MICROSCOPY

Reconstructing the third dimension

An approach to microscopy has been developed that can be used to determine, from a single imaging angle, both the position of a specimen's individual atoms in the plane of observation and the atoms' vertical position. SEE LETTER P.243

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In this issue (page 243)[1], Van Dyck and Chen report an electron-microscopy technique that draws on an analogy with the method used in astronomy for determining distances to galaxies. The technique allows high-resolution, three-dimensional information to be obtained about a sample using only one viewing direction.

A central observation in astronomy is that distant galaxies are moving away from us, and from each other, with a speed that is proportional to their distance from Earth. In other words, the farther away they are, the faster they are moving. Because the speeds of galaxies can be measured from the Doppler effect, which shifts the galaxies' light to the red end of the electromagnetic spectrum, their distances can be determined using the constant of proportionality between the speed and distance, known as the Hubble constant[2]. This central observation, called Hubble's law, is crucial evidence for the now accepted view that the Universe originated in a Big Bang, as a tiny, unimaginably dense entity that has been expanding ever since. What's more, it provides astronomers with a neat way of determining the distances to objects, which would otherwise be impossible using only the objects' observed positions on the sky.

The problem of calculating the distance of an object from the plane of observation (image plane) also exists in other fields of research. One such field is electron microscopy. Because an electron microscope produces a two-dimensional image of a sample, the lateral positions of the sample's atoms can be observed directly to high precision. However, as with most images recorded on two-dimensional media, including conventional cameras, the vertical positions (heights) of the specimen's constituents in the direction perpendicular to the image plane are not easily found.

One way to determine these heights involves tomographic electron microscopy, in which a three-dimensional image is reconstructed from projected two-dimensional images obtained from a range of viewing directions. But for imaging at atomic resolution, this method requires the microscope's electron gun to be mechanically tilted with sub-ångström precision over a large angular range, a feat that has not yet been achieved ***[OK?]***. Moreover, a typical electron microscope records only the intensity of the electron wave that is scattered by the sample. The wave's phase provides much of the important structural information about the sample, but the phase at different image points is not ordinarily recorded on an electron micrograph. However, it can be found using a process known as focal series reconstruction[3,4], or by creating interference between the scattered wave and a known (unscattered) reference wave, as is done in an imaging technique called electron holography[5].

Van Dyck and Chen suggest that it is possible to calculate the heights of atoms from the image plane using only one viewing direction, if the phase can also be determined. The authors point out that the rate at which the phase changes near the image of a particular atom is proportional to the height of that atom. The heights of the atoms can thus be calculated by determining the value of the constant of proportionality, which is roughly analogous to the Hubble constant. However, it should be noted that the proportionality quantity is constant only in the vicinity of the position of a particular atom in the image plane, and that because of aberrations in the microscope's lenses its value is approximate. Therefore, the constant of proportionality allows only ***[ok?]*** the height of that particular atom to be measured.

In applications of holography that have captured the public's imagination, a ghostly three-dimensional image of a macroscopic object is reconstructed from the information given by a two-dimensional interference pattern (the hologram) of two laser beams. The idea was first proposed[6] by the physicist Dennis Gabor for imaging microscopic objects using electron waves instead of light beams. For this, the macroscopic object may be regarded as an ensemble of point scatterers, and the fact that fringes in the interference pattern overlap is no obstacle to correctly reconstructing the spatial positions of these point scatterers. In this technique, the three-dimensional nature of the image automatically gives information about the third dimension. This is also the basis of atomic-source holography[7], which has been used, for example, to determine the positions (including the heights) of atoms adsorbed on a surface.

Van Dyck and Chen propose that knowledge about the third dimension can instead be obtained by first reconstructing the normally invisible phase of the electron wave, and then exploiting the analogy with Hubble's law. They demonstrate their technique for atoms in a system composed of two layers of graphene — a one-atom-thick, honeycomb-like lattice of carbon. For the proposed technique to be more generally applicable, it will be necessary to extend the algorithm to reconstruct truly three-dimensional objects, as Gabor envisaged. ■

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