Extracting the ANC for the ^{17}O 6.356 MeV 1/2^{+} state from transfer data: a cautionary tale

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Over the past decade the asymptotic normalisation coefficient (ANC) has been much in vogue as a means of expressing nuclear structure information extracted from direct reactions as a single quantity, thus facilitating comparisons.

However, for transfers of charged particles involving weakly-bound states the usual ANC can become inconveniently large. To overcome this difficulty the Coulomb renormalised ANC was introduced, see e.g. A. M. Mukhamedzhanov, Phys. Rev. C **86**, 044615 (2012).

In this talk we note the source of an intrinsic limit on the precision with which the Coulomb renormalised ANC for a specific state of astrophysical interest can be obtained which has not been discussed in the literature to the best of our knowledge.

We first recall the definition of the Coulomb renormalised ANC:

$$\widetilde{C} = \frac{\ell!}{\Gamma(\ell + 1 + \eta)} C \qquad (1)$$

where ℓ is the angular momentum of the transferred particle (a) relative to the core (A), $\eta = Z_a Z_A e^2 \mu_{aA}/k_{aA}$ the Sommerfeld parameter, $k_{aA} = \sqrt{2\mu_{aA}\epsilon}$ the wave number, μ_{aA} the reduced mass, ϵ the binding energy and Γ the gamma function. C is the usual ANC:

$$C^2 = S \left(\frac{R\, u(R)}{W_{-\eta,\ell+1/2}(2k_{aA}R)} \right)^2 \qquad (2)$$

for large values of R where the ANC reaches its asymptotic value and W is the Whittaker function of the second kind.

For the sake of brevity we shall refer to the square of the Coulomb renormalised ANC simply as “the ANC” from now on.

The $^{13}C(\alpha,n)^{16}O$ reaction is astrophysically important since it is considered to be the main source of neutrons for the s process in AGB stars.

However, the situation is complicated by the presence of a near-threshold $1/2^+$ resonance in ^{17}O at an excitation energy of 6.356 MeV. There is thus a considerable literature concerning the determination of the $\alpha + {}^{13}C$ ANC for this state, required to calculate its contribution to the reaction rate.

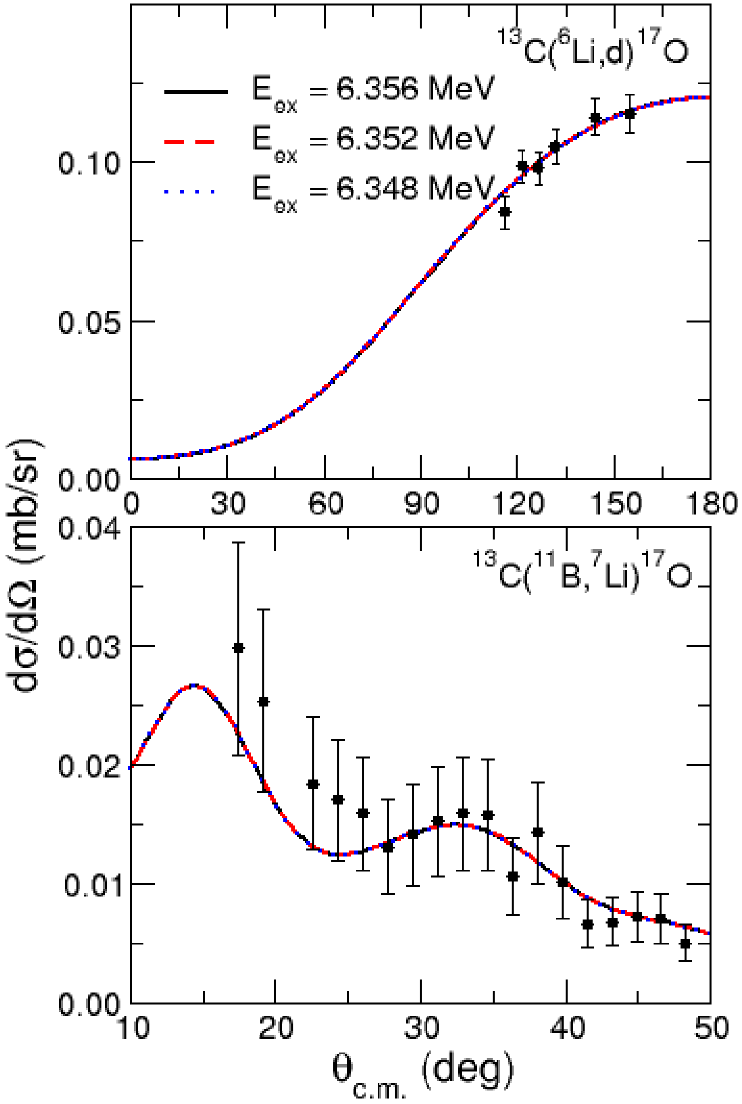
The excitation energy is given as 6.356 MeV with an uncertainty of ± 8 keV. Since the nominal energy is only ~3 keV below the α emission threshold how does this impact the ANC?

