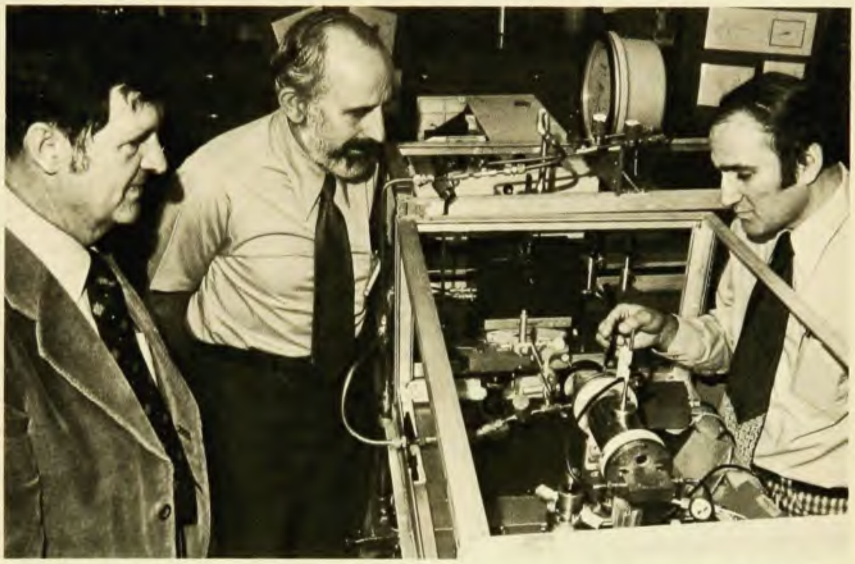
search & discovery

Resonance electron spectroscopy detects single atoms

A group at Oak Ridge National Laboratory reports that by means of the new technique of resonance ionization spectroscopy they have observed single atoms of cesium. They say that one atom in an environment of 10^{19} atoms or molecules of another kind can be measured with their method, and they do not believe this to be a limit. In subsequent experiments, the group has observed density fluctuations of atoms, absolute photodissociation cross sections, time-resolved diffusion and chemical reaction of atoms, and the detection of cesium atoms from the spontaneous fission of californium nuclei.

In 1975 William M. Fairbank Jr (now at Colorado State University), Theodor W. Hänsch and Arthur L. Schawlow (Stanford University) reported detecting as low as 100 atoms/cm^3 using cw resonance fluorescence in sodium vapor. A single atom was contained in the detector beam at any instant. The technique required a steady-state concentration of atoms.



The single-atom detector at Oak Ridge National Laboratory, with experimenters (left to right) G. Samuel Hurst, Jack P. Young and Munir H. Nayfeh. The group reports that with this device they have detected cesium at a concentration as low as one cesium atom in 10^{19} other atoms.

That same year G. Samuel Hurst, Marvin G. Payne, Munir H. Nayfeh, John Judish, E. Bryan Wagner, Chung-hsaun Chen and Jack P. Young (Oak Ridge) developed the resonance ionization spectroscopy method. Each atom in a selected quantum state was converted to a positive ion and a free electron by the absorption of two photons, one of which is resonant with an intermediate state, lying more than half the distance to the ionization continuum. With relatively small energy per pulse in a pulsed dye laser with a linewidth of several angstroms, the intermediate state comes into quasiequilibrium with the ground state. Then other photons from the same laser pulse photoionize the intermediate state. The method was initially applied to measuring the number of excited atoms created by proton interactions in a given volume. The group also showed that if enough photons/cm^2 are available, all the excited states would be ionized.

This year, Hurst, Nayfeh and Young

continued on page 20

Second "back bend" helps explain nuclear band crossing

A kink discovered in a curve describing the behavior of the moment of inertia of a nucleus at high angular momentum is providing a new clue to nuclear structure. The unusual behavior was found by making measurements on nuclei with spins as high as $32\hbar$ in an experiment done by a group at the Lawrence Berkeley Laboratory and reported in the 20 June 1977 *Physical Review Letters*.[1] The members of the group are I-Yang Lee, Marie-Madeleine Aleonard, Marie-Agnes Deleplanque, Youssef El-Masri, John Newton, Reinhard Simon, Richard Diamond and Frank Stephens.

