Systematics of M4 Transitions

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Abstract — Reduced probabilities of known γ transitions of M4 multipolarity are analyzed. Hindrance factors of 95 M4 transitions are calculated and presented. It is shown that the investigated M4 transitions are inhibited in regard to estimates using Moszkovsky formulas, and their mean hindrance factor is 5.5. The factors are close to unity in two cases only, but the intensity of a weak M4 transition could be overestimated in an experiment due to the summation effect. Dependences of the hindrance factors on the number of protons and neutrons are shown for M4 transitions between states with dominant single-particle components π1g9/2 → π2p1/2, v1h11/2 → v2d3/2, and v1l13/2 → v2f5/2.

DOI: 10.3103/S1062873812080242

Gamma transitions of M4 multipolarity are characterized by the ban on orbital angular momentum l not actually affecting them, in contrast to transitions of lower multipolarity. In addition, collective effects are quite unlikely to occur here. We may assume that these transitions are not affected by these factors, and it is therefore interesting to compare the reduced probabilities of such transitions with the values calculated using the single-particle model, of course considering the limited character of this model application.

Our calculations were performed using Moszkovsky’s formulas in [1], which take into account for the magnetic properties of nucleons. The formulas for nuclei with odd numbers of protons and neutrons are different due to differences in their magnetic moments (+2.79 nucl. magn. for a free proton and –1.91 nucl. magn. for a free neutron) and factors

\[ g_l (g_l = 1.0 \text{ for a proton and } g_l = 0 \text{ for a neutron}). \]

Our calculations considered statistical factors whose values were generally

\[ S = 1.5 - 1.8 \text{ for } M4 \text{ transitions}. \]

For the \( p1/2 \rightarrow g9/2 \) transition, the value is \( S = 5 \); and for the reverse transition, it is \( S = 1 \). M4 transitions are usually strongly converted, and the most advanced BRICC code was used to calculate the theoretical values for the coefficients of internal conversion [2].

Databases [2] and [3] were used to determine experimental values of the reduced probabilities of M4 transitions, and in each case these data were checked.

Hindrance factors of M4 transitions \( F_{\text{hind}} \) were determined as the ratio of experimental and theoretical values for the reduced probability of hindrance:

\[ F_{\text{hind}} = T_{1/2} \text{(M4)}_{\text{exp}} / T_{1/2} \text{(M4)}_{\text{th}}. \]

The Table presents data on 95 known M4 transitions. The data on M4 transitions are assigned to sections (a) through (e) of the Table, in accordance with the quantum single-particle configurations ascribed to the levels between which the investigated transitions occur (i.e., the main components). These configurations are indicated in the section subheadings. Section (f) presents data on M4 transitions in odd-odd nuclei; section (g) presents data on \(^{131}\text{Sb}, ^{133}\text{Cs}, \) and \(^{179}\text{Hf} \) nuclides. The second column gives the energies of M4 transitions. Quantum characteristics of the states between which transitions occur are given in the table’s third column. Fractions (% of the number of decays) of the M4 transitions for corresponding isomeric states are given in the table’s next to the last column. The last column gives the values for the M4-transition hindrance factors, calculated in the manner described above.

With regard to section (a), which presents data on transitions of the \( 2p1/2 \leftrightarrow 1g9/2 \) –type in nuclides with an odd number of protons, note that the experimental estimate of the intensity of the 64.3 keV M4 transition in a \(^{99}\text{Rh} \) nucleus (<0.16%) given in [4] correspond to the hindrance factor \( F > 40 \). This value falls out from the graph shown in Fig. 1 for the dependence of the hindrance factors of this type of M4 transition on \( Z \). In this case, the rather smooth dependence \( F(Z) \) allows us to estimate \( F \approx 4 \) by means of interpolation (the asterisk in Fig. 1). It corresponds to a possible intensity of \( \approx 2\% \) for an isomeric M4 transition in a \(^{99}\text{Rh} \) nucleus.

Figures 1–4 show the dependences of Moszkovsky hindrance factor \( F_{\text{hind}} \) on the number of protons or neutrons for M4 transitions of various types. Characteristics of the levels between which transitions occur are noted in the figure captions, signifying the components of the single-particle wave functions that make the main contribution to the probability of a considered M4 transition. The figures show that values of the hindrance factors calculated using Moszkovsky’s formulas tend to diminish as the number of protons or neutrons approaches the magic numbers \( N = 50 \) (Fig. 1), \( N = 82 \) (Fig. 2), \( N = 126 \) (Fig. 3), and \( Z = 50 \) (Fig. 4). In odd isotopes of Pb that have the magic...
### (a) 2p1/2 ↔ 1g9/2—type transitions in nuclides with an odd number of protons

<table>
<thead>
<tr>
<th>Nuclide</th>
<th>Energy of M4 transition, keV</th>
<th>$I^e \rightarrow I^n$</th>
<th>Fraction of isomeric M4 transition, %</th>
<th>Hindrance factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{87}\text{Sr}^{49}$</td>
<td>235.38</td>
<td>1/2$^+ \rightarrow 9/2^+$</td>
<td>76.6 (11)</td>
<td>2.95 (6)</td>
</tr>
<tr>
<td>$^{85}\text{Sr}^{47}$</td>
<td>239.35</td>
<td>1/2$^+ \rightarrow 9/2^+$</td>
<td>3.9 (5)</td>
<td>4.5 (6)</td>
</tr>
<tr>
<td>$^{81}\text{Ce}^{49}$</td>
<td>385.82</td>
<td>9/2$^+ \rightarrow 1/2^-$</td>
<td>98.4 (3)</td>
<td>5.44 (15)</td>
</tr>
</tbody>
</table>

### (b) $1h1/2 ↔ 2d3/2$—type transitions in nuclides with an odd number of neutrons

<table>
<thead>
<tr>
<th>Nuclide</th>
<th>Energy of M4 transition, keV</th>
<th>$I^e \rightarrow I^n$</th>
<th>Fraction of isomeric M4 transition, %</th>
<th>Hindrance factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{135}\text{Ba}^{69}$</td>
<td>277.93</td>
<td>11/2$^+ \rightarrow 3/2^+$</td>
<td>100</td>
<td>4.57 (4)</td>
</tr>
<tr>
<td>$^{137}\text{Ba}^{69}$</td>
<td>268.22</td>
<td>11/2$^+ \rightarrow 3/2^+$</td>
<td>100</td>
<td>4.2 (3)</td>
</tr>
</tbody>
</table>

### (c) 2p1/2 ↔ 1g9/2—type transitions in nuclides with an odd number of neutrons

<table>
<thead>
<tr>
<th>Nuclide</th>
<th>Energy of M4 transition, keV</th>
<th>$I^e \rightarrow I^n$</th>
<th>Fraction of isomeric M4 transition, %</th>
<th>Hindrance factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{87}\text{Zn}^{39}$</td>
<td>438.64</td>
<td>9/2$^+ \rightarrow 1/2^-$</td>
<td>99.967</td>
<td>5.61 (11)</td>
</tr>
<tr>
<td>$^{85}\text{Kr}^{49}$</td>
<td>304.87</td>
<td>1/2$^+ \rightarrow 9/2^+$</td>
<td>21.4 (4)</td>
<td>3.5 (14)</td>
</tr>
</tbody>
</table>

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Values for the hindrance factors of M4 transitions

BULLETIN OF THE RUSSIAN ACADEMY OF SCIENCES. PHYSICS Vol. 76 No. 8 2012