NUCLEAR EXCITATION BY $\gamma$ RAYS OF
RADIOACTIVE SOURCES

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Nuclear isomers of stable nuclei were excited by inelastic resonance scattering of Compton-scattered $\gamma$ rays from high-activity $^{40}$Sc, $^{60}$Co, $^{42}$Pr and $^{24}$Na radioactive sources. By counting isomeric transition rates, activation cross sections for thirty-five isomers were determined, some of them not previously published. Values of these cross sections lie between 0.003 and 214 $\mu$barn. The partial level widths $\mu = g I_0 I_1 T^{-1}$ for the transitions leading from the activation to the metastable levels, estimated for twelve activation levels belonging to eight nuclei, are between $4 \cdot 10^{-6}$ and $2 \cdot 10^{-4}$ eV.

1. Introduction

The production of isomers of stable nuclei by photoexcitation with bremsstrahlung and determination of the partial widths of the “activation” levels by subsequent measurement of the isomeric activity is a well known procedure [1–2]. The multicurie radioactive $\gamma$ sources now available make it possible to obtain photoexcitation with $\gamma$ rays scattered down to the energy of activation level by the electrons in the source itself, in the target, and in the surrounding materials [3–5]. Many nuclei having a long-lived isomeric state occur in the region of the closed shells, where low-lying states of large spin difference from the ground state exist. It is hoped that a systematic study of the higher states of such nuclei will shed more light on models coupling single-particle motion with core exitation.

2. The method

2.1. Basic relations

The isomeric activity produced by a given $\gamma$ flux, $f$, from a radioactive source may be expressed as

$$ I = f \sigma_{\text{exp}} \frac{N \cdot a \cdot m}{A} S = f \cdot \sigma_{\text{int}} \cdot \frac{N \cdot a \cdot m \cdot S}{A}, $$

(1)

where $\sigma_{\text{exp}}$ is the experimental isomer activation cross section,

$N$ is the Avogadro number,
\( a \) is the isotopic abundance,
\( m \) is the weight of the sample,
\( A \) is the atomic weight of the sample, and
\( S \) is the saturation factor \( 1 - \exp(-0.693 \cdot t \cdot T^{-1}) \).

The resonance flux density, \( f_r \), corresponding to the number of quanta scattered to the activation level energy, refers to an energy interval of 1 eV, while the integrated cross section can be obtained from the Breit–Wigner formula as

\[
\sigma_{\text{int}} = \int \sigma(E) dE \frac{\Gamma_i}{\Gamma} = \frac{\lambda^2 g \Gamma_0 \Gamma_i}{4 \Gamma} = \frac{1}{4} \lambda^2 u ,
\]

where \( \Gamma_0 \) is the partial width from the excited to the ground state,
\( \Gamma \) is the total width from the excited state,
\( \Gamma_i \) is the net width from the excited to the isomeric state,
\( g = (2J + 1)/(2J_0 + 1) \) and \( u = \frac{g \Gamma_0 \Gamma_i}{\Gamma} \).

As can be seen from Eq. (1), under defined experimental conditions \( \sigma_{\text{int}} \) can be deduced from \( \sigma_{\exp} \) by making use of the Klein–Nishina formula for the various activation level energies of a nucleus at a given primary \( \gamma \) energy. The value of \( f_r \) calculated in this way may be checked experimentally when the value of \( u \) is known.

2.2. The experimental arrangement

The use of gamma emitters of various energies permits the determination of activation cross sections and estimation of partial level widths at higher activation levels. The irradiations of targets were therefore performed with the following \( \gamma \) radiation sources:

<table>
<thead>
<tr>
<th>Source</th>
<th>gamma energy</th>
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<tbody>
<tr>
<td>(^{46}\text{Sc})</td>
<td>0.89 and 1.12 MeV</td>
</tr>
<tr>
<td>(^{60}\text{Co})</td>
<td>1.17 and 1.33 MeV</td>
</tr>
<tr>
<td>(^{142}\text{Pr})</td>
<td>1.57 MeV</td>
</tr>
<tr>
<td>(^{24}\text{Na})</td>
<td>1.38 and 2.75 MeV</td>
</tr>
</tbody>
</table>

The \(^{60}\text{Co}\) radiation source employed for exciting the isomer activities was of 60 000 Ci activity. The target material was placed at the geometrical centre of 20 source packages of 3 kCi (\( \approx 12 \times 400 \) mm) each, as shown in Fig. 1. The \(^{46}\text{Sc}\), \(^{142}\text{Pr}\) and \(^{24}\text{Na}\) sources, with activities varying between 400—2500 Ci, were placed in a hot cell and the target was transferred to the detector by