

is the mechanism by which their upper levels are populated. Here the basic factor is dielectronic recombination—capture of an electron with simultaneous excitation of a second electron, for example $1s^2 + e \rightarrow 1s2pnl \rightarrow 1s^22p + hv$. This mechanism, which was predicted theoretically for the solar corona, also plays a major role in the laboratory plasma. It explains, for example, the excitation of the strongest satellite line of Fe XXIV at $\lambda = 1.866 \text{ \AA}$.

The possibility of observing satellite lines simultaneously with resonance lines is explained as follows: a plasma of highly ionized atoms with $Z \geq 10$ is described even at very large N_e ($\leq 10^{22} \text{ cm}^{-3}$) by the so-called corona model—excitation of the resonance level is determined by electron impact, but its decay is governed not by the reverse process (second-order impact with electrons), but by radiative decay ($\langle\sigma\nu\rangle \sim 1/Z^3$, $A \approx Z^4$, i.e., at large Z , $\langle\sigma\nu\rangle N_e \ll A$). Hence the population of the resonance level is significantly lower than the Boltzmann population. The population of the autoionization levels, on the other hand, is determined by the rate of autoionization and by the reverse process—electron capture—and is therefore Boltzmannian. In the corona model of the plasma, therefore, the intensity ratio $J_{\text{sat}}/J_{\text{res}}$ is considerably larger than in the case of the thermal model. The intensities of certain satellite lines, in both the solar and laboratory-plasma spectra, become comparable with the intensities of the resonance lines. On the other hand, there are very many satellite lines: thus, for example, calculations indicate about 500 satellite lines in the region of the helium-like iron line from approximately 1.85 to 1.95 \AA , i.e., on $\Delta\lambda \approx 0.1 \text{ \AA}$. Needless to say, we cannot resolve them because of the Doppler broadening. This is an essentially new type of spectrum—a quasicontinuous spectrum. Similar satellites are observed in the spectrum of Mg XII (see Fig. 4) and in other spectra.

We offer a brief concluding remark on theoretical calculations of the spectra of highly ionized atoms.

Theoretical assistance is needed acutely in analysis of such spectra: without a reliable method of calculating the wavelengths of the lines, it is impossible to identify the lines correctly. This trend is being devel-

oped broadly at the ISAN. A feature of these calculations is their use of a series expansion of the energy in powers of Z ^[4]:

$$E = -E_0 Z^2 + E_1 Z^1 + E_2 Z^0 + E_3 \frac{1}{Z} + \dots$$

The Feynman diagram technique is used in calculating the terms of these series. For $Z \leq 30$, the relativistic energy of the electrons is a small correction to the total energy and can be treated as a perturbation. It will evidently be more advantageous to use Dirac functions as basis functions for ions with $Z > 30$.

The accuracy of the perturbation-theory calculation with expansion in powers of Z can be improved by extrapolating the experimental data for lower terms of the isoelectronic series. The error of values calculated in this way is $\approx 0.1\%$, and can be reduced to 0.01% by using a large number of experimental data or by extrapolating fewer terms ahead^[5].

Very good results have recently been obtained in theoretical calculations of line intensities.

Finally, we note that the highest degrees of "stripping" attained thus far are for W^{55+} in Z ($Z = 74$) (FIAN)^[6] and for Fe^{25+} ($\chi_i = 9 \text{ keV}$) in the ionization energy (ISAN).

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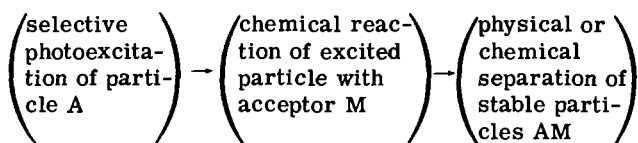
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R. V. Ambartsumyan and V. S. Letokhov. Collisionless Dissociation of Polyatomic Molecules in a Strong Infrared Laser Field, and Its Use for Separation of Isotopes. The effect discussed in the paper pertains to yet another method of isotopically selective action on molecules. All methods for selective action on atoms and molecules with the object of separating isotopes can be classified as either photophysical or photochemical. The photochemical methods are based on the following sequence of processes:



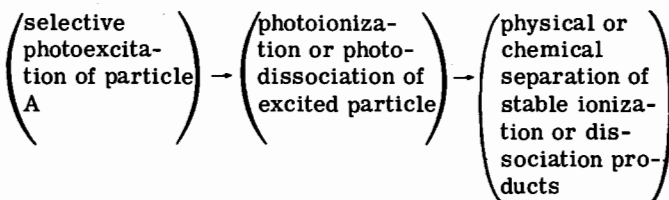
in which it is necessary to have not only selectivity of

excitation, but also a large difference between the chemical reaction rates of the excited and unexcited particles in order to obtain high selectivity. This process of isotope separation is not controlled entirely by the radiation, but depends strongly on the ratios of the rates of the various processes (reaction, deexcitation, excitation transfer) in the elementary collision event. Proposals and experiments for separation of isotopes by methods of selective photochemistry have been known almost since the discovery of isotopes (references to pre-laser papers are given in^[1,2]). The advent of the laser gave experimentors a highly convenient source of monochromatic radiation for photochemical isotope separation with excitation not only of electronic states^[3], but also of vibrational states of molecules^[4].

