

# Change of the rate of the conversion $E1$ transition of the isomer $^{110m}\text{Ag}$ ( $\hbar\omega = 1.11 \pm 0.03$ keV) on variation of the valence-band configuration of the atomic shell of silver

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(Submitted 19 March 1986)

*Zh. Eksp. Teor. Fiz.* **91**, 1969–1977 (December 1986)

The conversion spectrum for the  $^{110}\text{Ag}$   $E1$  transition of energy  $\hbar\omega = 1110 \pm 30$  eV is calculated for nine configurations of the valence band of the silver atom by using a relativistic variant of the Hartree-Fock-Slater method. It is found the orbits in the range  $3s$ – $4s$  attest to a rather high stability (variation  $\lesssim 0.05\%$ ) of the conversion spectrum to changes of the valence-band configuration of the atom. The spatial region where the probability for conversion on the  $4p^{1/2}$ ,  $4p^{3/2}$ , and  $4d^{3/2}$ ,  $4d^{5/2}$  orbits is formed extends substantially beyond a sphere of radius  $R = a_0$  ( $a_0 = 5.19 \cdot 10^{-9}$  cm). This gives grounds for expecting an appreciable effect of the chemical environment in the conversion spectrum, even though variational calculations for the valence-band configuration of an isolated atom leads to small changes of the decay rate ( $\Delta\lambda/\lambda \lesssim 2 \cdot 10^{-3}$ ).

## §1. DESCRIPTION OF CONVERSION METHOD

1. Conversion-electron spectra measured with high energy resolution ( $\Delta\varepsilon \leq 1$  eV) contain exclusive information on the structure of the electron shell of a chemical compound or a cluster in which an atom with an isomer nucleus "sits." This energy resolution was achieved by now for conversion transitions with energies  $\hbar\omega$  of the order of several kiloelectron volts (and lower). A systematic investigation of the conversion spectra of  $E3$  transitions of the isomers  $^{99m}\text{Tc}$  and  $^{235m}\text{U}$  was carried out in Refs. 1–4 in a number of chemical compounds of technetium and uranium, while  $^{90m}\text{Nb}$  was considered by us earlier.<sup>5</sup> The significance of the information obtained on the structure of the electron shells of the compounds and clusters (see Refs. 1–5) points to low-energy spectroscopy (at roughly  $\hbar\omega \lesssim 10$  keV) as a new method of investigating the structures of condensed media. Further development of this method and expansion of its applications call for expanding the experiments to include a sufficiently large assortment of isomers that differ in the energy and multipolarity of the transition.

Since the development of an experimental conversion-method routine for each new isomer is a rather laborious task, it is necessary, for a choice of suitable isomers, to summarize those main conversion-process features that distinguish it substantially from the widely used photoionization method and cause the conversion spectra to contain more information than that extracted from photoelectron spectra.

At low nuclear transition energies ( $\hbar\omega \lesssim 10$  keV) the conversion of all multipoles (except  $E1$ ) is very highly selective with respect to the angular and orbital ( $j$  and  $l$ ) angular momenta of the electron relative to the isomer nucleus.

In the range investigated, the conversion of all multipoles except  $E1$  is localized, for lines with relative spectral intensity not lower than  $10^{-3}$ – $10^{-4}$  and rather high density (higher than 99%), in a small space in the vicinity of the

isomer nucleus (i.e., in a sphere of radius  $R \lesssim (0.1\text{--}0.3)a_0$ , where  $a_0 = 5.29 \cdot 10^{-9}$  cm).

For all multipoles (except  $E1$ ) the localization of the conversion zone near the isomer nucleus is independent of the spatial dimension of the electron orbit in which the multipole conversion takes place. In the case of photoionization by photons having the same energy ( $\hbar\omega_\gamma \lesssim 10$  keV) the region where the photoionization takes place is determined by the structure of the bound electron orbit in the molecule or cluster. It is just the localization of the conversion in the vicinity of the isomer nucleus which affords the exclusive possibility of investigating the delocalization of the electron shells of contiguous or combining atoms by measuring the conversion spectra with high energy resolution ( $\Delta\varepsilon \leq 1$  eV). It becomes possible in this case to observe, and estimate from the spectra, the effects of hybridization and delocalization of deep electron orbits, effects manifested by a change of the intensity of the conversion lines relative to the calculated values for the isolated atom, and by the onset of new conversion lines missing from the spectra of the isolated atoms. This was first pointed out in Ref. 4.

