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Pole models of decay of natural radioactive carbon as dose-forming nuclide

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Abstract. The article presents the pole model of radiocarbon decay process. When using this model it is assumed that there is a pair bond in the form of an individual pole axis between proton and electron. This bond can change the tilt angle relative to the generalized axis, with increasing energy. Increase of the tilt angle of the pole axis is accompanied by increase of its energy, this process is interrelated with energy state of the paired electron. With increasing energy of the paired bond the energy of the electron decreases and it occupies the energy level located closer to the nucleus. At critical increase of energy of the pole axis it will deflect to the maximum angle, the electron takes the position located in the maximum proximity to the nucleus, which leads to the connection with the paired proton and formation of the neutron. The analysis of the decay process illustration is carried out. This article describes the β-decay process using pole models.

1 Introduction

Of all natural elements of the periodic table, carbon has a special role - it forms the structural basis of organic compounds, including those in living organisms.

Radionuclide ^{14}C is constantly formed in the upper layers of the atmosphere. At an altitude of 8 - 18 km nuclei of nitrogen interact with secondary nuclides of cosmic radiation by the reaction ^{14}N (n, p) ^{14}C. The role of other reactions such as ^{15}N (n, α) ^{14}C,^{16}O $(p, 3p)$ ^{14}C,^{17}O (n, α) ^{14}C,^{13}C (n, γ) ^{14}C in the formation of carbon-14 is insignificant because of the small cross-sections of interaction and low content of the nuclei of these isotopes in the natural mixture of elements [1]. Since carbon-14 is radioactive, it has a half-life of 5730 years, it is unstable and constantly transforms into nitrogen-14 atoms from which it was formed. In the process of such transformation, an electron is emitted. Electron is a negative ionizing particle - β-particle

2 Relevance

Radio carbon, oxidized in the stratosphere up to $^{14}CO_2$, penetrates the troposphere and as a result of mixing air masses freely spread throughout the Earth, including in the natural

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carbon cycle. On earth ^{14}C is accumulated in plants by photosynthesis, and then enters animal organisms through food chains and, as part of food, into human organisms. Participating in metabolic processes together with stable carbon, ^{14}C penetrates into all organs, tissues and molecular structures of living organisms [2].

Carbon has 2 stable isotopes - ^{12}C (98.89%) and ^{13}C (1.11%). The relative content of radiocarbon in natural is extremely low - about 1.2*10-12 g per 1 gram of carbon ^{12}C; the amount of radioactive isotope on Earth is 0.00000001%.

^{14}C decays according to beta decay reaction:

$$^{14}_{6}\mathrm{C} \xrightarrow[\mathrm{T}_{0,5}=5730\,years]{} {}^{14}_{7}N + \beta^{-} + \hat{\nu}$$

^{14}C emits an electron and the anti-neutrino turns into stable nitrogen.[3][4]. The combined effect of radioactive losses and new formations in the stratosphere results in a constant equilibrium ^{14}C concentration in the biosphere. The maximum energy β- particles is -156,keV 476 [5]. The average energy is 4.495 - 10-2 MeV. Maximal run in tissue is 0.38 mm, in air – 23 cm [6].

3 Data Analysis

The decomposition process can be schematically described using Feyman diagrams[7 - 9].

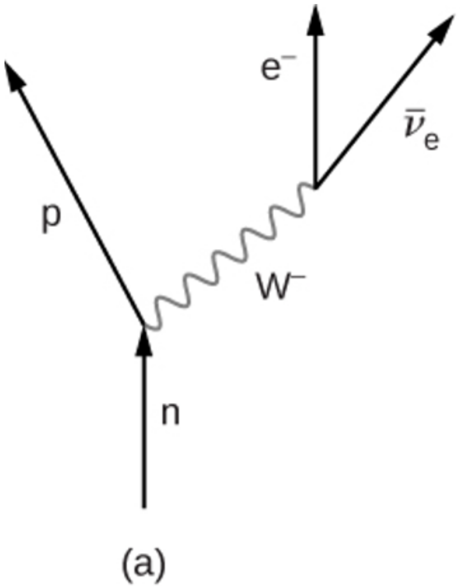

Fig. 1. Electronic Decay Faeman Diagram

Figure 1 shows the Feynman diagram of neutron decay, as a result of which the electron (β-particle) is formed.

