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Briefs

The short items on this page announce recent developments of importance. Some of these items may be amplified in future issues. None of this material is reported elsewhere in this issue; summaries of this month's articles appear on the opposite page.

MAJOR ADVANCE IN CTR RESEARCH

In mid-July, we attained the highest temperatures ever observed in a major fusion experiment – about 12 to 14 keV – using the 2XIIB magnetic mirror machine. Confinement time was 5 ms, a factor of 12 greater than that achieved by 2XII, the previous-generation experiment. We also observed a plasma density greater than 10^{13} ions/cm^3. These results mark the most significant advance for the mirror program since we obtained our first unequivocal evidence of neutrons from controlled thermonuclear fusion reactions in 1961.

Our results demonstrate that the hotter the plasma, the longer and more stably it can be confined by magnetic bottles of the mirror type. Most plasma losses in our recent experiments were not due to the internal instabilities that have plagued fusion experiments, but were due to the much less serious effects of collisions between plasma particles. We are now altering the 2XIIB to try to extend our results. In particular, we are doubling (to 40 keV) the injected neutral beam energy to investigate plasma stability at temperatures about twice as high as those achieved to date.

In equaling or exceeding all major experimental goals for the 2XIIB, our results strongly support the possibility that a next-generation experiment may be able to demonstrate the feasibility of the mirror approach to fusion. The 2XIIB presently approaches reactor temperatures and densities but does not have the needed confinement time (approximately 1 s for mirror reactors). However, Baseball IIT, a major companion experiment, uses a superconducting magnet to confine a much lower density plasma essentially as long as desired. A next-generation mirror fusion experiment would also use a superconducting magnet and would combine technologies developed in 2XIIB and Baseball IIT research. Such an experiment could be in operation in the early 1980's.

laser enrichment processes. The following is a brief summary of two experiments performed at LLL to clarify the basis for future large-scale laser isotope separation work.[2]

Design Options for Laser Isotope Separation

In general, photoseparation processes consist of three distinct steps: introduction of the isotopic mixture, selective excitation, and extraction of the enriched product. Because each step can be implemented in a variety of ways and the various possibilities can be combined, a large number of potential laser processes can be envisioned. However, a survey of possible methods of laser isotope separation generally presupposes that the operation will be performed on gases rather than on condensed phases. This may not be the most desirable commercial proposition, but present knowledge and currently attainable experimental conditions apply best to gases.

Spectroscopic studies of atomic uranium vapor reveal that the electronic energy levels of uranium-235 and uranium-238 are slightly different. The difference is known as the spectroscopic isotope effect and has a magnitude of about 1 part in 10^5. Although small, such energy-level separations are well within the resolution capabilities of present-day tunable lasers and, by selection of the correct wavelength, it is possible to produce excited uranium-235 atoms in a mixture of uranium-235 and uranium-238. These electronically excited states are not ionized, however, and will, if left alone, revert by radiative energy loss to the normally populated states within a few hundred nanoseconds. Because there are more than 1000 electronically excited states below the ionization threshold, there are obviously many transitions that can be tested for suitability as a primary excitation step.

The isotopic mixture can be introduced either as an atomic vapor or as a molecular vapor or gas. Because atomic spectra have been more thoroughly studied than molecular spectra, a process based on atomic vapor can be readily designed; however, system limitations are considerable. Raised to the temperature required to provide a high density of atoms in the vapor state, molten uranium appears to be a universal solvent; it alloys readily with refractory metals, carbon, and ceramics. We have overcome this problem by the use of special uranium-alloy vapor sources, and significant separation experiments using atomic vapor have been conducted.

Extraction of the selectively excited isotope from the system can be done by either a chemical or a physical process. Processes that use a chemical reaction are especially attractive. Unfortunately, insufficient data are available to propose a workable system. In our preliminary experiments, we have used a physical extraction process, separating ions from neutral atoms and subsequently collecting the ions on a charged plate.

We have tested the feasibility of selective photoionization separation processes in two experiments. The instrumentation used in one of these is shown in Fig. 2. A beam of uranium atoms is generated by thermal decompositions of URe_2 at 2100°C (in an oven at the left of the figure); it has a density of 5×10^{10} atoms/cm^3 at the intersection of the photon beams. The atom beam is irradiated (perpendicular to the plane of the drawing) with a dye laser tuned to excite only the uranium-235 atoms. The laser provides adequate spectral resolution to ensure monoisotopic excitation.

Radiation from a mercury arc lamp spectrally filtered by a monochromator provides the ultraviolet radiation for the second step in the photoionization process (see top left of Fig. 2). Ions are electrostatically deflected from the neutral atoms into a quadrupole mass filter.

Isotope Separation Experiments

Laser isotope separation experiments have been performed at LLL using both natural uranium and samples containing about 50% uranium-235. We have used several methods to prove the feasibility of the two-step photoseparation technique; in all experiments we observed isotopically selective photoionization.

