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THE DIRECTOR OF CENTRAL INTELLIGENCE

WASHINGTON, D. C. 20505

File
TAIWAN

National Intelligence Officers

NFAC 075-78
9 January 1978

NOTE TO: Ambassador Gerard C. Smith
           Special Representative for Non-Proliferation Matters
           Department of State

           Richard Holbrooke
           Assistant Secretary of State for East Asian and
             Pacific Affairs, Department of State

           Michael Oksenberg
           National Security Council

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           Deputy Director of Non-Proliferation Policy in the
             Bureau of Political Military Affairs, Department of State

FROM: National Intelligence Officer for Nuclear Proliferation

25X1, E.O.13526

A general reappraisal has
accordingly been undertaken, and the attached paper presents the
preliminary results that were requested by the NSC.

I plan to explore these and other questions

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I will inform you of their results and,
in the meantime, I would welcome any comments or suggestions you may have.

John Despres

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Update to July 1977 OSI Publication, "Worldwide Scientific Capabilities in Laser Isotope Separation"

The attached OSI publication, "Worldwide Scientific Capabilities in Laser Isotope Separation (LIS)," summarizes OSI analysis on this topic up to mid-1977. Although in the main our perceptions of the worldwide situation have not changed in the six months since publication, several events of interest have occurred during that time.

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Experiments in uranium enrichment by lasers are difficult, requiring advanced capability in spectroscopy, laser technology, materials technology, and uranium chemistry. Two approaches are under investigation in the US. In the first, tunable dye lasers operating with visible light excite atoms of one isotope of uranium. The excited atoms are then ionized by another laser and separated by electric or magnetic fields. This work has been mostly unclassified and widely published. Although commercial enrichment by this method requires much additional development, a small facility capable of enriching material for a few weapons could be developed from present US technology in a few years.

In the second approach, lasers operating with infrared light excite molecules of uranium hexafluoride. An ultraviolet laser is then used to dissociate the molecule. Development of these types of lasers has proven to be extremely difficult and would represent a serious obstacle for most countries.

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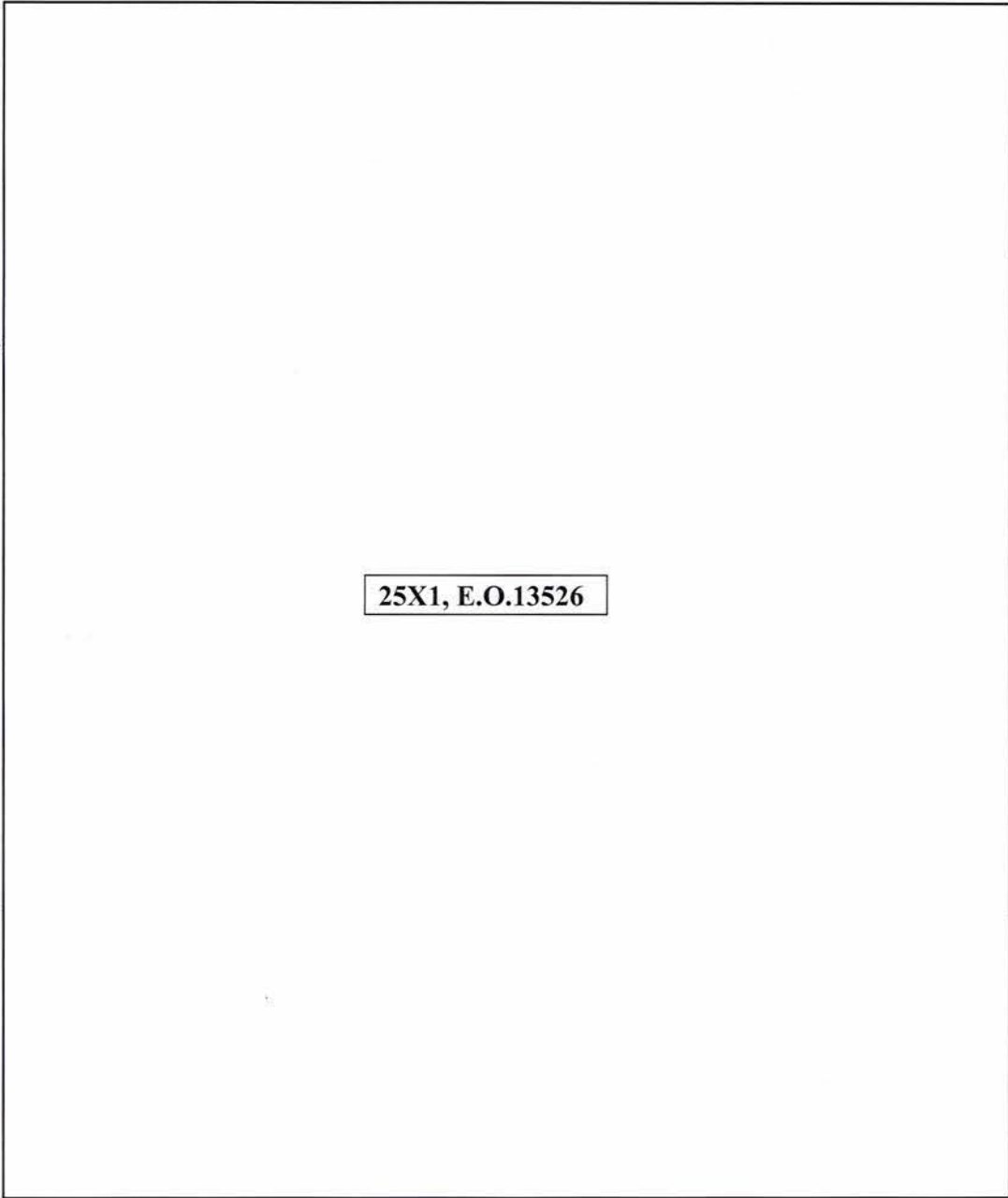Central Intelligence Agency Act of 1949 (50
U.S.C., section 403g)

