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# Coaxing Light From Single Atoms

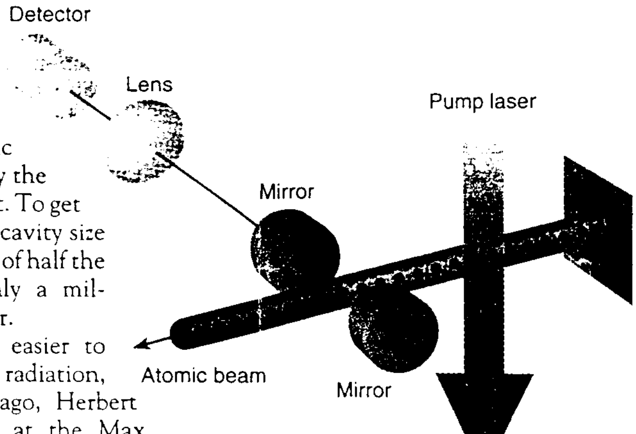
In the last few years, physicists have turned the atom from an abstract concept to a tangible entity they can isolate in traps, see with special microscopes, and pick up with optical "tweezers." They have even put single atoms to work as the moving part in nanoscale switches. Now a group of physicists at the Massachusetts Institute of Technology has taken atomic-scale technology a step further: They have built a laser that wrings its light from individual atoms.

This single-atom laser, described in last week's *Physical Review Letters*, is based on excited barium atoms trickling one by one through a tiny mirrored cavity, where the atoms release bursts of light that "resonate" in the cavity and build up into a laser beam. This microlaser isn't likely to find a use in surgery or metal-working, but it may eventually lead to advances in precise optical communication, say the researchers, led by physicists Michael Feld and Kyungwon An. In addition, says MIT physicist Daniel Kleppner (not a member of the group), "Life gets kind of interesting when you have just one atom at a time in a laser cavity." Over the last 20 years physicists have written hundreds of theoretical papers predicting how individual atoms would behave in these optical echo chambers. Now, by studying the light of the single-atom laser, says Feld, they can start testing these predictions against the real thing.

Conventional lasers rely on vast numbers of atoms "pumped" into unstable energetic states by an external light source so that they all will emit light in concert. The light emitted by each atom as it drops into a ground state bounces back and forth within the laser cavity and triggers other atoms to emit light of exactly the same frequency and phase, eventually leading to a sort of chain reaction. But researchers realized years ago that even if the cavity holds just one atom at a time, the light emitted by each atom can resonate for long enough to stimulate atoms entering the cavity a split-second later to emit light of the same frequency.

Even so, says An, extracting a measurable laser beam from single atoms was a demanding assignment. He and his colleagues needed superefficient mirrors that could trap light 10,000 times better than do the mirrors used in an ordinary laser. They also had to build the tiny mirrored cavity to exactly the right size so that the specific frequencies of light emitted by the atoms would resonate within it. To get the most from the atoms, the cavity size had to equal an exact multiple of half the light's wavelength—with only a millionth of a wavelength of error.

This sort of precision is easier to achieve for longer wavelength radiation, Kleppner notes. Ten years ago, Herbert Walther and his colleagues at the Max Planck Institute for Quantum Optics in Germany did manage to build a single-atom maser—a laserlike device that generated coherent microwaves from single atoms. But building a cavity that would work for visible light took the MIT group years of failed attempts, says An. To keep the spacing from getting jostled out of place by every passing footstep, they eventually rigged a sensitive feedback system that generates an electrical voltage in response to small tremors. The voltage in turn drives piezoelectric actuators that readjust the mirrors to the right position.




**Atoms marching one by one.** Barium atoms excited by a pump laser release their light in a mirrored cavity, where it builds up into a laser beam.

ILLUSTRATION: C. FABER SMITH
SOURCE: KYUNGWON AN/MIT

Through this tiny mirrored box, just a millimeter across, the MIT workers send a procession of barium atoms that have been boosted into an excited state by a conventional laser. As the individual atoms pass though the cavity, each one in turn couples to the electromagnetic field already resonating there from previous visitors, Feld says: "You have a stream of atoms that enter and leave the cavity and each time contribute more energy to the electromagnetic field." Eventually, he says, the intensity of the field reaches an equilibrium. At that point light leaking out of the cavity through one of the mirrors generates a faint beam of laser light that the researchers have been able to detect.

Part of the laser's appeal to quantum physicists is the effect that starts the lasing process when the first atom enters the cavity. It might seem that there's nothing in the dark, empty cavity to trigger light emission from the first atom. On the scale of the atom, however, this "quantum vacuum" bubbles with little fluctuations of energy at every possible wavelength. Because the resonator is exactly the right size to amplify wavelengths that match those emitted by the atom, the first atom to enter the cavity "feels" these vacuum fluctuations, and they are enough to stimulate emission. "I've always thought that was fascinating," says Kleppner. "The atom and the empty vacuum become coupled together."

Only when they are on their own can atoms display such quantum effects so vividly, say Feld and An; when atoms gather in crowds, these effects tend to be swamped by random behavior. As a result, the MIT researchers hope to put their single-atom laser to work in probing the workings of the uncertainty principle, which dictates that if you know too much about one property of a quantum system, such as an atom, you lose knowledge about another. In one demonstration, Feld and his colleagues will rig their laser to produce light in what they call a "pure number state," in which they will know the exact number of photons of light in the cavity. The cost, according to quantum theory, is all knowledge of the photons' phase. "No one has ever achieved this before," says Feld.

Eventually, the ability to reduce one form of uncertainty in the laser signal at the cost of increasing another could help researchers push back the limits of optical communication, says Feld. But for now, he and his co-workers want to focus on basic science. "The physics is rich," he says, and that will be enough to keep them busy.

–Faye Flam