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Proposal to the ISOLDE-Neutron Time of flight Committee

EXPLORING THE DIPOLE POLARIZABILITY OF ^{11}Li AT REX-ISOLDE

Letter of clarification to P134 (INTC 2000-042), August 2001

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Abstract

We present a clarification to some questions raised by the INTC to our proposal to study dipole polarizability of ^{11}Li by measuring elastic scattering on ^{208}Pb. Dipole polarizability refers to the effect of the excitation to negative parity states through the electric dipole interaction. We discuss the explicit form of the integral of the $B(E1)$ that will be obtained from our experiment, as well as the accuracy with which it should be obtained, for the experimental conditions proposed. We also illustrate the qualitative importance of nuclear effects in the analysis of the data.

1 Introduction

In this addendum we follow the recommendation of the INTC, and we investigate the statistical and systematic uncertainties of the B(E1) distribution that can be extracted from the cross section measurements. However, we would like to emphasise that the measurement of the B(E1) distribution of ^{11}Li is just one of the objectives of the experiment. We want to observe a new phenomenon in nuclear collisions, which is the strong reduction of sub-barrier elastic cross sections, we plan to learn about the reaction mechanisms for halo nuclei below the Coulomb barrier, and we expect to obtain information about the B(E1) distribution of the projectile at energies close to the break-up threshold. Let us recall the objectives of the proposal *P134 (INTC 2000-042): Exploring the dipole polarizability of ^{11}Li at REX-ISOLDE*:

a) To observe that, in contrast to what happens for all normal nuclei, for which the elastic cross sections at energies below the Coulomb barrier is accurately given by the Rutherford formula, ^{11}Li elastic cross sections are considerably smaller. This is due to its large polarizability.

b) To quantify the reduction of the elastic cross sections, and thus obtain information, complementary to the distribution measured by Zinser et al, that allows to determine more accurately the B(E1) distribution at energies close to the break-up threshold.

c) To see whether the dipole dynamic polarization potential is sufficient to describe the elastic differential cross section distribution, or, on the contrary, a more accurate treatment of the reaction mechanism is required.

For the calculations in this addendum, we will make use of the estimates of beam intensity used in the proposal: 125 ^{11}Li particles per second on the ^{208}Pb target, an array of annular detectors covering scattering angles from 5° to 45° (EF), 50° to 70° (MF), 110° to 130° (MB) and 135° to 175° (EB), which lead to the request of 22 shifts of ^{11}Li beam time.

2 Statistical uncertainties about the B(E1) distribution obtained from the experiment

Dipole polarizability produces a reduction in the elastic differential cross sections at backward angles. This reduction depends not only on the $B(E1)$ strength, but also on the energy of the break-up states. Thus, the same reduction in the elastic differential cross section could be caused by a strong dipole coupling to break-up states with certain excitation energies, or with a weaker coupling to break-up states with lower excitation energies. An analysis of the dipole dynamic polarization potential shows that the most important part of the energy dependence comes from a factor $\exp(-(\pi+2)\xi)$, where ξ is the Coulomb adiabaticity parameter, which is proportional to the excitation energy e_x. From that argument, we deduce that the effect of the coupling to break-up states on the elastic cross sections of a $B(E1)$ distribution is determined by the value of the weighted integral $B_w(E1)$ given by:

$$B_w(E1) = \int_b^\infty de_x \frac{dB(E1, e_x)}{de_x} \exp(-(\pi + 2)\xi(e_x)) \tag{1}$$

For our case, in which the bombarding energy is 2.2 MeV per nucleon, the exponential factor is $\exp(-2.93\, e_x)$, where e_x is expressed in MeV. The break-up energy is $b = 0.295$ MeV.