At low spin values—up to about $12\hbar$—a deformed (that is, non-spherical) nucleus with even numbers of both neutrons and protons rotates, experiments have shown, somewhat like a rigid body, with many of its nucleons joined in a collective motion. Stephens points out that the nucleus exhibits superfluid effects that generally reduce the moment of inertia to one half to one third of its rigid-body value. In such nuclei, the lowest energy E corresponding to a given angular momentum I varies in a smooth parabola with the angular momentum, that is, $E \propto I(I+1)$; these lowest states are known as "yrast" (from the Swedish word for "dizziest") states. But at higher spins there occurs a peculiarity known as "backbending," which was first observed in 1971, by Arnie Johnson, Hans Ryde and J. Sztarkier (Research Institute for Physics, Stockholm): The curve of the energy of the yrast states against their angular momentum has a slight but distinct kink. Plotted as the effective moment of inertia against the square of the angular velocity, the effect shows up as a turning back of the curve on itself and a subsequent bending forward. A sharp increase in the moment of inertia is accompanied (due to conservation of angular momentum) by a decrease in rotation rate, and hence an energy that is lower than expected.

By observing and identifying transitions to angular momenta considerably higher than had been seen before, the Berkeley group has now found, as reported in their Letter, a second discontinuity in the yrast levels of erbium 158. In of 10^9 neutrons/pulse have been achieved at Lawrence Livermore. However, time-of-flight measurements verified that the neutrons had an energy of 14 MeV.

McCall noted that their two-beam system could be modified to increase its intensity so that spectra could be obtained, but in any case these measurements should be done by next March, when a 10-kJ, eight-beam laser is expected to begin operation. Then McCall expects the experimenters will obtain yields of 10^{11}–10^{12} neutrons/pulse, at which time they will do spectral measurements both on neutrons and on charged particles.

In 1982 Los Alamos expects to complete the High-Energy Gas-Laser facility (postponed by budget cuts from its original target date of 1981), which will produce 100 kJ in 1 nanosec. With this device the Los Alamos workers expect to obtain fusion energy output from the target equal to the laser light energy striking the target, so-called "scientific breakeven." —GBL

References

1. T. H. Tau, D. Giovanielli, G. H. McCall, A. H. Williams, in *Proceedings* of the IEEE Conference on Plasma Science, Austin, Texas (published by IEEE, New York, 1976); page 95.
2. C. W. Cranfill, Los Alamos Report LA-6827-MS, 1977.

Single-atom detection

continued from page 17

reported[1] observing single atoms of cesium. In general, one would need two lasers to detect atoms in their ground states. Photons of one energy promote the atom to a low-lying excited state, then photons of a different energy promote the atom to a higher bound state. Photons from either laser complete the three-step photoionization process. The lasers are tuned to select a given type of atom. Thus, one electron is selectively removed from the atom, Hurst told us. Then a gas proportional counter detects one free electron, starting an avalanche that is proportional to the number of electrons that started the event. Alternatively, one electron can be detected with an evacuated electron multiplier. Such an approach theoretically should work in about half the elements, Hurst said. And for certain special elements, such as cesium or rubidium, only a single laser is required.

In the work reported in *Applied Physics Letters*, Hurst, Nayfeh and Young used a counter filled with a mixture of 90% argon and 10% methane. Cesium atoms were evaporated continuously, most of them reacting chemically with impurities. They increased the distance between the cesium source and the laser until they observed only an occasional single atom. Hurst explained that from Poisson statistics, he knows the probability of two atoms being present is vanishingly small. He said they obtained the same pulse-height spectrum as for a single electron.

More recently, Hurst, Nayfeh and Young used[2] resonance ionization spectroscopy to detect density fluctuations of free atoms in a small volume. They say that this is the first time such a measurement has been done and that previously, density fluctuations could only be deduced from such phenomena as Brownian motion or Rayleigh scattering. Hurst said that the ratio of the square root of the number of atoms to the number of atoms must be at least 5–10% or the fluctuation will not be observable; this implies numbers in the range 100–400.

