Nucleosynthesis in decompressed Neutron stars crust matter

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Introduction

It's being a challenging problem to understand the formation of heavy & super heavy nuclei in the universe [1]. The rapid neutron capture process (r-process) is believed be responsible for the synthesis of heavier elements in supernovae explosions & neutron stars (NS) crusts under extreme astrophysical conditions [2]. Some NSs have very high magnetic fields~$10^{17}G$. These are called as magnetars. The ground state properties of inner crusts of NSs are studied in the presence of strong magnetic fields [3]. We studied the r-process in the decompressed NSs crust matter in the presence of strong magnetic field using the calculations of [3] as input.

Nuclear Statistical Equilibrium

During fusion reactions inside the stars, once Si burning stage is reached, the temperature rises up to a limit, when various nuclei reach one large equilibrium group stretching from proton (p), neutron (n), **α**-particles to the iron peak nuclei. The system attains nuclear statistical equilibrium (NSE) with equal forward & backward reaction rates. We consider the hot and dense decompressed crust matter consists of free p, n & seed nuclei such as ^{56}Fe.

At NSE, mass & charge conservation imply [4],

$$\sum X_i = 1 \text{ ----------------- (1)}$$

$$\sum \frac{Z_i}{A_i} X_i = Y_e \text{ -------------- (2)}$$

where, Y_e is the proton fraction, X_i is the mass abundance for i-th nuclei with atomic number Z_i and mass number A_i & is given by,

$$X_i = \frac{1}{2} G_i(T) \left(\frac{1}{2}\rho N_A \lambda^3\right)^{A_i-1} A_i^{5/2} X_n^{A_i-Z_i} X_p^{Z_i} e^{Q_i/KT}. \text{ ------------ (3)}$$

Here, $G_i(T)$ is the partition function, N_A is the Avogadro's number, Q_i is the binding energy, ρ is the mas density, T is the temperature, K is the Boltzmann constant, X_p is the proton fraction, X_n is the neutron fraction & λ is the thermal De' Broglie wavelength given by, $\lambda = \frac{h}{\sqrt{2\pi m_H KT}}$ where h is the Planck's constant & m_H is the mass of a hydrogen atom.

We solve eqns.(1) & (2) using Newton-Raphson method for X_p& X_n & use these values to obtain the mass abundance of different nuclei. This leads to number abundances of different nuclei, $Y_i = \frac{X_i}{m_i}$ [5].

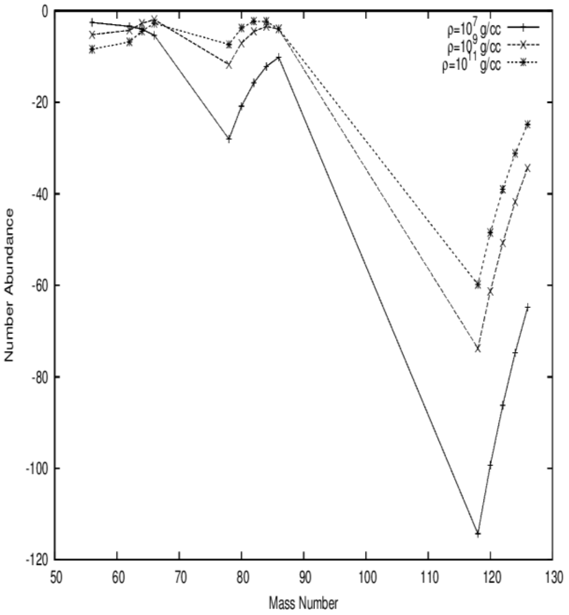

Fig.1 Abundance variation with mass number for T=9×10^9K & Y_e=0.4 with varying ρ

Result

We have shown the abundance variation with mass number for NS crust nuclei. Fig.1. shows the abundance variation with mass number for constant T & Y_e with varying density (ρ). It can be seen that abundance of nuclei increases with increasing ρ. ^{86}Kr is the most abundant nuclei & ^{118}Kr is the least abundant nuclei.

Fig.2. shows the variation of abundance for constant ρ & T with varying Y_e. Abundance of nuclei increases with decreasing Y_e. More nuclei present in low Y_e region.

We have also studied the abundance variation with mass number for constant Y_e & ρ with varying T and found that the nuclei are more abundant for low temperature values.

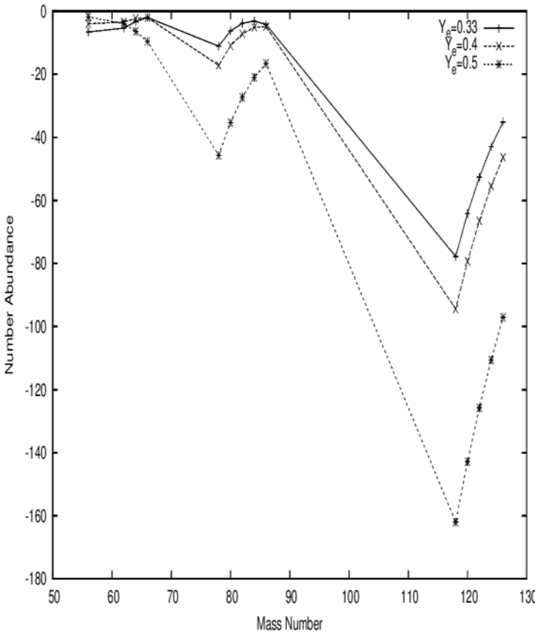

Fig. 2 Abundance variation with mass number for T=8×10^9K & $\rho=10^8 g/cc$ with varying Y_e

Summary

We have investigated the abundance of neutron star crust in the presence of high magnetic field in the outer crust of decompressed NSs crust matter.

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