Energy transitions in the atom during decay can be clearly illustrated with the help of matrices, arranging each energy transition into matrix rows. For this purpose, it is convenient to use the proposal of Werner Heisenberg. For a system with N basic states (where in most cases N = ∞) this corresponds to N x N (Fig.2a) a square ermitic matrix and for the description of some separate quantum state, the matrix column N x 1 (Fig.2b) [10].

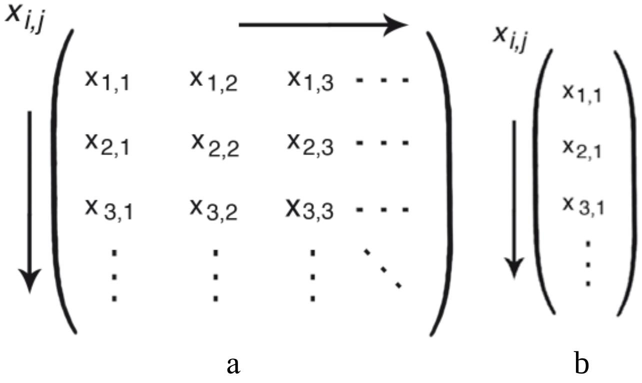

Fig. 2. Square Ermit Matrix of States (a) and Matrix Column (b)

When using such methods of describing the process it is necessary to take into account the existence of a paired bond between the proton and the electron, which is represented by an individual pole axis. When the energy of the paired bond increases, the pole axis can change the angle of its inclination relative to the generalized axis, which leads to an increase in its energy. The described process directly depends on the energy state of the paired electron: when the energy of the paired bond increases, the energy of the electron decreases and it occupies the energy level located closer to the nucleus. At a critical increase of the pole axis energy, the electron, having fully released the energy, occupies a position that is in maximum proximity to the nucleus.

This creates real preconditions for the process of combining the electron with a paired proton and, as a consequence, the formation of the neutron.

Thus, with the help of matrices it is possible to describe not only the process of radionuclide decay as a whole, highlighting the levels of energy transitions, but also to characterize each of the inherent states of the radionuclide at decay.

Radionuclide ^{14}C can exist in several pole configurations:

- with one generalized axis - unipolar;
- two-pole, with one generalized axis and one individual axis;
- three-pole, with one generalized axis and two individual axes;
-four-pole, with one generalized axis and three individual axes;
- five-pole, with one generalized axis and four individual axes [11].

Beta - decay of radiocarbon occurs regardless of the state of the radiocarbon atom, with the release of electron and antineutrino. The nucleus of the daughter atom becomes charged more by one, leading to an increase in the number of electrons in the orbit of the atom and to the transformation of the radiocarbon atom into a nitrogen atom.

The pole matrices for them look like this:

1. For the configuration of one generalized axis - unipolar,

$$\underset{1C}{\begin{bmatrix} 1_1s^2 2_1s^2 2p^{2(4)} \\ 1_2s^0 2_2s^0 2_2p^0 \\ 1_3s^0 2_3s^0 2_2p^0 \\ 1_4s^0 2_4s^0 2_4p^0 \\ 1_5s^0 2\ _5s^0 2_5p^0 \end{bmatrix}} \rightarrow \underset{1N}{\begin{bmatrix} 1_1s^2 2_1s^2 2p^{3(3)} \\ 1_2s^0 2_2s^0 2_2p^0 \\ 1_3s^0 2_3s^0 2_2p^0 \\ 1_4s^0 2_4s^0 2_4p^0 \\ 1_5s^0 2\ _5s^0 2_5p^0 \end{bmatrix}}$$

As can be seen from the maternal matrix, all electrons are on the first generalized axis, there are two electrons on 1s orbit, two electrons on 2s orbit, and on 2p orbit there are two electrons and four vacancies. In this state, radio carbon is quadrivalent.

After the beta decay, the daughter nitrogen matrix will have three vacancies in the outer shell, in which case the nitrogen is trivalent.

