Figure 2 **The atom laser in action.** Drops of coherent sodium fall under gravity, about five milliseconds apart.

or fermions, with half-integral spin. The crucial physical difference between the two is that no two fermions can occupy the same quantum state, so coherent behaviour is impossible.

Most alkali metals are bosons, so a bunch of alkali atoms can join together in identical states of motion. At sufficiently low temperatures, Einstein and Bose showed that the propensity to do this sets in with a vengeance, and all the atoms condense into the lowest-energy state — hence the term Bose–Einstein condensation. It is done in practice by cooling a magnetically trapped gas of atoms to extraordinarily low temperatures, below a microkelvin. So far, no other way has been found to make a pure laser-like assembly of atoms. A Bose–Einstein condensate was first made using rubidium in 1995, at the Joint Institute for Laboratory Astrophysics in Colorado³, and later that year at MIT.

In the new experiments at MIT, they have made the next step in producing a laser-source of atoms: the smooth transfer from the magnetic box in which the atoms are corralled to an atomic beam¹ (Fig. 1). At present, the beam is simply collimated by the magnetic fields of the trap, but in

principle it can be directed at will (for animations and other details see <http://bink.mit.edu/dallin/news.html#matterwave>). Ketterle and colleagues have also shown how to test the properties of the beam very precisely². They made a pair of sources, shining both of them on a screen, and looking at the regions where they overlap. If two such beams are coherent (that is, pure enough in wavelength) then a regular pattern of stripes will be observed on the screen, just as the MIT group saw.

These experiments have produced exquisite results that can go directly into the textbooks. There are other aspects of laser light, such as continuous output and stable intensity, that cannot yet be reproduced in the matter beam, and many would want to reserve the term atom-laser for the next generation of sources. But what cannot be doubted is that a huge step has been made towards making laser-like sources of atomic de Broglie waves a tool for science and technology.

The new source shares many of the practical advantages of laser light. It is an intense, precisely directed, beam of matter. It should be possible to focus such a beam using diffraction gratings or the equivalent of lenses for atomic waves — an atom passing through a laser beam that has an intensity gradient feels a position-dependent force, so a beam with the right geometry acts as a lens. Therefore, atoms can be directed to a point or feature on a material surface, for example. This is precisely what we need to produce systems on the nanometre scale, such as micro- (or rather nano-) electronic circuits.

Coherent matter waves may also surpass laser light beams as fundamental measuring sticks. The spacing between the lines on the ruler is set by the beam's wavelength, which is around a half a micrometre for visible light. But with matter waves, the wavelength can be tuned by changing their speed (light, of course, moves with a fixed speed in a given medium) and one should be able to produce matter waves with wavelengths a hundred times smaller than that of a visible photon. Accurate, continuous-wave atomic clocks will permit a wide range of new measurements. Atom-laser interferometers may be the best gyroscopes and accelerometers, making more precise measurements of gravity than ever before. They will also be used to test certain quantum theories that predict a divergence from conventional quantum behaviour on large scales. □

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Daedalus

Sheets of light

Optical fibres can not only transmit light-pulses; they can amplify them. When illuminated by a suitable pumping radiation, an erbium-doped silica fibre becomes a distributed laser, amplifying the pulses that travel along it. Daedalus is now extending the principle to two dimensions.

Imagine, he says, an optically transparent flat sheet a wavelength or so thick, doped with lasing material, and coated onto a transparent support of lower refractive index. Pump-radiation shines into the sheet through the support; a number of optical emitters around its periphery can launch pulses into it on command.

These pulses would travel and amplify out in two dimensions. Where they hit the edges of the sheet they would be reflected back into it. Where two such pulses passed through each other, each would lose gain as it entered a region depleted of excited states by the previous passage of the other. Highly complex energy distributions would develop; the whole thing would be an extremely subtle optical computer.

More usefully, however, it would be a splendid flat visual display screen, lit by the pumping radiation beamed into it from behind. Its brightness at any point would depend on the local attenuation of this radiation. This in turn would depend on how recently it had been depleted by the passage of a pulse. Any possible picture could be generated by a suitable choice of pulse-patterns from the emitters around the edge of the sheet. To compute the pattern needed to generate a given picture would be very tricky; but the resulting scanless high-resolution image could be updated continuously at megahertz rates.

A simpler and cheaper two-dimensional laser would be an oil slick on water. Such a slick can be a few wavelengths thick, or even thinner. It has optically smooth surfaces; its refractive index exceeds that of water and could trap radiation within it by total internal reflection, even in the presence of ripples. It could easily dissolve a suitable lasing organic erbium complex. And it could cover a huge area.

A pond or lake covered by a lasing slick would be a wonderful trap for solar energy. This powerful optical pump would excite it not in pulse mode, but continuously. The lake could be ringed with immersed reflectors, except for a small region bearing a photovoltaic-cell array. The intercepted energy would bounce around the slick till it hit the photocells and was absorbed. All the energy captured by the whole lake would be neatly delivered to that one point.

David Jones