Experimental Radii of Halo States in ^{17}F and ^{13}C Nuclei

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The experimental asymptotic normalization coefficient (ANC) determined from transfer reactions was used before to calculate the rms radius for the proton halo nucleus ^{8}B [1,2]. We showed that for the case of halo nuclear states, the use of the ANC gives a reliable and model independent value for the rms radius of the halo that can be extracted from experimental data. This is due both to the large radial extension of the halo states and to the nature of the operator that favors contributions from larger distances.

In order to illustrate and check this statement, we apply the same procedure to other nuclei. A known candidate for a proton halo is the first excited state in ^{17}F, $J^{\pi}=1/2^{+}$, $E_{exc}=0.495$ MeV. Two factors favor the proton in this state to be even more extended than in the ^{8}B ground state: the binding energy $\varepsilon_p=105$ keV is slightly lower, and it is in a *s*-wave (no centrifugal barrier). A somewhat larger Coulomb barrier due to the larger atomic number of the core works in the opposite direction. The extra node in the $2s_{1/2}$ wave function can be another complication. We have determined the ANCs for the ground state and for the first excited state in ^{17}F from an ^{16}O(^{3}He,d)^{17}F experiment [3]. A value $C^2=6480\pm680$ fm^{-1} was obtained for the weakly bound first excited state. We use the same grid procedure as in [2]. The rms radii of the $2s_{1/2}$ single particle wave functions calculated in Woods-Saxon wells adjusted to reproduce the experimental binding energy of the proton, range from 4.69 to 5.57 fm when the well parameters are varied from r_0=1.0 to 1.3 fm and a=0.5 to 0.7 fm. However, when we constrain the overlap integrals to have the asymptotic behavior given by the experimental ANC, the average over the 12 points of the (r_0,a) grid becomes $\langle r^2\rangle^{1/2}=5.56$ fm, with a standard deviation of 0.16 fm. This is about two times smaller than the $\delta\langle r^2\rangle^{1/2}=0.29$ fm uncertainty in the average value given by the 5.2% uncertainty of the ANC determination from experiment. Combining, we can conclude that the rms radius of the proton halo is $r_h=5.56\pm0.33$ fm. Searching for Woods-Saxon potentials that produce single particle ANCs matching the experimental one (that is, with spectroscopic factor unity), we find $r_{sp}=5.43$ fm, also within the margin of error. The value obtained is about 2 times larger than the radius of the ^{16}O core $r_c=2.73$ fm, and therefore, we can conclude that the first excited state in ^{17}F is a clear proton halo state. We find that, in average, the last proton is located with 76% probability at radii r>3.0 fm, and this region contributes about 98% to the rms radius. For r>5.0 fm, the numbers are 33% and 84%, respectively, which shows again the dominant contribution of the tail to the rms radius (Fig. 1). We expect the core excitation to give minimum contribution in this case because the next configuration of the same spin and parity $(2^{+}\cdot d_{5/2})1/2^{+}$ is about 7 MeV higher in the energy spectrum and therefore the mixing must be small.

Furthermore, if we try to apply the same procedure to the $5/2^{+}$ ground state of ^{17}F, we notice that the procedure does not work so well. Using the same grid as above, renormalizing the overlap function to the measured ANC increases, rather then decreases, the spread of the values around the average value $r_h(1d_{5/2})$=4.45 fm. The standard deviation is 0.42 fm, twice larger than the uncertainty due to the experimental uncertainty in the determination of the ANC. The asymptotic part of the wave function makes a significant contribution to the rms radius, but it does not dominate as in the case of the first excited state. The reasons are both the larger proton binding energy and the larger orbital angular momentum of this state.

Next we use the procedure for the first excited state in ^{13}C, $J^{\pi}=1/2^{+}$, E_{exc}=3.089 MeV. It has a somewhat larger binding energy ε_n=1.857 MeV, but is a neutron *s* state and, therefore, benefits from lacking a Coulomb or a centrifugal barrier. The state is important in determining the cross section for the neutron radiative capture ^{12}C(n,γ)^{13}C at astrophysical energies. The ANC for this state was determined from a ^{12}C(d,p) experiment at E_d=11.8 MeV at the University of Tokyo to be $C^2=3.65\pm0.49$ fm^{-1} [4]. If we use radial overlap integrals that have the asymptotic behavior given by the experimental ANC, we obtain an rms radius $\langle r^2\rangle^{1/2}=5.18\pm0.38$ fm. This is a good argument that it is a neutron halo state, because it is again more than a factor two larger than the rms radius of the ^{12}C core (r_c=2.47 fm) (fig.1, bottom).

We may conclude that one can reliably extract model independent radii for nuclear halo states from asymptotic normalization coefficients extracted from peripheral transfer reactions. The method does not depend on the spectroscopic factors of the states or on the details of the potential wells assumed in the

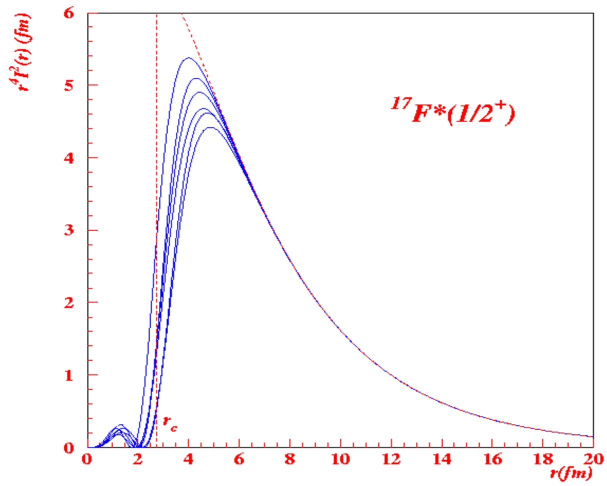

Figure 1: Comparison of various radial overlap integrals $r^4I^2(r)$ for $^{17}F^*(1/2)$ and $^{13}C^*(1/2^+)$ with the normalized Whittaker function (dashed curve). Most of the contribution to the rms radius comes from the region outside the core r_c.

usual single particle treatment. Nuclear halo states appear for a favorable combination of three factors: small nucleon binding energy, small or no Coulomb and centrifugal barriers.

References

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