MEASUREMENT OF THE LIFETIME OF THE 4^+ *LEVEL* (1282 keV) *OF THE* Cd^{114} *NUCLEUS BY THE RESONANCE SCATTERING METHOD*

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Using a model of elastic collisions of the molecules and the experimentally measured dependence on source density of the cross section for the resonance effect, the lifetime of the 4^+ (1282 keV) level of Cd^{114} was determined. The lifetime $\tau_2 = (7.5^{+1.2}_{-2.6}) \times 10^{-12}$ sec is compared with computed values found from various models of the nucleus. At the same time the self-absorption method was used to find the lifetime of the 2^+ level (557 keV) of Cd^{114}. The value was $\tau_1 = (1.53 \pm 0.53) \times 10^{-11}$ sec, in agreement with other experimental data.

THE measurement of lifetimes of excited states of nuclei is an important problem of nuclear spectroscopy. Most of the measurements of lifetimes done by Coulomb excitation, resonance scattering and the delayed coincidence method, are for the first excited state. Lifetimes of second and higher excited states have been measured in only a few cases. Some progress in filling this gap can be made by using the recently established Coulomb excitation of the second 2^+ level [1] and multiple excitation of the 4^+ level, [1,2] as well as by using the method of resonance scattering. In the latter case, one makes use of the dependence of the resonance effect on source density. Using this method has made possible the determination of the lifetime of the 402 keV level of As^{75} [3] and the lifetime of the 4^+ (2502 keV) level in Ni^{60}. [4] We have used a similar method to determine the lifetime of the 4^+ (1282 keV) level in Cd^{114}.

1. Usually in experiments on resonance scattering one uses a gaseous source of low density. Then the fraction of γ rays emitted by the recoil nuclei and satisfying the resonance conditions is a maximum. Suppose now that the recoil nucleus moves in a dense enough medium so that the time between successive collisions is comparable to the lifetime of the state. In this case there is a sizable loss of energy of the recoil nucleus because of collisions with the atoms (molecules) of the medium and, consequently, the cross section for the resonance effect drops. Knowing the law of slowing down of the recoil nuclei and the density of the medium, one can determine the lifetime of the excited state from the experimentally measured attenuation of the effect. In our case, where the cascade of two γ quanta (724 and 557 keV) is preceded by K capture, and the slowing down occurs as the result of collisions of $InCl_3$ molecules (cf. Sec. 4), it is not difficult to find the relative number of γ quanta whose energies lie in a given interval around the resonance energy E_p:

$$P(E_p) = \varphi[\tau_1, \tau_2, \lambda(\rho, d)], \quad (1)$$

where τ_1 and τ_2 are the lifetimes of the 2^+ (557 keV) and 4^+ (1282 keV) levels, λ is the mean free path of an $InCl_3$ molecule in a medium of density ρ for impact parameter d. The function $\varphi(\tau_1, \tau_2, \lambda)$ was calculated on the basis of an elastic collision model, using the electronic computer Ural-1.

2. The source in our experiments was the easily volatilized indium compound $InCl_3$, which does not dissociate up to 900°C (cf. [6]). To make sure of the right vapor density, sources of various specific activities were volatilized into quartz ampoules, which were then pumped down and sealed off.[1)] The ampoules containing the sources were put in hermetically sealed thin-walled stainless steel containers and then placed in an oven whose temperature could be varied smoothly from 300 to 900°C. The required vapor densities were reached, depending on the amount of $InCl_3$, somewhere in the temperature interval 500—800°C. In order to be certain that at the given temperature all the active material was in the vapor phase, we checked the integral counting rate of γ rays passing through a collimator (hole diameter 3 mm) placed over two different sections of the ampoule. The correspond-

[1)]The In^{114} activity in each ampoule was 10 mCi.

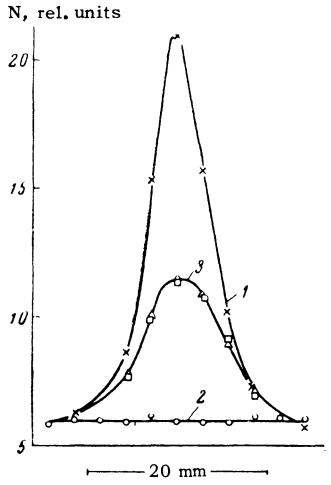

FIG. 1. Dependence on source temperature for the integral counting rate from two different sections of the source: 1, 2 – cold source, 3 – hot source (□, ×, first section; ○, △, second section).