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Central Intelligence Agency Act of 1949 (50
U.S.C., section 403g)

Worldwide Scientific Capabilities in Laser Isotope Separation (U)
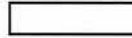
July 1977

Worldwide Scientific Capabilities in Laser Isotope Separation
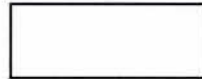
PRÉCIS

In the near future, various countries may use lasers to separate large quantities of valuable isotopes. Such a capability could result in tremendous savings in capital and operating expenses over isotope separation methods currently used, particularly in the case of uranium. It could have profound military significance as well. A related economically important potential application of lasers is to industrial chemical processing.

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Economically significant application of lasers to chemical processing or isotope separation probably will not occur for another 5 years, although economical laser separation of limited quantities of some specialized isotopes could occur before that time. Large-scale laser enrichment of uranium probably will not occur before 1985.

SI 77-10050

WORLDWIDE SCIENTIFIC CAPABILITIES IN LASER ISOTOPE SEPARATION

SI 77-10050
July 1977

CENTRAL INTELLIGENCE AGENCY

DIRECTORATE OF INTELLIGENCE

OFFICE OF SCIENTIFIC INTELLIGENCE

PREFACE

Laser isotope separation (LIS) is a process in which the interaction of accurately tuned laser light with a chemical species stimulates a reaction resulting in the separation of isotopes of a particular element.

Isotopes are atoms of the same element differing only in atomic mass—number of neutrons in the nucleus. Because the electron distributions of the isotopes are essentially the same, they are virtually identical chemically and therefore are very difficult to separate. Lasers open the way for cheaper and more efficient separation of isotopes than traditional methods such as gaseous diffusion. This paper addresses worldwide foreign capabilities in the principal scientific aspects of LIS, emphasizing lasers, high-resolution spectroscopy, and photochemistry in the context of LIS. It does not attempt to assess expertise in other scientific and industrial areas—such as materials technology, fluid dynamics, apparatus availability, and experimental technique—that is necessary for industrial-scale operation.

