

Use of the method of two-step photoionization and mass filtration for the study of the hfs of odd isotopes

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We present experimental results of the application of the method of two-step photoionization and mass filtration for the registration of the hfs of odd isotopes of Dy and Er in samples with natural isotope content.

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High-resolution laser spectroscopy offers new possibilities in the study of the hyperfine structure (hfs) of atomic spectra.^[1] However, in the case of elements with complicated isotopic composition and high percentage of odd isotopes in the natural mixture, the interpretation of the absorption spectra or luminescence spectra is a difficult task. By way of example, Fig. 1(a) shows the structure of the luminescence line of a well collimated beam of dysprosium atoms. The recording was effected by frequency scanning of the emission of a tunable highly monochromatic ($1.3 \times 10^{-3} \text{ cm}^{-1}$) dye laser which excited the luminescence. It is seen that this spectrum cannot be unambiguously identified.

It is known, however, in the case of two-step radiative action on atoms and molecules, the selectivity of the laser action proper is well preserved.^[2,3] This was recently demonstrated experimentally, for atoms of heavy metals, with selective two-step photoionization as an example.^[4–7] It follows from these experiments, in particular, that the combination of the selectivity of a mass spectrometer that measures the photoionization current with the selectivity of the two-step laser action greatly extends the capabilities of high-resolution laser spectroscopy.

We demonstrate in this paper the applicability of these new possibilities to the investigation of the hfs of the atoms of individual isotopes of the rare-earth elements Dy and Er of natural isotopic composition.

The experiment was performed with atomic beams obtained by evaporating the corresponding metal in vacuum. The residual-gas pressure was 10^{-7} Torr.

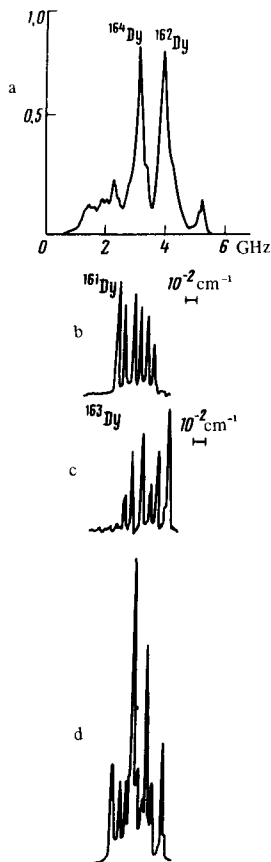


FIG. 1. Isotopic structure of Dy ($\lambda = 5988.56 \text{ \AA}$): a—luminescence spectrum, b—spectrum of ^{161}Dy photocurrent, c—spectrum of ^{163}Dy photocurrent, d—combined mass spectrum of Dy.

A molybdenum crucible was used for the evaporation. The beam was shaped by a system of diaphragms and a molybdenum collimator tube. On leaving the collimator, the atoms were excited by the radiation of a scanned narrow-band dye laser ($h\nu_1$) and were simultaneously subjected to ionizing radiation ($h\nu_2$). The conditions $h\nu_1 + h\nu_2 > I$; $h\nu_1, h\nu_2 < I$ were satisfied, where I is the ionization potential of the atom. The ions of the investigated elements, obtained by this two-step photoionization, were guided by a system of ion lenses to the removable pickup of a dynamic mass spectrometer. Rhodamine-6G was used in the dye laser. The power was 40 mW, and the tuning range 6100—5700 \AA . The pump was a cw argon laser rated 4 W. The mass spectrometer was tuned to a definite mass and thus served as a tunable selective mass filter. When the radiation frequency of the exciting laser was scanned, the recorded ion current corresponded to the excitation spectrum of only one previously selected isotope out of the number of isotopes contained in the atomic beam. We note that under real conditions it is easy to obtain a resolution of one atomic mass unit.

The spectral resolution of the method is determined by the width of the dye-laser generation line, in our case $1.3 \times 10^{-3} \text{ cm}^{-1}$, and the recording ability is determined by the sensitivity of the mass spectrometer and by the power of the

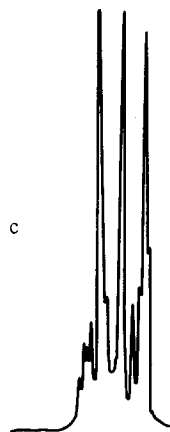
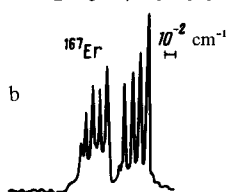
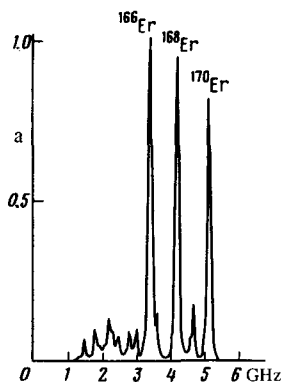


FIG. 2. Isotopic structure of Er($\lambda = 5828.78 \text{ \AA}$): a—luminescence spectrum, b—spectrum of ^{167}Er photocurrent, c—combined mass spectrum.

ionizing radiation (far from the ionization saturation regime). In our experiment the sensitivity was 200 ions/sec. The use of the "ion counting" technique made it possible to improve the sensitivity by 100 times and to carry out investigations of extremely low weights of the analyzed element.

Figure 1 shows typical plots of the spectra of individual dysprosium isotopes. The superposition of the spectra of the individual isotopes duplicate exactly the luminescence spectrum of the natural mixture of the dysprosium isotopes (Fig. 1(a)). Similar results were obtained for erbium isotopes (Fig. 2).

Thus, a combination of the selectivity of a two-step laser photoionization with ion-mass filtration makes it possible to register easily, accurately, with high sensitivity and with high resolution the hfs spectra of individual isotopes in their natural mixture.

Knowledge of the hfs of the atom in one electronic configuration or another makes it possible to calculate the magnetic-interaction constants A and the quadrupole interaction constants B , which determine the hyperfine splitting, to obtain the resultant electric and magnetic moments of the electron shell if the nuclear magnetic and quadrupole moments are known, etc.^[8]

The use of the method of two-step photoionization in conjunction with mass filtration for the investigation of the characteristics of atomic nuclei can be particularly effective in the case of rare isotopes, and also unstable elements, for which it is quite difficult to obtain amounts of appreciable weight.

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