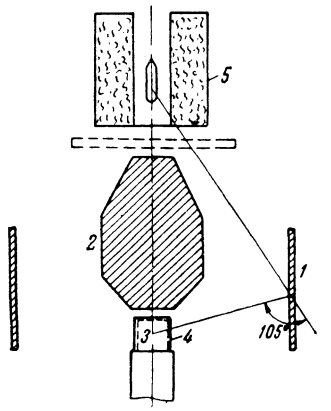

FIG. 2. Schematic of experimental arrangement: 1 – scatterer, 2 – lead cone, 3 – NaI(Tl) crystal, 4 – screen (1.5 mm Pb), 5 – furnace with source.

ing curves for the cold source and the source heated to 750°C are shown in Fig. 1.[2)]

The measurement of the resonance effect was done with the apparatus shown schematically in Fig. 2. The resonant (Cd) and nonresonant (Sn) scatterers were cylinders 31.5 cm in diameter, 15 cm high and 0.45 cm thick. A lead cone 19.5 cm long shielded the detector from the direct radiation. Disks of Cd and Sn (shown by the dashed lines in Fig. 2) could be placed between the furnace and the scatterers for the experiments on self-absorption. The average angle of scattering was 105°. The detector was a NaI(Tl) crystal of dimensions 40 × 40 mm^2, mounted on an FÉU-11 photomultiplier. Pulses from the output of the photomultiplier were fed to the input of an AZ-1 single-channel pulse-height analyzer, set at the resonance frequency 557 keV, with a window width of 10 V. To eliminate the effects of any possible drift of the electronic equipment, the scatterers were interchanged every 200 seconds.

3. With each of six sources having different vapor densities, an individual experiment was made to determine the resonance scattering cross section σ. We used the usual measurement technique.[7,8] In calculating the cross section we computed the absorption of the resonance radiation by numerical integration over the volume of the scatterer and took account of the angular distribution of the resonantly scattered quanta. Since measurements with each source were carried on continuously over a period of ~ 40 hr, corrections were made for decay of the source in making the computations. The results of analysis of the data are given below:

ρ, mg/cm^3:	3.85	9.57	21.22	24.55	63.71	233.84
σ, mb :	246±22.3	232.6±21	224±21.4	210.9±27.6	168±18.5	85.3±19.8

The interpretation of the results on resonance scattering for the case of a polyatomic gas is complicated by the lack of information about the energy loss of the recoil nuclei in breaking chemical bonds or exciting internal degrees of freedom. To check the assumption that the recoil as a result of the K capture and the subsequent γ transition is experienced by the whole $CdCl_3$ molecule (without bond rupture),[9] we made a separate experiment on self-absorption, which gives information about the level width, independent of the molecular state of the source.

The problem in the self-absorption experiment is to determine the relative attenuation of the resonance effect q due to additional scattering in a resonant absorber. For this purpose, disks of Cd and Sn were placed in turn between the source and the Cd scatterer 1 (Fig. 2). The disk thicknesses were chosen so that their attenuations of the radiation in the nonresonant region were the same to within 1%. From an analysis of 1200 such partial measurements, we found the value q = 0.033 ± 0.012. For thin absorbers the relation between q and the level width Γ is

$$q = \frac{ndgh^2c^2\Gamma}{4\left[\pi\left(\Delta_n^2 + \Delta_p^2\right)\right]^{1/2}E_0^2}. \qquad (2)$$

Here n is the number of atoms per cc, d is the average effective thickness of the scatterer, Δ_n and Δ_p are the Doppler widths due to the motion of the atoms of the absorber and scatterer, E_0 is the energy of the transition, and g is the spin factor. Using the known values for n, d, Δ_n, Δ_p,[3)] E_0, and q, we get $\Gamma = (4.26 \pm 1.47) \times 10^{-4}$ eV and then we find for the lifetime of the 2^+ (557 keV) level of

[2)]Heating the source to 850° did not change this picture.

