Laser-Assisted Coulomb Excitation of Nuclei.

R. M. O. Galvão, N. S. Almeida and L. C. M. Miranda

Divisão de Física Teórica, Instituto de Estudos Avançados
Centro Técnico Aeroespacial - 12.200 S. J. Campos, SP, Brazil

(ricevuto il 31 Maggio 1983)

PACS. 21.90. – Other topics in nuclear structure

Summary. – The Coulomb excitation of nuclei in the presence of an intense laser field is considered. It is shown that the laser field not only enhances the cross-section, but also allows the excitation of the nuclei to take place even when the proton energy is smaller than the transition energy of interest.

In recent papers (1-3) it has been discussed the influence of intense laser fields to the nuclear β decay and it is concluded that the effect of the laser field may be very significant, leading to a large enhancement of the decay process. The argument of these authors for considering the influence of the laser field on nuclear processes is based upon the fact that even though the nuclear bound states are hardly affected by the laser field, the quantum state of charged particles which evolve from nuclear processes are. This argument is, of course, equally applicable to the cases of electron scattering off nuclei or Coulomb excitation as well. In these two cases the incident charged particle can gain or lose energy to the laser field, while colliding with the nucleus, so that an extra channel for the exchange of energy of the colliding particle is open by the laser field.

In this paper we shall explore these new possibilities of the influence of lasers on nuclear processes by considering the case of the Coulomb excitation of nuclei by protons. Accordingly, we consider a beam of monoenergetic protons colliding with a nuclear target, which can be a gaseous one, as schematically shown in fig. 1. This system is simultaneously irradiated by an intense laser such as a CO₂ laser (λ = 10.6 μm) or a Nd: glass laser (λ = 1.06 μm). We assume that the incident proton «penetrates» very little into the nucleus in the course of the Collision. This is valid, provided the incident proton energy is not greater than the nuclear coulomb barrier. Under these circumstances, the nuclear interaction itself is expected to be small, so that the nucleus-proton interaction Hamiltonian is essentially governed by the proton-proton Coulomb inter-

Fig. 1. - Schematic arrangement for the laser-assisted Coulomb excitation experiment.

action. The laser field is assumed to be represented by a circularly polarized-plane electromagnetic wave propagating in the Z-direction with a vector potential $A(t) = A(\hat{x}\cos\omega t + \hat{y}\sin\omega t)$. As the electric field of the laser is much smaller than the intra-nuclear fields the interaction of the laser field with the bound proton is negligible, while the laser modulation of both the incident and the outgoing proton should be taken into account, since it can interact with the intense laser field through multiphoton processes (see, e.g., ref. (4e)). Under these conditions, the Hamiltonian for the Coulomb excitation is written as

$$
H = H_N + \frac{1}{2M} \left( \frac{\hbar}{e} A(t) \right)^2 + \sum_{i=1}^{n} \frac{e^2}{|\mathbf{r} - \mathbf{R}_i|},
$$

where $\mathbf{r}$ refers the colliding proton position, and $\mathbf{R}_i$ is the position of the $i$-th proton in the nucleus. In eq. (1), $H_N$ is the Hamiltonian for the free nucleus such that $H_N|\psi\rangle = -E_\alpha|\psi\rangle$, the second term is the kinetic energy of incident proton in the presence of the laser field, and the last term is the proton-nucleus Coulomb interaction.

Now, the state of a proton in the presence of a radiation field is given by (4e)

$$
\Psi_k = \exp[i\mathbf{k} \cdot (\mathbf{r} + \delta(t))] \exp[-iE_k t/\hbar] \exp[-i\eta t/\hbar],
$$

where $E_k = \hbar^2 k^2/2M$, $\eta = e^2 A^2/2Mc^2$ and

$$
\delta(t) = \frac{e}{Mc} \int_0^t dt' A(t') = a(\hat{x}\cos\omega t - \hat{y}\sin\omega t).
$$

Here, $a = eA/Mc\omega$ is the amplitude of the proton oscillation in the laser field, related to the laser intensity $I$ by $I = eM^2c^2a^2/4\pi\epsilon^2$. Hence, using eq. (2) to describe the

---