User's Guide for Neutron Star Matter EOS

— CQMC model within RHF approximation and Thomas-Fermi model —

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Abstract

This is a guide for users of EOS tables for Neutron Star Matter.

1 Introduction

The equation of state (EOS) for neutron stars in a wide-density range at zero temperature is constructed. The chiral quark-meson coupling (CQMC) model within relativistic Hartree-Fock (RHF) approximation is adopted for uniform nuclear matter. In the crust region, nuclei are taken into account within the Thomas-Fermi calculation. Here, we provide three tables, EOS, particle fractions and properties of nuclei in the crust region. For details on our model, please see in our original paper [1]. **Please reference it when you publish scientific articles using our tables.**

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2 EOS

Baryon mass density, energy density, pressure and lepton (= electron + muon) fraction

The EOS data is given in a file named

- `eosmyn.data`

and entries are as follows.

1. Baryon mass density: ρ_B [g/cm^3]
2. Baryon number density: n_B [1/fm^3]

   The baryon number density is related to the baryon mass density as

$$n_B = \frac{\rho_B}{m_u}, \tag{1}$$

   where $m_u = 931.494$ MeV is the atomic mass unit.

3. Energy density: ε [MeV/fm^3]
4. Pressure: P [MeV/fm^3]

   The pressure is calculated through the thermodynamic relation

$$P = n_B^2 \frac{\partial}{\partial n_B}\left(\frac{\varepsilon}{n_B}\right), \tag{2}$$

   where n_B is baryon number density.

5. Lepton (= electron + muon) fraction: Y_L

   The lepton fraction is given by

$$Y_L = \frac{n_e + n_\mu}{n_B}, \tag{3}$$

   where n_e and n_μ are electron number density and muon number density, respectively.

For users who favor other units, following formula would be useful:

$$\begin{aligned} \mathrm{MeV/fm^3} &= 1.7827 \times 10^{12}\ \mathrm{g/cm^3}, \\ &= 1.6022 \times 10^{33}\ \mathrm{dyne/cm^2}. \end{aligned} \tag{4}$$

3 Particle fractions

The particle fractions are listed in a file named

- `pfmyn.data`

and entries are as follows.

1. Baryon mass density: ρ_B [g/cm^3]
2. Baryon number density: n_B [1/fm^3]
3. Neutron fraction: Y_n
4. Proton fraction: Y_p
5. Λ fraction: Y_Λ
6. Σ^- fraction: Y_{Σ^-}
7. Σ^0 fraction: Y_{Σ^0}
8. Σ^+ fraction: Y_{Σ^+}
9. Ξ^- fraction: Y_{Ξ^-}
10. Ξ^0 fraction: Y_{Ξ^0}
11. Electron fraction: Y_e
12. Muon fraction: Y_μ

    The particle fractions of Entries 3-12 are given by

    $$Y_i = \frac{n_i}{n_B}, \tag{5}$$

    where n_i is number density of the particle i.

13. Nucleus fraction: Y_A

    The nucleus fraction is defined by

    $$Y_A = \frac{A}{\frac{4}{3}\pi R_{\mathrm{cell}}^3 n_B}, \tag{6}$$

    where mass number of the nucleus A and radius of Wigner-Seitz cell R_{cell} are given later.

Note that, only Ξ^- appears in neutron stars while all octet baryons are considered.

4 Properties of nuclei in the crust region

The properties of nuclei in the crust region are shown in a file named

- `crustmyn.data`

and entries are as follows.

1. Baryon mass density: ρ_B [g/cm^3]
2. Baryon number density: n_B [1/fm^3]
3. Nucleus number density: n_A [1/fm^3]
4. Mass number of the nucleus: A
5. Charge number of the nucleus: Z
6. Radius of Wigner-Seitz cell: $R_{\rm cell}$ [fm]

In the crust region, we treat the bcc lattice of nuclei approximately with a spherical Wigner-Seitz cell. For nucleon distributions in the Wigner-Seitz cell, we assume spherical symmetry and utilize the parameterization:

$$n_i(r) = \begin{cases} \left(n_i^{\rm in} - n_i^{\rm out}\right)\left[1 - \left(\frac{r}{R_i}\right)^{t_i}\right]^3 + n_i^{\rm out}, & r < R_i, \\ n_i^{\rm out}, & R_i \le r \le R_{\rm cell}, \end{cases} \tag{7}$$

with $i = n, p$. Since $R_{\rm cell}$ is the radius of Wigner-Seitz cell, the volume of Wigner-Seitz cell is $\frac{4}{3}\pi R_{\rm cell}^3$. Therefore, the nucleus number density is written as

$$n_A = \frac{1}{\frac{4}{3}\pi R_{\rm cell}^3}. \tag{8}$$

On the other hand, R_n and R_p represent the radii of neutron and proton distributions, respectively. Here, R_n is always larger than R_p in the neutron star crust and we difine the region of $r < R_n$ as "nucleus". Meanwhile, $n_n^{\rm out}$ corresponds to the dripped neutrons and we set $n_p^{\rm out} = 0$. Finally, t_n and t_p represent the relative surface diffuseness. Using them, the mass number of the nucleus A and the charge number of the nucleus Z are written as

$$A = \int_0^{R_n} \left[n_n(r) + n_p(r)\right] 4\pi r^2\, dr, \tag{9}$$

$$Z = \int_0^{R_p} n_p(r) 4\pi r^2\, dr. \tag{10}$$

5 Contact

If you find some strange problem, please contact us. We would appreciate it very much if you could give us comments or suggestions on the tables. The correspondence address is

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References

[1] T. Miyatsu, S. Yamamuro, and K. Nakazato, arXiv:1308.6121 [astro-ph.HE]