Foreword

Presently, there are many ways for isotope separation: gas diffusion, centrifugal, physicochemical, electromagnetic, optical, laser, etc. Each of them has proved to be suitable for separating specific classes of compounds in various aggregate states (gas, liquid, solid, or plasma) with various structures (atoms, two-atomic and polyatomic molecules, complex compounds, clusters) [1].

Optical and laser methods occupy a special place among other methods of isotope separation due to their high selectivity. In spite of the fact that first successful experiments on isotope separation were performed under lamp pumping [2–4], the modern development of optical methods is mainly based on employment of lasers. Presently, the possibilities of laser technique allow one to separate almost all chemical elements.

The fundamentals of laser isotope separation (LIS), including laser separation in atomic vapors, were discovered in the former USSR [5–7]. The theoretical and experimental study of physical processes responsible for LIS efficiency works on creating experimental laser complexes and systems for isotope separation [8–20] were also carried out in USSR. Nevertheless, the first promising experimental results on LIS in atomic vapors and considerable quantities of required isotopes were obtained in USA [20–22]. At that time this fact was related to the absence of a state program on the development of laser methods for isotope separation in atomic vapors. This branch was only developed in academic institutions.

At the same time, just after obtaining the promising experimental results at the Lawrence Livermore National Lab (USA) and many other countries large-scale research was started to create pilot and then semi-industrial laser complexes, first of all for uranium enrichment by $^{235}$U isotope [20–30]. The real laser complex for isotope separation was based on a gas-discharge self-heating copper-vapor laser elaborated somewhat earlier [31–34]. It was this visible-range laser with unique characteristics and high repetition frequency that provided progress in laser isotope separation in atomic vapors.

Since the invention of a self-heating copper-vapor laser, progress in the development of such lasers was mainly determined by the efforts of native scientific groups (at P. N. Lebedev Physical Institute, Institute of Atmospheric Optics SB
RAN, NPO "Astrofizika" and Institute of High Temperatures [31, 32, 34]). Nevertheless, the strong government financing of such investigations in the USA (about $2 billion) has powered their leadership since the middle 1980s in the development of atomic vapor laser isotope separation (AVLIS). The term AVLIS has become a standard in scientific literature [35].

From 1972 to 1999, intense scientific investigations and pilot developments were carried out at the Lawrence Livermore National Laboratory, which resulted in the creation of a unique complex for the enrichment of uranium by $^{235}$U isotope (used in nuclear power engineering), military plutonium by $^{239}$Pu, gadolinium by $^{157}$Gd, zirconium by $^{91}$Zr, ytterbium by $^{168}$Yb, and so forth. The production facilities helped to obtain hundreds of kilograms of required products. The complex of copper-vapor lasers developed, had a total average generation power of 72 kW, while the complex of tunable dye lasers had a power of 24 kW [20].

Similar AVLIS programs were started in France, Japan, and Israel [35].

A great interest in the practical mastering of laser isotope separation was also visible in Russia, Great Britain, China, India, Korea, and other countries. These investigations are partially reviewed in [1].

The qualitative evolution of a laser technique became noticeable in the last decade [36–56], which raises hope of a technological breakthrough in the production of industrial installations for isotope selection. It is significant that this method is universal for separating various isotopes, and can be applied to the separation of the required product from natural ores and industrial wastes with a high degree of purity.

Nevertheless, the works mentioned above were mainly carried out within the limits of the AVLIS method. Recent investigations carried out mainly in Russian scientific centers [44,46,49,50,54–56] show that there is a possibility of developing qualitatively new approaches to the problem of laser isotope separation in atomic vapors, which may result in the development of more efficient methods for isotope separation with accelerated accumulation of the required product.

The consideration presented below is devoted to the description of modern methods for isotope separation based on multiphoton coherent interactions and fast chemical reactions with selectively excited atoms. The results of the theoretical and experimental investigations of scientifically and practically important elements (Pb, Zn, Rb, B, Si), which can be used in fundamental investigations, in the development of quantum computers, and in microelectronic, atomic, and biomedical technologies, are generalized.

The choice of the considered elements was defined, on the one hand, by needs of science and technique, and on the other hand, by potential possibilities of modern laser techniques and competitive capabilities of laser methods as compared to other methods.

Attention is also paid to physicochemical aspects of isotope separation, the state and the evolution of laser technique.
Preface

Wide employment of isotopes in such fields as atomic and thermonuclear power, fundamental science, medicine, biology, isotopic geochronology, Mössbauer spectroscopy, agriculture, activation analysis, ecology, and production of new materials attracts increasing interest in the development of new highly efficient methods for isotope separation.

Modern development of optical spectroscopy, in particular, laser spectroscopy, makes it possible to obtain exhaustive information about the structures and shifts of spectral lines caused by isotopic effects. Recent progress in laser physics, methods of laser frequency tuning, control, and stabilization turns laser sources from laboratory devices to industrial installations. Laser methods for isotope separation have become easier to employ and new possibilities for obtaining isotopically modified and chemically pure substances have been opened. A unique possibility has arisen of not only separating isotopes of various atoms, but also separating isomers and isobars. This is important for mastering the industrial laser isotope separation and for further progress in fundamental investigations including the diagnostic problem of synthesizing new superheavy elements.

Laser isotope separation methods were developed in many countries in the framework of wide programs, first of all in the USA, France, and Japan. Most of the works were devoted to the method of selective photoionization, which was termed AVLIS (atomic vapor laser isotope separation) in these programs. Presently, it is necessary to develop more efficient methods for isotope separation anticipating their competitive ability in economy and ecology. In our opinion it has become possible, first of all, due to the development of laser spectroscopy and laser technique, investigations performed in the field of coherent interaction between radiation and atoms, in particular, the two-photon coherent effects, the nonlinear parametric processes, etc.

One more important feature of the development of modern methods is a great success achieved in studying single-photon and multiphoton light-induced chemical reactions with high rate constants.

In this book we present well-known investigations described in numerous publications that were performed by a conventional AVLIS scheme. The aim of this
book is to give a general description of the problem of laser isotope separation in atomic vapors. Attention is mainly paid to the development of the photochemical method of isotope separation, which has economical prospects for large-scale industrial production.

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