PHY983 - Nuclear Astrophysics - Spring 2013
Homework Set 6
Due: Friday March 11, 2013 at beginning of class
Key words: reaction rates

1. [10 pts] Consider the ^{23}Al(p,γ) reaction, which has been shown to be important in X-ray bursts. Go to the National Nuclear Data Center (NNDC) ENSDF database (easy to google – search for the nucleus you want and display "adopted levels") to obtain information on possible final states for direct capture, and for resonance states.

You will need the spin of one of the levels, which is not experimentally known and therefore not listed. You can use a trick to make a good guess. Because the strong force does not distinguish between protons and neutrons you can use information on the so called "mirror" nucleus, where proton and neutron numbers are switched. This nucleus will have a similar level structure (you can check that by comparing). While the energies are slightly shifted it should be clear which state corresponds to which thereby providing you with spin and parity.

a. Determine which of the known states will be resonances and which states can only be reached by direct capture.

b. For the states that can only be reached by direct capture, calculate the likely dominant orbital angular momentum in the entrance channel, and the likely multipolarity of the emitted gamma ray.

c. For the states that can be reached as resonances, calculate the center of mass resonance energy, and the minimum orbital angular momentum needed to populate it

d. What would be the laboratory beam energy needed if one wanted to populate the resonance by bombarding a proton target with a ^{23}Al beam (give energy in MeV/nucleon) (we will do at MSU with the FRIB facility).

e. Calculate the Gamow window for 0.8 GK.

2. [6 pts] If for the highest known resonance from Problem 1 the proton width is 1.26 eV and the gamma width is 0.017 eV,

a. calculate the resonance strength and the resonant reaction rate at 0.8 GK

b. calculate the total lifetime of the state and compare with the experimental limit in the mirror nucleus (though one had to correct this for the slightly different energy)

3. [6 pts] The direct capture S-factor for ^{23}Al(p,γ) is 4.37e-3 MeV barn.

a. Calculate the direct capture rate contribution at 0.8 GK and compare to the resonant contribution calculated in problem 2.

b. Calculate the direct capture cross section in the center of the Gamow window for 0.8 GK.

c. Compare the total rate (direct capture plus resonant capture) at 0.8 GK with the rate listed in the JINA reaclib database (give both numbers).