In the past few years the availability of high power, stable, tunable, extremely monochromatic (narrow bandwidth) lasers has permitted countries having sound laser bases and expertise in connected fields to study and develop numerous techniques for the photoseparation of isotopes and the photostimulation of chemical reactions by lasers. Advances in LIS have facilitated application of lasers to various fields of scientific research—especially rate analysis in chemistry—and LIS soon will have an impact on biological research and medical treatment. In addition, the economic consequences of projected successes in industrial scale LIS of uranium and other elements, as well as related successes in laser catalysis by the chemical industries, are potentially immense. The economic advantages of uranium LIS derive from tremendously reduced capital and especially from operating expenses below other isotopic separation methods and the ability to process the substantial tails left by the other methods. Possible military consequences from the spreading of uranium LIS technology are several years in the future.

Both LIS and photochemistry, with emphasis placed on relevant laser technology, are considered in this report and will be lumped together under the term LIS. The laser requirements for true LIS are usually more stringent than those for photochemistry, including photocatalysis. Technical matters are discussed in an appendix.

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This report, ⬚ was prepared by the Office of Scientific Intelligence and coordinated within CIA. The cutoff for information is April 1977.

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FIGURE

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WORLDWIDE SCIENTIFIC CAPABILITIES
IN LASER ISOTOPE SEPARATION

PROBLEM

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SUMMARY AND CONCLUSIONS

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Laser enrichment of uranium currently seems to be the most significant potential application of LIS in terms of military (nuclear weapons), political (proliferation), and economic (reactor fuel market) consequences. Use of lasers in chemical processing and chemical engineering—such as laser separation of other isotopes, laser fractionation of compounds, laser catalysis of reactions, and spectroscopic and diagnostic use of lasers—is also likely to have a substantial economic, scientific, and medical impact.

DISCUSSION

INTRODUCTION

There are some 60 elements having two or more naturally occurring isotopes. Certain of these isotopes are more valuable than others. For example, uranium-235 is more valuable than U-238 as a fuel in nuclear reactors or in nuclear weapons. Deuterium (hydrogen-2) as a component of heavy water is useful as a moderator in some nuclear reactors and also, along with tritium (hydrogen-3), is useful in thermonuclear weapons. The titanium isotope (titanium-50) having the lowest thermal neutron absorption cross section could be used to make improved reactor cladding. Oxygen-18 is useful in medicine as a nonradioactive tracer for studies of metabolism. The ability to concentrate at a controlled rate the carbon-14 in archaeological remnants would help date relics so old that their carbon-14 content has declined to the point where local radioactivity is below the noise background of the counters used to detect the unconcentrated carbon-14.

Unfortunately, it is now very expensive and time-consuming to separate most of these isotopes, costing from thousands to millions of dollars per kilogram. This cost is not because of the rarity of the particular isotope but rather because of the capital expense and inefficient methods currently used to do the separating. Almost all of these methods depend directly on the small percentage of mass differences between different isotopes or between similar compounds of different isotopes. The most important large-scale methods are the gaseous diffusion process, used for example in uranium enrichment and consuming some 2 to 3% of the gross national power output in its operation, and the gaseous centrifuge process, cheaper to build but about as inefficient in its use of power. The gaseous diffusion process depends on the very small difference in diffusion rates caused by differences in mass. The gaseous centrifuge process depends on centrifugal settling of heavier circulating material to the outside of a channel. Both of these processes require many stages to reach the desired enrichment.