The USSR Academy of Sciences Institute of Spectro-

scopy is developing an essentially different conception of optical isotope separation based on various proposed and successfully implemented methods of selective photophysical action on atoms and molecules with laser radiation: selective two-stage ionization of atoms (first experiments with Rb^(5,6)), selective two-stage dissociation of molecules (first experiments with HCl^(6,1), NH₃⁽⁷⁾ and separation of the isotopes ¹⁴N and ¹⁵N⁽⁸⁾), selective photopredissociation of molecules (proposal for scheme with H₂CO⁽⁹⁾, experiments with ortho-para-iodine⁽¹⁰⁾, and separation of the isotopes H and D⁽¹¹⁾), and the subject of the present paper: collisionless selective dissociation of molecules in a strong IR field (discovery of the effect in NH₃ and C₂F₃Cl⁽¹²⁾, investigations for BCl₃⁽¹³⁾, and separation of boron⁽¹⁴⁾ and sulfur⁽¹⁵⁾ isotopes).

The photophysical methods are based on the sequence of processes



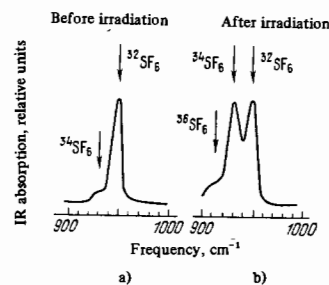
in which high selectivity is attained by selective photoionization or photodissociation of atoms or molecules under the action of laser radiation alone, without the need for collisions of the excited particle with an acceptor. This makes possible complete control of the entire isotope-separation process with the light field. It is this feature of the photophysical methods that makes them potentially capable of exceptionally high selectivity (considerably higher than that of the photochemical processes) and useful not only for separation of isotopes, but also for separation of chemical elements (to obtain especially pure substances), fast separation of excited and unexcited nuclei⁽¹⁶⁾, etc.

The paper reports experimental results from laser separation of sulfur and boron isotopes with radiation from a powerful (10⁸-10⁹ W/cm²) CO₂ laser. It was shown in⁽¹⁴⁾ that multiphoton absorption in the field of such a laser makes possible selective collisionless dissociation of molecules of the isotopic composition that gives resonant absorption of infrared radiation. After isotopically selective dissociation of the molecules, the resulting radicals combine chemically to form new chemical compounds. Thus, the selective-dissociation products of the molecule ¹⁰BCl₃ or ¹¹BCl₃ were bound by oxygen. As a result, B₂O₃ formed in the cell and fell out as a solid precipitate. Measurements indicated that the enrichment is K ≈ 7 in the BCl₃ experiments, where the enrichment coefficient for a single filling of the irradiated cell (the single-stage coefficient of separation) is defined as

$$k \left(\frac{{}^{10}\text{B}}{{}^{11}\text{B}} \right) = \frac{[{}^{10}\text{BCl}_3]^*}{[{}^{11}\text{BCl}_3]^*} : \frac{[{}^{10}\text{BCl}_3]^0}{[{}^{11}\text{BCl}_3]^0} \approx 7,$$

where the superscripts "*" and "0" identify the BCl₃ concentrations in the gas before and after irradiation.

In the case of the sulfur-isotope separation, we carried out an isotopically selective dissociation of SF₆ molecules. It was shown that the highest enrichment coefficient obtained was K ≈ 2800, which is comparable to or better than the enrichment obtained in electromagnetic methods.



Infrared spectrum of ν_3 band of SF₆: a) natural mixture before irradiation; b) enriched mixture after irradiation by pulses in P(16) line of CO₂ laser.

The figure shows the IR absorption spectrum of the natural compound SF₆ (³²S ≈ 95.5%, ³³S = 0.75%, ³⁴S = 4.2%, ³⁶S = 0.018%) and the spectrum after irradiation at a comparatively, low enrichment coefficient K ≈ 20, at which the ³²SF₆ and ³⁴SF₆ concentrations are equalized.

We also investigated the enrichment coefficient as a function of the initial SF₆ pressure in the cell and the power of the incident radiation. It was shown that the enrichment coefficient decreases monotonically at initial SF₆ pressures in the range from 0.2 to ~1 Torr, and that it depends almost exponentially on the power of the IR radiation in the cell. The productivity of the method was estimated. Thus, 10⁴ g of SF₆ was enriched to K = 20 after about 100 pulses (in 1 min). Results of a study of excitation of vibrational levels of the SF₆ molecule were also reported; they indicate an exceptionally rapid pickup of vibrational energy by the molecules (3-5 eV) at relatively low power levels (10-15 MW/cm²).

The isotope-separation method based on use of the collisionless dissociation process is extremely simple and efficient considering the availability of CO₂ laser radiation.

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