We consider two data sets typical of those used to extract the ANC for the state of interest, for the ^{13}C(^{6}Li,*d*)^{17}O reaction at a sub-barrier energy [M. Avila *et al.*, Phys. Rev. C **91**, 048801 (2015)] and the ^{13}C(^{11}B,^{7}Li)^{17}O reaction at 45 MeV [S. Yu. Mezhevych *et al.*, Phys. Rev. C **95**, 034607 (2017)].

The calculations assume that DWBA is an adequate reaction model for these cases and the optical potentials, projectile overlaps and other details are as in the original publications.

We investigate just the influence of varying the excitation energy from the “nominal” value of 6.356 MeV to 6.348 MeV.

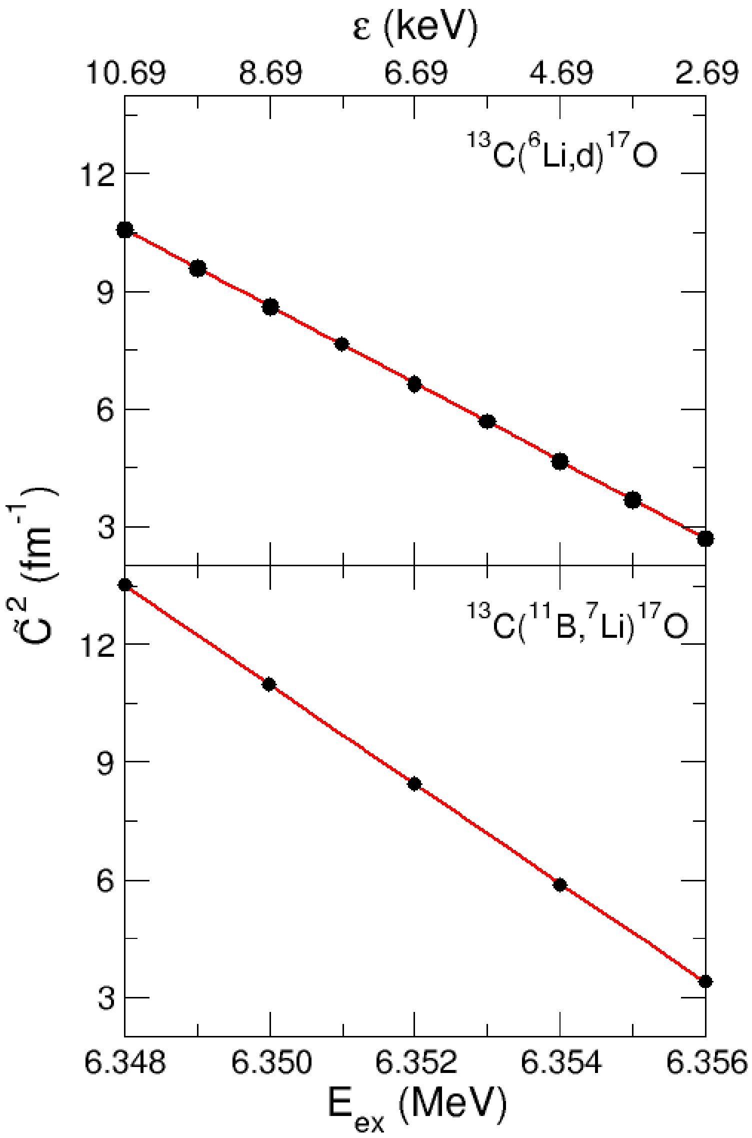
To avoid subjective judgements as far as possible the calculations were normalised to the data by minimising χ^2 using SFRESCO.



For a given R_0, a_0 ($R_0 = 1.50 \times 13^{1/3}$ fm, $a_0 = 0.65$ fm in the figure, giving an rms charge radius of 3.06 fm for this state in the α + ^{13}C cluster model) the shape and normalisation of the angular distributions is not affected by the change in *ε*.

However, *k* changes significantly, as does *η*. Therefore, the ANC varies as a function of *ε* (since the wave function *u(r)* remains almost unaffected).

How important is this variation over the stated uncertainty in *ε* of ±8 keV?



The points denote the square of the Coulomb renormalised ANC obtained at each value of ε. The lines are straight line regression fits.

In varying ε by 8 keV the ANC changes by a factor of 4. This result is independent of the choice of r_0 (there is some slight variation in the slope for the ^{11}B + ^{13}C system due to the nature of the data but this is not significant).