Laser isotope separation, on the other hand, does not depend directly on a difference in mass but rather takes advantage of mass-caused optical spectroscopic differences between isotopes to cause chemical, electrical, or velocity differences that can be taken advantage of, usually in one stage of operation. If typically 20% of the energy of a kilowatt laser can be used in a photoionization scheme with isotopes having typically 10 electronvolt (eV) ionization potential, approximately a mole of substance per hour can be separated, resulting in tons of pure substance per year.
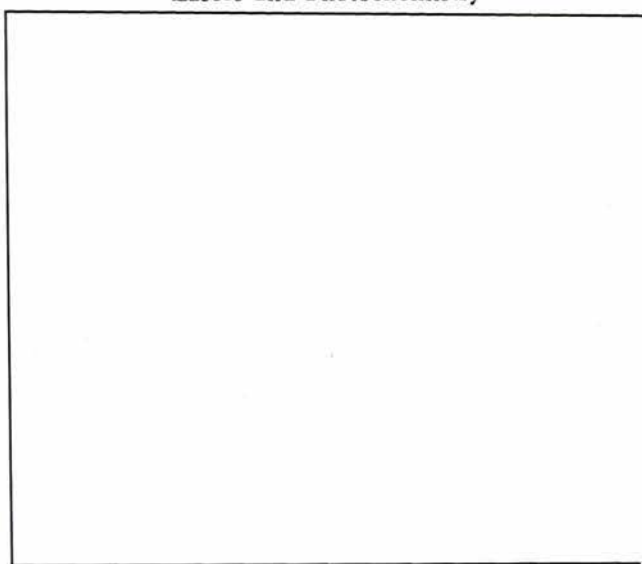
Besides isotope separation, other economically significant chemistry applications of lasers include photocatalysis of difficult reactions; purification of reagents; detection of specific atoms or complex molecules, e.g., pollution monitoring or medical research or diagnosis; ionic implementation of boron, arsenic, phosphorus, or other dopant materials in semiconductors; and stoichiometrically controlled production of thin films or surfaces of complex compounds.

Table 1 ranks the leading countries in order of overall laser technology and photochemistry expertise. It is essentially from these two listings, the balance between them, and our assessment of the quality of LIS research already under way that the overall LIS rankings in the Summary and Conclusions were derived.*

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*Of all the LIS technology requirements, possession of a diversified laser base along with the capability to develop new lasers which are stable, tunable, precise (have narrow bandwidth), and have high efficiency and power is the most critical. Since such laser technology is generally the least developed LIS-related technology, it is considered to be the field to watch first for major advances. Advances in another critical area, high-resolution laser spectroscopy, tend to go hand in hand with advances in tunable, stabilized, line narrowed lasers and will not be addressed separately. Photochemistry is the area that probably contains the next most important achievement possibilities for LIS after laser technology.
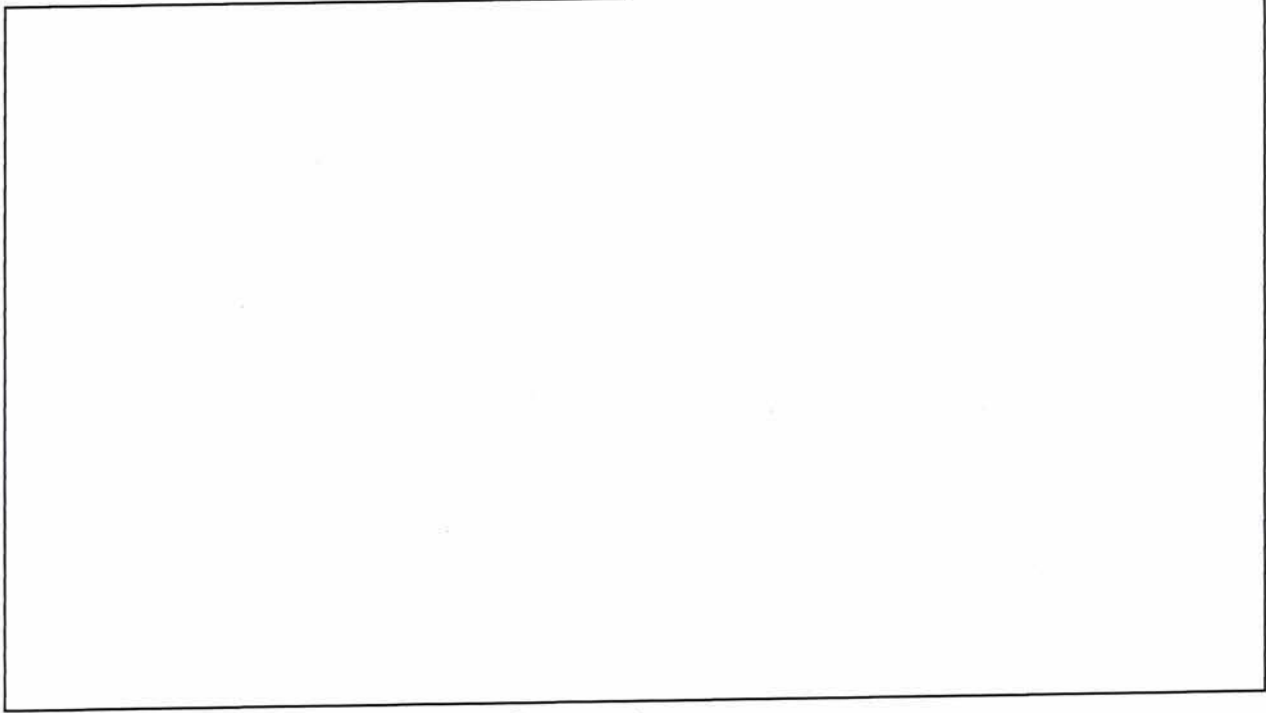
Table 1

