Excitation of isomeric nuclear levels by laser radiation via the mechanism of inverse interval electron conversion

V. I. Gol'danskiĭ and V. A. Namiot

Institute of Chemical Physics, USSR Academy of Sciences
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With U^{235m} as an example, we state that it is possible to observe excitation of isomeric nuclear levels via electron capture from the continuous spectrum on the electron shells freed by the action of laser radiation, and the possibility of transferring to the nucleus the energy of this capture, i.e., via the mechanism of inverse internal electron conversion.

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The process of internal electron conversion, in which the excitation energy o an isomeric nuclear level Q is transferred directly to the electrons shells and is used to eject into the continuous spectrum an electron with kinetic energy $E_i = Q - V_i$, where V_i is the ionization potential for the ith shell, is well known.

It is obvious that in principle it is possible to have an inverse electron-conversion process, wherein the electron is captured from the continuous spectrui by a vacant place in the ith shell, and the energy $Q = E + V_i$ released thereby is used to excite an isomeric level. In this case, however, it is necessary to produce conditions such that the electron shells participating in the conversion are vacant to a sufficient degree, and when the inverse conversion is observable despite the extremely small fraction of the continuous-spectrum electrons used in this process, a fraction obviously equal to Γ/Δ, where Γ is the natural widtl of the populated isomeric level and Δ is the effective width of the continuous spectrum.

As will be shown below, these conditions can be realized by applying pulsed laser radiation on the medium in which the inverse electron conversion is to be initiated. By way of an illustrative example we consider a fully-converted isometric transition in nuclei U^{235m} (transition energy $Q \approx 73$ eV, half-life $T_{1/2} \approx 26$ min, i.e., 3×10^{-19} eV).[1,2]

The probability of excitation of a nuclear level within the lifetime (τ), ensured by a laser pulse, of an ionized target, is, obviously,

$$w = n_{\text{res}\,e}\,\sigma_{\text{res}}\,v_e\tau, \qquad (1)$$

where $n_{\text{res}\,e}$ is the concentration of the resonant electrons with energy within the width Γ, σ_{res} is the cross section for the excitation of the level by these electrons, and v_e is their velocity.

In order of magnitude we have $n_{\text{res}} \approx n_e\Gamma/T$, where n_e is the total concentration of the free electrons and T is the target temperature, which should be clos to the energy Q of the populated nuclear level if the inverse-conversion effi-

:iency is to be high enough. It can be further assumed that $m_e v_e^2 = 2E$, and $\sigma_{res} \sim (\hbar/m_e v_e)^2$, so that

$$w = n_e \frac{\Gamma}{Q} \frac{\hbar^2}{m_e \sqrt{2m_e E}} \tau. \qquad (2)$$

n the considered case of U^{235m} we have $w \approx 3\times10^{-29}\, n_e(1/\mathrm{cm}^3)\tau(\mathrm{sec})$. At a laser-)eam energy $\mathcal{E} \approx 10$ J and an ionization potential Q (the number of electrons in he uranium nucleus having an ionization potential of this value or lower is ıbout 10), the number of produced ions can obviously reach $\sim 5\times10^{16}$. This ıumber corresponds to a laser-heated uranium with an approximate volume .0^{-6} cm^3 or an approximate radius 10^{-2} cm (in this case $n_e \approx 10^{24}$ cm^{-3}). The ıtoms of this granule, heated to a temperature Q ($r \sim 10^{-2}$ cm, $V \sim 10^6$ cm/sec), lisperse within a time on the order of 10^{-8} sec. The cooling of the granule at a emperature Q, in accordance with the Stefan-Boltzmann law, would carry away luring this time an energy of approximately 100 J, which is more than ten imes the laser-beam energy $\mathcal{E}$ cited above. The real time required for laser 'pumping" of the isomeric level must therefore be assumed to be one-tenth as arge, $\tau \sim 10^{-9}$ sec.

Substitution of the indicated values of n_e and τ in (2) yields $w \approx 3\times10^{-14}$, i.e., he number of U^{235} nuclei produced in one laser pulse (at an energy input of 10 J to the uranium granule) can reach $N \approx 1000$. Accumulation of the effect via rradiation of many uranium granules by a sequence consisting of a number of aser flashes during the lifetime of the U^{235m} level can greatly increase the iso-ner yield, but even single laser pulses suffice to observe the inverse electron :onversion.

The described method can be used to excited also other isomeric levels with ıigh energies and low conversion coefficients (this makes the task more diffi-:ult), but on the other hand with shorter lifetimes, i.e., large natural widths this increases the effectiveness of utilization of the continuous-spectrum elec-:rons in the inverse-conversion process). It seems possible to use the deter-nination of the yield of nuclear isomers for an *a posteriori* diagnostic of the :onditions existing in a laser plasma.

We note in conclusion that the feasibility of realizing inverse internal con-/ersion was analyzed by Morita,[3] who reported later observation of this pro-:ess for ^{189}Os,[4] but considered not the capture of electrons from the contin-ıous spectrum, but transitions between electron shells, thereby, of course, greatly decreasing the probability of realizing the resonant process of internal :onversion.

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