The strongly pronounced localization of the electron  $K$  orbit is manifest in the characteristics of the x rays produced by electron transition from an external molecular orbit to a  $K$ -hole of a definite atom in a molecule (see Refs. 6 and 7). This fact is used in x-ray-emission spectroscopy of molecules, a method that should be compared with the conversion method. The two methods differ substantially in their other characteristics: The energy width of the x-ray emission line in the considered extreme case of a  $K$  hole is bounded from below by the width  $\Gamma (K^{-1})$  of the  $K$  hole, which increases rapidly with the nuclear charge [ $\Gamma (K^{-1}) \sim Z^{3.5}$ ] and reaches  $\gtrsim 3\text{--}5$  eV at  $Z \gtrsim 40$ . Thus, for heavy atoms (where the conversion method works), we encounter the problem of separating, from the observed wide x-ray peaks, the contributions of transitions with individual high-lying

molecular orbits, while the x-ray transition produces a line with a proper width on the order of  $\Gamma$  ( $K^{-1}$ ). This problem of separating the contribution is not encountered in the conversion method. In the latter case, at all nuclear charges, the proper width of the conversion line is determined by the width of the hole produced in the act of conversion on the investigated molecular shell, since the proper width of the nuclear isomers employed is negligibly small ( $\lesssim 10^{-7}$  eV). With decreasing binding energy of the molecular orbit, the width of the hole in this shell decreases and becomes negligibly small for orbits of the valence band, where the energy resolution of the conversion method is in essence not subject to principal limitations; in contrast to x-ray spectroscopy, it is determined only by the instrumental width. This circumstance takes place also for x-ray transition to an  $L$ -hole and an  $M$ -hole. The width of an  $L$ -hole or an  $M$ -hole is, naturally, smaller than  $\Gamma$  ( $K^{-1}$ ), but on the other hand the spatial localization of the x-ray transition is worse, i.e., the better energy resolution is obtained at the cost of locality loss.

The described picture of the conversion process can be distorted by two possible parasitic mechanisms: conversion of the nuclear multipole on the localized shell of the neighboring atom, and ejection of an electron from the neighboring-atom shell through the "electron-bridge" channel. These processes always accompany the main conversion process, and cannot be eliminated in principle. Our earlier estimates,<sup>5</sup> however, have shown that the relative probability of these parasitic mechanisms, which imitate the effects of delocalization and hybridization of the electron orbits, is low ( $\lesssim 10^{-2}$ ).

2. A theoretical analysis of the experimental conversion spectra should make use of relativistic wave functions of the electron orbits, including the orbits of the valence band, since the conversion process takes place in a small vicinity of the isomer nucleus even at very low energies of the nuclear transitions (see Ref. 8). At the present time the wave functions of coupled electron orbits in molecules or clusters are either constructed by a direct variational method (the relativistic discrete-variation method), or obtained by numerically integrating the Dirac equation within the framework of the relativistic variant of the  $X\alpha$  scattered-wave method. The latter method was implemented by one of us (see Ref. 9) and used in an analysis of the experimental conversion spectra of the  $^{99m}\text{Tc}$  isomer spectra (see Ref. 3) in various technetium compounds. Both methods of constructing the electron-orbit functions are approximate and require task-oriented modification. The information contained in a well-resolved conversion spectrum ( $\Delta\varepsilon \ll 1$  eV) concerning the local behavior of electron functions in the vicinity of the isomer nucleus offers such a possibility of a purposeful departure from the initial scheme of the muffin-tin method<sup>9</sup> and points the way towards a broadening of the basis for finding a new variational trial function aimed at a more accurate description of the electron-orbit structure.

