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Electron capture ratios

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1. Introduction

Theoretical values of electron capture ratios depend on two quantities which can be obtained only from extended numerical calculations, namely

1) the ratios of bound state electron radial wave functions (ERWFs) for the atomic shells under consideration evaluated at the nucleus 1] and

2) the atomic overlap and exchange correction factor introduced by Bahcall 2].

While it seemed some years ago that all the experimental results could be brought into agreement with the theoretical results by applying the Bahcall corrections, the situation is now less clear, after some new or more accurate measurements as well as new calculations of ERWFs have been performed by various authors. We, therefore, want to report our calculations of ERWFs and to compare them with those of other authors and with the experiments.

2. Method of calculation

We have solved the one electron Dirac radial equations numerically for a potential corresponding to an extended (uniform) nuclear charge distribution which is screened by the atomic electrons 3], 4]. The screening function is represented by a linear combination of exponential functions, the parameters of which were determined by comparison with Hartree-Fock potentials 5] in the case of low atomic numbers $Z \leq 36$ and with Thomas-Fermi-Dirac-Potentials 6] in the case of $Z > 36$. An exchange potential according to Slater was also included. In order to get some idea of the dependence on the potential used, we have performed additional calculations using parameters obtained by fitting the Herman-Skillman-potentials (HS) (These authors have performed nonrelativistic Hartree-Fock-Slater calculations and published extensive tables for potentials and wave functions 7]). The differences between the results of these two sets of calculations are negligible in the case of L_I/K-ratios for $Z > 16$ but they are larger for M_I/L_I ratios decreasing from 8 % for Z = 30 to less than 1 % for $Z > 60$. We do not further consider our results based on the Herman-Skillman-potentials in what follows.

3. Results and discussion

a. L/K capture

Fig. 1 shows our results (curve 1) for L_I/K-capture together with those of other authors as a function of the nuclear charge Z. First it should be noted that the curve 4 of HS 7] is based on a nonrelativistic calculation and therefore is not directly comparable with the other curves, except for very small Z values. It has been included merely in order to show the importance of the relativistic treatment. Then one sees that all the other curves essentially are in agreement except the curve 3 of Brysk and Rose (BR) 8]. The reason for this discrepancy is not quite clear, it may partly be due to the omission of the exchange potential. Furthermore one notices from fig. 1 that for $Z < 10$ the curves 4 and 5 of Winter 10], who used the analytic Hartree-Fock wave functions of Watson and Freeman 11], and of HS do not coincide any longer. This is not surprising, however, since for $Z < 10$ the L shell is incompletely filled and then the results are extremely sensitive to details of the atomic potential. For similar reasons the curve 1 deviates for $Z < 16$.

Fig. 2 has been drawn in order to compare the theoretical and experimental results. Since the theoretical results of different authors as shown in fig. 1 with the exception of BR 8] are in good agreement, we consider now only <u>our</u> curve from fig. 1 modified in so far as it has been corrected for L_{II} capture (curve 1). Furthermore, curve 3 is obtained from curve 1 by applying the exchange correction of Bahcall 2].

The experimental points 12], 13] have been obtained by averaging if more than one measurement was available for the same nucleus. The error bars include uncertainties of the neutrino momenta, which are in some cases rather large, i.e. transition energies. In order to guide the eye of the reader we have drawn a curve (2) through the experimental points, which has been obtained by fitting with least squares an <u>empirical</u> function of the type $(a_0 + a_1Z)/(b_0 + b_1Z)$.

While for Argon (Z = 18) the experimental point is nearly on the Bahcall corrected curve, it seems that for larger Z values the experimental results tend to be between the Bahcall corrected and uncorrected curves.

b. M/L capture

Fig. 3 shows various theoretical curves together with the experimental points 14] for M/L-capture. Let us first consider the curves (1)-(4) which do not contain the Bahcall correction factor. The disagreement between the theoretical curves for the lighter nuclei are not unexpected since the outer electron shells are rather sensitive to the details of the average atomic potential which is treated differently by different authors. For heavier nuclei better agreement is to be expected. The curve 4 does not contradict this expectation, because this curve is based on non-relativistic (point nucleus) calculations and therefore, for the heavier nuclei, should not directly be compared with the other curves. There remains an apparent discrepancy between curve 1 and curve 2. In order to resolve this discrepancy we note that the curve 2 which has been extensively used for analysing experimental data until now, has been obtained by dividing the M shell wave functions of Brewer et al (BHH) 15] by the L shell wave functions of BR 8]. If we, instead, divide the BHH M shell wave funtions by <u>our</u> L shell wave functions then the resulting curve would lie slightly (1,7 %) above our curve 1. This shows that our M-shell calculations are in satisfactory agreement with those of BHH.

Now let us look at curve 5, which has been obtained by applying the Bahcall correction factor to curve 3. Despite of the discrepancies between the theoretical curves from different authors it is evident that the experimental data in particular for Ar (Z = 18) and Ge (Z = 32) strongly favour the curves without any Bahcall correction factor.

In conclusion we note that the agreement between the experimental data and the theoretical results for both L/K and M/L capture ratios is no longer satisfactory. We do not expect that more refined calculations of the bound state wave functions can solve this problem.

