

Consequence of total lepton number violation in strongly magnetized iron white dwarfs

V.B. Belyaev^a, P. Ricci^b, F. Šimkovic^{c,a}, J. Adam Jr.^d, M. Tater^d,
E. Truhlík^{d,*}

^a *Bogolyubov Laboratory of Theoretical Physics, Joint Institute for Nuclear Research, Dubna 141980, Russia*

^b *Istituto Nazionale di Fisica Nucleare, Sezione di Firenze, I-50019 Sesto Fiorentino (Firenze), Italy*

^c *Department of Nuclear Physics and Biophysics, Comenius University, Mlynská dolina F1, SK-842 15, Bratislava, Slovakia*

^d *Institute of Nuclear Physics ASCR, CZ-250 68 Řež, Czech Republic*

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Abstract

The influence of a neutrinoless electron to positron conversion on a cooling of strongly magnetized iron white dwarfs is studied. It is shown that they can be good candidates for soft gamma-ray repeaters and anomalous X-ray pulsars.

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1. Introduction

The white dwarfs (WDs) are quite numerous in the Milky Way [1] and the astrophysics of these compact objects is nowadays a well developed domain [2–4]. Since the interior of the WDs is considered to be fully degenerate, studying their properties provides a fundamental test of the concept of stellar degeneracy. The important observables, which could test models of structure and evolution of WDs, are the luminosity and the effective (surface) temperature.

* Corresponding author.

E-mail address: truhlik@ujf.cas.cz (E. Truhlík).

Steady progress in understanding of the WDs cooling processes and precise measurements of their luminosity curve and of their effective temperature open a door to their possible use as a laboratory for analyzing some problems of elementary particles physics. Thus, Isern et al. [5, 6] suggested studying possible existence of axions on a basis of the WDs luminosity function. Following this idea, we analyze the influence of the lepton number violation on the luminosity and the effective temperature of strongly magnetized iron WDs (SMIWDs).¹ As it is well known, the existence of the Majorana type neutrino would imply the lepton number violating process of electron capture by a nucleus $X(A, Z)$

$$e^- + X(A, Z) \rightarrow X(A, Z - 2) + e^+. \quad (1.1)$$

This reaction is an analogue of the neutrinoless double beta-decay, intensively studied these days [7]. Very recent experimental results on this process, obtained with the ^{76}Ge detectors, can be found in Refs. [8,9]. An estimate [9] shows that to attain for the neutrino masses sensitivities in the region of 15–50 meV, tonne-scale detectors are needed. At present the detectors [8,9] comprise tens of kilograms of ^{76}Ge . Since 1 kg of ^{76}Ge includes 8.31×10^{24} atoms, a tonne device would contain $\sim 10^{28}$ of ^{76}Ge atoms. On the other hand, the matter density of the SMIWDs is at the level of $10^{33}/\text{cm}^3$ and more, which is by several orders of magnitude larger. This fact makes the study of reaction (1.1) in stellar medium attractive.

For the weak reaction (1.1) with the rate proportional to the square of a small neutrino mass to be detectable, it has to take place in a bulk of the stellar body with a well understood background. It is allowed energetically when the Fermi energy E_F of the electron gas is larger than the threshold energy $\Delta_Z^{\beta\beta}$ given by the mass difference between the final and the initial nuclei plus the electron mass. However, as it can be seen from Table 1, in the WDs consisting of the even–even nuclei the threshold energy of the inverse beta decay Δ_Z^β is smaller than $\Delta_Z^{\beta\beta} + m_e c^2$ (m_e is the electron mass and c is the light velocity). Since usually $\Delta_{Z-1}^\beta < \Delta_Z^\beta$, two successive decays [10–14]

$$(A, Z) \rightarrow (A, Z - 1) \rightarrow (A, Z - 2) \quad (1.2)$$

proceed, unless all (A, Z) nuclei transform to $(A, Z - 2)$ nuclei, and the reaction (1.1) cannot occur. The point is that in the WDs, the electron Fermi energy E_F cannot overcome the energy at which the inverse beta decay proceeds. For the case of the $^{56}_{26}\text{Fe}$ nuclei, this situation is discussed in detail in Ch. 3 of Ref. [11]. Instead of compression increasing E_F and, therefore, the pressure, the electrons are captured by the iron nuclei which are transformed in the two-step process (1.2) into the chrome ones. So the onset of the inverse beta decay at the density $\rho_B = (1.14\text{--}1.18) \times 10^9 \text{ g cm}^{-3}$ terminates the iron WD [11,12]. As can be seen from Table III of Ref. [12], this density is also critical one for the onset of the instability due to the general relativity and the subsequent collapse of the $^{56}_{24}\text{Cr}$ WD happens.² So, the only chance to have the reaction (1.1) in the bulk of compact objects are the SMWDs, where it can hold $E_F > \Delta_Z^{\beta\beta} + m_e c^2$ due to the presence of the strong magnetic field.

Besides our choice for $X(A, Z) = ^{56}_{26}\text{Fe}(0, 0^+)$ and for $X(A, Z - 2) = ^{56}_{24}\text{Cr}(0, 0^+)$ in the process (1.1), other pairs of the even–even nuclei in the ground state $(0, 0^+)$ can be taken. They

¹ We will use acronyms WDs (SMWDs) for the white dwarfs with the magnetic field of $B \ll B_c = 4.414 \times 10^{13} \text{ G}$ ($B \geq B_c$), respectively.

² See also the discussion in the paragraph containing Eq. (1.7) below.

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