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NUCLEAR RESONANCE FLUORESCENCE OF HIGHLY EXCITED STATES OF Ni^{62}, Cd^{114}, Pb^{208}

Using a new method for determining the radiative widths of high-energy nuclear states ([1]), we investigated the nuclear resonance fluorescence of Ni^{62}, Cd^{114}, and Pb^{208}, using γ-rays from the capture of thermal neutrons in iron.

The γ-rays scattered by the scatterer at an angle of $\sim 135°$ to the incident beam are recorded by an NaJ(Tl) crystal, $d = 7$ cm and $h = 7$ cm, connected to an FEU-52 and to a multichannel pulse analyzer. The crystal is shielded in front by a filter consisting of 1 cm of lead and 10 cm of boroparaffin. The source –scatterer–detector distance is ~ 4 m. The results of all control experiments show that the resulting signals are γ-rays from the iron source scattered by the given scatterer.

$Fe^{57} \rightarrow Ni^{62}$. The physical parameters characterizing the resonance level are the total width Γ, the partial width for the radiative transition to the ground state $\Gamma_{\gamma 0}$, and the statistical factor g. In addition, the distance $\delta = |E_e - E_p|$ between the emission and absorption lines must be taken into account, since the resonant-scattering cross section depends on it. These parameters can be determined by measurements of the scattering and absorption cross sections at different temperatures.

The effective cross section $\langle \sigma_{rp} \rangle$ was found to be (0.53 ± 0.02) barn for the 7.64 MeV resonance in nickel; it was calculated under the assumption of a dipole angular distribution.

Analysis of the observed temperature effect in the range 78–600°K gives the value $\delta = (12.5 \pm 0.5)$ eV.

The existence of inelastic scattering clearly shows that, after resonant excitation of the 7.64 MeV (1−) level of nickel, quanta with energies 6.47, 5.60, 5.34, 5.0, and 4.7 MeV are emitted. This occurs in competition with emission of elastically scattered quanta with energy 7.64 MeV; that is, upon de-excitation of the excited state, cascades arise and γ-quanta of lower energy appear, leaving the nucleus in an excited state.

Indeed, in addition to the 7.64 MeV transition to the ground state, we observe the indicated transitions with the intensity ratio
$I_0(7.64) : I_1(6.47) : I_2(5.60) : I_3(5.34) : I_4(5.0) : I_5(4.7) \approx 1.0 : 0.2 : 0.5 : 0.2 : 0.1 : 0.5$.

These observed transitions from the 7.64 MeV (1−) level occur to the levels of Ni^{62}: 1.17 (2+); 2.05 MeV (2+); 2.30 MeV (0+); 2.66 MeV (2+), and 2.94 MeV (2+).

Using the method of self-absorption of nuclear fluorescence ([1,3]), with ($R_0 = 0.040 \pm 0.004$) and $n_p = 3.17 \cdot 10^{21}$ cm^{-3}, $d = 1.5$ cm, $\lambda^2 = 2.65 \cdot 10^{-22}$ cm^2, $\delta = 12.5$ eV, $\Delta_a = 7.54$ eV, $\Delta_e = 8.2$ eV, we succeeded for the first time in determining the partial widths of all the observed $E1$-transitions from the 7.64 MeV (1−) excited level of Ni^{62}. The values obtained for the partial widths of the Γ_γ transitions, presented in Table 1, make it possible to determine the total width $\Gamma = (5.4 \pm 1.6)$ eV and the corresponding mean lifetime of the 7.64 MeV (1−) level of Ni^{62}: $\tau = (1.22 \pm 0.36) \cdot 10^{-16}$ sec.

The partial lifetime of the 7.64 MeV radiative transition to the ground state ($1^- \to 0^+$) proved to be $\tau_\gamma^0 = (6.6 \pm 0.7) \cdot 10^{-16}$ sec.

The Weisskopf formula, based on the single-particle model, gives for this transition $\tau_{\gamma\,\text{single}} = 13.8 \cdot 10^{-19}$ sec. Thus, the $E1$ transition from the 7.64 MeV (1^-) level of Ni^{62} turns out to be retarded by approximately 3 orders of magnitude.

