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# CONVERSION OF AN ATOMIC ELECTRON INTO A POSITRON AND DOUBLE $\beta^+$-DECAY

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Experimental indications for the neutrino nonzero mass obtained at ITEP [1] have revived the interest in the neutrinoless $2\beta$-decay of nuclei as a source of information on the nature of the neutrino mass (see, e.g., refs. [2-4] ). It is just this decay that could be initiated by the diagonal Majorana mass term in the neutrino mass matrix.

In the cases of partical importance $2\beta^-$-decay is more probable than $2\beta^+$-decay because of the Coulomb repulsion of positrons by a daughter nucleus in the latter case. Therefore till now $2\beta^+$-decay has not drawn attention of investigators. However, despite a considerably smaller probability, $2\beta^+$-decay may be interesting as it can be easier identified. In fact, the positrons produced in the course of decay give after annihilation four gamma-quanta. The detection in coincidence of two positrons and four gamma-quanta makes it possible to distinguish such events with great confidence. From this point of view $2\beta^+$-decay has recently been analyzed in paper [4].

If $2\beta^+$-decay takes place, there should also occur the conversion of the atomic electron into the positron just as the conventional $\beta^+$-decay is followed by capture of the atomic electron [5]. In this note we show that the ratio of probabilities of conversion of the atomic electron into the positron and $2\beta^+$-decay does not practically depend on nuclear matrix elements and is determined by the nuclear charge and energy release, the conversion in all real transitions being considerably intensified.

For allowed transitions the ratio of rates of neutrinoless processes of conversion and $2\beta^+$-decay, when the transitions are initiated by the Majorana neutrino mass, can be written as

$$\frac{W_{e^- \to \beta^+}}{W_{2\beta^+}} = \frac{2\frac{1}{\pi}\Delta^2 m_e^2 |\psi(0)|^2 f(\Delta)}{\frac{1}{2}\frac{1}{2\pi^3} m_e^5 \int_1^{\Delta-1} \epsilon_1^2 (\Delta-\epsilon_1)^2 f(\epsilon_1) f(\Delta-\epsilon_1) d\epsilon_1}, \qquad (1)$$

where $\Delta$ is the difference of the mass of the initial and daughter nuclei in units of $m_e$, $\epsilon_1$ is the positron energy in the same units; $\psi(0)$, the wave function of a k-electron in the point: $r=0$; $|\psi(0)|^2 \approx (\alpha z m_e)^3/\pi$ $f(\epsilon) = 2\pi\alpha z |\{\exp(2\pi\alpha z/v)-1\}|$

is the factor related to the Coulomb repulsion of the positron by the daughter nucleus, $v_1 = (1-\epsilon_1^{-2})^{1/2}$, $v_2 = [1-(\Delta-\epsilon_1)^{-2}]^{1/2}$. Factor 2 in the numerator signifies the presence of two electrons on K-shell, and factor 1/2 in the denominator comes from the identity of positrons in $2\beta^+$ final state. If the transitions are initiated by right currents, expression (1) should contain an extra factor $\Delta^2/(\epsilon_1-\epsilon_2)^2$. The mean value of this factor is about 10. Therefore such a difference in capture rates can in principle discriminate the mechanism of the $2\beta$ processes without neutrino emission. However, the right currents hypothesis itself seems to be unnatural.

In the two-neutrino processes, besides the capture of one K-electron, the capture of both K-electrons is also possible. The ratio of the corresponding three probabilities can be written as

$$W_{2e^-\to 2\nu} : W_{e^-\to\beta^+ + 2\nu} : W_{2\beta^+ + 2\nu} =$$
$$= 16\pi^4 |\psi(0)|^4 \Delta^5 : 8\pi^2 |\psi(0)|^2 \int_0^{\Delta-1} f(\Delta-w)(\Delta-w)^2 w^5 dw : \tag{2}$$
$$: \int_0^{\Delta-2} J(\Delta-w) w^5 dw,$$

where $J(\Delta-w)$ is the same-type integral as in the denominator of formula (1), corresponding to the energy release $(\Delta-w)$. Using formulae (1) and (2) we calculated the ratios of the probabilities of conversion of an atomic electron and of $2\beta^+$-decay both for the neutrinoless transition and for the emission of two neutrinos. The results are listed in the Table. The transitions presented in the Table exhaust all possible cases of $2\beta^+$-decay. It is seen that the probability of conversion of the atomic electron exceeds considerably the probability of neutrinoless $2\beta^+$-decay in all transitions of interest. Note also that the probability of conversion itself weakly depends on the energy release and is mainly determined by the nuclear matrix element. In case of the two-neutrino emission the rate of the atomic electron conversion is by three and more orders of magnitude higher than that of the $2\beta 2\nu$-decay.