We have previously<sup>10</sup> chosen tentatively promising soft isomers with transition energy  $\hbar\omega \lesssim 3$  keV. To include these possible isomers in the routine of the conversion method and to use them to calculate the conversion spectra of com-

pounds of these possible isomers, it is necessary first of all to know the transition energy with high (better than 1 eV) accuracy. Otherwise a search for the variants that are permissible within the error limit  $\Delta\hbar\omega$  makes the calculation procedure excessively expensive, and the results are indeterminate. For the isomers given in our preliminary list,<sup>10</sup> however, the transition energies are in fact known with large error (e.g.,  $\Delta\hbar\omega = 400$  eV for  $^{90}\text{Nb}$ ). In this situation, with an aim at stimulating precise nuclear-physics investigations of the decay schemes of isomers suitable for the conversion method, it is advisable to calculate beforehand the conversion spectrum of each prospective isomer by using the simple isolated-atom schemes. The effect of the medium can be imitated (however, not completely) by varying the configuration of the valence band of the atom shell. We have previously performed calculations of this kind for the isomers  $^{235}\text{U}(E3)$  and  $^{90}\text{Nb}(M2 \text{ and } E3)$  (see Refs. 8 and 5). We consider here, in this scheme, the promising isomer  $^{110}\text{Ag}(E1)$ , the needed amounts of which can apparently be obtained by an ( $n\gamma$ ) reaction in intense fluxes of thermal neutrons, particularly from neutron sources of meson factories.<sup>11</sup> A number of the characteristics of the  $E1$ -multipole conversion differ qualitatively from the previously investigated cases of  $M2$  and  $E3$  isomers. This makes the  $E1$  isomers particularly interesting, since they can provide information that differs substantially from that of other multipole transitions.

3. The presently known energy of the  $E1$  transition of  $^{110}\text{Ag}$  from the isomer level  $|2-\rangle$  to the ground level  $|1+\rangle$  is subject to a large error; according to Ref. 12, it amounts to  $\hbar\omega = 1.28 \pm 0.10$  keV; this quantity was used in Ref. 13 and also tabulated.<sup>14</sup> The same tables, however, contain also another value  $\hbar\omega = 1110 \pm 30$  eV, which is used in Ref. 15, where it is noted that the possible effect of the source medium (i.e., the change of the decay rate of the  $^{110m}\text{Ag}$  isomer) is apparently less than 1%. We have therefore calculated the probabilities of conversion on the electron orbits of an isolated silver atom in a number of valence-band configurations of the atom for the isomer transition energies  $\hbar\omega$  equal to 1140, 1110, and 1080 eV. The calculation was carried out within the framework of the relativistic variant of the Hartree-Fock-Slater method with Latter's correction [HFS(L)] (see Refs. 16 and 17), using for the constant in the exchange term the value  $\alpha = 0.7$ . To estimate the sensitivity of the probabilities of conversion on the outer shells of the silver atoms from the parameters of the  $X\alpha$  model of the atom, we made a number of calculations also for  $\alpha = 1$ . A simplified scheme for imitating the effects of the source medium, by varying the configuration of the atom's valence band, permits a preliminary estimate of the values of the expected effects, information needed when the experiments are planned.

## §2. RESULTS OF CALCULATION OF CONVERSION PROBABILITIES

1. The rate of conversion of an  $EL$  multipole in the nuclear transition  $E_1 I_1 \Pi_1 \rightarrow E_2 I_2 \Pi_2$  between levels of energy  $E_i$ , spin  $I_i$ , and parity  $\Pi_i$  ( $i = 1, 2$ ), in the terminology pre-

viously introduced by us and used in Refs. 5, 8, and 10, is given by

$$W(EL; I_1 \rightarrow I_2; \hbar\omega) = \frac{e^4 m}{\hbar^3} \left( \frac{R_0}{a_0} \right)^{2L} \chi \left( \frac{2I_2+1}{2I_1+1} \right) |\langle I_2 || EL || I_1 \rangle|^2 \xi(EL), \quad (1)$$

where  $\hbar\omega = E_1 - E_2$ ,  $R_0$  is the radius of the nucleus,  $e^4 m / \hbar^3 = 4,1341 \cdot 10^{16} \text{ s}^{-1}$ ,  $\langle I_2 || EL || I_1 \rangle$  is the dimensionless reduced matrix element of the  $EL$  multipole of the nucleus and is connected with the standard published (see Ref. 18) reduced probability  $B(EL; I_1 \rightarrow I_2)$  of the  $EL$  transition by the relation ( $L \neq 0$ )

$$e^2 R_0^{2L} \left( \frac{2I_2+1}{2I_1+1} \right) |\langle I_2 || EL || I_1 \rangle|^2 = B(EL; I_1 \rightarrow I_2). \quad (2)$$

