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Unexpected Result of the Two-Body Decay of Neutrons

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ABSTRACT: The lifetime of free neutrons was measured as τ_{beam} = 879.6±0.8 s in the beam experiments [1] or it was measured as τ_{trap} = 877.75+0.50─0.44 s in the trap experiments [2]: the difference was well beyond the experimental error margins. Typically, neutron decays into a proton, and electron, and an antineutrino (the three-body decay). However, rarely there occurs the two-body decay: the neutron decays in a hydrogen atom and an antineutrino. In the present paper we show that with the overwhelming probability the resulting atom will be not the usual hydrogen atom, but the Second Flavor of Hydrogen Atoms (SFHA). This increases the Branching Ratio (BR), i.e., the ratio of the probabilities of the two-body decay to the three-body decay, by a factor of approximately 3300: from the previously considered value of BR = 0.000004 to BR ~ 1% - in the excellent agreement with the "experimental" BR ~ 1% required for required for reconciling τ_{beam} (in the beam experiments only the resulting protons were counted) with τ_{trap}. Thus, our result solves the puzzle of the neutron lifetime *completely*. It should be emphasized that the existence of the SFHA (regardless of the decay of neutrons) has been evidenced in four different types of atomic or molecular experiments. The primary feature of the SFHA is that, because they have only the s-states and due to the selection rules of quantum mechanics, they do not emit or absorb the electromagnetic radiation (with the exception of the 21 cm spectral line originating from the spin-flip transitions between the two hyperfine sublevels of the ground state): the SFHA remain practically *dark*. The SFHA became one of the leading candidates for dark matter or for a part of it – because it helped explaining the recent perplexing observation of the anomalous absorption in the redshifted 21 cm line from the early Universe: without introducing exotic, never discovered subatomic particles and without changing physical laws, in distinction to all other hypotheses for explaining that perplexing observation. Thus, the two-body decay of neutrons in the Universe – the neutrons from neutron stars – seems to provide the continuous supply of baryonic dark matter in the form of the SFHA.

Keywords: two-body decay of neutrons; second flavor of hydrogen atoms; dark matter

1. INTRODUCTION

A free neutron has a mean lifetime of 879.6±0.8 s [1] or 877.75+0.50 – 0.44 s [2] since it decays into a proton, and electron, and an antineutrino (the beta decay). Typically, this is the three-body decay. However, in about 4 occasions out of million, there occurs the two-body decay: the neutron decays in a hydrogen atom and an antineutrino (the process also known as bound beta decay) – see, e.g., papers [3-9] listed in the reversed chronological order. The resulting hydrogen atom is in an S-state: with the overwhelming probability of 83.2% in the ground state 1s and with the probability 10.4% in the state 2s [4, 5].

In the present paper we show that with the overwhelming probability the resulting atom will be not the usual hydrogen atom, but the Second Flavor of Hydrogen Atoms (SFHA). The SFHA have only the s-states. It should be emphasized that the existence of the SFHA (regardless of the decay of neutrons) has been evidenced in four different types of atomic or molecular experiments – Refs. [10 - 22] point to the relevant experiments and their analysis.

2. CALCULATIONS

The probability of the neutron two-body decay, i.e., the process where the neutron disappears and in its place – i.e., *within its radius* – there appear a proton and an electron (such that the electron then cannot escape the proton, so that a hydrogen atom is formed), is proportional to the probability P to find the electron in the hydrogen atom at the distance equal to the neutron radius R (which is approximately the same as the proton charge radius):

$$P = \text{const } |\Psi_0(R)|^2, \tag{1}$$

where $\Psi_0(R)|$ is the value of the ground state wave function $\Psi_0(r)$ at r = R. In the mixture of the SFHA with usual hydrogen atoms in the ratio ε to 1, outside the proton, the radial part of the Dirac bispinor, based on Eq. (17) from paper [10], can be written in the following form (see also Eq. (2) from paper [23]), where all quantities are in the natural units ($\hbar = m_e = c = 1$):

$$f(r, \varepsilon) \approx -\beta^{5/4} \{1 + \varepsilon\Delta/(2\beta^2 r^2)]\}/(1 + \varepsilon^2)^{1/2},$$

