Laser Separation of Isotopes: Big Step

Isotopes of the same chemical element differ in the number of neutrons in their nuclei. This is more than a curiosity of nuclear physics: Neutron-heavy nuclei tend to be radioactive. Nowadays everybody can think of uses for radioactive substances in medicine, science and industry, in addition to which is that shadow no bigger than a mushroom cloud that haunts us all—uranium.

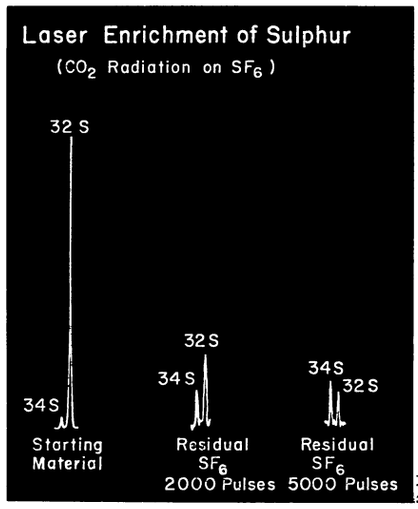
But the radioactive isotopes tend to be rarer than their inert congeners, and methods of isotope separation—ways to enrich a sample of element X so that it has a higher proportion of the radioactive isotope than the run of the mine output—are a practical necessity. At a conference sponsored by the New York Academy of Sciences last week, C. Paul Robinson of the Los Alamos Scientific Laboratory announced a method of isotope separation using laser light that seems to be the simplest yet made public and potentially able to save energy and money over methods now in use.

Success in a similar endeavor is reported in the Soviet Union by a group led by R. V. Ambartsumian (son of the renowned Armenian astronomer). Success in a related endeavor is reported by teams of scientists at the U.S. National Bureau of Standards led by Richard D. Deslattes.

The basic problem in isotope separation is that isotopes behave identically in chemical processes, so chemical methods alone are unable to separate them. The different numbers of neutrons do give the isotopes different masses, and traditional methods of isotope separation, mass spectrometry for small samples, gaseous diffusion or centrifuge methods for large ones, depend on the physical fact that heavier things settle lower or fly farther than light ones.

But the traditional methods are expensive and cumbersome. Development of the gaseous diffusion method and construction of the plants at Oak Ridge and Hanford was probably the greatest industrial difficulty faced by the Manhattan Project in World War II. Robinson notes that gaseous diffusion uses about 10 million times as much energy to accomplish the separation as the minimum nature would require if the job could be done with thermodynamic efficiency.

"If we ask where does this energy go, we find that it is primarily invested in the majority isotope, U-238. Since the separation process depends on a small percentage difference in total mass, we must repeat the diffusion process many thousands of times in order to achieve appreciable separation. What is clearly desirable is an enrichment process that can selectively remove the U-235 with little or no energy investment in the other isotopes."



Changing isotope proportion in SF_6.

Lasers, with their precise frequencies, offer such an opportunity. The mass difference between isotopes means that their excitation spectra will be slightly shifted from one to another. A given atom or molecule can accept energy only in discrete amounts called quanta. In terms of light this means that a given atom or molecule will absorb only a certain spectrum of frequencies, rejecting those that do not correspond to its quanta.

This means that a laser of the proper wavelength can energize one isotope and not another. Energetically excited atoms are chemically and physically more reactive, and such reactions can be used to separate them. In fact, a whole world of laser-induced and laser-enhanced chemistry opens up, of which isotope separation is only one part. Robinson estimates that this work, "if completely successful," could reduce the energy requirement for uranium separation by a factor of 100 to 1,000.

Previously reported methods of laser separation (SN: 6/22/74, p. 396) were generally photophysical and involve two irradiations, a preliminary excitation and then an ionization, after which physical (generally electrical) means are used to sweep out the desired isotope. The present methods are photochemical. They involve a single irradiation, with a carbon dioxide laser.

Robinson's method depends on exciting a series of energy states that relate to vibrations of the molecule. His most prominent example: sulfur hexafluoride. If one can successively excite the vibrational state from lowest to highest, going "up the ladder," as Robinson puts it, the molecule will come apart. The free sulfur, which is preferentially the desired isotope, sulfur 34, can simply be removed from the chamber. The NBS method also depends on exciting vibrational states, but it uses them to preferentially induce chemical reactions with other substances, and the new compounds then carry the desired isotope away.

Los Alamos claims success with boron, chlorine and sulfur; NBS has done boron and chlorine, and Ambartsumian and his group, sulfur. Enrichments up to 3,300 percent are reported by Los Alamos and even higher ones by Ambartsumian. The NBS group reports "significant amounts" of separated substances, up to milligrams.

Robinson puts it in dollars and cents: "Sulfur 34 [the desired isotope] costs approximately $1,000 a gram, whereas the energy requirement for our process is approximately 40 cents a gram."

The method works well for light isotopes that have spectral shifts around the wavelength of the carbon dioxide laser, 10.6 microns. Robinson expects that every chemistry professor with access to a carbon dioxide laser is likely to begin such experiments. But though it works for sulfur hexafluoride, it does not work in this form for uranium hexafluoride, contrary to impressions that may have been gained in other reports. "If it did," Robinson points out, "nobody would be talking about it in public."

The spectra of heavy elements are very complicated, and unambiguous isotope shifts are difficult to find.

Nevertheless, work on an analogous method for uranium goes forward under heavy secrecy and classification for obvious reasons. The Irish have a ballad that celebrates the things that can be done with "a couple o'sticks o'gelignite and me auld alarum clock." Well, with the proper laser and a canister of uranium hexafluoride. . . . "It could cause a worsening of the nuclear weapons proliferation problem," Robinson warns. □