The dimensionless factor  $\xi(EL)$  is determined by the structure of the electron shell: in the approximation of the mean spherically-symmetric self-consistent atomic field, the factor  $\xi(EL)$  for an isolated atom is specified by the population numbers  $N(nlj)$  of the electron orbits, fixed by the principal quantum number  $n$  and by the orbital ( $l$ ) and total ( $j$ ) angular momenta; the chosen numbers  $N(nlj)$  form within the framework of the HFS method the actual configuration  $\{c\}$  of the shell:

$$\xi_c(EL) = \sum_{(nlj)} N(nlj) w_e(EL[nlj]^L \hbar\omega) = \sum_{(nlj)} \xi_c(nlj), \quad (3)$$

and the definition of  $\xi_c(nlj)$  follows from (3). Here we have the single-electron conversion factors of the  $EL$  multipole on the  $nlj$  shell of the atom in the configuration specified by the numbers  $N(nlj)$ . They were introduced by us in Refs. 5, 8, and 10 and tabulated for the principal configurations of a number of atoms in Ref. 10 for the set of selected isomers aimed at obtaining preliminary estimates of the effects of the medium. These factors  $w_e$  fix the structure of the conversion spectrum of the isomer.

In the case of the  $E1$  transition of the  $^{110}\text{Ag}$  isomer the internal-conversion coefficient is quite large ( $\sim 10^3$ ) (see

Ref. 15). The measured decay rate  $\lambda$  of the isomer can therefore be wholly attributed to the change of the conversion probability (1), due to the change of the electron-shell structure. In the isolated-atom scheme, the transition of the shell from the configuration  $\{1\}$  to the configuration  $\{c\}$  leads to a change  $\sigma\lambda_c = \lambda_c - \lambda_1$ , due to the change of the factor  $\xi(E1)$  [see Eq. (1)]:

$$\frac{\delta\lambda_c}{\lambda_1} = \frac{\lambda_c - \lambda_1}{\lambda_1} = \frac{\xi_c(E1) - \xi_1(E1)}{\xi_1(E1)} = \frac{\delta\xi_{c1}}{\xi_1}, \quad (4)$$

with  $\delta\xi_{c1}$  due to the change of the numbers  $N(nlj)$  themselves and of the conversion factors  $w_e(E_1[nlj]^L \hbar\omega)$ , which depend indirectly on the numbers  $N(nlj)$  that specify the shell configuration.

2. To estimate the dependence on the isomer transition energy, the factors  $w_e(E_1[nlj]^L \hbar\omega)$  were calculated at values  $\hbar\omega = 1080, 1110$  and  $1140 \text{ eV}$  for nine configurations of the silver-atom shell, in which we varied the populations of the  $4d$  orbit and of the orbit lying above  $4d$ ; the populations of the orbits of the core  $\{\text{Kr}\}$  were not changed. Note that the orbits  $4p^{1/2}$  and  $4p^{3/2}$  with binding energies on the order of  $50\text{--}80 \text{ eV}$  also belong to the  $\{\text{Kr}\}$  core, and these  $4p$  orbits can in principle become hybridized when a chemical compound is formed. Specific calculations were made by us for the following configurations:

$$\begin{aligned} \{1\} &= (4d^{5/2})^6 (5s^{1/2})^4, \quad \{2\} = (4d^{5/2})^6 (5p^{1/2})^4, \\ \{3\} &= (4d^{5/2})^6 (6s^{1/2})^4, \\ \{4\} &= (4d^{5/2})^6 (4f^{5/2})^4, \quad \{5\} = (4d^{5/2})^6 (5d^{3/2})^4, \\ \{6\} &= (4d^{5/2})^5 (5s^{1/2})^2, \\ \{7\} &= (4d^{5/2})^5 (5s^{1/2})^4 (5p^{1/2})^4, \\ \{8\} &= (4d^{5/2})^5 (5p^{1/2})^2, \quad \{9\} = (4d^{5/2})^5 (4f^{5/2})^2. \end{aligned} \quad (5)$$

The configuration numbers  $\{c\}$  are used by us in Tables I and II below. We emphasize that the factors  $w_e(E1[nlj]^L \hbar\omega)$  for all the orbits in the range from  $3s$  to  $4s$  are stable to the performed variations of the atom's valence-band configuration. This stability of the conversion spec-

TABLE I. One-electron factor  $w_e(E1[nlj]^L \hbar\omega)$  of the  $^{110}\text{Ag}$  isomer at  $\hbar\omega = 1110 \text{ eV}$ .

