SCIENCE NEWS of the week

Stopping an Atom in its Tracks

For a long time physicists have sought methods of studying a single atom in isolation. To do this they must trap the atoms — that is, somehow stop or at least sharply curtail the various motions in which an atom naturally engages and hold the atom more or less at rest in the laboratory where they study it. One motivation for doing this is to study the basic foundations of quantum mechanics, the science of how things happen inside atoms and smaller structures. For nearly 80 years, physicists have built up this science on the basis of inferences drawn from the behavior of large aggregates of atoms. Physicists — or at least some of them — are eager to see whether the basic processes proposed by quantum mechanics really happen on the level of the single atom.

Experimenters have pursued two approaches to atomic trapping more or less in parallel. One is to use ions, atoms that have either lost a few electrons or gained a few extra and so are electrically charged, and confine them through the influence of electric and magnetic forces. The other method is to take atoms as they usually come — that is, electrically neutral — and confine them under the influence of beams of laser light. This technique has just succeeded in the trapping of single atoms of sodium.

This method of trapping neutral bodies is applicable to a wide range of neutral objects, from atoms, which are characteristically 1 angstrom across, to objects up to 100,000 times as large, including viruses, bacteria, small solid spheres and tiny oil drops. The procedure holds promise in studies of very basic chemistry — how one atom relates to and binds itself to another atom — and in microbiology. Physicists John E. Bjorkholm, Steve Chu, Arthur Ashkin and Alex Cable, from AT&T Bell Laboratories in Holmdel, N.J., developed the method. Ashkin and Bjorkholm described it last week at the International Quantum Electronics Conference '86 in San Francisco. It is the outcome of an effort that began in 1970 with some theoretical papers by Ashkin.

Light pressure from a laser beam will stop the forward motion of a small object, but in the absence of some restoring force, the light pressure will then kick the object backward. For objects a good deal larger than the wavelength of the light, gravity will work as the restoring force: The object's weight balances the thrust of a laser beam coming from below. For objects very much smaller than a light wave — and an atom's size lies between one-thousandth and one-ten-thousandth of a light wave — gravity is not a sufficient restoring force.

It seemed for a long time that there was no way to get one, but in 1978 Ashkin showed that if the laser beam were sharply focused, it would supply the restoring force itself. The shape of the light wave front near the focus produces the restoring force, and if everything is properly arranged, an object will be trapped at a point just short of the focus.

With this arrangement the experimenters in the late 1970s were able to trap small solid particles and oil drops. They tried tobacco mosaic viruses, which are cylinders 180 angstroms in diameter and 3,000 angstroms long. The trap could hold them for days without damage, and it also inhibited the tumbling that they naturally do. At this point, according to Ashkin, some bugs swam into range (the experiments were performed in water). They turned out to be real biological bugs — bacteria, that is; the trap could hold a living bacterium for several hours. Then the experimenters decided, as Ashkin puts it, to "optocute" it. They increased the power of the laser beam until it killed the bacterium. The carcass stayed in the trap also.

A limitation of these optical traps is that the objects must be cooled — in physical terms, their thermal vibrations must be damped. Otherwise they skitter out of range before they can be trapped. A viscous liquid (water) will cool the larger objects, but single atoms are too small for that.

The solution, worked out last year and performed only a few weeks before the meeting, is what the experimenters call "optical molasses." It consists of shooting a number of laser beams at the atom from all sides. This procedure looks like trapping, Bjorkholm says, but it really isn't, as there are no restoring forces. The "molasses" laser beams bounce the atoms in such a way as to reduce their thermal vibrations. Then the sharply focused trapping beam comes on, and the atoms are caught.

Ashkin and Bjorkholm point out that the optical molasses produces what amounts to a new state of matter, an ultracooled gas. These atoms are cooled to a temperature of 1 millikelvin, a thousandth of a degree above absolute zero, which is well below the solidification temperature for any substance under ordinary circumstances, yet they remain physically a gas. The experimenters expect fascinating new physics from this also. *— D. E. Thomsen*

Taking quantum leaps one at a time

Niels Bohr made a revolution in physics by proposing that physical processes inside atoms do not go in the smooth, continuous way familiar in classical physics, but in sudden sharp, discontinuous acts that became known as quantum jumps. Bohr's proposal was accepted because it solved the difficulties encountered in trying to interpret data on atomic processes in a classical way, but until now the justification for it rested on the behavior of large aggregates of atoms. Nobody had been able to test the theory of quantum jumps on the level of the single atom.

Now there are two claims to the observation of single quantum jumps in single atoms, one from a group at the University of Washington in Seattle (Warren Nagourney, Jon Sandberg and Hans Dehmelt), the other from a group at the University of Hamburg (Thomas Sauter, Werner Neuhauser, Rainer Blatt and Peter E. Toschek).

As described last week in San Francisco at the International Quantum Electronics Conference '86, the two experiments are quite similar. Both used barium ions in electromagnetic traps. In such an apparatus, an electromagnetic field of a complicated shape holds the electrically charged ions in place. Red and green lasers irradiate them to excite a series of quantum transitions that yield fluorescent light. The amount of fluorescence recorded varies according to how many atoms are radiating at any moment, and the data the experimenters present show jumps that indicate whether one, two, three, etc. ions are in the trap and radiating. Thus, they say they have observed individual quantum jumps.

A questioner at the conference wanted to know whether the experimenters would try to see whether quantum jumps are truly instantaneous — another radical difference from classical physics, where changes and interactions always take time. Toschek said he had thought of doing it, but had not figured out a scheme.

Toschek also pointed out that this work opens to experiment a question that has so far been purely philosophical: "Do photons [or other subatomic particles] have an individuality?" Physicists have tended to assume that photons, other subatomic particles and atoms themselves were indistinguishable from others of their class. At higher levels of organization this is not so: One tree is distinguishable from another, one person from another. Perhaps we shall have to start naming photons and barium atoms. *— D. E. Thomsen*