Larry Grossman (University of Kentucky), Hurst, Payne and Steve L. Allman used[3] one laser to dissociate cesium-iodide molecules and then another laser to detect single atoms of cesium. Because the system could be saturated, Hurst said, it was not necessary to know the density of cesium-iodide molecules to obtain the absolute cross section for photodissociation as a function of wavelength.

In related work, Grossman, Hurst, Steven D. Kramer, Payne and Young studied[4] the diffusion coefficient of cesium in argon gas and of cesium reactions with O_2 in argon gas. They feel that this method will serve as a new way of studying diffusion and chemical-reaction kinetics. Hurst notes that the approach should be useful for studying combustion processes, in particular.

The Oak Ridge group is continuing work on statistical fluctuations, both of density and photons. Very recently, Curtis E. Bemis, Young, Kramer and Hurst have been observing cesium atoms produced by the fission of an individual Cf^{252} nucleus. In approximately 16% of the fissions, a highly stripped cesium ion is produced among the heavy-mass fission products. These are injected into a gas and allowed to come to rest in a laser beam. Now Hurst is collaborating with Bemis, Young and Kramer in studies of a nuclear isomer state of Am^{240}, which is produced in a heavy-ion reaction in the ORIC cyclotron. The Am^{240} is a spontaneous fission-isomer state that decays with a halflife of about 1 millisec. Because the fission-isomer state of Am^{240} is highly deformed, the electronic energy levels of the americium would be shifted. The laser or lasers will be tuned to that shift (an optical isomer shift), and resonance ionization spectroscopy will be used to ionize Am^{240} before fission. Then a single electron from that atom might be observed.

Fairbank (who is the son of low-temperature physicist William Fairbank of Stanford, who recently reported evidence for isolated quarks), is using resonance fluorescence to look for a quark atom, whose spectral lines would be drastically shifted. The existence of such a shift had been proposed by Fairbank, Hänsch and Schawlow. Nayfeh hopes to do a quark experiment with single-atom detection at his new post at Yale University.

Hurst believes that resonance ionization spectroscopy will have many applications, aside from the ones already made. In solid-state physics, one can look at the evaporation of atoms from surfaces or the transport of atoms through a medium. Hurst feels that the one-atom detector could become a very useful device for analytical chemistry and should have many environmental applications. —GBL

References

1. G. S. Hurst, M. H. Nayfeh, J. P. Young, Appl. Phys. Lett. 30, 229 (1977).
2. G. S. Hurst, M. H. Nayfeh, J. P. Young, Phys. Rev. A15, 2283 (1977).
3. L. W. Grossman, G. S. Hurst, M. G. Payne, S. L. Allman, Chem. Phys. Lett., in press.
4. L. W. Grossman, G. S. Hurst, S. D. Kramer, M. G. Payne, S. L. Allman, Chem. Phys. Lett., in press.

SQUID magnetometer used in geothermal survey

A three-axis dc SQUID magnetometer with a sensitivity of 10^{-14} tesla $Hz^{-1/2}$ has been used in a magnetotelluric survey that has revealed an anomaly in the apparent resistivity near Leach Hot Springs in Grass Valley, Nevada. In magnetotellurics, fluctuations in Earth's magnetic field and in the electric field induced in the ground are measured simultaneously. From these data, the apparent resistivity of the ground as a function of frequency can be computed. The survey was conducted by John Clarke and Frank Morrison of Lawrence Berkeley Laboratory and their collaborators. In principle, the group says, the technique has the capability of detecting geothermal sources as much as a few tens of kilometers below Earth's surface. Electromagnetic methods are useful in identifying the position, depth and extent of a geothermal reservoir.

Argonne magnet flown to Moscow for MHD project

Recently a 40-ton superconducting magnet was airlifted to Moscow from O'Hare Airport near Chicago as part of a joint US–USSR effort to develop magnetohydrodynamics. The magnet, built by Argonne National Laboratory, has a field of 50 kG (PHYSICS TODAY, July, page 38). It will be used as the second loop in the U-25 magnetohydrodynamic facility at the Institute for High Temperatures near Moscow. The magnet will be used in a variety of tests to be conducted jointly by the US and the Soviet Union for at least two years as a part of the US–USSR Energy Agreement of 1974. □