(nlj)	{c}								
	1	2	3	4	5	6	7	8	9
$3s^{1/2}$	1.5322	1.5340	1.5323	1.5319	1.5322	1.5329	1.5334	1.5342	1.5308
$3p^{1/2}$	4.5530	4.5500	4.5503	4.5504	4.5571	4.5508	4.5530	4.5505	4.5515
$3p^{3/2}$	5.0011	5.0008	5.0003	4.9994	5.0073	5.0005	5.0021	5.0006	5.0005
$3d^{3/2}$	11.2513	11.2436	11.2490	11.2430	11.2435	11.2483	11.2486	11.2462	11.2453
$3d^{5/2}$	10.9808	10.9758	10.9787	10.9756	10.9775	10.9772	10.9799	10.9782	10.9769
$4s^{1/2}$	0.3920	0.3914	0.3910	0.3912	0.3909	0.3938	0.3936	0.3935	0.3931
$4p^{1/2}$	0.8305	0.8289	0.8277	0.8278	0.8274	0.8375	0.8369	0.8366	0.8365
$4p^{3/2}$	0.8703	0.8683	0.8670	0.8671	0.8668	0.8789	0.8781	0.8779	0.8776
$4d^{3/2}$	0.8226	0.8311	0.8345	0.8369	0.8359	0.8819	0.8884	0.8956	0.9085
$4d^{5/2}$	0.7897	0.7995	0.8042	0.8064	0.8057	0.8516	0.8588	0.8665	0.8798
$5s^{1/2}$	0.0204	—	—	—	—	0.0263	0.0310	—	—
$5p^{1/2}$	—	0.0158	—	—	—	—	0.0225	0.0301	—
$6s^{1/2}$	—	—	0.0036	—	—	—	—	—	—
$5d^{3/2}$	—	—	—	—	0.0045	—	—	—	—
$4f^{5/2}$	—	—	—	$0.27 \cdot 10^{-7}$	—	—	—	—	$0.42 \cdot 10^{-5}$

Note. The HFS(L) method is used;  $\alpha = 0$ . The fourth significant figure is rounded off.

TABLE II. Changes  $\sigma\lambda/\lambda_1$  of the decay rate of the  $E1$  isomer of  $^{110}\text{Ag}$  on variation of the orbit population of the valence band of the silver atom.

{c}	$\delta\lambda/\lambda_1$ (1100)	$\delta\lambda/\lambda_1$ (1080)	$\delta\lambda/\lambda_1$ (1140)
2	$7.26 \cdot 10^{-5}$	$2.39 \cdot 10^{-5}$	$2.60 \cdot 10^{-4}$
3	$4.46 \cdot 10^{-4}$	$3.10 \cdot 10^{-4}$	$6.00 \cdot 10^{-4}$
4	$2.56 \cdot 10^{-4}$	$3.21 \cdot 10^{-4}$	$3.96 \cdot 10^{-4}$
5	$5.92 \cdot 10^{-4}$	$9.33 \cdot 10^{-4}$	$4.21 \cdot 10^{-4}$
6	$-1.43 \cdot 10^{-3}$	$-1.29 \cdot 10^{-3}$	$-1.15 \cdot 10^{-3}$
7	$-7.04 \cdot 10^{-4}$	$-6.36 \cdot 10^{-4}$	$-7.52 \cdot 10^{-4}$
8	$-6.20 \cdot 10^{-4}$	$-5.10 \cdot 10^{-4}$	$-4.46 \cdot 10^{-4}$
9	$-1.80 \cdot 10^{-4}$	$-5.03 \cdot 10^{-5}$	$-1.41 \cdot 10^{-4}$

