GAMMA RAY SPECTRA FOLLOWING RESONANCE CAPTURE OF NEUTRONS

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A programmed time-pulse height analyzer was used to study the γ-ray spectrum emitted following resonance capture to individual levels of various isotopes of W, Hg, Pt, and Au. A one-crystal (NaI) γ spectrometer was used; for Au the spectrum was found with a pair spectrometer. Sizable fluctuations were seen in the unresolved part of the spectra ($E_\gamma \sim 5$—6 MeV), which may be explained as due to a high probability for single particle transitions. No essential changes in the spectrum were seen when Hg^{199} was excited to levels of different spin.

THE study of the mechanism of radiative capture enables us to check the degree of validity of various nuclear models. The study of the γ-ray spectrum following resonance capture of neutrons to individual levels gives more definite information than one can get from capture of thermal neutrons or of neutrons with a whole range of energies.

We have studied the γ rays accompanying resonance capture of neutrons by heavy nuclei with A = 180—200. In the ground states of these nuclei the 3P neutron shell is being filled, and one can hope for a theoretical interpretation of the experimental data, since one knows the angular momenta of the initial and final states, and one can use single particle estimates for the intensity of the transitions in these nuclei. In comparing the spectra of γ rays from different neutron resonances of the same isotope (and the same spin) we are essentially comparing transitions from close highly excited states of the compound nucleus (which differ by a few eV for a total excitation energy of 7—9 MeV). Such a comparison of γ-ray spectra has two important aspects. First, it is important for a correct averaging of the experimental intensities, since it is the average values which must be compared to those computed from the models. For example, the intensity of γ rays gotten from a thermal spectrum of neutrons may differ markedly from this average, since the contribution in the thermal region is usually from a single neutron level, and the intensity of individual transitions from it may fluctuate. Second, the character of the fluctuations of the intensities of transitions (or the partial widths $\Gamma_{\gamma i}$) is of intrinsic interest. For example, we may expect that transitions which are close to single-particle and transitions in which many particles participate will have different degrees of fluctuation.

This is the second in a series of experiments carried out at the neutron spectrometer of the cyclotron of the Institute,[1,2] to obtain information about values of $\Gamma_{\gamma i}$ for heavy nuclei. The first work, done in 1958, showed the presence of sizable fluctuations in the intensity of transitions to the ground state in W and Pt. These were somewhat at odds with the results of Corge et al.,[4] who observed no strong fluctuations in several strong transitions in Pt^{196} and U^{239}. Interest in measurements of γ-ray spectra for heavy nuclei (for transitions to excited as well as ground states) increased after the publication of the paper of Lane and Lynn,[5] which showed the importance of the contribution of single-particle transitions in resonance capture by heavy nuclei. We therefore choose the isotopes with A = 180—200 (W^{182}, W^{183}, Pt^{195}, Au^{197}, Hg^{198}, Hg^{199}) for a systematic study of γ rays following resonance capture. The nuclei with lower values of A have large and undetermined values of the spin of the neutron levels, while those with larger A have no neutron resonances below 200 eV.

The measurements were made possible by the use of a multichannel programmed analyzer,[6] which permitted simultaneous measurement of γ ray spectra from a large number of individual neutron levels. As in the previous work,[3] for most of the measurements we used a single medium size NaI crystal (diameter 140 mm, height 70 mm). This detector, together with the sample, was placed in a shield of boron carbide and lead at the end of the 11-meter flight path of the neutron spectrometer. The resolution of the

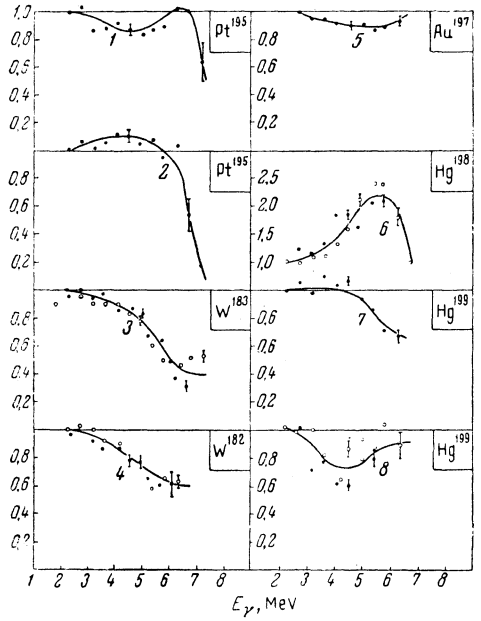

FIG. 1. Ratios of γ-ray spectra for different resonances.

spectrometer was 0.2—0.02 μsec/m. After subtracting the background, which is 10—30% of the effect, we compare the spectra with one another, normalizing the amplitude ratio for a channel at the point $E_\gamma \sim 2$ Mev (cf Fig. 1 and table).