The present knowledge of the $B(E1)$ distribution for ^{11}Li comes from the measurements by Zinser et al. (Nucl. Phys. **A619** (1997) 151). There, the $B(E1)$ distribution is parameterized in terms of two gaussians, each determined by three parameters (energy, width and strength) whose central values and uncertainties are given in table 5 of the above mentioned paper. We claim that a measurement of the elastic scattering of ^{11}Li on ^{208}Pb at 2.2 MeV per nucleon can provide additional information on the $B(E1)$ distribution of ^{11}Li. In particular, it will provide a more precise value of the weighted integral $B_w(E1)$. To justify this claim, we have taken 15 different $B(E1)$ distributions for ^{11}Li corresponding to a two-gaussian parameterization, whose parameters are chosen randomly within the ranges allowed by Zinser experiment. We required that all the distributions went to zero at the break-up energy. We obtained the dynamic polarization potentials for each of these distributions, and made the elastic scattering calculations. We have found that different $B(E1)$ distributions which have a similar $B_w(E1)$ value produce an equivalent effect on cross sections. Thus, we see that, although the complete $B(E1)$ distribution is required in principle to obtain the polarization potential, only the integrated value $B_w(E1)$ has a significant influence on the elastic cross section.

In figure 1 we represent the elastic cross sections, for different scattering angles, as a function of the value of $B_w(E1)$ for the 15 different $B(E1)$ distributions considered. We have found that there is a clear linear relation

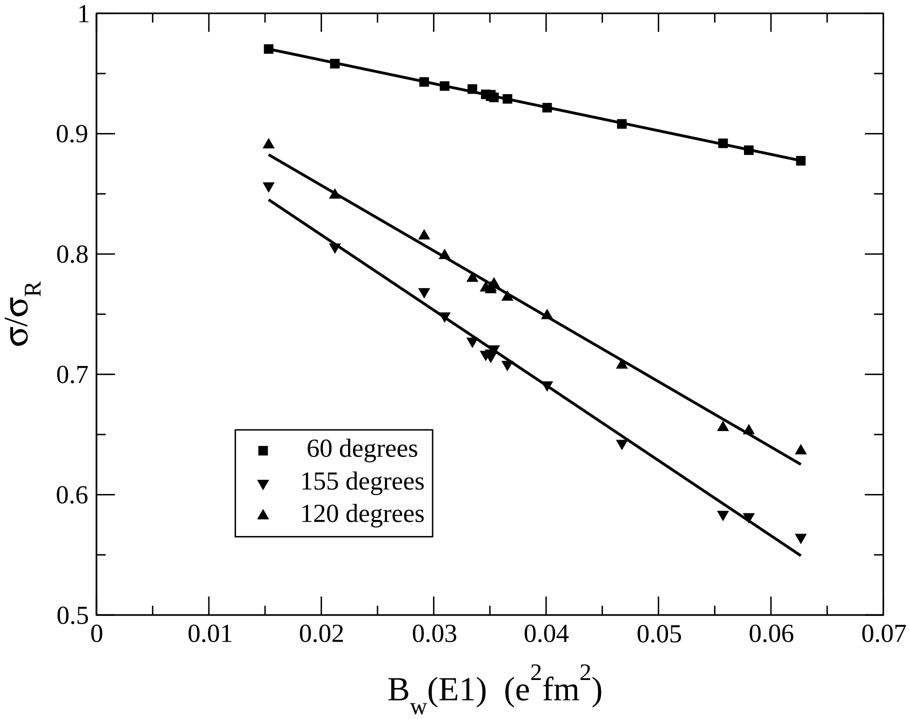

Figure 1: Relationship between the elastic cross sections for ^{11}Li + ^{208}Pb at 2.2 MeV/A and $B_w(E1)$ for 15 random B(E1) distributions compatible with previous measurements

between the elastic cross sections and the value of $B_w(E1)$, which is more pronounced for larger scattering angles.

The linear fits in Figure 1 can be used to extract structure information on ^{11}Li from an elastic differential cross section measurement. Cross section measurements give points in the y-axis of the figure, which, for each scattering angle, correspond to the values of $B_w(E1)$ in the x-axis. The cross sections measured at different angles should give the same value of $B_w(E1)$, provided that the reaction mechanism is properly described by the dipole polarization potential.

