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# Physics

Corresponding Member of the Academy of Sciences of the USSR V.  
I. GOL' DANSKII

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**Abstract**

**Full Text**

**Physics**

Corresponding Member of the Academy of Sciences of the USSR V. I. GOL'DANSKII

## ON THE EMISSION OF DELAYED PROTONS IN THE POSITRON DECAY OF NEUTRON- DEFICIENT NUCLEI

In recent years the literature has repeatedly discussed the question of the possibility of emission of delayed protons after positron  $\beta$ -decay of nuclei of neutron-deficient isotopes of light elements (see, for example, (1), where references to earlier work are given). At the same time, however, no concrete estimates have been given either of the range of occurrence of this phenomenon, or of the list of isotopes for which it should be observed, or of the half-lives determining the delayed proton activity of positron  $\beta$ -decay.

All such estimates can be obtained with sufficient accuracy on the basis of the method, developed by us earlier, for determining the properties of neutron-deficient isotopes of light nuclei, already used to predict two-proton radioactivity (2) and confirmed over the last two years by data on the newly discovered isotopes Mg<sup>22</sup>, Si<sup>26</sup>, and S<sup>30</sup>.

For a few of the lightest elements, the phenomenon of delayed-proton emission can be predicted and analyzed by direct comparison of the mechanism of positron  $\beta$ -decay of as yet undiscovered neutron-deficient isotopes and electron  $\beta$ -decay of known mirror nuclei with an excess of neutrons.

Let us consider, as an example, the lightest of the isotopes for which delayed-proton emission should be observed,  ${}_{10}\text{Ne}^{17}$  (the mirror isotope  ${}_{7}\text{N}^{17}$  is known to be an emitter of delayed neutrons). The mass defect of N<sup>17</sup> is  ${}_{10}D_7^{17} = 21.4$  MeV (2), which corresponds to the maximum energy of  $\beta^+$ -decay to the ground state of F<sup>17</sup>, equal to 13.4 MeV. The proton binding energy in the F<sup>17</sup> nucleus is  $B_p = 0.6$  MeV (3). Since the ground state of Ne<sup>17</sup> (like N<sup>17</sup>) should be 1/2-, and the ground state of F<sup>17</sup> is 5/2+,  $\beta^+$ -decay of Ne<sup>17</sup> should predominate with formation of excited levels of F<sup>17</sup>: 3.1 MeV (1/2-) and 4.4 MeV (3/2-), followed by emission of protons with energies 2.5 and 3.8 MeV. On the basis of charge-invariance considerations for analogous transitions in isotopically conjugate nuclei, the value of  $\log ft$  should be the same, and therefore the lifetime of Ne<sup>17</sup> (i.e., the delay time for proton emission) can be estimated from the value  $\log ft \approx 3.7$  for the  $\beta$ -decay of N<sup>17</sup>. Such an estimate gives  $T_{1/2} = 0.03$  sec.

The next example is the isotope  ${}_{12}\text{Mg}_8^{20}$  ( $0^+$ ), for which the mass defect  ${}_{12}D_8^{20} = 23.1$  MeV <sup>(2)</sup>. The maximum energy of  $\beta^+$ -decay to the ground state  $\text{Na}^{20}$  ( $2^+$ ) is in this case 7.9 MeV, whereas the proton binding energy in the  $\text{Na}^{20}$  nucleus is only 0.8 MeV <sup>(3)</sup>. Since for the mirror sodium isotope  $\text{F}^{20}$  a number of excited levels are known in the states  $0^+$ ,  $1^+$  with energy greater than 0.9 MeV,  $\beta^+$ -decay of  $\text{Mg}^{20}$  precisely to such levels should predominate, followed by the emission of delayed protons. For a number of levels of  $\text{F}^{20}$  the literature <sup>(3)</sup> gives several possible spin values (for example,  $1^+$ ,  $2^+$ , or  $3^+$  for the levels 0.83; 0.99; 2.05 and 2.20 MeV). It is easy to see that observation of the spectrum of delayed protons in the decay of  $\text{Mg}^{20}$  will make it possible in these cases to distinguish the  $1^+$  levels from the  $2^+$  and  $3^+$  levels.

We shall not consider other examples here in as much detail, and shall confine ourselves only to a general rule establishing the prevalence of nuclei that emit delayed protons.

Beginning approximately with argon, for all isotopes with a large neutron deficiency the predominant variants of  $\beta^+$  decay become “superallowed” transitions without a change in isotopic spin, for which  $\log ft \simeq 3.5$  (in such transitions there is practically no rearrangement of the nuclear wave function). The energy of  $\beta^+$  decay in transitions with  $\Delta T = 0$  is determined by the simple relation <sup>(2)</sup>:

$$E_{\beta^+}(\Delta T = 0) = \left(1.2 \frac{Z}{A^{1/3}} - 1.8\right) \text{ MeV}, \quad (1)$$

where  $1.8 \text{ MeV} = C^2(2m_e + m_n - m_H)$ .