Note. The HFS(L) method is used;  $\alpha = 0.7$ ,  $\lambda_1$  is the rate of decay of the isomer for a valence-band configuration  $(4d^{5/2})^6(5s^{1/2})^1$ . The transition energies  $\hbar\omega$  equal to 1100, 1080, and 1140 eV are noted.

trum can be used as a natural reference point for an experimental estimate of the changes of the contributions of the  $4p$  and  $4d$  shells and of the atom valence-band orbits, which are not stable against the action of the neighboring-atom fields. The calculated changes of the decay rate  $\sigma\lambda/\lambda$  of the isomers are given in Table II. The largest changes are observed when the number of the  $4d$  electrons changes. The relative variations of the contribution of the group of orbits in the  $3s$ – $4s$  range are found to be of the order of  $\lesssim 0.05\%$ , thus attesting to the high stability of the conversion spectrum on these orbits, even for appreciable variations of the atom's valence-band orbit populations. The relative changes of the contribution of the  $4d$  orbits reach  $\sim 3\%$ .

3. Within the framework of the isolated-atom scheme with variation of the configuration of the shell's valence band, we obtain a small change of the decay constant,  $\sigma\lambda/\lambda \lesssim 10^{-3}$ . Such values of  $\sigma\lambda/\lambda$  are typical of most conversion isomers (see, e.g., Ref. 19 for  $^{99}\text{Tc}$ ), exceptions being  $^{235}\text{U}$  and  $^{50}\text{Nb}$  (see Ref. 20), where the  $\sigma\lambda/\lambda$  effect reaches several percent. In the special case of  $^{90}\text{Nb}$ , the values  $\sigma\lambda/\lambda \sim 5\%$  are due to the threshold effect of conversion on  $2p^{3/2}$  or  $2p^{1/2}$  orbits, whereas the variations of the contribution of all the other orbits (except the threshold orbit  $2p$ ) equal  $(0.1\% - 0.3)\%$  according to our calculations (see Ref. 5). In the case of the  $^{110}\text{Ag}$   $E1$  isomer, however, there are grounds for expecting a substantially larger effect in  $\sigma\lambda/\lambda$  than that given by our simplified estimate. The basis for this is the character of the accumulation of the factors  $w_3(E1[nlj]^1\hbar\omega;x)$ , regarded as functions of the upper limit  $x$  ( $x = r/a_0$ ) of the radial conversion integrals (see Refs. 5 and 8). The procedure of separating the spatial region of formation of the internal-conversion coefficient was first used in Ref. 21. We, however, are interested in specific quantitative relations, and therefore carried out a number of calculations of the accumulation of the factors  $w_3(E1[nlj]^1\hbar\omega;x)$  on the outer orbits of the electron in the set of isomers that are promising for use in the conversion method. These are the  $E1$  isomer of  $^{110}\text{Ag}$ , the  $(M1 + E2)$  isomer of  $^{193}\text{Pt}$ , and the  $(E3 + M2)$  isomer of  $^{90}\text{Nb}$ ; all have a transition energy  $\hbar\omega \approx 1 - 1.25$  keV. To compare the accumulation of the  $w_e$  factors of these isomers, we consider the ratio  $\nu(nlj;x)$ —of the accumulated factor  $w_e$ —to its asymptotic value as  $x \rightarrow \infty$ . We define a factor—accumulation sphere of radius  $x$  ( $x < \sigma$ ), outside of

which the difference  $|\nu(nlj;x) - 1|$  no longer exceeds the chosen value  $\sigma$  anywhere. It has been established that the radii  $x$  ( $x < \sigma$ ) of the accumulation spheres of the multipoles  $(M1, E2, M2)$  for soft isomers ( $\hbar\omega \lesssim 3$  keV) are determined mainly by the angular ( $j$ ) and orbital ( $l$ ) momenta of the electron relative to the isomer radius, and depend very little on the binding energy (or on the number  $n$ ) of the orbit. At  $\sigma = 1\%$  the radius  $x$  ( $x < \sigma$ ) is everywhere less than 0.5. More intense transitions, regardless of  $n$ , form the  $w_e$  factor in spheres of much smaller radius than the weaker transitions. This is the general picture for these isomers.

