ISOTOPIC EFFECT OF HYPERFINE BROADENING OF X-RAY LINES

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The interaction between magnetic moments of nuclei and electrons of x-ray levels, called the hyperfine interaction (HI) effect and predicted in 1930 by Breit [1], was searched for experimentally many times but without success [2 - 5][1]. In 1961, Merrill and DuMond reported finding the HI effect in the x-ray L spectrum of neptunium, as revealed by the deviation of the line width from a smooth dependence on Z for the sequence of elements from U to Am [7]. This apparently was the first successful observation of the HI effect in x-ray spectra. However, since the effect was not observed isotopically, the differences between the electron shells of the compared elements could lead to a broadening of non-nuclear origin [8]. The observed effect was about twice as large as expected from theoretical estimates.

We wish to report the results of an experiment in which we observed isotopic HI broadening of the x-ray $K\alpha_1(1s_{1/2} - 2p_{3/2})$ line of Eu^{151} compared with Eu^{153}. The HI splitting of the $1s_{1/2}$ level is described by the relation [1]:

$$\Delta = \frac{4\pi R_\infty h c \alpha^2 a_0^3}{3\rho(2\rho - 1)} \frac{m_e}{m_n} \frac{2I + 1}{I} k \psi_{1s}^2(0)\, \xi, \qquad (1)$$

where Δ is the energy distance between the components of the doublet, $\psi_{1s}^2(0) = Z^3/\pi a_0^3$ is the density of the $1s_{1/2}$ electron in the region of the nucleus, ξ is a factor that takes into account the influence of the finite dimension of the nucleus and equals 0.95 in the case of Eu (Z = 63) [9], $\rho = \sqrt{1 - \alpha^2 Z^2}$, I and k are the spin and the magnetic moment of the nucleus, m_e and m_n are the masses of the electron and of the nucleon, R_∞, h, α, c, and a_0 are the Rydberg, Planck, and fine-structure constants, the speed of light, and the Bohr radius. It is easy to show that when $\Delta \ll \Delta E$, where ΔE is the line width, the broadening is proportional to $(\Delta/\Delta E)^2$ and amounts to only $10^{-3} - 10^{-4}$ of the line width. This prevented the experimental observation of the effect.

In our experiment, using a Cauchois diffraction spectrometer with compensated aperture aberration [10], we measured the $K\alpha_1$ lines from six Eu_2O_3 sources. Three sources were made of a mixture of enriched Eu^{151} (97.5%), and the three others with Eu^{153}(99.3%). The compared samples were introduced alternately in the field of view of the instrument. The counting rates at the maxima of the lines amounted to ~50 000 min^{-1} at a background of ~500 min^{-1}. The total number of counts accumulated was ~4 × 10^8 per isotope. The line width at half the height was ~40 eV (25"). The isotopic shift $\delta_{is} = E_{K\alpha_1}^{Eu^{151}} - E_{K\alpha_1}^{Eu^{153}}$ and the HI splitting Δ^{151} of the Eu^{151} line were determined with an electronic computer by least squares. To eliminate the influence of chemical effects [8, 11], the sources were subjected periodically to chemical standardization. As an additional control, we measured periodically the $K\beta_1$ $(1s_{1/2} - 3p_{1/2})$ line, the chemical shift of which is 2.26 times larger than that of $K\alpha_1$ [11] and the isotopic shift and broadening are the same since they are determined practically by the $1s_{1/2}$ level. The joint data reduction has made it possible to obtain

[1]The HI effect is well known in optical spectra. It is observed also in x-ray spectra of μ-mesic atoms (see, e.g., [6]).

separately the effects of the isotopic shift (δ_{is}) and of the chemical shift (δ_{cs}), by monitoring the identity of the chemical state of the isotopes during the course of the experiment.

Series Number	Chemical shift δ_{cs}, MeV	Isotopic shift δ_{is}, MeV	Isotopic SI broadening Δ^2, eV^2
1	−8 ± 23	191 ±21	1,57 ±0,47
2	−6 ± 27	191 ±28	1,35 ± 0,58
3	22 ± 13	150 ± 17	1,87 ± 0,61
4	−41 ± 38	218 ± 39	1,13 ± 0,94
5	7 ± 19	195 ± 19	1,19 ± 0,83
Average:	8 ±9	180 ±10	1,50 ± 0,27

The results are summarized in the table. The figure showing the resultant positions and widths of the $K\alpha_1$ lines from the individual sources characterizes the degree of absence of false effects. As a net result we obtained:

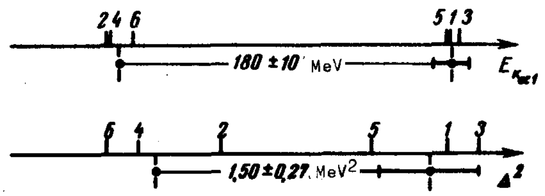
$$\delta_{is} = 180 \pm 10 \text{ MeV}, \tag{2}$$

$$\Delta^{151} = 1.36 \begin{array}{l} +\,0.11 \\ -\,0.13 \end{array} \text{ eV}. \tag{3}$$

The errors are external mean-squared[2]. The value of Δ^{151} was corrected (~10%) for the magnetic moment of Eu^{153}.

The obtained values can be compared with the calculated ones. Using the value $\gamma \equiv \Delta \langle r^2 \rangle / \Delta \langle r^2 \rangle_{r \sim A^{1/3}} = 2.98 \pm 0.32$ from the isotopic shift of the optical lines [12] and the theoretical value $\delta = 64.7$ MeV for the isotopic shift of the $K\alpha_1$ line of Eu at $r \sim A^{1/3}$ [13], we obtain

$$\delta_{calc} = 64.7 \cdot 2.98 = 193 \pm 21 \text{ MeV}. \tag{4}$$



Positions and broadenings (Δ^2) of the $K\alpha_1$ lines from the compared samples. Samples 1, 3, 5 - Eu^{151}; 2, 4, 6 - Eu^{153}.

The values of (2) and (4) are in good agreement. This is of certain independent interest, making it possible to verify the anomalously large value (the highest of all the known ones [9]) of γ for the $Eu^{151-153}$ pair. It was measured earlier only by means of the isotopic optical shift, where there was a danger of an influence of non-nuclear multi-electron effects.

Calculation by means of relation (1) yields

$$\Delta^{151}_{ther} = 1.50 \text{ eV} \tag{5}$$

in agreement with the experimental value (3).

Summarizing, we can conclude that in the experiment we observed for the

[2] The normally distributed quantity is Δ^2.

first time, in so far as we know, isotopic HI broadening of the x-ray K line. The experimental value agrees with the theoretical one.

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POWERFUL STIMULATED RADIATION IN RUBIDIUM VAPOR IN EXCITATION OF A LASER WITH ADJUSTABLE FREQUENCY

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In [1 - 5] stimulated emission from a number of levels of potassium was produced by irradiating potassium vapor with a pulse from a Q-switched ruby laser and by the Stokes SRS component excited by the same pulse in nitrobenzene. In the present study we have obtained powerful directed emission in rubidium vapor at frequencies close to the transitions $5^2S_{1/2}-6^2P_{3/2}$ (4202 Å) and $5^2S_{1/2} - 6^2P_{1/2}$ (4215 Å), and also less intense directed radiation at the resonant rubidium lines $5^2S_{1/2} - 5^2P_{3/2}$ (7800 Å) and $5^2S_{1/2} - 5^2P_{1/2}$ (7047 Å), see Fig. 1. The use of a laser with tunable frequency has made it possible to investigate the dependence of the threshold of the directed radiation on the frequency of the exciting radiation.

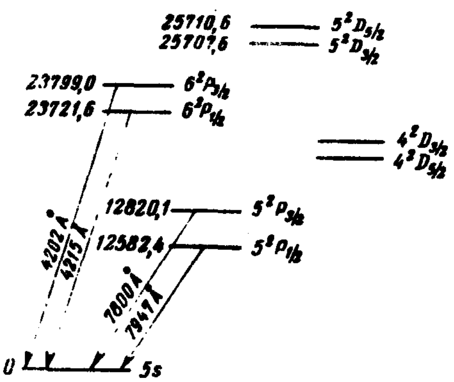

Fig. 1. Rubidium term scheme.

We used an organic-dye laser excited by a giant pulse from a ruby laser. Smooth variation of the wavelength in the range 7730 - 7900 Å was effected with the aid of the diffraction grating. The duration of the pulse at half-height was ~50 nsec, and the generation spectral line width was ~4 Å. The dye-laser radiation passed through a telescopic system which decreased the beam cross section to 2 - 3 mm and was incident on a cell with rubidium vapor, 15 cm long. The rubidium vapor pressure ranged from 0.001 to 1.2 mm Hg. The spectrum of the directed radiation was investigated with the