Figure 1 shows eight ratios of intensities of γ-ray spectra (i.e., ratios for 16 pairs of resonances), measured in two series of experiments (solid and open circles). The paired ratios were taken for resonances of the same isotope (with the same spin J for the resonance), and to give a definite procedure the spectrum of the resonance with the larger neutron width Γ_n was divided by the spectrum of the resonance with the smaller neutron width. The sequence of ratios in Fig. 1 corresponds to the numbers in the table, where we give values of E_0, J, Γ_n and Γ_γ from [7]. The values of Γ_n for the Pt^{195} resonances are taken from [8].

The instrumental line width is ~1.5 MeV for energies above 4 MeV, so individual transitions cannot be resolved. The appearance of sharp fluctuations in the γ-ray spectra therefore indicates marked changes in the intensities of individual lines (or groups of lines). Let us consider some of the results in more detail.

In Pt, the first resonance (E_0 = 11.8 eV) gives the dominant contribution for thermal neutrons. Thus we may compare the ratio of the spectra for the resonances at E_0 = 11.8 eV and E_0 = 68.9 eV (No. 1 in the table) and the spectrum following thermal capture.[9] The drop in the value of the ratio for $E_\gamma \sim 6.5$ MeV corresponds to the fluctuation in the intensity of transitions to the ground and first excited states, which was already noted above. The constancy of the intensity (on the average) over the region (5—6 MeV) agrees with the results of Corge et al.[4] Possibly the slight decrease of this ratio is related to one of the intense lines of the spectrum for $E_\gamma \sim 5$ MeV.

For the W isotopes we observed changes in the intensity of the high energy lines in going from one level to another, which may be correlated with the values of Γ_n.

Of interest is the absence of fluctuations for the strong line at E_γ = 6.25 MeV in the Au spectrum. An experiment was made specially to get the γ-ray spectrum from a neutron resonance in Au, in which the resonance capture γ rays were recorded by a scintillation pair spectrometer. For this work we constructed a neutron channel with a 3-meter flight path, giving an intense beam of neutrons. The spectrometer was placed in a shield of carbide and lead, together with the sample, at the end of the flight path. The construction of the pair spectrometer does not differ essentially

Comparison of γ-ray spectra

No.	Isotope and spin	E_0, eV	Γ_n, mV	Γ_γ, mV	Relative changes of spectra	
					E_γ = 4-5 Mev	E_γ = 6.5 Mev
1	Pt^{195}, $J=1$	68.9 11.8	99.0 10.1	89±30 109±12	0.9	1.0
2	Pt^{195}, $J=1$	19.4 11.8	8.0 10.1	104±12 109±12	1.1	1.0
3	W^{183}, $J=1$	27.1 7.6	39.0 2.0	77±6 67±5	0.9	0.5
4	W^{182}, $J=1/2$	21.2 4.14	36.7 1.45	58±11 46.3±1.8	0.9	0.6
5	Au^{197}, $J=2$	61.2 4.9	109 15.6	170±80 124±3	0.95	0.95
6	Hg^{198}, $J=1/2$	89.8 23.0	29 6.9	150±20 116±6	1.5	2.0
7	Hg^{199}, $J=1$	175.0 33.5	290 47.7	290±75 273±11	1.0	0.7
8	Hg^{199}, $J=0$	129.3 2.0	175 —	340±45 —	0.7	0.9

from these described in the literature.[10] To increase the efficiency we used a second pair of lateral crystals, recording the annihilation quanta. The resolution of the spectrometer for the line E_γ = 4.43 MeV from a Po + Be source was 3.8%. The γ-ray spectrum from the gold resonance is shown in Fig. 2.

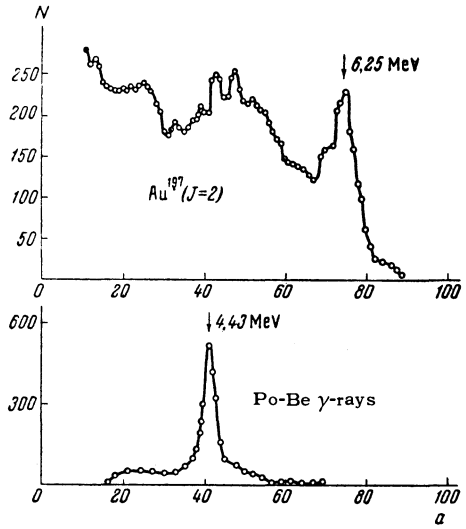

FIG. 2. Gamma-ray spectrum from a neutron resonance in Au (a is the pulse height). On the lower curve: Po – Be γ rays.