Foreign Rankings in the LIS-Related Fields of
Lasers and Photochemistry

After the laboratory-scale problems of lasers, high-resolution spectroscopy, and photochemistry are solved, the chief technologies to be mastered before proceeding to engineering industrial-scale production facilities are generally apparatus engineering, material science (feedstock preparation and handling), and fluid dynamics.

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APPENDIX

LIS and Lasers for LIS

Each atom and molecule has a collection of excited states, or discrete energy levels, whose distances from each other determine the discrete amounts of energy that the atom or molecule can absorb or emit in one lump (quantum or photon). Any particular species of atom or molecule has a particular set of excited states, different for each species, and even different isotopes of the same element absorb or emit light at slightly different frequencies.

A distinguishing feature of laser light is its near monochromaticity (narrow bandwidth): photons of light leaving a laser are typically of one precise energy (or frequency or wavelength) with very little energy spread. If the laser can be tuned over a range of frequencies to a frequency peculiar to one particular atomic or molecular species, its light can excite through resonant interaction only that single species in a mixture containing several very similar species. If the atoms or molecules in the mixture differ only in isotopic content, i.e., neutron number—or atomic weight—of one element, and are, therefore, electrically and chemically identical originally, this process effectively makes one isotopic species electrically or chemically, or in some other way, distinguishable from other isotopes of the same element so that the tagged isotopes can be separated from other isotopes of the same element by electrical, chemical, or other means.

There are essentially four basic methods of laser isotope separation (LIS), characterized by the way the laser tags the desired atoms or molecules. These methods are summarized in the figure. In photoionization, which is usually performed on atomic species, the key laser is tuned to excite the resonant level of the one isotope in a mixture of different isotopes of the same element; a second laser or other light source then typically delivers photons which have enough energy to ionize the already excited isotope, but are not energetic enough to ionize the other unexcited isotopes at the same time. Actual separation is then achieved by pulling the ionized isotope out with an electric field.

Photodissociation is a similar process, but is performed on molecular species. Here the key laser excites a compound containing the desired isotope in a mixture of similar compounds, and a second laser or other light source delivers just enough energy to split, or dissociate, the tagged molecules into radicals. Separation is achieved when these desired radicals either precipitate from the mixture or participate in chemical reactions in which the other molecules do not participate. Both photoionization and photodissociation can use more than two steps—frequently a second key laser is used to further excite the already excited species before the ionization or dissociation step takes place. (A subcategory of photodissociation, called photopredissociation, uses only one step by exciting the desired molecule to a discrete but unstable state from which the molecule dissociates spontaneously. Another subcategory of photodissociation, called multiphoton photodissociation, uses only a single intense laser beam tuned to the molecule's first excited state to accomplish the first step and subsequently "ladder up" rapidly to dissociation on equally spaced short-lived unstable states before they have a chance to decay.)

Photoionization and photodissociation are the two most studied LIS methods. Photoionization has been used in the laboratory to separate isotopes of carbon, oxygen, calcium, and uranium with lasers. Photodissociation, including photopredissociation and multiphoton photodissociation, has been used in the laboratory to separate isotopes of hydrogen, boron, carbon, nitrogen, sulfur, silicon, osmium, and titanium.