$$g(r, \varepsilon) \approx 2\beta^{3/2} \{1 + \varepsilon\Delta/(4\beta^2 r)]\}/(1 + \varepsilon^2)^{1/2}, \tag{2}$$

$$\Delta = E_0 - E = -4\beta^{3/2} \int_0^R [V_{inter}(r) + 1/r]r^2 dr.$$

In Eq. (2), $\beta = \alpha^2$, α being the fine structure constant; E_0 and E are the unperturbed and the perturbed energies (for the ground state), respectively; $V_{inter}(r)$ is the potential inside the proton, corresponding to the experimental charge distribution inside the proton from work "*The Frontiers of Nuclear Science, A Long Range Plan*, DOE/NSF, Nuclear Science Advisory Committee (2008) and arXiv:0809.3137 (2008)". Equation (2) is valid for $R \le r << 1/\alpha$. Then the probability from Eq. (1) is

$$P(R, \varepsilon) = \text{const } [f(R, \varepsilon)^2 + g(R, \varepsilon)^2]. \tag{3}$$

Now we calculate the ratio of the probability P(R, ∞), corresponding to the SFHA without any usual hydrogen atoms, to P(R, 0), corresponding to the usual hydrogen atoms without the SFHA:

$$\rho = P(R, \infty)/P(R, 0). \tag{4}$$

On substituting in Eq. (4) the numerical value of $\beta \approx 0.0000533$ and $R \approx 0.00218$ (the latter being translated in the natural units from R = 0.84 fm), we obtain:

$$\rho \approx 3300. \tag{5}$$

Thus, the outcome of the two-body decay of the neutron is – with the overwhelming probability – the SFHA, rather than the usual hydrogen atom. The significantly enhanced two-body decay of neutrons has profound cosmological implications. Namely, it is the mechanism by which neutron stars, in three different situations, are slowly but continuously producing baryonic dark matter in the form of the SFHA. The three situations are: 1) old neutron stars (of ages 10^7 years or older) releasing neutrons into the stars atmospheres; 2) neutron stars whose mass became slightly less than the minimum mass $M_{min} \sim 0.1$ of the solar mass resulting in the explosive destruction of these neutron star resulting in the ejection of neutrons into the interstellar medium; 3) mergers of a neutron star with another neutron star or with a black hole, the process accompanied by the ejection of neutron-rich material.

3. CONCLUSIONS

We showed that in the two-body decay of neutrons, the resulting atoms with the overwhelming probability will be not the usual hydrogen atoms, but the SFHA. The primary feature of the SFHA is that, because they have only the s-states and due to the selection rules of quantum mechanics, they do not emit or absorb the electromagnetic radiation (with the exception of the 21 cm spectral line originating from the spin-flip transitions between the two hyperfine sublevels of the ground state): the SFHA remain practically *dark*. There are two consequences of this fact.

The first one concerns the methods of the detection of the two-body decay of neutrons. For example, one of the two methods proposed in paper [4] was to detect the hydrogen atoms in the state 2s by the quenching technique: by applying an electric field that would mix the state 2s with the state 2p and recording the emission of the Lyman-alpha line from the state 2p to the ground state 1s. However, by this method one can detect only the usual hydrogen atoms, but not the SFHA. This is because the SFHA do not have the state 2p: they have only the s-states. Therefore, detecting the two-body decay of neutrons in this way would significantly underestimate the actual detection rate.

The second consequence concerns the fact that the SFHA became one of the leading candidates for dark matter or for a part of it. This is because the existence of the SFHA, evidenced by four different types of atomic/molecular experiments (quoted above), helped explaining the perplexing observation by Bowman et al [24] of the anomalous absorption in the redshifted 21 cm line from the early Universe: the explanation that did not introduce exotic, never discovered subatomic particles and did not change physical laws [11] – in distinction to all other hypotheses for explaining the observation by Bowman et al (see, e.g., review [25]). The SFHA, as the candidate for dark matter or for a part of it, does not require going beyond the Standard Model – in distinction to almost all other dark matter hypotheses: the theory of the SFHA is based on the standard quantum mechanics (the Dirac equation). Therefore, the SFHA as the dark matter candidate is favored by the Occam razor principle, as explained in detail in review [25].

Thus, the significantly enhanced two-body decay of neutrons in the Universe seems to provide the continuous supply of dark matter.

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