FIG. 2 Geometry of a zone plate. A cylindrical beam can be considered to pass through a series of concentric circular zones (Fresnel zone). By blocking off the odd-numbered zones (or even-numbered ones) with opaque rings, one can increase the amplitude at the image plane I produced by waves from an object at O by allowing only paths that interfere constructively.

Optics, 2nd edition, published by Addison-Wesley in 1989).

Curiously, the total amplitude and the intensity, proportional to the square of the amplitude, are much larger with the zone plate than in its absence. Thus the presence of the opaque rings actually increases the intensity at the image point over what would be observed if there were no zone plate — a rather counter-intuitive result. This prediction was verified by Lord Rayleigh in 1871 by making a zone plate for visible light (the first zone radius is of order a millimetre). Zone plates are not generally used for wavelengths for which suitable materials exist for making conventional lenses, but Fresnel lenses which are based on an extension of the same principle are commonly used in overhead projectors because they provide economical large-area lenses for collecting light from the bulb.

Carnal *et al.* used a commercial Fresnel lens suitable for focusing X-rays in their new experiment with atom beams. A beam of helium atoms, excited into a long-lived (metastable) excited state for ease of detection, was directed through an object structure — a single slit or pair of slits — and then diffracted by the zone plate to form an image (Fig. 3). The distribution of the focused atoms in the image plane was recorded by a detector sensitive to metastable atoms.

The authors found the image to be 7/8 of the object size, in proportion to the ratio of the image-to-object distances just as expected for any lens. To obtain clear images, they needed to make several refinements. The atoms all had to have similar de Broglie wavelengths (to make the beam 'monochromatic').

Carnal *et al.* achieved this by using a supersonic source of helium which produces atoms with only a small spread in velocities, and by exciting these atoms to the metastable state with a collinear electron beam. Moreover, the temperature of the source could be varied from room temperature down to 12 K by cooling with liquid helium.

This changes the mean atomic velocity, which is inversely proportional to the wavelength, so that the authors verified that a well-defined image is formed only at a particular wavelength for a particular distance of the detector from the lens. A further refinement was to place a wire across the centre of the zone plate, greatly increasing the contrast by blocking the undiffracted zeroth order of the beam which would give a high background intensity. Nonetheless, 6 per cent of the metastable atom flux before the zone plate was focused into the image. The radial bars in the zone plate, which hold the rings in place, do not influence the imaging properties.

This first experiment has shown that a Fresnel zone plate is a useful element in atomic optics. It has a great advantage over other methods for focusing atoms, based on static magnetic or electric fields, as it depends only on the de Broglie wavelength of the atoms, not on

FIG. 3 The experiment of Carnal *et al.* The metastable helium atoms (He^*) pass through an object structure before being focused by a Fresnel zone plate, and cause the moveable detector (a secondary electron multiplier; SEM) to give out a small pulse of charge on each impact.

their internal properties, and so is not specific to any particular atom.

The performance of the system could be improved by using a more monoenergetic atom beam produced by laser cooling of the atoms, and also the intensity could be increased by pushing current microfabrication techniques to their limit to make a larger zone plate. Carnal and colleagues suggest that finely focused atomic beams could achieve a spatial resolution of a few nanometres and that matter waves produced by this technique could be used to probe material surfaces. □

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Economy of scale

ACCORDING to one theory of smell, our noses respond to the various frequencies at which smelly molecules vibrate. Last week, Daedalus proposed that micro-organisms work the same way. They sense their chemical environment by reacting to the vibrational modes of nearby molecules. If so, says Daedalus, they should also react to radiation of the same frequency or set of frequencies as those molecular vibrations.

Unfortunately, this radiation would be in the far infrared or higher microwave region, which is strongly absorbed by the water in which the organisms live. So Daedalus proposes to irradiate them with visible light, modulated at the relevant far infrared frequencies. This is easily generated by modern optical methods and travels readily through air and water. Its interaction with the organisms' receptors, however, will be strongly non-linear. The light will be demodulated, the modulation frequency will be re-instated on the surface of the organisms, and will trigger their chemoreceptors.

At a stroke, our control over the little beasts will be wonderfully enhanced. Genetic engineers trying to persuade a group of reluctant *E. coli* to swallow some crafty plasmid will merely have to irradiate the colony with light carrying the correct trigger frequencies, when they will all obediently gulp it down. Doctors faced with a staphylococcal infection resistant to the usual antibiotics could shine light on it designed to trigger the cell wall opening response of the creatures, when they would leak to death. Protozoa such as paramecia, which navigate on chemical clues, could be steered around at will. 'Tickled' with light designed to imitate a noxious chemical, they would immediately turn away; a second flash mimicking a nutrient particle would turn them towards it. Under light simulating the attachment signal of a second organism, they would bind to an object presented to them. In fact they could be taken over completely.

Nanotechnologists will welcome these willing workers. Under properly programmed light, a paramecium could seize a fine copper wire, and carry out point-to-point wiring on the most complex microchip. A whole squad of them in the same programmed light could even wire up a big matrix of chips simultaneously, each conducting an identical 'walk' around its local environment. Other optical command sequences could instruct the creatures in microweaving, micro-engraving with tiny diamond scalpels, and even the assembly, operation and improvement of micromachines. The industrial revolution could be repeated on a microscopic scale.

David Jones