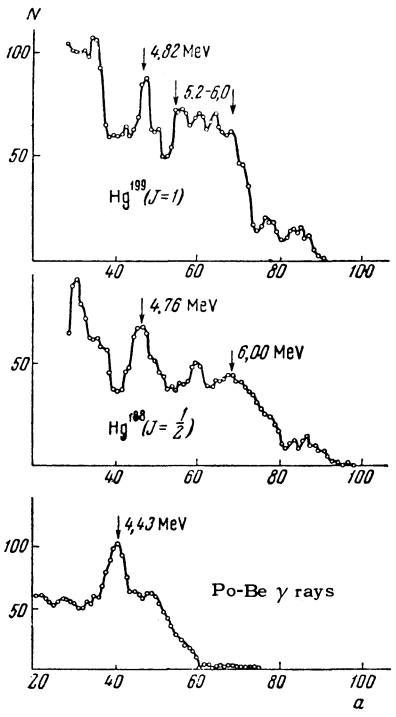

FIG. 3

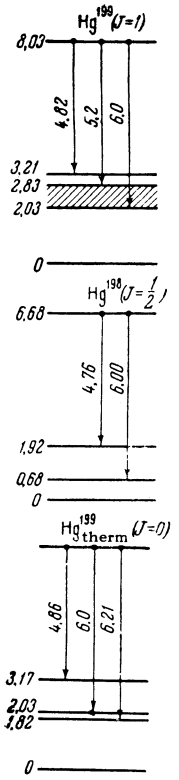

FIG. 4

FIG. 3. Gama-ray spectra from neutron resonances in Hg on the figure: Po-Be γ rays.

FIG. 4. Scheme of γ-ray transitions from neutron resonances for Hg (enrgies of levels and transitions given in Mev) on the Figure: $Hg_{therm}(J = 0)$.

The largest fluctuations in the shape of the γ-ray spectrum were observed for Hg. Thus, in Hg^{198}, despite the large instrumental width of the γ-ray detector, which should smooth out the fluctuations, we observed a change of more than a factor of two in the intensity of the γ rays with energy 5—6 MeV. This undoubtedly shows that as we approach the doubly magic closed shell the single-particle transitions, whose probability may be strongly dependent on the quantum numbers of the levels, play an important part. To verify this we made measurements of the spectra for the first two resonances of Hg, using a spectrometer consisting of nine photomultipliers with small NaI crystals.

Figure 3 shows the spectra for resonances in Hg^{198} (E_0 = 23 eV) and Hg^{199} (J = 1, E_0 = 33.5 eV), while Fig. 4 shows the transition schemes. Also shown are some of the transitions seen after thermal capture. An interesting point is the coincidence of the transitions to the level at E ~ 2 MeV, which apparently indicates that this is a single-particle level. The level at E = 3.2 MeV appears both in the transition from the J = 1, E_0 = 33.5 eV level and in the thermal spectrum. Its intensity fluctuations (No. 8 in Fig. 1) also favor its being single-particle. It should be mentioned that, contrary to expectations, the shape of the spectrum from the level at E_0 = 33 eV (J = 1) is similar to the spectrum from thermal capture (J = 0). Thus it is not so much the spin of the excited state, but rather the nature of the low-lying excited levels, that determines the γ-ray spectrum following resonance capture.

Further work on capture γ rays is planned using better neutron resolution and with different isotopes, to observe and systematize the transitions to single particle states.

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[1] Ignat'ev, Kirpichnikov and Sukhoruchkin, PTÉ, No. 4, 25 (1959).

[2] Ignat'ev, Kirpichnikov and Sukhoruchkin, IAEA Nuclear Electronics II, Vienna, 1962, p. 215.

[3] Ignat'ev, Kirpichnikov and Sukhoruchkin,

Nuclear Reactions at Low and Medium Energies, Second All-union Conference, 1960, Academy of Sciences, U.S.S.R., 1962, p. 551.

[4] C. Corge et al, J. Phys. radium **22**, 722 (1961).

[5] A. M. Lane and J. E. Lynn, Nuclear Phys. **17**, 563 (1960).

[6] Ignat'ev, Kirpichnikov, and Sukhoruchkin, Preprint, Inst. Theor. Exp. Phys. No 200, 1963.

[7] Hughes, Magurno, and Brussel, Neutron Cross Sections, BNL-325, Suppl. 1, 1960.

[8] Ignat'ev, Kirpichnikov, and Sukhoruchkin, JETP **45**, 875 (1963), this issue p. 602.

[9] Groshev, Demidov, Lutsenko, and Pelekhov, Atlas spektrov γ-lucheĭ radiatsionnogo zakhvata teplovykh neĭtronov (Atlas of γ-ray Spectra from Radiative Neutron Capture), Glavatom, 1958.

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