PHY983 - Nuclear Astrophysics - Spring 2007
Homework set 8
Due: Friday, **March 30**, 2007, in class
Keywords: reverse rates, photodisintegration

1. In explosive astrophysical scenarios temperatures are so high that often inverse photodisintegration reactions become equally important as the particle induced rates. In this case, one needs to calculate the reverse rates from the forward particle induced rates, which can be done using the so called detailed balance principle. Here, you can derive the equation needed to calculate the reverse rate for any forward rate from simple equilibrium considerations:

   a. [10pts] Consider a proton capture reaction A(p,γ)B with a stellar reaction rate of $N_A<\sigma v>_{(p,\gamma)}$. Derive the equation that allows you to calculate the reverse photodisintegration rate (disintegrations per second and target nucleus $\lambda_{(\gamma,p)}$) from the proton capture reaction rate by considering the case where the (p,γ) and the (γ,p) reaction are in equilibrium. This gives you two constraints a) in equilibrium the abundances of A and B are constant in time (you can write a differential equation for the time dependence of the abundance of A or B and set it to zero) and b) in equilibrium the sum of the chemical potentials on both sides of the reaction equation are equal. For particles A, B, p use the chemical potential μ of an ideal Maxwell-Boltzmann gas:

   $$\mu = mc^2 + kT\ln\left(\frac{n\Lambda^3}{g}\right) \text{ with } \Lambda = \sqrt{\frac{h^2}{2\pi mkT}}$$

   with m as particle mass, k the Boltzmann constant, T the temperature, n the particle number density, and g the partition function. Recall from class

   $$g = \sum_i (2J_i + 1)\exp\left(-\frac{E_i}{kT}\right)$$

   though this is not needed for the derivation (but for problem 2). (no chemical potential for the gamma ray).

   b. [5pts] Read pages 79-81 (section 2.2.) and 158 - 161 (Section 3.1.4) of the book "Nuclear Physics of Stars". Check whether the equation you derived in 1a. is the same as in the book (You will need it in 2.). List the main basic assumptions that are being made in the book to derive the equation for photodisintegration rates.

   c. [2pts] BONUS QUESTION: where are these assumptions in the derivation we used here? As the book states, in their derivation the equation is an approximation that does not hold for small Q-values - is that also true for our derivation?

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2. Problem: [10pts]
   Calculate and compare the lifetime against (γ,α) photodisintegration of 16O under typical oxygen burning conditions (T=2GK, density=10e7 g/cm^3) of 20Ne against under typical neon burning conditions (T=1.5GK, density=10e6 g/cm^3)
   What is the main cause of the difference ? How does this impact the nature of stellar oxygen and neon burning respectively ?
   Hint: use the NACRE compilation for the inverse reaction rates (the corresponding alpha capture) and use the equation derived in 1. Excited states can be neglected for the partition functions.

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