PHY983 - Nuclear Astrophysics - Spring 2007
Homework set 6
Due: Friday, **March 16**, 2007, in my mailbox
Keywords: S-factor, cross section, direct and resonant reaction rate, Gamov widow

1. We just identified 23Al(p,g) as an important reaction in X-ray bursts. We are considering to propose a new experiment to improve the 23Al(p,g) reaction rate.
    a. [2pts] Use the BNL Nuclear Data Compilation ENSDF (http://www.nndc.bnl.gov/) and determine the CM energy of the lowest lying resonance
    b. [2pts] Is the resonance in the Gamow window for a typical temperature during the early stages of an X-ray burst of 0.5 GK? What does your result mean?
    c. [2pts] For protons that hit 23Al at this resonance energy, into which states can direct capture occur? What are the energies of the associated gamma-ray emitted by the direct capture process?
    d. [4pts] How would you go about measuring the 23Al(p,g) reaction rate? (What kind of beam, target, what would one detect, and which quantities would one have to determine to extract a reaction cross section).

2. Towards the end of the main sequence life of a star hydrogen is running out. This would lead to a decrease in energy generation rate. To compensate the star contracts slightly and burns the remaining hydrogen at a higher temperature via the CNO cycle. The 14N(p,g) reaction therefore directly determines the late main sequence evolution and the point in time when the star finally turns away from the main sequence as hydrogen burning in its core ceases. The 14N(p,g) rate therefore needs to be known accurately to use globular cluster observations to constrain the age of the universe (see previous homework set).

    a. [10pts] Use the NACRE compilation to calculate the direct contribution (assume constant S-factor) and the contribution of the first 260 keV resonance (assume it is narrow) to the stellar reaction rate of 14N(p,g) at a temperature of 0.1 GK (typical temperature at main sequence turn off). Which contribution is more important (in this case, for this temperature) ?

       For this problem, use the S-factor and resonance parameters given in NACRE to calculate direct capture and resonant contribution respectively.

    b. [2pts] Compare your result with the reaction rate table.

    c. [2pts] At which proton energy would one observe that resonance in the laboratory when bombarding a 14N target with protons ? (Laboratory frame). What is the l-value of the protons populating the resonance? (you can get the levels from the lecture notes) ?

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d. [10pts] In a recent experiment at LENA (TUNL Lab at Duke) (http://scitation.aip.org/jhtml/doi.jsp) the 14N(p,g) rate was measured by bombarding a Ta target (just a piece of Ta sheet metal) that had on its surface a 1.5μm layer with implanted 14N atoms (stochiometry Ta/N=0.718) with a 150μA (electrical current) proton beam and detecting the gamma-rays that were emitted in the reaction. Determine the number of gamma-rays produced in the target per second in such an experiment if one would choose the proton energy most relevant for the stellar rate at 0.1 GK (assume constant S-factor of 1.68 keV b - which is what they found).

e. [2pts bonus] Why do you think the experiment could only be performed down to a proton energy of 155 KeV.

f. [2pts bonus] Why can't one just make the target thicker ?

g. [5pts] In the new measurement it was found that the S-factor for 14N(p,g) is 1.68 keV b instead of 3.20 keV b that were previously assumed. Does the new S-factor increase or decrease the age determined for globular clusters (when determined from the main sequence turn off point) ? Justify your answer.

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