The situation is entirely different in the case of an  $E1$  transition of the  $^{110}\text{Ag}$  nucleus. On the whole it is well illustrated in the Fig. 1: The accumulation of the  $E1$  factor goes outside the boundary of the sphere  $x = 1$ . This fact is quantitatively represented in Table III. Even for rather deep electron orbits of the  $3s$ – $4s$  group the factors do not reach an asymptotic value on the sphere radius  $x = 1$ . For the spatially extended  $4p^{1/2}$  and  $4p^{3/2}$  orbits, and particularly for  $4d$  orbits ( $4d|x^2|4d\rangle = 1.6$ ) the accumulation of the factor  $w_e$  takes place to a considerable degree outside the sphere  $x = 1$ . The extended  $4p$  and  $4d$  orbits should undoubtedly become strongly deformed by the neighboring atoms, and it is there-

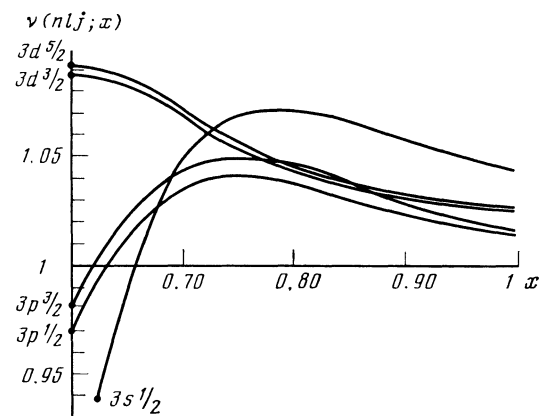


FIG. 1. Ratio  $\nu(nlj;x)$  of the conversion factor  $w_e(E1[nlj]^1\hbar\omega;x)$ , regarded as a function of the upper limit of the conversion integrals to its value  $w_e(E1[nlj]^1\hbar\omega)$  as  $x \rightarrow \infty$  for the  $E1$  transition of  $^{110}\text{Ag}$  ( $\hbar\omega = 1.10$  keV) on electrons of the  $(nlj)$  orbit. HFS(L) method;  $\alpha = 0.7$ .

TABLE III. Ratio  $\nu(nlj)$  of the conversion factor  $w_e(E1[nlj] \hbar\omega, x)$  accumulated in a sphere of radius  $r = 1$  ( $x = r/a_0$ ;  $a_0 = 5.29 \cdot 10^{-10}$  cm) to its asymptotic value (as  $x \rightarrow \infty$ ) for the  $^{110}\text{Ag}$  isomer ( $\hbar\omega = 1.11$  keV). The mean squared of the orbit radii and the orbit energies are given for the atom configuration  $\{1\} = (4d^{5/2})^6(5s^{1/2})^1$ . (HFS) method,  $\alpha = 0.7$ .

	(nlj)						
	$3s^{1/2}$	$3p^{1/2}$	$3p^{3/2}$	$3d^{3/2}$	$3d^{5/2}$	$4p^{1/2}$	$4p^{3/2}$
$\epsilon(nlj)$ , eV	684.2	580.2	549.3	364.3	358.1	62.96	57.77
$\langle nlj x^2 nlj\rangle^{1/2}$	0.394	0.388	0.400	0.375	0.379	1.046	1.081
$\nu(nlj)$	1.042	1.014	1.016	1.026	1.026	1.20	1.20

fore natural to expect appreciable changes in the structure of the conversion spectrum of the  $^{110}\text{Ag}$  isomer in chemical compounds, as well as appreciable variations of  $\sigma\lambda/\lambda$ , since the combined contribution of the  $4p$  and  $4d$  orbits to  $\lambda$  is 8%. Although to analyze the electron structure of silver compounds it is necessary above all to obtain, with good resolution, the spectrum of the conversion electrons, interest attaches also to the simpler measurement of the integral value of  $\sigma\lambda/\lambda$  in a number of compounds, say of the  $\text{AgX}$  type, where a strong change takes place both in the equilibrium distance  $r_0/a_0$  between the atoms, and in the nuclear charge  $Z$  of the neighboring atom [see (22, 23)]:

AgX:	AgH	AgF	AgCl	AgBr	AgI	AgO	Ag <sub>2</sub>
$r_0/a_0$ :	3.00	3.75	4.31	4.52	4.81	3.79	4.73

The values of  $\sigma\lambda/\lambda$  for a number of such compounds can be estimated at present within the framework of the  $X\alpha$  scattered wave method in the muffin-tin scheme,<sup>9</sup> but at the existing large uncertainty of the value of  $\hbar\omega$  such a calculation is not suitable for  $^{110}\text{Ag}$ , since a search through the numerous variants makes this calculation too expensive and makes the results indeterminate in view of the dependence on  $\hbar\omega$ .

