# Determination of the S_{18} Astrophysical Factor for ^{8}B(p,γ)^{9}C from the Breakup of ^{9}C at Intermediate Energies

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Previously we have shown [1] that one can use breakup reactions of loosely bound nuclei at intermediate energies (tens to hundreds MeV/u) to determine astrophysical S factors for proton radiative capture reactions at stellar energies (a few keV). We report here on new results from the breakup of ^{9}C. The asymptotic normalization coefficient (ANC) for ^{9}C→ ^{8}B +p, specifying the amplitude of the tail of the ^{9}C wave function projected on the two body channel ^{8}B +p, has been determined using existing experimental data for the breakup of ^{9}C projectiles at 285 MeV/u on four different targets: carbon, aluminum, tin, and lead [2]. By comparing the cross sections from these experiments with calculations we are able to extract information about the structure of the wave function of this unstable nucleus. ^{9}C is a loosely-bound nucleus and consequently the breakup reactions are peripheral, even at high energies. This allows us to extract the ANC and thus obtain the direct part of the radiative capture reaction at stellar energies. The calculations were done using a Glauber type model in two approaches. The first one is the same extended Glauber model we applied for the breakup of ^{8}B, but here we use two prescriptions to obtain the folded potentials for the S-matrix calculations needed in the reaction. One approach uses the same JLM interaction based on the G-matrix as before, and the other one uses the T-matrix interaction of Franey and Love [3]. These interactions were folded with Hartree-Fock densities for the partners to obtain the

interaction potentials used to calculate the scattering matrix elements. In a second approach, the Glauber model in the optical limit was used. The breakup process is treated as multiple elementary interactions between the partners' nucleons, and cross sections and complex scattering amplitudes are taken from compilations of nucleon-nucleon scattering data at these energies by Ray [4]. Calculations were done using 3 different ranges for the elementary interactions: zero-range (μ=0 fm), a standard range (μ=1.5 fm), and the ranges determined for each elementary interaction by Ray. All results are consistent with each other.

From the comparison with experiment we find $C^2_{p3/2}+ C^2_{p1/2}=1.22\pm0.13$ fm^1.
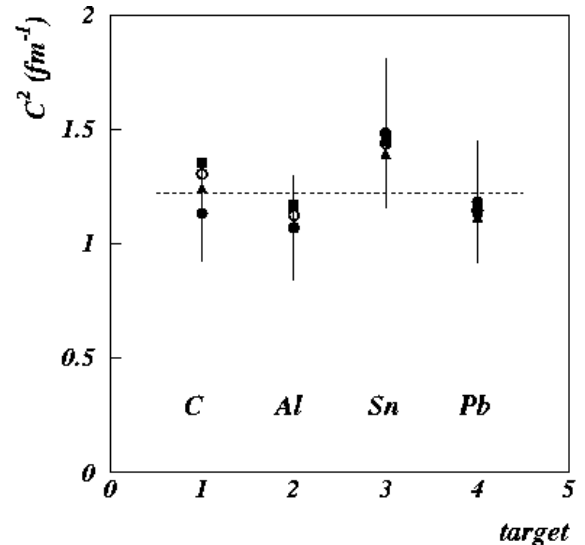

Figure 1: The asymptotic normalization coefficients determined using the calculations in the four approaches or parameter sets described in text. The experimental data for the breakup of ^{9}C at 285 MeV/u on C, Al, Sn and Pb (left to right) are from Ref. [2].

In Fig. 1 we show the results of these calculations. The wave function of the ground state of ^{9}C is a mixture of $1p_{3/2}$ and $1p_{1/2}$ orbitals, around a ^{8}B core. Only the quantity $C^2_{tot}=C^2_{p3/2}+C^2_{p1/2}$ can be extracted from these experiments. For each target the ANC was determined independently using the above quoted five calculations. The results are shown with different symbols for four of the calculations. The results of the zero-range calculations are 5 to 16% higher compared with the other calculations and are not shown. The average value quoted above includes only the results of JLM, Franey-Love, "standard," and Ray calculations. The error bars sum up quadratically the experimental and calculational uncertainties.

In a recent publication [5], the determination of the same ANC using the proton transfer reaction d(^{8}B,^{9}C)n at 14.4 MeV/u incident energy was reported. The experimental statistics are rather poor, according to their Fig. 1, and the authors present the results of a range of DWBA calculations, with different optical potentials from the literature. They report an effective ANC that ranges from 0.97 to 1.42 fm^{-1}, with an average that we found to be $<C^2_{tot}>=1.18$ fm^{-1}. From their assessment of the final uncertainty we obtain $*C^2_{tot}=0.34$ fm^{-1}. This uncertainty is large (30%), and the (d,n) reactions were criticized before [6] for not being good peripheral reactions, and thus inadequate for the determination of the ANC. However, their values (and particularly the average) are very close to those extracted by us from different experimental data and using a different reaction mechanism.

To calculate the S factor we use the potential model, similar with that described in Ref. [7]. Electric dipole and quadrupole transitions are included for the final channel,

with E1 giving the largest contribution, and practically all waves are considered in the entrance channel (but the s-wave dominates the major E1 term and the d-wave contributes only a few percent). The calculations are done with a single proton p_j wave function normalized to unity and having the asymptotic normalization coefficient b_p. Then the result is scaled by C^2_{tot}/b_p (such a procedure avoids any complications that might appear when a Whittaker function normalized by C^2_{tot} is used in the whole integration range). The calculations are done for the proton energy range $E_{cm}=0$-0.8 MeV. The contribution of the resonant state at $E_{res}=922$ keV with known width $\ni$ =100 keV is not found to be important here, because it is rather far away and most probably its spin is $J^B=1/2^-$. Hence it is forbidden by selection rules to contribute to the major term. We find $S_{18}(0)=46\pm6$ eVθb. A very weak dependence on energy is observed: $S(E)=45.8-15.1E+7.34E^2$ (E in MeV), less than a 15% decrease over the whole range that we considered.
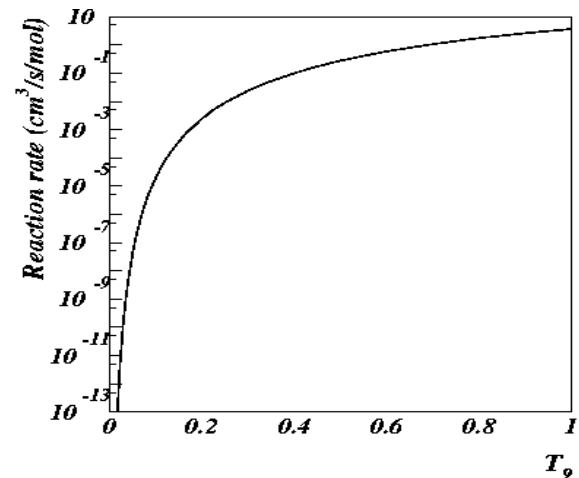
Figure 2: The reaction rate calculated using the average ANC and the astrophysical S factor.

Using this S factor we can calculate the reaction rate at different temperatures. In Fig. 2 this rate is shown for the range $T_9=0$-1.

References

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