ELECTRIC QUADRUPOLE γ TRANSITIONS IN EVEN-EVEN NUCLEI

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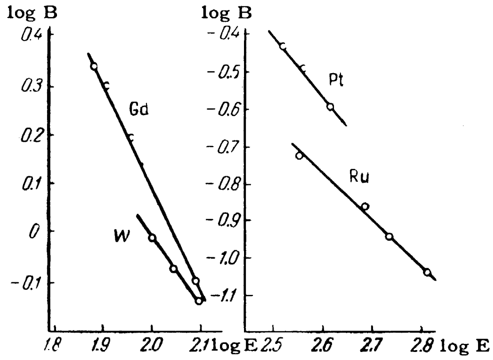
LET us consider the first excited states of even-even nuclei, which have quantum numbers 2^+ and are deexcited by electric quadrupole radiation. The extensive experimental data available at present concerning lifetimes of these states enable us to compute for these E2 transitions the reduced probabilities B(E2), which are equal (to within a statistical factor which is the same for all the nuclei considered) to the square of the transition matrix element. One then discovers a connection between the value of B(E2) and the energy E of the excited state.

Earlier, McGowan[1] treated the nuclei in the mass number range 90 < A < 130 from this point of view. He showed that for these nuclei the relation between B(E2) and E can be represented satisfactorily in the form $B(E2) \sim E^{-1}$, independently of the atomic number Z. We have considered the nuclei in the broad range of mass numbers from A = 46 (Ti) to A = 198 (Pt). In computing the values of B(E2) we used experimental data collected in summaries[2,3] as well as original papers published during 1958-1959 and not included in the survey reports.

The comparison of B(E2) and E was made separately for the isotopes of different elements. For the isotopes of all the elements considered, B(E2) decreases when E increases. For nuclei with a large deformation parameter, whose first excited state is a rotational state, this relation between B(E2) and E is natural: an increase in deformation in such nuclei is associated with an increase of the quadrupole moment and the moment of inertia, which causes an increase of B(E2) and a decrease of the excitation energy. It appears that such a dependence of B(E2) on E holds not only for nuclei with large deformation parameters but for even-even nuclei in general. The relation between B(E2) and E becomes even more apparent if we look at the dependence of log B(E2) on log E. This dependence is shown in the figure for the isotopes of Ru[2-4], Gd[2,3], W[2,3,5] and Pt[2,3]. [B(E2) is in units of $e^2 \times (\text{barns})^2$ and E is in kev.] It



is apparent that the relation between log B(E2) and log E is linear and can be represented by the formula

$$\log B(E2) = a \log E + b, \qquad (1)$$

where a and b are constant for the isotopes of a given element. For isotopes whose first excited state is a rotational state, formula (1) could have been predicted, by taking account of the quadratic dependence of B(E2) on the deformation parameter for such levels, and by assuming a power law dependence of the nuclear moment of inertia on the deformation parameter. However formula (1) proves to be valid for nuclei in various regions of mass number, independently of whether or not these nuclei have a rotational spectrum of their low lying excited states; a linear dependence similar to that shown on the figure for the isotopes of Ru, Gd, W and Pt also holds for the isotopes of Se, Pd, Cd, Te, Sm and Dy. For these ten elements, the values of the constant a in (1) were computed from the experimental data using least squares. For seven of the elements (Ru, Pd, Cd, Te, Sm, W, Pt) the values of a were very close to one another, lying in the range -1.2 ± 0.2, which shows that the power law dependence of B(E2) on E is approximately the same for these elements. Of these seven elements, the isotopes of W and two of the four Sm isotopes have rotational spectra for their lowest excited states, whereas the other nuclei do not have such spectra, and are treated as spherically symmetric in the uniform model of the nucleus.[2] A typical example is samarium, whose isotopes with A = 152 and 154 are deformed nuclei whose lowest states are rotational in character, while the isotopes with A = 148 and 150 do not have rotational spectra, and their excitation is treated in the uniform model as resulting from quadrupole vibration. However the experimental data favor the same dependence of B(E2) on E for all four isotopes of Sm, and the computed value of the constant a differs from that for Ru, W, Pt, and the other elements by no more than 15%.