2.For a bipolar configuration with one individual axis, we have a matrix of the following kind:

$$\underset{2_1C}{\begin{bmatrix} 1_1s^2 2_1s^2 2p^{1(5)} \\ 1_2s^{1(1)} 2_2s^0 2_2p^0 \\ 1_3s^0 2_3s^0 2_2p^0 \\ 1_4s^0 2_4s^0 2_4p^0 \\ 1_5s^0 2\ {}_5s^0 2_5p^0 \end{bmatrix}} \rightarrow \underset{2_1N}{\begin{bmatrix} 1_1s^2 2_1s^2 2p^{2(4)} \\ 1_2s^{1(1)} 2_2s^0 2_2p^0 \\ 1_3s^0 2_3s^0 2_2p^0 \\ 1_4s^0 2_4s^0 2_4p^0 \\ 1_5s^0 2\ {}_5s^0 2_5p^0 \end{bmatrix}}$$

This pentavalent model of the radiocarbon atom represented by matrix 21C is not stable. After beta decay, the daughter atom acquires the configuration shown in matrix 21N and in this case it becomes pentavalent with unstable state.

2.1 For a bipolar configuration with two generalized axes, the pole matrix takes the following form:

$$\underset{2_2C}{\begin{bmatrix} 1_1s^2 2_1s^2 2p^{0(0)} \\ 1_2s^{2(0)} 2_2s^0 2_2p^0 \\ 1_3s^0 2_3s^0 2_2p^0 \\ 1_4s^0 2_4s^0 2_4p^0 \\ 1_5s^0 2\ {}_5s^0 2_5p^0 \end{bmatrix}} \rightarrow \underset{2_2N}{\begin{bmatrix} 1_1s^2 2_1s^2 2p^{1(5)} \\ 1_2s^{2(0)} 2_2s^0 2_2p^0 \\ 1_3s^0 2_3s^0 2_2p^0 \\ 1_4s^0 2_4s^0 2_4p^0 \\ 1_5s^0 2\ {}_5s^0 2_5p^0 \end{bmatrix}}$$

This model of the atom, represented by matrix 22C, has no vacancies and can be classified as noble. The resulting beta decay of the daughter nitrogen atom, shown in Matrix 22C, will have a valence of five.

3. In the case of the three-pole model of the 14C atom with two generalized atoms and one individual pole matrix will have the form:

$$\underset{3C}{\begin{bmatrix} 1_1s^2 2_1s^{0(0)} 2p^{1(1)} \\ 1_2s^{2(0)} 2_2s^0 2_2p^0 \\ 1_3s^{2(2)} 2_3s^0 2_2p^0 \\ 1_4s^0 2_4s^0 2_4p^0 \\ 1_5s^0 2\ {}_5s^0 2_5p^0 \end{bmatrix}} \rightarrow \underset{3N}{\begin{bmatrix} 1_1s^2 2_1s^{0(0)} 2p^{2(0)} \\ 1_2s^{2(0)} 2_2s^0 2_2p^0 \\ 1_3s^{2(2)} 2_3s^0 2_2p^0 \\ 1_4s^0 2_4s^0 2_4p^0 \\ 1_5s^0 2\ {}_5s^0 2_5p^0 \end{bmatrix}}$$

It is a single-valent unstable system with one vacancy in orbit 2s on the outer shell. The result of the beta decay is noble nitrogen with no free orbital vacancies. The configuration of this state is represented by matrix 3N.

4. The four-pole model is represented by a matrix:

$$\underset{4C}{\begin{bmatrix} 1_1s^2 2_1s^{0(0)} 2p^{0(0)} \\ 1_2s^{2(0)} 2_2s^0 2_2p^0 \\ 1_3s^{1(1)} 2_3s^0 2_2p^0 \\ 1_4s^{1(1)} 2_4s^0 2_4p^0 \\ 1_5s^0 2\ {}_5s^0 2_5p^0 \end{bmatrix}} \rightarrow \underset{4N}{\begin{bmatrix} 1_1s^2 2_1s^{0(0)} 2p^{0(0)} \\ 1_2s^{2(0)} 2_2s^0 2_2p^0 \\ 1_3s^{2(0)} 2_3s^0 2_2p^0 \\ 1_4s^{1(1)} 2_4s^0 2_4p^0 \\ 1_5s^0 2\ {}_5s^0 2_5p^0 \end{bmatrix}}$$

In such a configuration (matrix 4C), the model of the atom is divalent; on the third and fourth poles there is one orbit, each of which has one vacancy. The formed nitrogen atom has a valence equal to one; this state is shown in matrix 4N.