Table 1

Nucleus	Transition energy, MeV	$I_i^\pi \to I_f^\pi$	Γ_γ, eV	Nucleus	Transition energy, MeV	$I_i^\pi \to I_f^\pi$	Γ_γ, eV
$^{62}_{28}Ni_{34}$	7.64	$1^- \to 0^+$	1.0 ± 0.10	$^{114}_{48}Cd_{66}$	7.64	$1^- \to 0^+$	0.20 ± 0.05
$^{62}_{28}Ni_{34}$	6.47	$1^- \to 2^+$	0.33 ± 0.11	$^{114}_{48}Cd_{66}$	7.08	$1^- \to 2^+$	0.05 ± 0.01
$^{62}_{28}Ni_{34}$	5.60	$1^- \to 2^+$	1.26 ± 0.38	$^{114}_{48}Cd_{66}$	6.50	$1^- \to 0^+$	0.13 ± 0.03
$^{62}_{28}Ni_{34}$	5.34	$1^- \to 0^+$	0.60 ± 0.18	$^{114}_{48}Cd_{66}$	5.80	$1^- \to 2^+$	0.18 ± 0.04
$^{62}_{28}Ni_{34}$	5.0	$1^- \to 2^+$	0.36 ± 0.14	$^{208}_{82}Pb_{126}$	7.28	$1^- \to 0^+$	0.78 ± 0.03
$^{62}_{28}Ni_{34}$	4.70	$1^- \to 2^+$	2.15 ± 0.64				

The value obtained by us for $\Gamma_\gamma^0/\Gamma = 0.185$ by the self-absorption method is well confirmed by the result ($\Gamma_\gamma^0/\Gamma = 0.170$) of work on elastic scattering of photons using bremsstrahlung from betatron electrons ([2]), but it does not confirm the ratio $\Gamma_\gamma^0/\Gamma = 1$ assumed in ([3]).

$Fe^{57} \rightarrow Cd^{114}$. We obtained γ-spectra due to nuclear resonance fluorescence in a cadmium scatterer with Sn and Cd absorbers relative to an Sn scatterer and background. The detected photons have energies 7.64; 7.08; 6.50; 5.80 MeV, i.e., when the 7.64 MeV excited state is illuminated, cascades arise and γ-quanta of lower energy appear, leaving the nucleus in an excited state.

For the first time using the method of self-absorption of nuclear fluorescence, we were able to determine the partial widths of all transitions from the 7.64 MeV excited level of Cd^{114}. The values obtained for the partial widths Γ_γ of transitions from the 7.64 MeV (1^-) level of Cd^{114}, presented in Table 1, make it possible to determine the total width $\Gamma = (0.56 \pm 0.13)$ eV and the corresponding mean lifetime $\tau = (1.18 \pm 0.26) \cdot 10^{-15}$ sec of the 7.64 MeV (1^-) level of Cd^{114}. The partial lifetime of the 7.64 MeV radiative transition to the ground state ($1^- \rightarrow 0^+$) turns out to be $\tau_\gamma^0 = (3.3 \pm 0.8) \cdot 10^{-15}$ sec. The Weisskopf formula, based on the single-particle model, gives $\tau_{\gamma\,\mathrm{single}} = 9.2 \cdot 10^{-19}$ sec. Thus, the $E1$ transition with $E_\gamma = 7.64$ MeV turns out to be retarded by approximately 4 orders of magnitude.

$Fe^{57} \rightarrow Pb^{208}$. In order to test the correctness of the measurement method, we studied resonance scattering of γ-rays $Fe^{56}(n,\gamma)$ on Pb^{208}, which is the most studied.

Experiments with self-absorption (Pb and Bi absorbers of various thicknesses were used) showed that the 7.28 MeV resonance is caused by a level with width $\Gamma_\gamma^0 = (0.78 \pm 0.03)$ eV. This is in good agreement with (0.80 ± 0.03) eV ([3]) and may be compared with the Doppler broadening data (0.6 ± 0.2) eV ([2]).

To check the validity of the relation $\Gamma_\gamma^0/\Gamma \approx 1$ ([3]), we measured nuclear fluorescence at different absorber and scatterer temperatures (78; 300; 680° K), in order to detect the presence of inelastic scattering. A small resonant fluorescence was found in the energy region 4.7 and 4.1 MeV, which should have corresponded to transitions to the 2.61 MeV (3^-) and 3.2 MeV (5^-) states of Pb^{208}. However, the spin values do not allow us to consider these transitions as electric dipole transitions from the 7.28 MeV (1^-) state of Pb^{208} to these levels.

In our experiment $\Gamma_\gamma^0 = 0.62\,\Gamma$, which is well confirmed by measurements of self-absorption of elastically scattered photons using the $(p, \alpha\gamma)$ reaction ([4]).

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Note: Figure translations are in progress. See original paper for figures.