be supported by CO_2 diffusion to the cell surface[7] (~0.3 divisions per day; Fig. 2). This provides compelling evidence that HCO_3^- is an important source of inorganic carbon for the natural diatom population.

Bloom-forming diatoms use HCO_3^- as a source of DIC, they possess a carbon concentrating mechanism, and as a result, are not limited by CO_2 availability. If this is the case in productive coastal waters it is probably also the case in the open ocean where higher ratios of DIC to nitrate and phosphate, lower maximum pH during the growth season, and smaller phytoplankton size should make the acquisition of inorganic carbon easier. It is doubtful that inorganic carbon is limiting in the open ocean, unless some other factor, such as low zinc availability[11], impairs its uptake and fixation by phytoplankton[10]. Our results have important implications for ocean carbon cycling, and suggest that a critical evaluation of carbon isotope fractionation models[5,6] which assume passive CO_2 uptake by phytoplankton is needed.

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An atom-focusing mirror

The recent interest in atom-optics has mainly been directed at the manipulation of atomic beams by static fields or lasers[1–3]. Using an alternative approach we have succeeded in focusing in two dimensions a neutral atomic helium beam at room temperature with a reflective optical element (an atom mirror). Such focusing relies on specular elastic scattering, which leaves the coherence of incoming wavepackets unchanged.

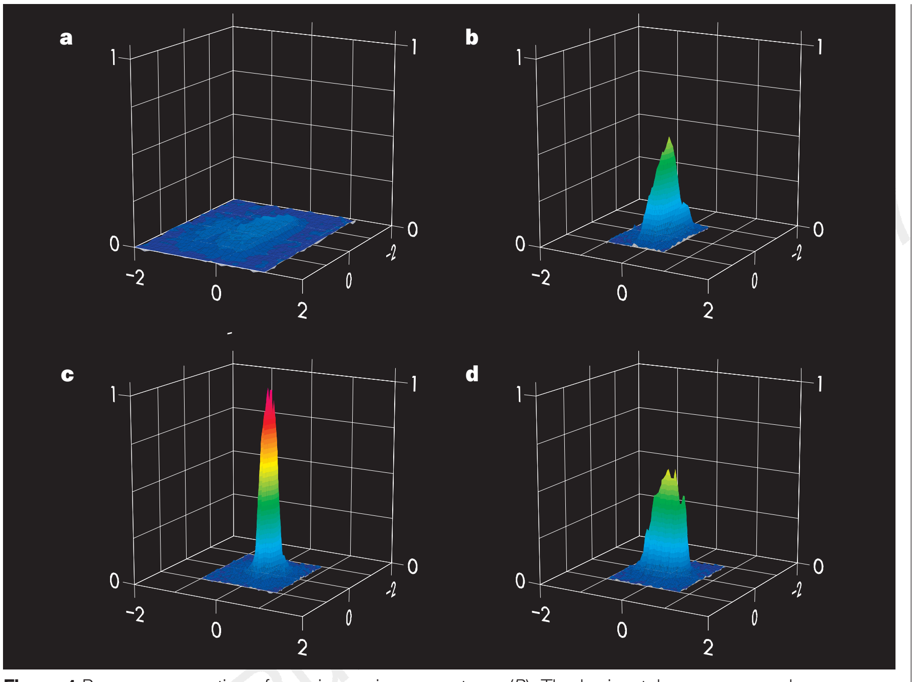

Figure 1 Beam cross-sections for various mirror curvatures (*R*). The horizontal axes span a plane perpendicular to the beam direction of travel (scale in mm). The vertical axis shows normalized intensity. **a,** Unfocused beam. **b,** First focus in scattering plane ($R\approx1.2$ m). **c,** Disk of least confusion ($R\approx0.8$ m). **d,** Second focus perpendicular to scattering plane ($R\approx0.5$ m).

We created the atom mirror from a single 50-µm-thick silicon crystal cut along the (111) crystal plane. The surface was hydrogen-passivated *ex-situ*[4] making it inert (the reflectivity remained constant over several months at 10^{-6} mbar). The crystal was deformed electrostatically in an arrangement similar to a parallel plate capacitor to give a parabolic profile for focusing. The focal length can be varied *in situ* simply by adjusting the electric field.

We produced a helium beam in a supersonic expansion source[5] at room temperature (corresponding to a wavelength of 0.52 Å). We placed the mirror 0.7 m from the source and 0.8 m from the detector with the beam incident at 45°. We measured beam cross-sections for different mirror curvatures (Fig. 1) by scanning the beam across a 100 µm pinhole in front of the detector. Focusing in the geometry used here is necessarily astigmatic. The intermediate disk of least confusion (Fig. 1c) has a spot diameter of 210 ± 50 µm. The solid angle of the unfocused beam is reduced by a factor of about 100. There is a corresponding increase in intensity. The spot size is not limited by aberrations of the mirror, but solely by the geometry of the system and the size of the object (confirmed by computer simulations to be the surface of last scattering in the supersonic expansion[5]).

The ultimate performance of the mirror is limited by the geometrical abberations[6] and diffraction[7] due to the finite size of the mirror (elastic scattering gives no chromatic aberrations). The only other atom-focusing method that relies solely on the de Broglie wavelength of the atoms is a Fresnel zone plate[8]. A zone plate is diffraction-limited because of the necessary constraints on the plate diameter (about 0.2 mm with current technology). A mirror, on the other hand, has no such inherent limit on its size. With normal incidence, a point source, and image planes 1 m and 0.1 m from the focusing element, the best spot size would be about 2.5 nm with the beam spanning about 2 mm on the mirror surface.

It follows that a helium microscope with nanometre resolution is possible. A helium atom microscope would be a unique non-destructive tool for reflection or transmission microscopy. It could be used to investigate fragile and insulating materials such as polymers and certain biological samples. Focusing mirrors also have the potential to increase spatial resolution and intensity in conventional helium-surface scattering instruments.

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