The third basic method of LIS is photoexcitation, which can be performed with atomic or molecular species. Here there is usually only one light source, a key laser again tuned to excite selectively either the desired isotope or a compound containing the desired isotope. An ionization or dissociation step is not performed. If the researcher is clever and knows his chemistry, he can then arrange for this excited species to participate in various chemical reactions in which the nonexcited species either does not participate, or participates at a much slower rate, and therefore separation of the desired isotope again takes place

Feedstock	Laser selects U-235 by:	Final separation
U	photoionization	EM field
UF$_6$	photodissociation	Chemical reaction or precipitation
U, UF$_6$	photoexcitation	Chemical reaction
U	photodeflection	Spatial separation (differential velocity)

Example: "2 step" photoionization process
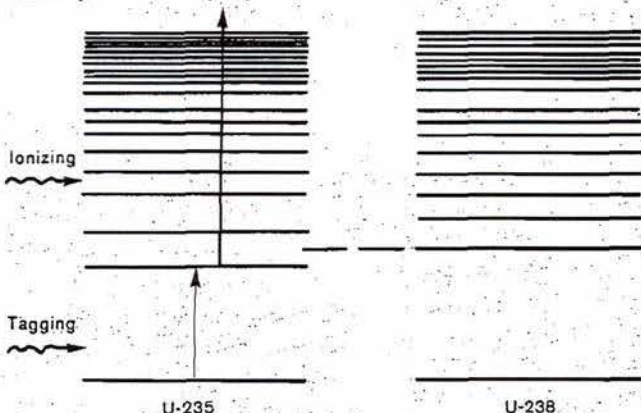
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The Four Basic LIS Methods

chemically. It is clear that the photoexcitation method, and to a lesser extent, also the photodissociation method, is of interest to the chemical industry apart from isotope separation capabilities. Partly by lifting the reactants above a certain energy threshold or changing the electron shell structure, both of these techniques can catalyze effectively otherwise slow reactions. Furthermore, the chemist interested in photocatalysis does not need lasers having as narrow a bandwidth as is required in LIS since he is usually not interested in actually distinguishing between isotopes. Photoexcitation has been used in the laboratory to separate isotopes of chlorine and bromine with lasers.

The fourth LIS method is photodeflection, expected to be used exclusively with atoms because they are lighter than molecules. In photodeflection, a single key laser shines across the path of a beam of atoms. The laser light photons are absorbed only by the desired isotopes, which recoil at an angle away from their original direction of travel and pass through a slit into a separate container. (The process is complicated a little when the excited isotopes—which have absorbed the light—emit it again and recoil randomly; after a number of absorptions and emissions, the net average change of direction is predictable.) Photodeflection has been used in the laboratory to separate isotopes of barium.

Table 6 summarizes some of the laser criteria for LIS. To separate a given isotope or catalyze a given reaction, the laser light must have the correct frequency to excite the atom or molecule. To excite atoms typically requires laser light in the visible (0.4-0.8 μm wavelength) part of the electromagnetic spectrum, and to excite molecules typically requires laser light in the infrared (5-20 μm). The final ionizing or dissociating laser or other light source typically will

Table 6

Laser Characteristics For LIS

Laser wavelengths:

	atom	molecule
(two-step process)		
step 1	visible	infrared
step 2	ultraviolet	ultraviolet

Other laser requirements:

stable

tunable

precise

high power

Type	Spectral range	Typical characteristics and applications
Dye	0.3-0.9 μm	1-MW peak, 1-W average power; Narrow line, tunable; Laser (high prf) or flashlamp (low prf) pumped; Primarily for feasibility demonstration; Atom excitation, ionization dissociation
Lead salt	4 to 20 μm	1-W peak, 1-MW average power; Very narrow line, tunable; High resolution spectroscopy
CO_2	9-11 μm	100-MW peak, 100-W average power; Efficient, many narrow lines; Source for multiphoton excitation; Pump for 16-μm laser (for UF_6);
	16 μm	Potential for 16-μm laser, low power
CO	5-6 μm	Heterodyne with CO_2 to produce 16 μm (for UF_6); Primarily feasibility demonstration
Nd: YAG, glass	1.06 μm	10-MW peak, 10-W average power; Slightly tunable (glass); Source for optical parametric oscillators; Raman-shifted lasers; For feasibility demonstration
Excimer	visible, UV	Potential for UV process laser
Metal vapor	green/blue	10-W average, 1-20 kHz; High prf dye laser pump; atom process

generate in the ultraviolet (0.1-0.3 μm) or visible portion of the spectrum.