In one experiment, the dye laser was tuned to an absorption line corresponding to a uranium-238 transition and stabilized at the absorption peak. A mass scan with the spectrometer gave the upper trace of Fig. 3, where the mass peak current corresponded (before normalization) to about 1×10^9 ions/s. In this case, no uranium-235 was detected. The second trace shows the mass scan as a function of ion current when the laser was tuned to the uranium-235 transition line and the uranium-238 line is missing. Apart from the clear illustration of isotopically selective photoionization, these two traces show a very interesting phenomenon. Despite the use of 50%-enriched uranium in this experiment, the ion current from the uranium-235 is only 15% the ion

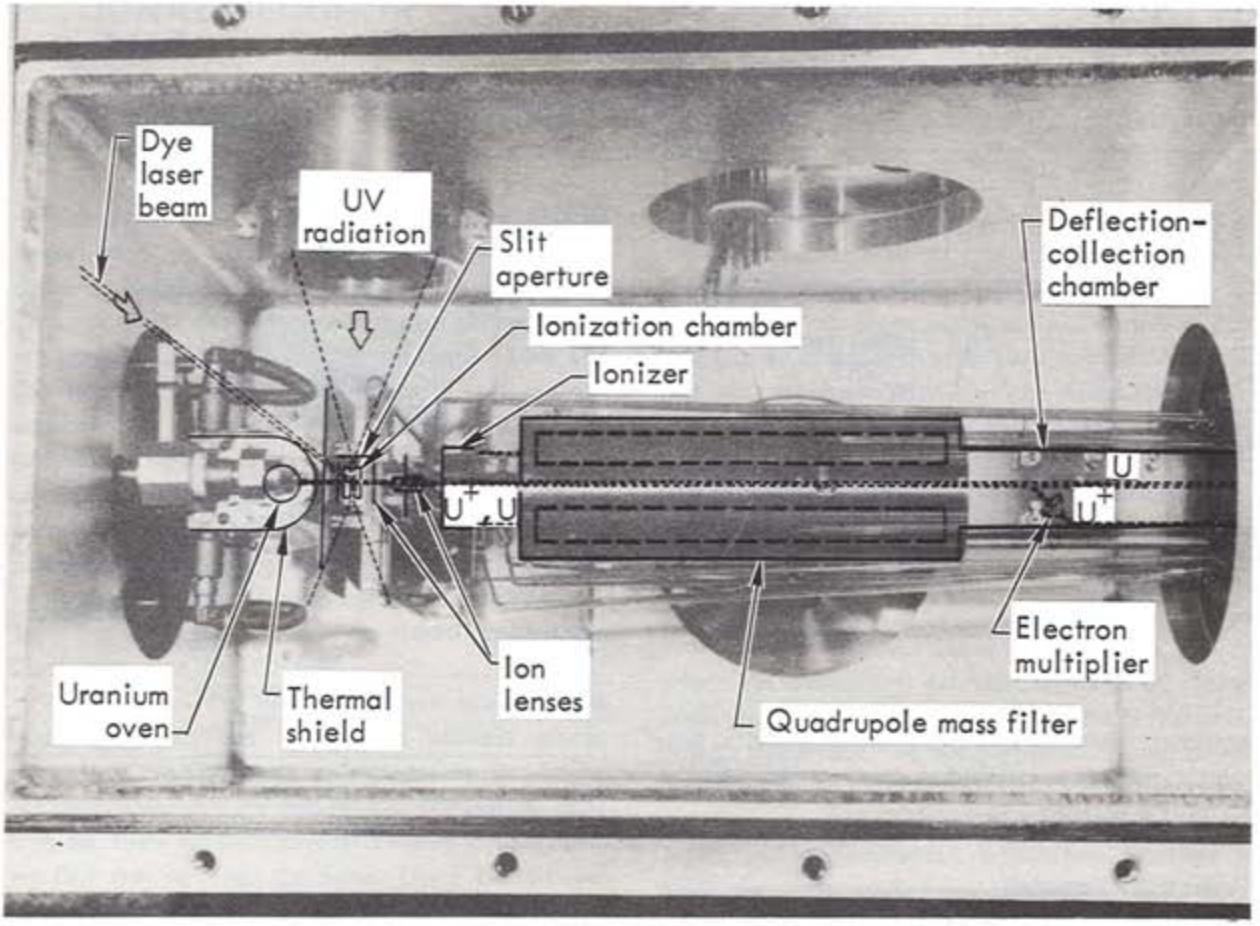

Fig. 2. Photoionization vacuum chamber used to demonstrate isotope separation.

current from the uranium-238 (after separation). This discrepancy is due to the hyperfine splitting that occurs in the particular uranium-235 absorption line. The eight major line components are separated by intervals of 0.3 to 1.5 GHz, so the 30-MHz bandwidth of the laser could be tuned to only one hyperfine component of the uranium-235 at a time. The third trace in Fig. 3 was taken with the uv light on but the laser beam blocked, to demonstrate that the production of ions was not an experimental artifact.

In Fig. 4 we show the results of similar experiments performed with a natural uranium sample. Again, the known isotope ratio of 1 to 140 was further reduced by the inability of the laser to be tuned to more than one hyperfine component in the uranium-235 absorption line.

In more recent experiments, we have enriched macroscopic quantities of natural uranium by irradiating a vapor stream of uranium with two collinear laser beams (see Fig. 5). The uranium-235 atoms were excited by the 378.1-nm output from a xenon ion laser and ionized by uv radiation from a krypton ion laser. The ions were then electrostatically separated from the neutral atoms and collected on a

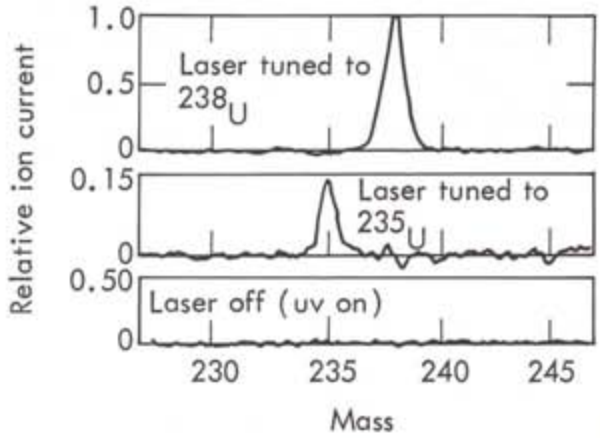

Fig. 3. Mass analyzer output for the laser isotope separation experiments on uranium enriched to 50% uranium-235.