QUANTUM CALCULATION OF COOPERATIVE MUON-NUCLEAR PROCESSES: DISCHARGE OF METASTABLE NUCLEI DURING NEGATIVE MUON CAPTURE

S.-V. MALINOVSKAYA, A.-V. GLUSHKOV,
Y.-V. DUBROVSKAYA AND L.-A.VITAVETSKAYA

Department of Quantum Optics and Nuclear Physics, Odessa University, P.O. Box 24A, Odessa-9, 65009, Ukraine
glushkov@paco.net

Abstract. There is presented a consistent energy approach to the quantum electrodynamics (QED) theory of the discharge of a nucleus with emission of a γ radiation and further muon conversion, which initiates this discharge. A numerical calculation is carried out for nucleus ${}^{49}_{21}Sc_{28}$.

1. Introduction

A negative muon μ capture by a metastable nucleus may accelerate the discharge of the latter by many orders of magnitude [1-3]. Principal possibility of storage of significant quantities of metastable nuclei in processes of nuclear technology and their concentrating by chemical and laser methods lead to questions regarding methods of governing the velocity of their decay. It has been studied [1] a possibility of action on processes of decay of nuclei with a participation of the electrons of atomic shells (K-capture and internal conversion) by means of their ionization [1]. It has been considered a possibility of accelerating the discharge of a metastable nucleus by means of the angular momentum part of the electron shells of atoms [3]. A comprehensive QED theory of cooperative laser-electron-nucleus processes is developed in refs. [4-6]. Electron shell effect is quite small, as the parameter r_n/r_a is small (r_n being the radius of the nucleus and r_a that of the atom). In this respect, a meso-atomic system differs advantageously of a usual atom, as the ratio r_n/r_a may vary in wide limits depending on the nuclear charge. For a certain ratio between the energy range of the nuclear and muonic levels the

J.-P. Julien et al. (eds.),
Recent Advances in the Theory of Chemical and Physical Systems, 301–307.
© 2006 *Springer. Printed in the Netherlands.*

discharge may be followed by the ejection of a muon, which may then participate in the discharge of other nuclei.

In this paper we present a consistent energy approach to the QED theory of the discharge of a nucleus with emission of γ radiation and further muon conversion, which initiates this discharge. Traditional processes of muon capture are studied in fundamental papers [7-9, 10-13] and are not considered here. Within the QED energy approach [4-6, 14-19], a decay probability is presented as the imaginary part of the energy shift. In our situation the probability of the corresponding process (decay) is linked to the imaginary part of the "nucleus core + proton + muon" system. For radiative decays it is manifested as an effect of the retardation in interaction and self-action.

2. Model and channels of decay for meso-atomic system: Energy approach

We consider a simple one-particle system of nucleus. It is supposed that the system consists of a twice-magic core. A single proton and single muon moves in the core field. The proton and muon interact through the Coulomb potential. This interaction will be accounted for in the first order of the atomic perturbation theory (PT) or second order of the QED PT. Surely a majority of known excited nuclear states have the multi-particle character and it is hardly possible to describe their structure within one-particle model. Nevertheless, the studied effects of muon-proton interaction are not connected with one-particle character of the model. In principle it is possible to consider also a dynamical interaction of two particles through the core. It accounts for the mass finiteness of the core. However, this interaction may decrease the multipolity of nuclear transitions only by unit. Indeed, an interest attracts strongly forbidden transitions of high multipolity. We will calculate probabilities of decay to different channels of the system, which consists of a proton (in an excited state $\Phi_{N_1 J_1}$) and a muon (in the ground state $\Psi^{\mu}{}_{1s}$).

Three channels should be taken into account [3]: i) a radiative, purely nuclear 2^j-pole transition (probability P_1); ii) a non-radiative decay, when the proton transits to the ground state and the muon leaves the nucleus with the following energy: $E = \Delta E^{p}_{N_1 J_1} - E^{i}_{\mu}$; here $\Delta E^{p}_{N_1 J_1}$ is the energy of the nuclear transition and E^{i}_{μ} is the bond energy of the muon in the *1s* state (P_2); iii) a transition of the proton to the ground state with muon excitation and emission of γ radiation with energy $h\omega = \Delta E^{p}_{N_1 J_1} - \Delta E^{\mu}_{nl}$ (P_3). Corresponding Feynman diagrams are given in Figure 1.