[3)]In computing Δ and Δ_p, the Debye temperature was taken equal to 172° C.[10]

Cd^{114}, $\tau_1 = (1.53 \pm 0.53) \times 10^{-11}$ sec. This lifetime is in agreement with the value of $\tau = (1.42 \pm 0.21) \times 10^{-11}$ sec, determined from Delyagin's work.[6] We may therefore assume that the whole $CdCl_3$ molecule takes up the recoil resulting from the radiative transitions.

Figure 3 shows a series of curves for $P(E_p) = \varphi(\tau_2, \rho)$ computed from formula (1). From the figure we see that the experimental points fit curve 2 best. Considering only the statistical uncertainty of the experiment,[4)] we find for the lifetime of the 4^+ level the value $\tau_2 = (7.5^{+1.2}_{-2.6}) \times 10^{-12}$ sec.

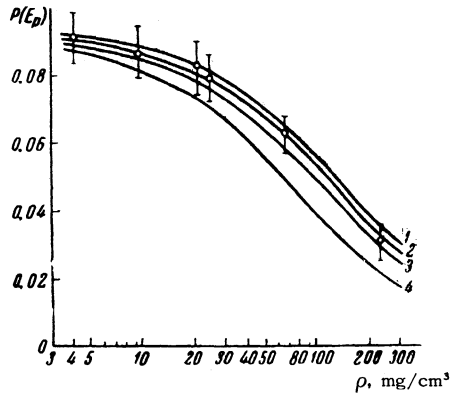

FIG. 3. Dependence of $P(E_p)$ (number of quanta per eV near $E = E_p$) on source density. Curves computed from formula (1): $1 - \tau_2 = 1 \times 10^{-12}$ sec; $2 - \tau_2 = 7.5 \times 10^{-12}$ sec; $3 - \tau_2 = 15 \times 10^{-12}$ sec; $4 - \tau_2 = 45 \times 10^{-12}$ sec. The circles are the experimental data.

4. Many properties of the medium-weight even-even nuclei (the ratio E_2/E_1 of the energies of the second and first levels, the sequence of spins of second levels 2^+, 4^+, etc) are satisfactorily described by several models: the purely vibrational model,[11] the model of the axially unsymmetric rotator,[12] the model in which pairing interaction of the nucleons and collective interaction with the surface is included.[13] But in estimating the ratio of the reduced probabilities $R = B(E2, 4 \rightarrow 2)/B(E2, 2 \rightarrow 0)$, these models give quite different results. We shall compare the results of computations of the lifetime of the 4^+ level of Cd^{114} by each of these models with the two experimental values of τ_2, ours and the one from [1], which was found by Coulomb excitation of the 4^+ level (where we have taken the parameter γ of the model to be 25° (cf. [14]), which corresponds to a ratio $E_2/E_1 = 2.3$ for the energies of the levels in Cd^{114}):

Reference:	Our data	[1]	[11]	[12], $\gamma=25°$	[13]
τ_2, 10^{-12} sec:	7.5	2.1 ± 1.1	2.1	3.0	>4.4

The low accuracy of the two experiments[5)] prevents a definite conclusion about the correctness of any one model. Nevertheless, the agreement of the results of Stelson and McGowan[1] with the model of Scharff-Goldhaber and Weneser[11] is hard to understand, since most data on the excitation of the second 2^+ level contradict this model.[15] Our results may be fitted to Raz's model[13] with the deformation parameter $x \sim 0.5$. For this value of x, the pairing interaction of the nucleons is important. But the comparison of the experimental results with Raz's model[13] at this stage has only a qualitative significance. More detailed computations for specific nuclei are needed on this model.

The results of such computations for Pb^{206} which have been published recently (cf. [16]), confirm the importance of including pairing interaction of nucleons.

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[4)] The systematic error associated with the uncertainty in choosing the collision diameter (d = 2.4 A in our case) is difficult to estimate.

[5)] Preliminary estimates show that one way of improving the accuracy of the experiment is to use coincidence methods to study the dependence of the differential cross section for resonance scattering on the angle between the emerging cascade γ rays, for different source densities.

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