Note, that the double neutrinoless K-capture would represent a considerable interest if there existed a pair of nuclei, for which this process could proceed in a resonance way, i.e., if the mass of the daughter atom with K-shell electrons shifted into an excited state coincided with the mass of the initial atom in the ground state with an accuracy of



Table

| Transition | % | $\Delta_k/m_e$ | $W_{e^-\to\beta^+}/W_{2\beta^+}$ | $W_{2e^-\to 2\nu}/W_{e^-\to\beta^+ 2\nu}/W_{2\beta^+ 2\nu}$ |
|---|---|---|---|---|
| $^{78}_{36}Kr \to Se$ | 0.36 | 3.64 | 2.6 | 1900:580:1 |
| $^{96}_{44}Ru \to Mo$ | 5.7 | 3.33 | 13 | $7.9\cdot10^4 : 5.8\cdot10^3 : 1$ |
| $^{106}_{48}Cd \to Pd$ | 1.22 | 3.44 | 16 | $1.1\cdot10^5 : 6.2\cdot10^3 : 1$ |
| $^{124}_{54}Xe \to Te$ | 0.10 | 4.00 | 11 | $2.9\cdot10^4 : 2.0\cdot10^3 : 1$ |
| $^{130}_{56}Ba \to Xe$ | 0.10 | 3.045 | 115 | $1.2\cdot10^7 : 1.4\cdot10^5 : 1$ |
| $^{136}_{58}Ce \to Ba$ | 0.19 | 2.71 | 650 | $8.2\cdot10^8 : 3.7\cdot10^6 : 1$ |

order 10 eV. The only candidate is the pair $^{180}_{74}W \to ^{180}_{72}Hf$, the mass difference of which equals 155±10 keV that is close to the doubled binding energy of K-electron. However, the coincidence of masses within the required accuracy seems unplansible. The resonant transition could be realized to an excited state of a daughter nucleus too. For such a case one needs the coincidence of the mass difference between atoms and the excitation energy with the same accuracy.

So, if an attempt is undertaken to investigate $2\beta^+$-decay it should be kept in mind that the conversion of the atomic electron will proceed with higher probability, and apparently, it is reasonable to look first for this process. Will the observation of the neutrinoless process be a success is still an open question. Nevertheless, even if the process with two-neutrino emission is observed, it will also be important as the double $\beta$-transition involving two neutrinos is not yet detected reliably. Thereby for the pair of nuclei the value of transition matrix element will be fixed which will allow one to discriminate between models used for calculation of matrix elements. An observation of such transition will also make it possible to estimate the background from the two-neutrino process in a search for the neutrinoless $2\beta$-decay.

If for some pair of nuclei both the conversion of an atomic electron into a positron and $2\beta$-decay are observed, the ratio of the relevant probabilities can be applied for identifying the neutrinoless transition, just in the same way as the argument of B.Pontecorvo /6/ on the ratio of probabilities of $2\beta^-$-transitions in $^{130}Te$ and $^{128}Te$ has been used /3/.

The atomic electron conversion can occur in a considerably greater number of nuclei than $2\beta$-decay since in the latter case energy is required for producing two electrons. A nearly complete list of nuclei in which the atomic electron conversion may occur is given in the review article /4/. Note that the abundance of some of the listed isotopes is large: $^{58}Ni$- 67.8%, $^{92}Mo$ - 15.9%. These isotopes seem to be interesting for practical studies of the $2\beta$-transition.

Thus, for all pairs of nuclei the atomic electron conversion appears to be more probable than $2\beta^{+}$-decay. The ratio of probabilities of these processes is practically independent of nucleus and energy release.

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