Beyond having the correct frequency, a laser for LIS must have an extremely narrow bandwidth so that it excites precisely one isotopic species without disturbing other isotopes of the same element whose energy levels lie extremely close to those in the desired isotope. The laser must be very stable so that its frequency does not wander enough to tag the other isotopes accidentally, and tunable, so that its frequency can be focused exactly on the desired isotope's energy level spacing to start with. Finally, to saturate the feedstock effectively requires high power density of laser radiation so that doing LIS on an industrial scale will require high-energy microsecond-pulse lasers (longer pulses waste energy since the fluorescent lifetimes of materials exceed this by orders of magnitude) which can be operated at a high enough pulse rate that the flowing feedstock is efficiently illuminated.

Some lasers capable of satisfying the LIS requirements of stability, tunability, and narrow bandwidth are becoming available in advanced countries. Devices emitting in the visible portion of the electromagnetic spectrum and appropriate for atomic spectroscopy and excitation include optical parametric oscillators/amplifiers, other nonlinear optical devices and techniques, dye lasers, and some gas lasers (excimer, metal vapor).* (Dye lasers unfortunately are inherently inefficient and low-power devices.) Infrared lasers appropriate for molecular spectroscopy and excitation include spin flip Raman lasers, the semiconductor lasers, and some gas lasers—CO, CO_2, chemical. Semiconductor lasers unfortunately are inherently inefficient low-power devices. Ultraviolet lasers which may become useful in completing the final ionization or dissociation step include some gas lasers such as excimer, hydrogen, nitrogen, and rare gas ion.

LIS offers a potentially tremendous cost advantage over most other isotope separation methods in terms of capital investment and operating expenses. In some cases, e.g., for separating very large molecules like tracer compounds in biology or medicine or for separating chemical isomers, which differ from each other in molecular structure rather than atomic or

*An excimer is a compound involving a noble gas atom, and exists only when that atom is in an excited state.

even isotopic composition, LIS may be the only means available.

A country also needs expertise in other disciplines besides laser technology, high resolution excited state spectroscopy, and photochemistry before it can embark on LIS programs, especially on an industrial scale. For example, to be effective on an industrial scale, LIS seems to require that the material feedstock be a low temperature, low pressure vapor; in liquids the high collision rates would cause smearing of the different species' characteristic frequencies into each other and could also cause the excited species to drop back down to its ground state before ionization, dissociation, or chemical reactions can take place, and thermal noise (brownian motion) would make photodeflection impractical. And although species embedded in solid crystal lattices would not suffer the collision problems that liquids do and may be useful in the laboratory, such a working material is not well suited to high throughput applications.

A vapor can be used for high throughput applications but should have low enough pressure and temperature that collision rates are acceptably small and that thermal population of low-lying excited states is minimized—such population would confuse the spacings (frequencies) between the species' energy levels. Preparation and handling of this vapor in some cases will tax the country's ingenuity in materials science and fluid dynamics. Of course, the country must also have a sufficient repertoire of experimental techniques and apparatus available to proceed from laboratory to industrial scale operation.

Strictly speaking, "LIS" methods do not always have to rely only on lasers: a narrowly tuned mercury vapor fluorescent lamp was used in 1935 to selectively photoexcite four of the six mercury isotopes in a mixture—the mixture was subsequently enriched in the remaining two isotopes by precipitating the tagged four in a reaction with water. Furthermore, laser catalyzed chemistry, which does not require such narrow bandwidths as needed in LIS to distinguish between isotopes, may occasionally be able to get by with alternative light sources, although the higher power and directivity of lasers generally make them the preferred light source. Their extreme monochromaticity and the broad range of the electromagnetic spectrum that the various lasers span make their advent into chemistry and isotope separation a truly significant development.

REFERENCES

25X1, E.O.13526