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Chinese Astronomy and Astrophysics 34 (2010) 386–393

CHINESE
ASTRONOMY
AND ASTROPHYSICS

Gaussian Modification of Neutrino Energy Losses in Electron Capture Processes of Nuclides ^{56}Fe, ^{56}Co, ^{56}Ni and ^{56}Mn in Stellar Interiors

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Abstract By using the Gaussian modification method, the neutrino energy losses in the electron capture processes of nuclides ^{56}Fe, ^{56}Co, ^{56}Ni and ^{56}Mn are investigated. The results show that the energy loss rate of neutrinos is increased due to the Gaussian modification of the energy level distribution of the Gamow-Teller (GT) resonance transitions of nuclides. In the reactions dominated by the electron capture processes of the low-energy transitions, the Gaussian modification has a very small influence on the neutrino energy losses. When the high-energy G-T resonance transition is the main electron capture process, the influence on the neutrino energy losses will be greatly increased. For example, the correctional differences of nuclide ^{56}Fe are about 2 orders of magnitude when the density $\rho_7 = 100$ (ρ_7 is in units of 10^7 mol·cm^{-3}) and the half width of Gaussian function Δ =14.3, 18.3, 22.3 Mev, and those of nuclide ^{56}Ni are about 60% and 40% when Δ =6.3, 18.3 Mev, respectively.

Key words: stars: evolution — stars: interiors — neutrinos

† Supported by Special Foundation of Sanya Municipality for Higher Education, Natural Science Foundation of Hainan Province, Research Foundation of Education Department of Hainan Province for Higher Education and National Natural Science Foundation

Received 2009–09–22

⋆ A translation of *Acta Astron. Sin.* Vol. 51, No. 2, pp. 144–150, 2010

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doi:10.1016/j.chinastron.2010.10.007

1. INTRODUCTION

According to the theory of stellar evolution, the neutrino energy loss plays a very important role and even makes a major contribution in various kinds of the cooling mechanisms in stellar evolution, the models of X-ray bursts and the physical processes of the collapse in the cores of supernovae. The annihilation of electron pairs, photoneutrino process, plasma decay, nuclear bremsstrahlung process and other weak interaction processes, such as the electron capture and β decay, strongly influence the cooling rate and evolutionary timescale of stellar evolution. In the late evolutionary phase of massive stars, how the variation of this kind of cooling rate influences the structure and component of iron core in the mechanism of supernova outburst, which for a long time since lacks theoretical support, deserves our investigation.

The electron capture process plays an important role in the process of supernova outburst. In the core collapse process of supernova, it is not only the main production base of neutrinos, but also plays an important role in influencing the neutronization process of the matter in cores, causing the core collapse of type II supernovae and the outburst of type Ia supernovae. The neutrinos produced in this process carry a great deal of energy and escape from celestial objects, making the stellar temperature rapidly decrease. Undoubtedly, the energy loss of neutrinos is of inestimable significance to the cooling of evolved stars. This highly interesting and challenging topic has been studied by many scholars. For example, Fuller et al.[1−3] made many pioneering works in this field. Liu et al.[4−8], Luo et al.[9−10] and Brachwitz et al.[11] analyzed the relations of the energy distribution of the G-T transitions and the quenching effect with the electron capture, β decay, electron abundance of stars with masses in different ranges of solar mass. Langanke et al.[12] discussed in detail the G-T energy distributions of some isotopes with neutron-rich nuclei and the electron capture rates.

Analyses indicate that in the environment of stellar interiors with both high temperature and high density, the Fermi energy of the electron gas is relatively high and may exceed 10 MeV. Therefore, in the electron capture process, the G-T resonance transition makes an important contribution, even plays a dominative role. This definitely influences the neutrino energy loss of the electron capture process. So it is very important and necessary to study the neutrino energy loss of the electron capture of the G-T resonance transition in the state of excitation. Based on the $p-f$ shell model and according to the method adopted by Kar et al.[13] to treat the energy distribution of the G-T transitions, the Gaussian modifications are made to the energy states of the G-T resonance transitions in the state of excitation for typical nuclides ^{56}Fe, ^{56}Co, ^{56}Ni and ^{56}Mn in stellar interiors.

2. GAUSSIAN MODIFICATION OF NEUTRINO ENERGY LOSS IN ELECTRON CAPTURE PROCESS IN STELLAR INTERIORS

It is assumed that after capturing an electron a nucleus k in stellar interior makes a transition from the initial state i to the final state f. When considering the contributions from all the possible final states which correspond to this initial state, the neutrino energy loss rate