5. For a five-pole model, the matrix has the form.

$$\underset{5C}{\begin{bmatrix} 1_1s^2 2_1s^{0(0)} 2p^{0(0)} \\ 1_2s^{1(1)} 2_2s^0 2_2p^0 \\ 1_3s^{1(1)} 2_3s^0 2_2p^0 \\ 1_4s^{1(1)} 2_4s^0 2_4p^0 \\ 1_5s^{1(1)} 2\,_5s^0 2_5p^0 \end{bmatrix}} \rightarrow \underset{5N}{\begin{bmatrix} 1_1s^2 2_1s^{0(0)} 2p^{0(0)} \\ 1_2s^{2(0)} 2_2s^0 2_2p^0 \\ 1_3s^{1(1)} 2_3s^0 2_2p^0 \\ 1_4s^{1(1)} 2_4s^0 2_4p^0 \\ 1_5s^{1(1)} 2\,_5s^0 2_5p^0 \end{bmatrix}}$$

In such a model, the radiocarbon atom (matrix 5C) has four vacancies: one for each of the 12s, 13s, 14s, 15s. This system is fourvalent. In beta decay, trivalent nitrogen (matrix 5N) is obtained.

Thus, it can be concluded that in each of the presented pole models, beta decay leads to a change in the valence of the daughter nitrogen atom, which may cause disruption in the system in which the radiocarbon atom is located.

4 Conclusion

The use of pole models of radiocarbon decay using pole matrices allows to illustrate features of the decay process itself. We can observe stepwise energy transitions of the atom, and the process of emission of the ionizing particle **-** β- particle with electron neutrino emission. Visibility allows us to predict the stages of energy release and motion in the atom.

References

1. I. Ya. Vasilenko, V. A. Osipov, V. P. Rublevsky, *Radioactive carbon*, Nature, v. **12**, pp. 59-65 (1992) (in Russian).
2. V.P. Rublevsky, S.P. Golenetsky, G.S. Kirdin, *Radioactive carbon in the biosphere* (Moscow: Atomizdat, 1972) (in Russian).
3. Radiouglerodnoe datirovanie. .Library Krugosvet. 26.04.2020. Available at: http://www.krugosvet.ru (in Russian).
4. M. Stuiver, H.A. Polach, *Discussion Reporting of 14C*, Radiocarbon, v. **19(3)**, pp. 355-363 (1977).
5. G. Audi, A. H.Wapstra, C.Thibault. *The AME2003 atomic mass evaluation (II). Tables, graphs, and references.* Nuclear Physics. v. **729**. pp. 337—676 (2003).
6. V.A. Bazhenov, L.A.Buldakov, I.I.Vasilenko. *Harmful chemicals. Radioactive substances.* (L., Chemistry, 1990) (in Russian).
7. Feynman diagrams. The project of the Department of General Nuclear Physics of the Physics Department of Moscow State University is supported by the Research Institute of Nuclear Physics, Moscow State University 27.04.2020. Available at: http://nuclphys.sinp.msu.ru/enc/e172.htm (in Russian).
8. R. Feynman. *CED - a strange theory of light and substance* (Library «Quantum», Moscow: Science, 1988) (in Russian).
9. R.Feynman, R.Leighton, M. Sands. *Feynman lectures on physics*. Quantum Mechanics. Translation from English (Edition 3). **v. 8, 9** (2016) (in Russian).

10. Am. J. Phys. *Nine formulations of quantum mechanics*. Wotherspoon Department of Physics. 01.05.2020. Available at: http://timeorigin21.narod.ru/rus_translation/QM_formulations.pdf.
11. S. D. Strekalov, *Fizicheskaya himiya: polyusnyie modeli elementov i sistem* (M-vo obrazovaniya i nauki Rossiyskoy Federatsii, Gos. obrazovatelnoe uchrezhdenie vyissh. prof. obrazovaniya "Volgogradskiy gos. un-t", Uryupinskiy fil. - Volgograd : Izd-vo Volgogradskogo gos. un-ta, 2011) (in Russian).