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ORIGINAL ARTICLE

Electron capture of nuclei in the region surrounding magnetar

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Abstract Effects of ultra-strong magnetic field on electron capture rates for ^{57}Fe, ^{58}Co and ^{59}Ni have been analyzed in the nuclear shell model and under the Landau energy levels quantized approximation in the ultra-strong magnetic field, the result increase about 3 orders magnitude. The rate of change of electron abundance, $\dot{Y}_e$, for every nuclide and total $\dot{Y}_e$ in the condition without magnetic field and $B = 4.414 \times 10^{15}$ G have been calculated, and exceed about 6 orders of magnitude generally. These conclusions play an important role in future studying the evolution of magnetar.

Keywords Electron capture · Ultra-strong magnetic field · The rate of change of electron abundance

1 Introduction

Electron capture plays an important role in each stage of stellar evolution and many nuclear synthetic processes. On the one hand, electron on heavy nuclei stimulates the gravitational collapse of the core of a great star causing supernova explosion. on the other hand, it dominations the entropy of nucleon and lepton-to-baryon ratio (Liu and Luo 2007). Electron capture on iron group nuclei has been deeply researched for years. Now, the existence of ultra-strong magnetic field in neutron stars is well proven by a large number of astronomical observations. Especially, the magnetic field strength of magnetars (neutron stars with ultra-strong magnetic field) can reach 10^{13}–10^{16} G. A large number of iron group nuclei exist in the shell of neutron stars and magnetars. Neutron stars and magnetars provide an ideal laboratory for all kinds of nuclear physics processes.

Recent studies (Peng 2004; Wang et al. 2012) show that in the ultra-strong magnetic field ($B \gg B_{cr} = 4.414 \times 10^{13}$ G) the Fermi surface of an electron will be elongated along the magnetic field direction from Fermi spherical into Landau cylinder, the Landau energy level is perpendicular to the direction of magnetic field and quantized. Now, the non-relativistic Landau energy levels theory was revised (Liu et al. 2007). Then, we found that the electron capture in the ultra-strong magnetic field didn't decrease along with the increase of magnetic field, but presented a trend of increase. The conclusion will affect the electron capture and β decay in the core of stars. In view of the importance of iron group nuclide, influence of ultra-strong magnetic field on electron capture for ^{57}Fe, ^{58}Co and ^{59}Ni was analyzed in this paper.

Neither nuclei of high abundance ratios nor nuclei of high capture rates can determine the total electron capture rates in the stellar surroundings, the total electron capture rates should be determined by all of nuclei in the stellar surroundings. For the stellar evolution, most important parameter is not electron abundance, Y_e, but the total rate of change of electron abundance, $\dot{Y}_e$. Aufderheide et al. (1994) have studied and analyzed the total $\dot{Y}_e$ in the stellar surrounding, and then Luo (2001) has studied in-depth it, but they didn't refer to effect of magnetic field on the total $\dot{Y}_e$ in the stellar surrounding. So we have calculated and analyzed change of $\dot{Y}_e$ in the magnetars surrounding with ultra-strong magnetic field at the typical temperature-density point.

2 Electron capture in ultra-strong magnetic field

When the energy and momentum are in of $m_e c^2$ and $m_e c$ separately, we can obtain the Landau energy levels by solv-

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