Displacement, induced by hyperfine interaction, of x-ray lines excited in internal conversion

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A new effect has been observed experimentally, namely the energy shift of x-ray K lines excited in internal conversion of nuclear transitions. The effect is due to the interaction of the electron with the magnetic moment of the nucleus (hyperfine interaction—HI) under conditions of non-static component population determined by the spin selection rules, and can be used as a method of measuring the magnetic moments of nuclear states independently of their lifetimes.

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Interactions between magnetic moments of a nucleus and the inner (K,L) electrons of the atom—the so-called hyperfine interaction—was considered theoretically by Breit[1] and first observed[2] as a broadening of the x-ray K_{α_1} lines, due to the K-level doublet $(I\pm\frac{1}{2})$ splitting which is small compared with the natural width (here I is the spin of the nucleus).

It was noted in[3] and in a recent paper[4] that in K capture it is possible to have non-static (in contrast to photoexcitation[2]) population of the $I+\frac{1}{2}$ and $I-\frac{1}{2}$ components, leading not to broadening but to a shift of the K lines. It was observed experimentally[4] in an investigation of the K_{α_1} radiation accompanying the $^{131}Cs(\epsilon_K)^{131}Xe$ and $^{132}Cs(\epsilon_K)\,^{132}Xe$ K capture.

We note that precisely the same situation arises in internal conversion, where the end result of the transition of the nucleus from the state I_i to I_f is also the appearance of a hole on the K shell and of a free fermion (neutron in K capture or electron in internal conversion). This circumstance is in fact the basis of our present work.[1)] In Table I are given the HF-component selection rules that hold for allowed K capture[4] and internal $M1$ conversion.

We chose for the experiments the isotope ^{141}Ce, which undergoes β^- decay into ^{141}Pr. The internal K conversion of the $M1$ transition with energy 145 keV to the

TABLE I. Populations of HF components and displacements of x-ray lines in K capture and interval conversion of $M1$ transitions.

$\Delta I \equiv I_f - I_i$	Populations		Displacements
	$F = I_f + ½$	$F = I_f - ½$	
−1	1	0	$½AI$
1	0	1	$-½A(I+1)$

ground state of ^{141}Pr was the source of the x-ray photons; the K_{α_1} and K_{β_1} were measured with a Cauchois-type diffraction spectrometer in accordance with the scheme used by us earlier (see, e.g.[2]). The ^{141}Ce source was prepared by irradiating the isotope ^{140}Ce (in the form of CeO_2) in a reactor in a flux $\approx 1 \times 10^{14}$ neut/cm^2 sec. This reference was a fluorescent ^{141}Pr source excited by radioactive ^{170}Tm.

The results are listed in Table II. In the first and second experiments the refer-

TABLE II. Experimental results.

Experiment	$\Delta E_{K_{\alpha_1}}$, meV	$\Delta E_{K_{\beta_1}}$, meV	ΔE_{HI}, meV	$\Delta E_{X,K_{\alpha_1}}$, meV
1	772 ± 17	1325 ± 200	443 ± 120	329 ± 120
2	445 ± 26	190 ± 180	597 ± 115	−152 ± 110
3	512 ± 21	395 ± 93	582 ± 65	− 70 ± 57

ences were the compounds PrO_2 and Pr_2O_3, respectively. The measured displacements $\Delta E_{K_{\alpha_1}}$ and $\Delta E_{K_{\beta_1}}$ turned out to be different, thus pointing to the presence, besides the sought HI effect (ΔE_{HI}), of also a chemical shift ($\Delta E_{X,K_{\alpha_1}}$,$\Delta E_{X,K_{\beta_1}}$), due to the partial transition of the praseodymium after the β decay of ^{141}Ce into CeO_2 in the trivalent state. Using these data and the fact that the chemical shift of the $K\beta_1$ line is 2.68 times larger than the shifts of the $K\alpha_1$ line,[6] while the HI shifts are equal, it is possible to determine separately the sought HI effect that interferes with the chemical shift (see Table II), as well as the valence state of the radiating atom: $m = 3.28 \pm 0.21$.

In the third experiment, the refrence was a mixture of Pr_2O_3 and PrO_2 having precisely this average valence, so that the chemical effect was cancelled out to a considerable degree.

The final experimental value of the K shift due to the HI interaction, $\overline{\Delta E_{HI}} = 560 \pm 50$ meV, can be easily calculated (see, e.g.,[2]) into the value of the magnetic moment of the ground state of ^{141}Pr and compared with the tabulated values: $\mu_{exp} = 4.1 \pm 0.4$ n.m.; $\mu_{tab} = 4.24 \pm 0.01$ [7] and 4.09 ± 0.06.[8] Good agreement is observed.

The effect can be used as a new method of measuring the magnetic moments of the excited states of the nuclei. Besides its large abundance, it has the advantage over K capture in that the reference need not be a second radioactive nucleus, as in K

capture, but fluorescent x radiation excited in the ground state of the investigated isotope.[4]

We note in conclusion that the effect should lead to analogous shifts of the energies of the conversion (electron) line themselves, which consequently carry direct information on the magnetic moments of the final states of the corresponding transitions.

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[1)]The difference between the masses of the neutrino and the electron makes it more probable that the electron will carry away the orbital angular momentum, but at small kinetic energies of the electrons (up to several hundred keV) this circumstance is of little importance.[5]

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