On the decay of ^{193m}Ir

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It is shown that the electronic bridge effect in the decay of ^{193m}Ir reported earlier strongly contradicts the theoretical estimates of the effect as well as other experiments.

A paper recently published in JETP[1] reports the first measurement of the electronic bridge effect in nuclear decay that was predicted in Ref. 2. Observation of this effect of higher order perturbation theory is undoubtedly of interest. The authors of Ref. 1 reached the conclusion about the measurement of the deexcitation of ^{193m}Ir through the electronic bridge effect on the following basis. The coefficient of internal conversion (CIC) in the K-shell α_K for the M4-transition at 80.27 keV which they measured was 9.26 ∓ 0.9, while the theoretical value according to their data was 122.1 or 21% higher. It was maintained in Ref. 1 that possible changes of the physical premises in the calculation of CIC (without taking into account higher orders or perturbation theory) could only increase the theoretical value of α_K.

At the same time another value of CIC was obtained for the case discussed in Ref. 3 in which CIC in all shells of ^{193m}Ir were measured[1)] α_K (80.22 keV) $= 1.04 \mp 3$ and the interpolation of tabulated values[4] in agreement with Ref. 3 gave for his transition α_K (M4) $= 103$. Thus the authors of Ref. 3 did not find disagreement with theory.

Because of the disagreement between the results of the two articles and because the interpretation of the transition ^{193m}Ir is important for the question of measuring a new effect in nuclear decay, we studied all facets of this case. We calculated separately the real and imaginary parts of the conversion matrix elements for this transition and with their ratios in agreement with theory[2] with the equations from Refs. 2, 5, and 6 we found the relative change of CIC due to the appearance of additional gamma radiation with energy 80.27 keV through the electronic bridge effect. This change is 4×10^{-5} % so that for CIC in all shells and subshells as well as for the total CIC α_T it is almost exactly identical. In other words, the change of CIC at the 80.27 keV transition of ^{193m}Ir due to the electronic bridge effect is practically zero.

At the same time we are not maintaining at all here that theory[2] gives an insignificantly small effect arbitrary nuclei and arbitrary transitions. In particular, we carried out a similar calculation for the 75 eV transition in ^{235}U and were satisfied that in this case all theoretical CIC decrease due to the electronic bridge effect by a factor of 2×10^5, i.e., instead of $\alpha_T = 3.2\times 10^{20}$ (without the bridge effect) $\alpha_T = 1.6\times 10^{15}$ is expected (with the bridge effect). This result agrees with the results of a similar calculation for uranium in Ref. 6. Thus if in agreement with Ref. 1, α_K (experimental) for ^{193m}Ir really differs from the tabulated α_K and from the data of Ref. 3, then it is impossible to explain its presence by the bridge effect and a different reason must be sought.

We first considered the effect of taking into account screening of the CIC of this transition. In the tables[4,7,8] CIC was calculated in the atomic field by the self-consistent Dirac-Fok-Schleuter (DFS) method in which the bulk interaction of electrons is taken into account approximately with a statistical model. Different authors use different values for the constant C in the expression for the bulk interaction. In Refs. 4 and 8 $C = 1$ was proposed, and in Ref. 7 $C = 2/3$ was proposed. We now have a program for calculating CIC with electron wave functions (WWF) for both discrete and continuous spectra using the Dirac-Fok (DF) method without any approximation taking into account fully the volume interaction.[9,10] This program was used for calculating CIC of ^{193m}Ir.