The condition necessary for the emission of delayed protons is that the excitation energy  $E^*$  of the residual (after  $\beta$  decay) nucleus exceed

$$E^* = ({}_Z D_N^A - {}_{Z-1} D_{N+1}^A - 1.02) - \left[1.2 \frac{Z}{A^{1/3}} - 1.8\right] \text{ MeV} \quad (2)$$

above the proton binding energy in this nucleus, equal to

$$B_p = ({}_{Z-2} D_{N+1}^{A-1} + 7.58 - {}_{Z-1} D_{N+1}^A) \text{ MeV}. \quad (3)$$

It is easy to see that (2) and (3) lead to the following simple condition for the possibility of emitting delayed protons after the  $\beta^+$  decay of the nucleus  ${}_Z M_N^A$ :

$${}_Z D_N^A - {}_{Z-2} D_{N+1}^{A-1} > \left[1.2 \frac{Z}{A^{1/3}} + 6.8\right] \text{ MeV}. \quad (4)$$

Using our <sup>(2)</sup> or Cameron' s <sup>(4)</sup> values for the masses of atoms of neutron-deficient isotopes, we come to the conclusion that emission of delayed protons after  $\beta^+$  decay becomes (as the neutron deficiency increases) probable beginning with

the following isotopes of even elements: Ar<sup>33</sup>, Ca<sup>37</sup> <sup>(2)</sup> or Ca<sup>35</sup> <sup>(4)</sup>, Ti<sup>39</sup>, Cr<sup>43</sup>, Fe<sup>47</sup>, Ni<sup>51</sup>, Zn<sup>57</sup>, Ge<sup>61</sup>, Se<sup>65</sup>, Kr<sup>69</sup>, Sr<sup>73</sup>, Zr<sup>77</sup>, Mo<sup>81</sup>, Ru<sup>87</sup> (?), Pd<sup>91</sup>, Cd<sup>95</sup>, Sn<sup>99</sup>.

The delay time for proton emission is, of course, determined by the half-lives of  $\beta^+$  decay (one-proton radioactivity with half-lives greater than those for  $\beta^+$  is extremely unlikely) and should decrease smoothly from  $\sim 1$  sec (for Ar) to  $\sim 0.01$  sec (Sn). A fairly accurate estimate of the  $\beta^+$ -decay time in each given case can be obtained from the values of the energy of the superallowed  $\beta^+$  transition (1) and  $\log ft = 3.5$ .

In individual cases (Ti<sup>39</sup>, Se<sup>64</sup>, Pd<sup>90</sup>, Cd<sup>95</sup>, Sn<sup>99</sup>) the emission of delayed protons proves possible in  $\beta^+$  decay not only to the excited state, but also to the ground state, since here  $\beta^+$  decay leads to the formation of proton-radioactive nuclei.

Using (4), one may note, incidentally, that the examples of the nuclei Ti<sup>41</sup> and Se<sup>67</sup> given in <sup>(1)</sup> are unsuccessful—the difference

$$({}_Z D_N^A - {}_{Z-2} D_{N+1}^{A-1}) - \left(1.2 \frac{Z}{A^{1/3}} + 6.8\right)$$

for Ti<sup>41</sup> is close to zero, and for Se<sup>67</sup> is even negative. Meanwhile, in order that delayed protons with kinetic energy  $T_p$  may be emitted after the  $\beta^+$  decay of a given nucleus, the indicated difference must be not only positive, but also exceed  $T_p$ . For elements heavier than tin, emission of delayed protons should in general not be observed, since for neutron-deficient isotopes of these elements, before instability to decay with proton emission occurs and at still rather small  $\beta^+$ -decay energies,  $\alpha$ -instability sets in. Emission of delayed protons is most characteristic of isotopes of even elements—despite the

the decrease of the neutron deficit in the  $\beta^+$  decay of the parent nucleus, the binding of a proton in the daughter nucleus with odd  $Z$  may prove weaker because of the loss of proton-pairing energy. It is precisely for this reason that even the cases listed above of delayed-proton emission after  $\beta^+$  decay of proton-even nuclei into the ground state of proton-odd nuclei become possible. For four odd-odd isotopes (K<sup>34</sup>, V<sup>42</sup>, Mn<sup>46</sup>, Co<sup>50</sup>), delayed-proton emission may also be observed—but only as a consequence of superallowed  $\beta^+$  transitions with the formation of excited daughter nuclei. Owing to pairing effects, in a number of cases the binding energy of a proton pair in nuclei formed after the  $\beta^+$  decay of isotopes with odd  $Z$  proves to be smaller than the binding energy of single protons in these nuclei. Therefore, it would seem that emission of delayed proton pairs after  $\beta^+$  decay of proton-odd nuclei should also be observed. However, such a phenomenon could occur only in the  $\beta^+$  decay of isotopes with so strong a neutron deficiency (Al<sup>20</sup>, Cl<sup>27</sup>, K<sup>31</sup>, Sc<sup>34</sup>, etc.) that they are already proton-unstable and therefore do not have time to undergo  $\beta^+$  decay.

In conclusion it should be noted that the delayed protons observed in the experiments of I. Preiss\*, who is now carrying out at Yale University in the USA a search for two-proton radioactivity in the products of the reaction  $\text{Be}^9 + \text{C}^{12}$

(energy  $C 126 \pm 6$  MeV), are probably, at least in part, due not to the formation of the two-proton-radioactive nucleus  $\text{Ne}^{16}$  (threshold  $\sim 121$  MeV), but to the  $\beta^+$  decay of  $\text{Ne}^{17}$  (formation threshold 87 MeV) to excited levels of  $\text{F}^{17}$ .

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Institute of Chemical Physics  
Academy of Sciences of the USSR

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### CITED LITERATURE

- <sup>1</sup> V. A. Karnaukhov, N. I. Tarantin, *ZhETF*, **39**, 1106 (1960).
- <sup>2</sup> V. I. Goldansky, *Nuclear Phys.*, **19**, 482 (1960); **27**, 648 (1961).
- <sup>3</sup> F. Ajzenberg-Selove, T. Lauritsen, *Nuclear Phys.*, **11**, 1 (1959).
- <sup>4</sup> A. G. Cameron, Report CRP-690 (1957).

\* Private communications of 23 IV and 27 VI 1962.

*Note: Figure translations are in progress. See original paper for figures.*

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