For a large class of nuclei (in the mass number interval $150 < A < 190$ and $A > 222$) the lowest excited states of even-even nuclei are uniquely interpreted to be rotational states. Nuclei lying outside this mass number range are treated on the uniform model as spherically symmetric and their excitation attributed to quadrupole vibration. The lack of a quantitative theory of such vibrations makes a direct test of this assumption difficult. An alternative point of view was proposed in the paper of Davydov and Filippov,[6] where it was shown that the lowest excited states of even-even nuclei can be interpreted to be rotational states even if they are outside the mass number range $150 < A < 190$, $A > 222$, if one assumes that the nucleus is not axially symmetric. Then when we go from highly deformed nuclei to nuclei which are close to a filled shell the nature of the excitation does not change; only the parameters describing the deformation and the axial asymmetry change, resulting in a change in the energy of the levels and the separation of levels with the same spin. Possibly the regularities noted here in the dependence of B(E2) on energy could be explained on the basis of such a model.

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EXCITATION OF ROTATIONAL STATES OF NONAXIAL NUCLEI IN ALPHA-PARTICLE SCATTERING

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In the present paper an estimate is made of the probability of excitation of the second 2^+ level in even-even nonaxial nuclei resulting from scattering of α particles with energy $E \gtrsim E_B$ (where E_B is the height of the Coulomb barrier), for the purpose of determining the role of the competing mechanisms of excitation — direct nuclear interaction and Coulomb excitation.

Since the quasi-classical approximation is valid for the scattering of α particles with $E \gtrsim E_B$ by heavy nuclei ($kR \gg 1$), in solving our problem we can use a method which was developed in the classical theory of Coulomb excitation. In this treatment the excitation of the nucleus occurs as the result of time-dependent nuclear and electric interactions.

It is not hard to show (cf. reference 1) that the conditions under which one can treat the potential energy of interaction as a perturbation are expressible in the following form: $(kR_0)^2 M(I_i \rightarrow I_f) \ll 1$ (for the nuclear interaction) and $\eta^2 M(I_i \rightarrow I_f) \ll 1$ (for the Coulomb interaction). Here

$$M(I_i \rightarrow I_f) = \frac{1}{2I_i + 1} \sum_{m_i m_f} |\langle I_i m_i | a_\mu | I_f m_f \rangle|^2$$

is the matrix element for transition of the nucleus from the ground state to the excited state, a_μ are coordinates characterizing the deformation of the nuclear surface in a coordinate system fixed in the nucleus, and $\eta = Z_1 Z_2 e^2/\hbar v$. In the case of excitation of the second 2^+ level in a nonaxial nucleus (denoted in the sequel by 2^+) we have, according to Davydov and Filippov:[2]

$$M(0 \rightarrow 2^+) = \frac{\beta^2}{10}\left[1 - \frac{3 - 2\sin^2 3\gamma}{\sqrt{9 - 8\sin^2 3\gamma}}\right], \qquad \beta^2 = \sum_\mu |a_\mu|^2,$$

where γ is the parameter describing the deviation of the nucleus from axial symmetry. The quantity $M(0 \rightarrow 2^+)$ goes to zero for $\gamma \rightarrow 0$ and $\gamma \rightarrow 30°$, while it attains its maximum value $\sim 7 \times 10^{-3} \beta^2$ for $\gamma \approx 20°$. From these estimates it follows that perturbation theory is applicable to the excitation of the 2^+ level.

If we take account of the change of the orbit of the bombarding particles and the change of the electric multipole fields when the particles enter the nucleus by using the method proposed by the author,[3] then in calculating the probability of exci-