1. **A simple NSE equation of state**

   — Take a mixture of neutrons, protons, deuterons and α-particles (^{4}He). Determine the composition assuming a perfect NSE as function of n_B for different temperatures between 1 and 20 MeV and equal number of protons and neutrons (symmetric matter). Repeat the exercice for $Y_q = 0.25$ and $Y_q = 0.1$. (deuteron binding energy is 2.2 MeV and α-particle binding energy is 28.3 MeV, degeneracy factors are $g_n = g_p = 2; g_a = 1; g_d = 3$)

2. Correction :

   — The chemical potentials are

$$\mu_n = \mu_B \quad \mu_p = \mu_B + \mu_q \quad \mu_d = 2\mu_B + \mu_q \quad \mu_\alpha = 4\mu_B + 2\mu_q \ , \tag{1}$$

   and the masses are

$$m_n = 939.56\text{MeV} \quad m_p = 938.27\text{MeV} \quad m_d = m_p + m_n - B_d \quad m_\alpha = 2m_n + 2m_p - B_\alpha \ . \tag{2}$$

   — The next step is to use the expression

$$n_i = g_i \frac{(m_i T)^{3/2}}{(2\pi)^{3/2}} \exp(\frac{\mu_i - m_i}{T}) \tag{3}$$

   to obtain the individual densities. Baryon number density is then $n_B = n_n + n_p + 2n_d + 4n_\alpha$ and the charge fraction $Y_q = n_q/n_B$ with the charge density given by (counting the number of protons in each particle) $n_q = 2n_p + n_d + 2n_\alpha$.

   — The last step is to vary the two chemical potentials μ_B and μ_q to obtain the desired n_B and Y_q. This can be done, e.g. with a Newton-Raphson algorithm. Or in a less sophisticated way, if you are not interested to have a regular grid in n_B, you can simply vary μ_B and adjust μ_q to obtain the desired Y_q (e.g. with a robust and simple dichotomy).

   — The results can be found on the web page. The files are named `nse_Tx_Yy.d` with x indicating the temperature in MeV and y the charge fraction.

   — In order to obtain the EoS, the pressure p and the energy density ε under the same conditions can be obtained readily from the formulas given during the lecture.