5. In the calculations of the conversion probabilities (or of the internal-conversion coefficients) of nuclear transitions one uses a relativistic variant of the HFS (L) method. It is therefore necessary to estimate the sensitivity of the results to the parameters of the chosen model of the atom. Our calculations have permitted such a comparative estimate for the  $E1$  isomer of  $^{110}\text{Ag}$ , since we have used in the HFS(L) scheme the values  $\alpha = 0.7$  and 1 for the electron exchange-interaction constant. So large a change of  $\alpha$  leads to noticeable shifts of the energies  $\epsilon(nlj)$  of the electron orbits: by  $\sim 20$  eV for the  $n = 3$  shell and  $\sim 5$  eV for  $n = 4$ , in agreement with the results of similar calculations in Ref. 17. For these variations of the parameter  $\alpha$ , however, the conversion factors of the deep orbits of the  $3s-4s$  group (up to  $4p^{3/2}$ ) change by an amount of the order of 1-4%, the changes reach  $\sim 10\%$  for the weakly bound  $4d$  orbit, and a very large change of the conversion factors ( $\sim 30\%$ ) takes place for the orbits of the valence band. Also observed is an approximate nonuniform change of the conversion factors of different orbits when the exchange-interaction parameter is varied. In this situation, the HFS(L) scheme can claim to provide only an estimate of the approximate regularities in the relative changes of the conversion spectrum on variation of the electron-shell state due to the change of the chemical surrounding of the atom.

For the  $E1$  transition of the  $^{110}\text{Ag}$  isomer, in contrast to the previously investigated other multipoles (see Ref. 5), no strong dependence of the conversion factors  $w_e(E1[nlj])$  on the angular momenta of the electron ( $l$  and  $j$ ) is observed relative to the isomer nucleus. The change of the  $w_e$  factors with decrease of the orbit binding energy  $\epsilon(nlj)$  is similar to the change of the photoionization cross sections for these orbits at photon energies of the order of the nuclear transition energy.

6. The half-life  $T_{1/2} = (660 \pm 40) \cdot 10^{-9}$  sec obtained in Ref. 15 for the  $^{110}\text{Ag}$  isomer, and the conversion factors  $\xi(E1)$  obtained by us (see Table II) yield, according to Eq. (1), for the reduced matrix element of the  $E1$  transition of  $^{110}\text{Ag}$  from the excited  $|2-\rangle$  state to the ground  $|1+\rangle$  state, the value

$$|R_0 \langle 1+ || E1 || 2- \rangle|^2 = 7.55 \cdot 10^{-4} (\text{Fm})^2 (\pm 6\%).$$

The error ( $\pm 6\%$ ) is now determined by the error in the measurement of the half-life  $T_{1/2}$ ; the error due to the energy inaccuracy ( $\Delta\hbar\omega = 30$  eV) is substantially lower.

At a  $^{110}\text{Ag}$  nuclear radius  $R_0 = 5.94$  Fm, we have for the dimensionless  $E1$  element

$$|\langle 1+ || E1 || 2- \rangle| = 0.46 \cdot 10^{-2} (\pm 3\%).$$

The  $E1$  transition of  $^{110}\text{Ag}$  is, thus, rather strongly hindered. Note that if we confine ourselves to those simple nucleon configurations which are ascribed (see Ref. 2) to the states  $|2-\rangle$  and  $|1+\rangle$  of the  $^{110}\text{Ag}$  nucleus, then the  $E1$  transition is forbidden in this situation, and it can take place in the presence of admixtures of other configurations. The available data do not permit identification of these configurations.

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Translated by J. G. Adashko