tunnel through a potential barrier if there is a state of identical energy for them then to attain. What is called the scanning tunnelling microscope is for practical purposes a device for arranging that the tip of a fine electrode will physically follow the profile of a surface at a distance of 10 ångströms or less.

In the usual application to the measurement of the profiles of semiconductor surfaces, the voltage between the electrode and the semiconductor is maintained at a value sufficient to promote an electron from the filled valence band to one of the energy states of the largely unfilled conduction band (usually a mere fraction of a volt), but which is less than the work function of the material of which the electrode tip is made, and which then serves as the potential barrier. The electrode tip can then be made to follow the surface profile by means of circuitry, including a piezo-electric crystal, designed to keep the tunnelling current constant, and at a value which may be no more than a few nano-amperes. For all the world, the device is the electronic analogue of the engineering devices for measuring successive profiles of a surface by ampli-

fying electro-mechanically or otherwise the displacements perpendicular to the surface of a small ballbearing that is rolled along in contact with it.

The sensitivity of the quantum tunnelling effect is vividly illustrated by the way in which Baró *et al.* show a series of profiles along a surface of pyrolytic graphite which indicate a step-like structure corresponding to the abrupt termination of a couple of layers of the carbon atoms accounting for less than 7 ångströms of thickness.

Indeed, the resolution of the microscope is reckoned to be of the order of 1 ångström perpendicular to the surface and between 5 and 10 ångströms laterally. Baró *et al.* explain clearly enough how they have been able to correlate the known shapes (from electron microscopy) of bits and pieces of the bacteriophage $\phi 29$ dried on a graphite surface with the measured tunnel profiles, but their promised account of the mechanism of conduction through these biological molecules could be of great interest in its own right. Their technical achievement, however, is to have made the microscope work in air at ordinary pressure, which should make this type of instrument more versatile even in the measurement of semiconductor surfaces.

The other new development is the first realistic account of a neutron microscope, a goal long advocated by the Soviet physicist I.M. Frank but now realized by a group at the Technical University of Munich and the Laue-Langevin Institute at Grenoble (Herrmann, P. *et al. Phys. Rev. Lett.* **54**, 1969; 1985). This microscope uses "ultra-cold" neutrons from the source at Grenoble, while the microscope itself consists of a pair of mirrors — a large parabolic mirror 20 cm in diameter and a smaller (5 cm) mirror which is convex and spherical.

Ultra-cold neutrons are neutrons moving very slowly, some 6 metres a second in this case. Their interest for would-be neutron microscopists is that they can be reflected from suitable surfaces as if they were photons, which is a simple consequence of the circumstance that, at speeds like this, their wavelength is greater than the internuclear spacing in materials such as nickel-58 (used for coating the "optical" elements in the Munich design).

The snag is that the trajectories of neutrons moving so slowly will be affected by gravity, which is why the two mirrors are arranged in a vertical direction, with the

secondary mirror above the primary (and each of them fixed in a horizontal plane with a precision of 10^{-4} radians). Even so, neutrons moving vertically will be decelerated, so that neutrons starting out with slightly different speeds will, left to themselves, come to a focus at different points, which is the equivalent in this field of what those who design optical instruments know as chromatic aberration.

It turns out that the chromatic aberrations of the two mirrors will cancel out only if the neutrons reflected from the parabolic mirror are allowed to reach the peak of their trajectory, at a height of 2 metres or so, and then allowed to fall back onto the secondary mirror, whose reflecting convex surface must therefore point upwards, like the larger primary.

The system has been designed to yield a magnification of 50, with the object placed near the optical focus of the parabolic mirror. The image is formed after reflection from the secondary mirror some 1.5 metres above the primary, whence neutrons are reflected sideways (and downwards, so that they can pick up a little speed) into a neutron detector, which simply counts the numbers arriving. Herrmann *et al.* say that a suitably faceted mirror deflecting neutrons from different parts of the field into different detectors would allow almost instantaneous observations.

So far, they have only the most humdrum observation to report, that of the profile of the neutron intensity across a slit placed in the object plane. The measured resolution of this neutron microscope is 0.1 mm, but that, the authors say, is determined by the counting errors with the low-intensity source of ultra-cold neutrons now available. (Grenoble plans 100 times as much intensity soon.) Aberration with the present arrangement should limit resolution to about 0.02 mm, but preselection of the velocity of the neutrons should allow that to be reduced.

But to what end? The authors' dream is that the reasons and techniques that have made the scattering of thermal neutrons a powerful means of telling the distribution of hydrogen in matter of all kinds can be translated simply into neutron microscopy. But one guesses that a large part of their motivation must be a little like the familiar reason for climbing Everest. Nobody else has made a neutron microscope function at a reasonable magnification, although Frank's Soviet group is well on the way.

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