The slope of the linear fits also allows to evaluate the errors in the magnitude $B_w(E1)$ from the errors of the differential cross sections, as measured in our detector set-up over the 22 shifts. For the end-backward detector, whose average scattering angle is about 155°, we estimate an error of 0.07 in $\sigma/\sigma(R)$ which leads to an error of $0.011 e^2 fm^2$ in $B_w(E1)$. For the middle-backward detector, the estimated error of $\sigma/\sigma(R)$ is 0.056, leading to an error of $0.010 e^2 fm^2$ in $B_w(E1)$. For the middle-forward detector, the estimated error of $\sigma/\sigma(R)$ is 0.020, leading to an error in $B_w(E1)$ is $0.010 e^2 fm^2$. It should be noticed that, as one considers detectors placed at smaller scattering angles, the number of counts increases, leading to smaller errors in the cross sections, but the slope of the linear fit is smaller, leading to similar errors in $B_w(E1)$ of about $0.010 e^2 fm^2$ for all the detectors. These errors should be compared with the average value of all the calculations, which is $B_w(E1) = 0.038 e^2 fm^2$.

Thus, we conclude that our experiment will be able to measure the integral $B_w(E1)$, which depends on the values of the B(E1) distributions at energies very close to the break-up threshold, with a precision of 25%. The three detectors of our set-up would give information of $B_w(E1)$ with a similar precision. However, as we will see in the next section, the information of the middle-forward MF detector will be unaffected by uncertainties in the nuclear forces, and therefore it provides a more accurate value.

3 Effect of nuclear forces

The interplay of nuclear forces and Coulomb forces in the collisions of halo nuclei is a difficult problem to solve from the theoretical point of view.

At high scattering energies, the dynamics of the collision can be approximated in terms of an eikonal approach, which is formally equivalent to consider straight line trajectories. For these trajectories, one can explicitly take into account the effect of Coulomb and nuclear form factors, and thus break-up cross sections can be calculated and compared with experiment. Thus, to extract electric magnitudes such as the B(E1) distribution from high energy data it is required to subtract in some way the contribution of nuclear forces.

At low scattering energies, below the Coulomb barrier, one might consider that nuclear effects could be unimportant and therefore electro-magnetic properties from the colliding nuclei could be obtained from the cross sections, without nuclear interference. However, for the collision that we want to investigate, ^{11}Li+^{208}Pb at 2.2 MeV per nucleon, the cross sections at backward angles show some sensitivity to the nuclear potential. In Figure 2 we show the results of our calculations, where we have taken a nuclear optical potential for ^{11}Li+^{208}Pb which is taken to have the same parameters as the one for ^{7}Li+^{208}Pb. If we increase the diffuseness of the optical potential from 0.65 fm to 1.00 fm, the resulting effect is that the elastic cross section at backward angles decreases significantly. Thus, the reduction of the elastic cross section at backward angles is not only a result of dipole polarizability, but also of a possible long-range nuclear absorption. However, at the forward scattering angles around 60°, which correspond to the Middle-Forward detector of our array, the effect of nuclear forces is negligible. This can be understood in classical terms by looking at the turning point of the classical trajectories corresponding to the different angles. For $\theta = 180°$, the distance of closest approach is 15.5 fm, which is not too much larger than the typical estimate of the strong absorption radius, which is, for normal nuclei, $R_{sa} = 1.45(A_1^{1/3} + A_2^{1/3}) = 11.8$ fm, although it could be larger for halo nuclei. For $\theta = 150°$, the distance of closest approach is 15.8 fm. For $\theta = 120°$, it is 16.7 fm. So, it is not surprising that one finds sizeable nuclear effects for those angles, when the diffuseness of the nuclear potential is relatively large. However, for $\theta = 60°$, the distance of closest approach is 23.3 fm. It is unlikely that any nuclear effect will play a significant role at that distance.

Thus, we see that the information of the MF detector would be the least affected by the nuclear potential, and so it should give a clean signal of the $B_w(E1)$ magnitude. The cross sections measured in the other detectors MB and EB will depend on Coulomb dipole polarizability, as well as on nuclear effects, if the relevant optical potentials are very diffuse. Note that it is by no means clear that the optical potential is an adequate concept to describe the scattering of nuclei so weakly bound at energies below the barrier. We consider that the experiment that we propose, apart from increasing our knowledge of the $B(E1)$ distribution of ^{11}Li, will give us information about the nuclear effects, and thus it will motivate further theoretical work about the role of nuclear forces in collisions produced by weakly bound systems at energies below the Coulomb barrier.