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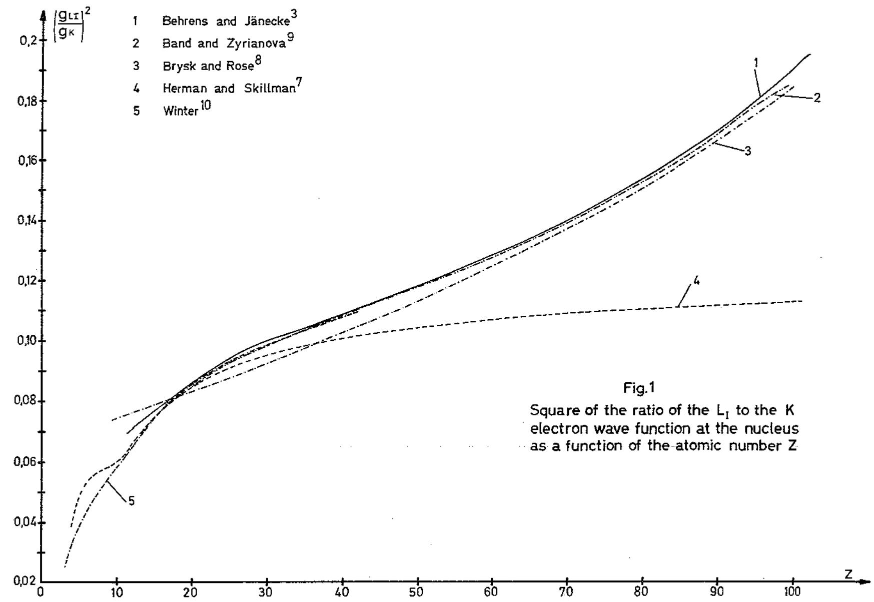

Fig.1
Square of the ratio of the L_I to the K electron wave function at the nucleus as a function of the atomic number Z

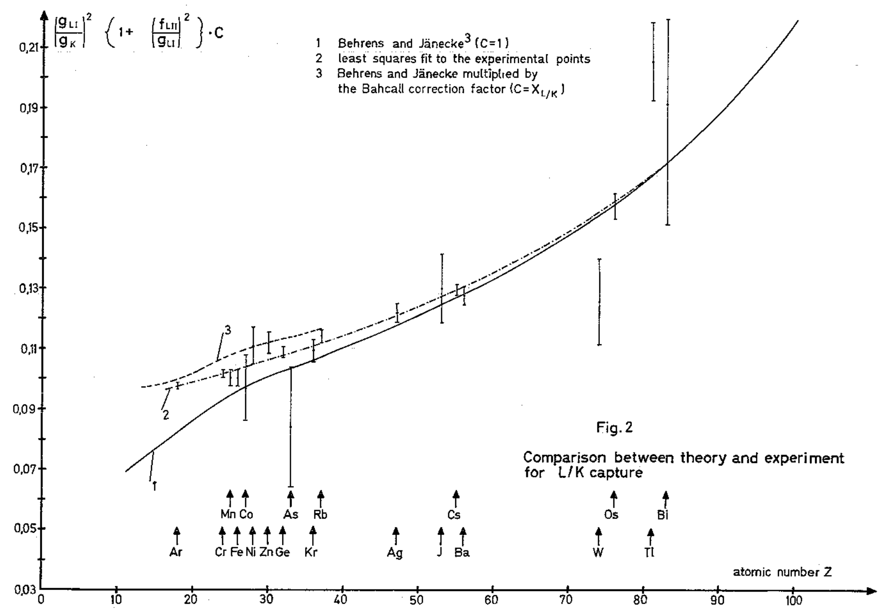

Fig. 2
Comparison between theory and experiment for L/K capture

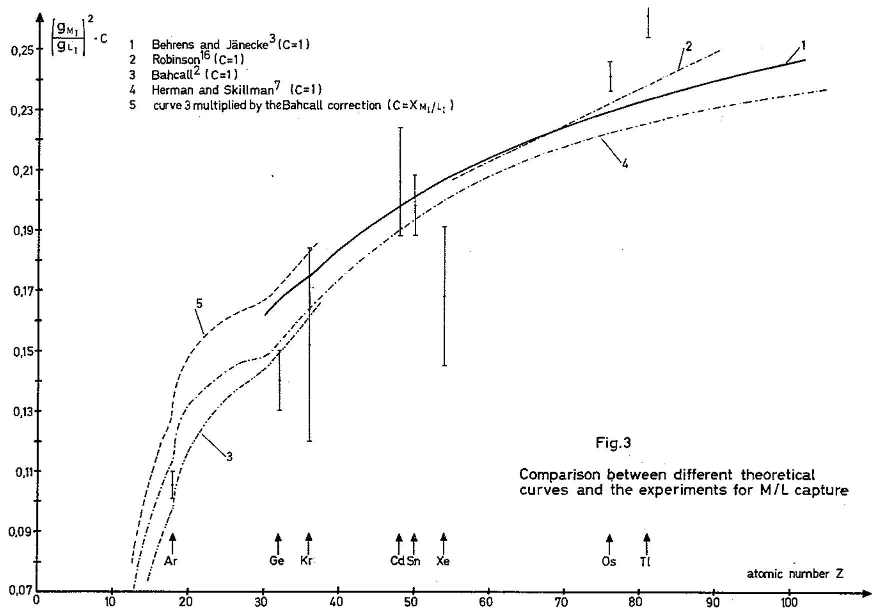

Fig.3
Comparison between different theoretical curves and the experiments for M/L capture