Remember each point represents the ANC extracted from an *identical* angular distribution.

In conclusion

We have investigated the influence of the stated uncertainty in the excitation energy of the 6.356 MeV $1/2^+$ state in ^{17}O on the ANC for the corresponding $<^{17}\mathrm{O}|^{13}\mathrm{C} + \alpha>$ overlap.

We find a linear variation in the ANC as a function of ε; **the ANC increases by a factor of 4 when ε is reduced by 8 keV** (we have not investigated the effect of increasing ε since this would render the state unbound with respect to α emission).

This is an intrinsic limit which appears to be independent of the reaction employed. It cannot be reduced unless or until the excitation energy of the state is measured to better precision.

The 6.356 MeV $1/2^+$ state in ^{17}O is a particular case and may be unique in this sensitivity. However, it is a possibility that should be investigated for other near-threshold states.

Work done in collaboration with:

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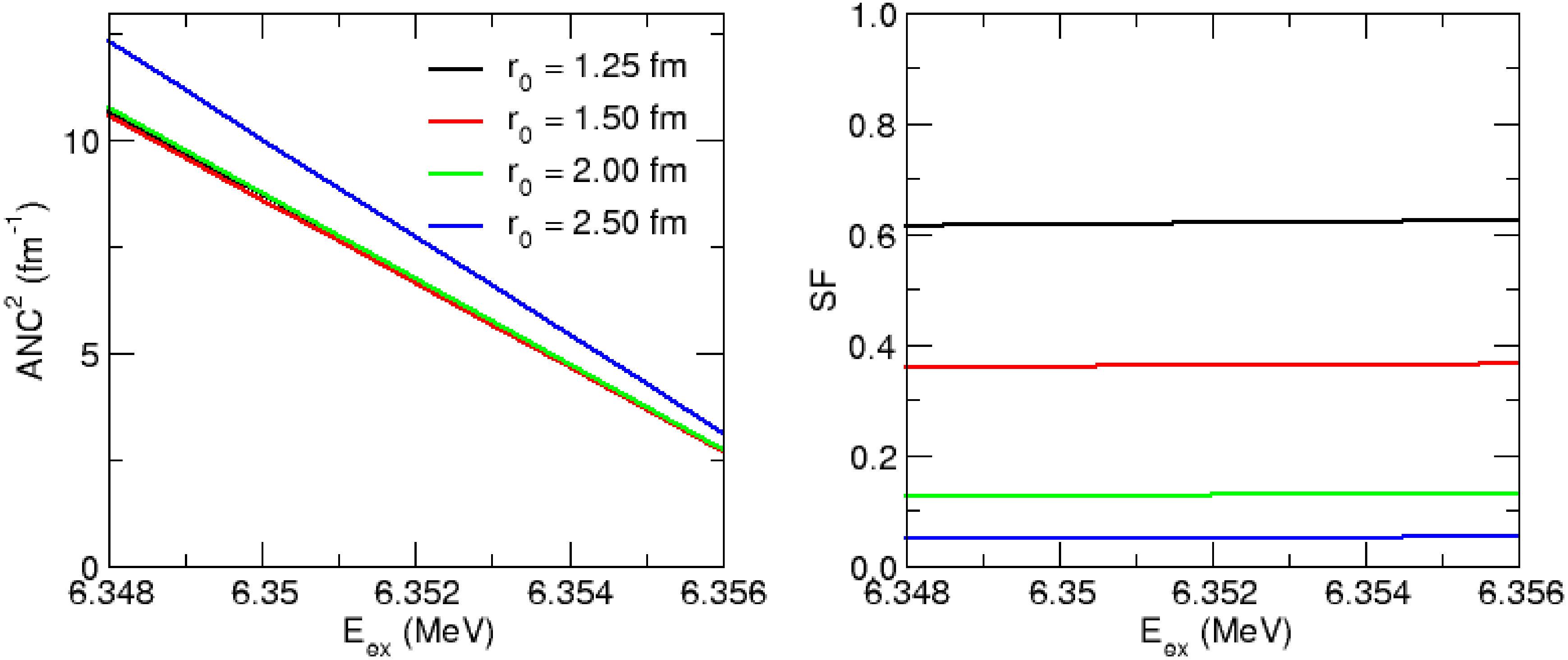
Published as letter to the editor, Eur. Phys. J. A **54**, 71 (2018).



r.m.s. charge radii are: 2.97 fm, 3.06 fm, 3.25 fm and 3.46 fm for r_0 = 1.25 fm, 1.50 fm, 2.00 fm and 2.50 fm respectively; ground state r.m.s. charge radius is 2.662 fm (experimental)