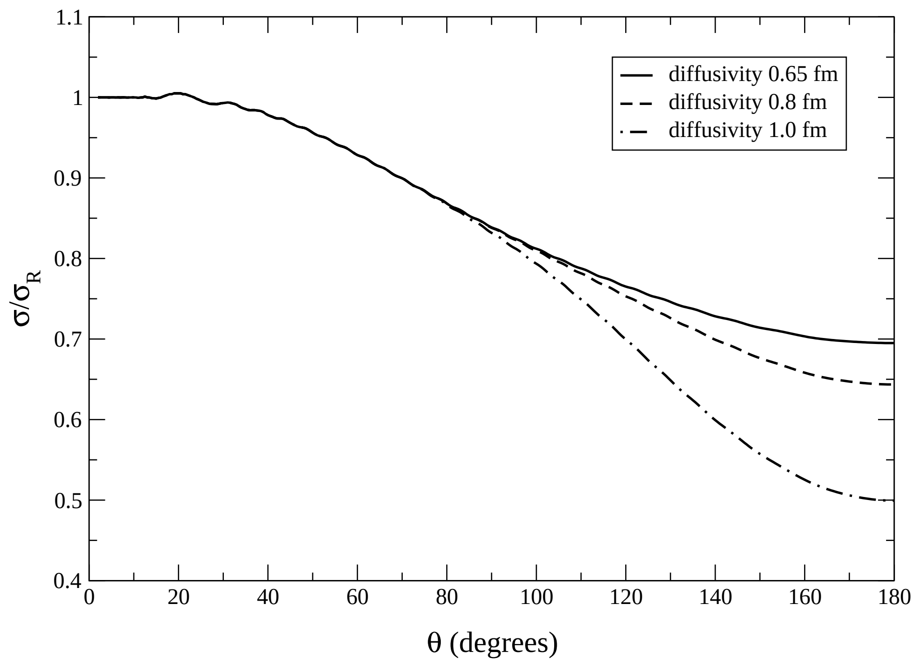

Figure 2: Effect of the nuclear diffuseness on the elastic differential cross section of ^{11}Li on ^{208}Pb at 2.2 MeV/A

4 Concluding remarks

In this addendum we have analyzed the effect of statistical and systematic uncertainties in the values of the $B(E1)$ distribution of ^{11}Li that can be extracted from the elastic scattering experiment. Assuming the present estimates of beam intensity, we expect to obtain from the values of the elastic differential cross sections an integrated value of the $B(E1)$ distribution for energies close to the break-up threshold with a precision of 25%. It should be noticed that the present experimental information on the $B(E1)$ distribution is both inaccurate and imprecise at energies close to the break-up threshold. It is inaccurate because it relies on a gaussian fit of the energy dependence, which is reliable in the vicinity of the maximum values, but inadequate for energies close to the break-up threshold. It is imprecise because the uncertainties on the $B(E1)$ values close to the break-up threshold coming from error propagation in the gaussian fit of Zinser et al is of 50%. Thus, our proposed experiment will provide a new piece of experimental information for the $B(E1)$ distribution of ^{11}Li, which is complementary to the present data.

We expect that the effect of nuclear forces will be small for scattering angles around 60 degrees, for which the effects of electric dipole polarizability are still sizeable, and hence the extraction of the integrated $B_w(E1)$ from the cross sections measured in the MF detectors will be rather free from uncertainties in the nuclear effects. The cross sections at backward angles measured in the MB and EB detectors will be affected by dipole polarizability, and also, to a smaller degree, by nuclear forces. So, using the Coulomb dipole polarization potential, which is determined from the information of $B_w(E1)$ obtained from the MF detector, as well as a suitably parameterized nuclear potential, we can fit the cross sections measured in the MB and EB detectors. That will allow us to obtain information not only on $B_w(E1)$ but also on the long range part of the nuclear optical potential.

Our proposal shows that even with a very weak beam of ^{11}Li, of just 125 particles per second, one can extract interesting physics by measuring elastic cross sections. Nevertheless, we are aware that there are still technical difficulties to get such beam in REX-ISOLDE. We hope that our proposal will motivate the necessary developments in REX-ISOLDE, and we in the collaboration are willing to contribute to these efforts.