and theory indicates that the nucleus would become oblate in shape. If this is indeed what happens, the two observed discontinuities represent only the first and second steps in this process. —HRL

References

1. I. Y. Lee, M. M. Aleonard, M. A. Deleplanque, Y. El-Masri, J. O. Newton, R. S. Simon, R. M. Diamond, F. S. Stephens, Phys. Rev. Lett. 38, 1454 (1977).
2. I. Y. Lee, D. Cline, R. S. Simon, P. A. Butler, P. Colombani, M. W. Guidry, F. S. Stephens, R. M. Diamond, N. R. Johnson, E. Eichler, Phys. Rev. Lett. 37, 420 (1976).

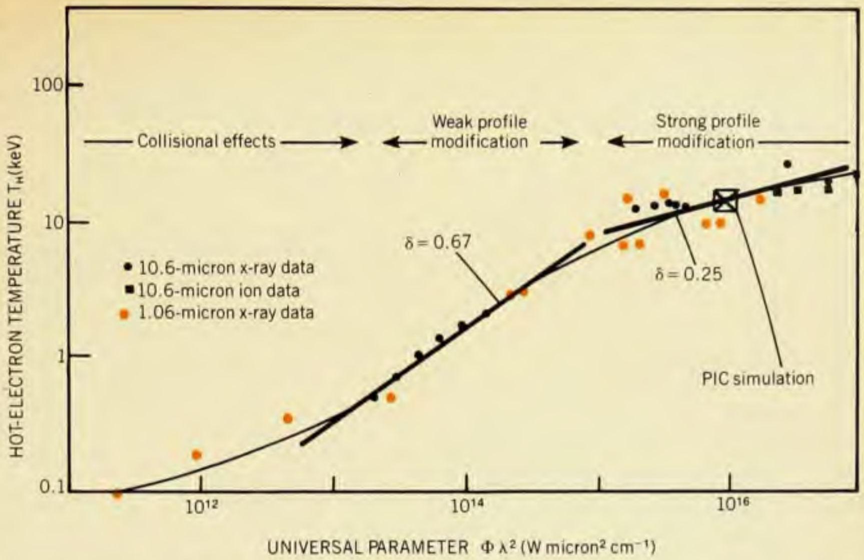
Tests show CO_2 laser is suitable for fusion

Two kinds of lasers are widely used for laser-fusion research, the neodymium-glass laser with 1.06-micron output and the carbon-dioxide laser with 10.6 micron output. It has been a widely held belief that the neodymium-glass laser was far superior for compression of the pellet because of its shorter wavelength. However, recent results at Los Alamos, which were reported at the Conference on Laser Engineering and Applications held in Washington in June, have called this belief into question. The Los Alamos group has compared results with the two kinds of lasers and finds striking similarities despite the factor of ten difference in wavelength. The report was made by Damon Giovanielli, Dale Henderson, Gene McCall and Roger Perkins.

Carbon-dioxide lasers have a calculated efficiency of 3%, the group notes, whereas neodymium glass has an efficiency of 0.1% when operated with the required short pulse lengths. Furthermore, because the carbon-dioxide lasing medium is a gas, it can have a higher repetition rate, and it is therefore of great interest for laser fusion.

However, it was generally believed that the carbon-dioxide laser would be less suitable for laser fusion because, for a given amount of energy, one would produce hotter electrons than with neodymium glass. These hot electrons have a very long range and heat the entire target, making it more difficult to compress, McCall told us. A relatively cold fuel is required because one wants heating to be the result of PdV work. If energy is supplied from outside the target, the process is no longer adiabatic and more energy is needed to compress the target. Very early theoretical predictions were that for a given input intensity, the electron energy would be 100 times higher from carbon dioxide than from glass.

In a series of experiments at Los Alamos, both carbon dioxide and neodymium glass were used, each with an intensity of 3×10^{15} W/cm^2. The group found a hot-electron temperature produced by carbon-dioxide radiation of 15–20 keV, three times the energy found with the glass.[1]



Comparison of data from CO_2 and neodymium-glass laser-fusion experiments. The temperature of high-energy electrons is plotted as a function of the product of laser intensity Φ and the square of the wavelength λ for the two types of lasers. Note that $\Phi\lambda^2$ is a universal scaling parameter. The break in the curve coincides with the laser flux at which profile modification becomes important. Two straight-line fits to the data are marked with their slopes δ.

This unexpectedly low temperature occurs because of a steep density gradient produced by light pressure. The position in the target at which the laser energy is absorbed is not very different when the two sources are compared by x-ray pinhole photography, for either flat or spherical targets. Typically the radiating radius of a spherical target is 20 microns larger than the original target radius. Similarly, for flat targets, x-ray emission occurs from a region about 20 microns thick.

The group plotted the hot-electron temperature for both lasers as a function of $\Phi\lambda^2$, where Φ is the laser intensity and λ is the wavelength, and found a single curve with a very shallow rise at intensities relevant to laser fusion. Theoretical calculations of resonant absorption in self-consistently steepened profiles agree very well with the experimental results. The slopes δ of the straight lines in the figure on this page are predicted by this theory.

Most of the basic physics experiments on electron transport were done on a slab target, with thickness varying from 100 Å to hundreds of microns. Polyethylene (plain and deuterated), solid deuterium and solid hydrogen were used. Most of the work was done with a single-beam laser, but recently the group has used a two-beam device.

The group determined electron energy from the x-ray spectrum emitted by the target, extracting the temperature from the time-integrated spectrum. The team has used x-ray imaging, x-ray line spectra and total emission.

For flat targets, the Los Alamos workers found that for both carbon dioxide and neodymium glass, the absorbed energy fraction was 45±7% for flat polyethylene targets over a wide intensity range.

Another problem anticipated with carbon-dioxide irradiation was that the heated surface would boil off fast ions. It was feared that 90% of the absorbed laser light energy would be carried away by fast ions. Instead, Los Alamos measurements show that the loss of energy is at most 20% of the absorbed energy and does not depend on which laser wavelength is used.

Pellets. After convincing themselves that laser-light–plasma-interaction physics produces similar results for both wavelengths, the group revised their computer codes to incorporate the new data and designed glass microballoons filled with deuterium–tritium gas.[2] They bombarded the pellets with the two-beam carbon-dioxide laser, which began operating for target experiments last December. Total laser power available on target was 0.3–0.4 TW. Pulse lengths were 1–1.5 nanosec, although the implosion time is only 0.2–0.3 nanosec, so that some of the laser energy is lost. As targets are made bigger, however, the pulse length will become better matched to the implosion time, McCall said.

Neutron yields from the target were 10^4–3×10^5 neutrons/pulse, in agreement with predictions. McCall believes that the observed neutrons were indeed thermonuclear in origin because of the similarity of the results to earlier neodymium-glass results and because the low density of hot electrons is unlikely to accelerate particles into the high-density fuel. Because yields were so small, it was not possible to measure a neutron or alpha-particle spectrum from the carbon-dioxide bombardment, as has been done for neodymium glass, where yields 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

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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. □