Internal conversion of gamma rays on muons

I. M. Band, M. A. Listengarten, and L. A. Sliv

Leningrad Institute of Nuclear Physics, USSR Academy of Sciences; Leningrad State University
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The internal conversion coefficients (ICC) of gamma rays on muons were calculated for a number of values of the atomic number and of the energy and multiplicity of the transition. It is shown that allowance for the nuclear sizes is essential in the calculations, that conversion on a muon is an important method of lifting the excitation of the fission fragments, and that ICC of different multipolarities differ greatly from one another.

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Nuclear fission is possible in mesic atoms of heavy elements in the case of nonradiative transition of the muon into the 1*s* state.[1] The muon usually remains on the *K* shell of the fragment, more frequently of the larger one.[2] The purpose of this paper is to demonstrate by exact calculation the great role played by internal conversion on the muon in the competition between various channels of the deexcitation of a strongly excited fragment.

One might assume that muonic ICC could be easily obtained from the usual tables[3] for electronic conversion, by taking the ICC for the energy $E_\gamma(m_e/m_\gamma)+E_\gamma/206.8$. Actually, however, this is not the case, owing to the large effect of allowance for the influence of the nuclear sizes on the mesic ICC (static and dynamic effects).

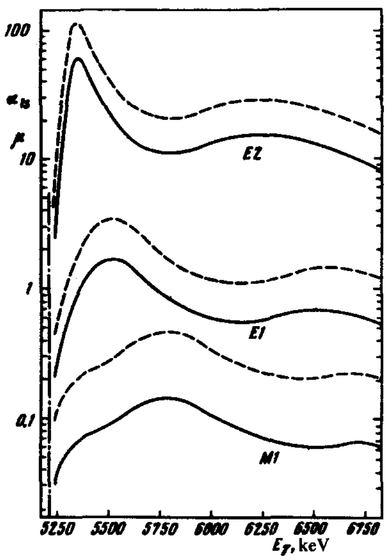
We calculated the ICC on muons for the *K* shell for the atomic numbers *Z* from 10 to 90, for electric and magnetic multipoles with $L \leq 3$ for several values of the gamma-ray energies E_γ from 30 keV above the *K*-conversion threshold to 10 MeV (and higher at large *Z*).

To take the static effect into account, the radial muon wave functions were obtained by numerically integrating the Dirac equations in the field of a nucleus with a given charge distribution. Whereas in relativistic electron units ($\hbar/m_e c$) the equivalent radius R_0 of the atom is a small quantity ($R_0 \approx 0.015$), in muonic units $R_0 \approx 3$. The approximation $R_0 \ll 1$ used in individual cases in the usual ICC theory does not hold here.

To take into account the influence of the distribution of the transition currents over the nucleus (the dynamic effect or the penetration effect), the ICC were calculated in two extreme models, a model of transition surface currents, and a model "without penetration." These models are convenient in that the ICC in these models do not contain integrals in the nuclear variables and do not depend on further details of the nuclear structure. The surface current model is closer to reality. In the less realistic model "without penetration" the transition currents become infinite at the center of the nucleus, and this makes the calculated ICC two or three times larger than the ICC in the surface-current model.

By way of example, the figure shows the calculated ICC for $Z=50$ (average *Z* in fission). It is seen that in the $Z=30$–60 region the ICC are large, exceeding unity for *E*1 and exceeding 50 for *E*2. Particularly large are the ICC for *E*1 and *E*2 at the very threshold of the conversion. Thus, the internal conversion of fission-fragment gamma rays on muons can play an important role. We emphasize also that the ICC of various multipoles differ so greatly, that measurement of muonic ICC could yield information on the spin and parity of high-lying nuclear levels far from the stability region.

For $Z=50$, the *M*1 muonic ICC are smaller by two orders of magnitude than the electronic ICC per electron on the *K* shell at a comparable (i.e., differing by 206.8 times!) kinetic energy of the emitted particle, and the *E*2 ICC are larger than the electronic ones by one order of magnitude. For $Z=10$, when the nuclear radius is smaller by one order of magnitude than the muonic *K* orbit, the effect of the nuclear size decreases only slightly the magnetic ICC and has very little effect on the electronic ICC. At the same time, at $Z=90$ and at high transition energies, the nuclear-size effect decreases the *M*1 muonic ICC by several thousand times in comparison with the electronic ICC at the comparable



Internal conversion coefficients per 1*s* muon at $Z=50$. Solid lines marked *M*1, *E*1, and *E*2—calculation in the model of surface currents of the transition at a uniform distribution of the charge over the nucleus with radius $R_0=1.2A^{1/3}$ F. The unlabeled dashed lines above the solid ones were obtained in the model "without penetration."

energy. This confirms once more the sensitivity of the $M1$ ICC to the nuclear structure.[4]

The calculated binding energies and energies of the K_{α_1} mesic x-ray transitions are in good agreement with the earlier calculations for the same charge distribution.[5]

We note that to take into account the dynamic effect in mesic conversion with different choice of nuclear wave functions, the theory of[6] is not valid, since it essentially makes use of the condition $R_0 \ll 1$. A muonic-ICC theory suitable for any model of the nucleus should follow the theory of the Auger effect. For the double integrals of the mesic and nuclear wave functions, which enter in the expression for the ICC in this case, see[7].

We are presently refining the values of the mesic ICC by taking into account the Fermi distribution of the charge in the nucleus, the polarization of vacuum, and the deformation.

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