We further determine whether anomalies in CIC are possible in this transition due to the penetration effect. This gamma-transition is not delayed. Thus the Weisskopf exclusion factor is $F_w - 1$, so the appearance of similar anomalies in this case is practically excluded. The expected deviation of CIC from tabulated values from this cause is $\lesssim 1\%$ (Ref. 11). To take into account the penetration effect in nondelayed transitions with a tabulated calculation[8] we use the Sliv model[12] of nuclear transition surface currents (SC), while in Refs. 4 and 7 the Rose model[13] was used without penetration (WP) in which the penetration effect was completely ignored. (For more details about the difference of these models, see Ref. 11.) We consider that the SC model more adequately describes the physical situation because it excludes the infinity in the zero for potentials of the nuclear transition used in model WP. We found in the case of ^{193m}Ir that α_K (WP) is only 2% larger than α_K (SC).

The value of the theoretical CIC depends on the choice of transition energy E_γ. It was shown in Ref. 1 that it is 80.27 keV. The same value was used in tables[14] but in Ref. 3 $E_\gamma = 80.22$ keV was taken. With the transition from $E_\gamma = 80.27$ keV to $E_\gamma = 80.22$ keV α_K decreases by 0.9%. In our calculations we used $E_\gamma = 80.27$ keV.

An important question is how to take into account the hole formed after conversion in the same atomic shell or subshell from which the converted electron was ejected. This question is connected with the relation between the collapse time of the hole and the time of finding the electron in the atom. If the K shell width of iridium is $\Gamma = 40$ eV the average collapse time of the hole is $\sim 2\times 10^{-17}$ s, i.e., the hole collapses significantly more slowly than the conversion occurs and, apparently, it is correct to consider CIC calculated taking into account the hole. In the case of ^{193m}Ir the difference between CIC with the hole and without a hole is $\cong 12\%$ (the coefficient α_K calculated taking into account the hole is larger than α_K without taking it into account). Nevertheless, because only a rough estimate was given above and the difference between the two versions of the calculation is large, it

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TABLE I. Theoretical values of CIC in K-shells α_K for the $M4$ transition with $E_\gamma = 80.27$ keV ^{193m}Ir in various models.

Atomic field	Model			
	SC	WP	SC	WP
	With account of hole		Without account of hole	
DF	103.5	105.4	92.29	93.94
DFS $c = 2/3$	105.0	107.1	97.50	99.50
DFS $c = 1$	108.0	110.2	100.8	102.8

Note: The energy of the K-shell of ^{193m} Ir was taken as 76.115 keV.

makes sense to study this problem experimentally. The values of CIC calculated in various models are given in Table I.

We estimated the corrections to CIC due to restructuring of the electron shell through conversion and consequently the possible nonorthogonality of atomic wave functions before and after conversion. In analogy with the theory of electron capture such a correction is often called the "volume and overlapping" correction. With respect to conversion this question was studied by us in Ref. 15. Analogously to Ref. 15, we found by calculation of the corresponding determinants that taking into account the effect of volume and overlapping increases the theoretical value of α_K by 0.1%.

There are other possible corrections to CIC of ^{193m}Ir: taking into account the vacuum polarization gives a correction much less than 1%; taking into account inter-electron correlations for K shells in heavy atoms gives very small corrections which are less than 1% in the present case.

Thus the assertion by the authors of Ref. 1 that refinement of the model could only increase CIC in comparison with $\alpha_K = 112$ has no basis. The data of Table I show that the value of CIC in the case studied depends most of all on the way the hole is accounted for after conversion. However, the value $\alpha_K = 103.5$ in the DF model taking the hole into account should be closest to the real value of CIC (because the DFS model is only a statistical approximation to the method of DF).

Here we have considered only the theoretical side of the question about the influence of the electronic bridge effect and other effects on the value of α_K of ^{193m}Ir in the 80.27 keV transition and did not consider the execution of the experiments themselves.[1,3] Nevertheless, one can draw the completely definite conclusion: the results of calculations and their comparison with the results of experiments give no basis for supposing that the electronic bridge effect has an influence in the case of the decay of the 80.27 keV isomeric level of ^{193m}Ir.

[1)] In Ref. 3 the energy of the transition E_γ was taken as 80.22 keV and in Ref. 1 as 80.27 keV.

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