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

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Abstract

Dipole polarizability refers to the effect of the excitation to negative parity states through the electric dipole interaction. In nuclear physics dipole polarizability has not yet played a major role. For nuclei close to the drip lines where the separation energies of neutrons (or protons) are small, a substantial part of the dipole strength function occurs at low excitation energies. We here propose to investigate this effect by measuring elastic scattering at energies close to the Coulomb barrier. REX-ISOLDE together with the new improved yields of ^{11}Li provides the ideal setting for this experiment. We ask for a total of 24 shifts with proton beam plus 3 shifts of stable beam from a Ta-foil target.

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1 Introduction

Halo nuclei are composed of a core nucleus and one or two almost unbound neutrons. Due to the loosely bound structure, they should be easily polarizable. Thus, in the presence of a strong electric field, the nucleus will be distorted, so that, with respect to the centre of mass of the nucleus, the halo neutrons will move opposite to the electric field, while the positively charged core will move in the direction of the field.

The B(E1) distribution is a measurement of the importance of polarizability. Large B(E1) values at low excitation energies (close to the break-up threshold) indicate that the nucleus is easily polarizable. In terms of the ground state wavefunction, large B(E1) values at energies close to the break-up threshold indicate a large probability that the halo neutrons are in the extreme asymptotic tail [1, 2].

The phenomenon of dipole polarizability should strongly affect the elastic scattering of halo nuclei on heavy targets, even at energies below the Coulomb barrier, where the nuclear force should not be of importance [3, 4]. Two effects are relevant: First, Coulomb break-up will reduce the elastic cross section. Second, the distortion of the wavefunction generated by the displacement of the charged core with respect to the centre of mass of the nucleus will reduce the Coulomb repulsion, and with it the elastic cross sections.

A simple way of describing the effect of polarizability is by means of a dipole dynamic polarization potential (DDPP). It has an attractive real part, that describes the reduction of the Coulomb repulsion, and an absorptive imaginary part, which describes the reduction of the elastic cross section due to Coulomb break-up. The DDPP can be obtained using a semiclassical derivation [5], and it is such that, given the B(E1) distribution, the projectile and target and the scattering energy, it is completely determined by an analytic expression. When the DDPP, along with the standard Coulomb and nuclear potentials, is used in an optical model calculation, the results of the elastic cross sections are very close to those of a full coupled channels calculations explicitly including the dipole Coulomb excitation [6]. The DDPP has been used to describe experimental data on scattering of d+^{208}Pb [7] and ^{7}Li+^{208}Pb [8] at energies around and below the Coulomb barrier. It was found that the inclusion of the DDP-potential in the calculations done using standard Coulomb and nuclear potentials accounts for the small reduction observed in the experimental cross sections.

Recently, we have made use of the experimental values of the B(E1) distribution of ^{11}Li, measured by Zinser et al [9], to calculate the effect of dipole polarizability on the elastic scattering of ^{11}Li on ^{208}Pb at 24 MeV (2.2 MeV/u), which is well below the Coulomb barrier [10]. The parameters that describe the B(E1) distribution [9] have important uncertainties. A proper treatment of error propagation gives rise to three distributions of B(E1) [10] corresponding to the denomination of high, medium and low polarizability used in figure 1 and table 1. The medium polarizability distribution is the most probable, but any distribution contained within the high and low polarizability ones is consistent with the experimental data at one sigma level. For this distribution we predict a 30% reduction around 150 degrees, 25% around 120 degrees and 8% reduction around 60 degrees. Thus, we conclude that a measurement of this reaction is of interest, as it will allow to determine the values of the DDPP, and thus to reduce the uncertainties in the B(E1) distribution of ^{11}Li.

1.1 Systematics of Li isotopes

It should be stressed that the strong effect of dipole polarizability in ^{11}Li scattering is a consequence of the low break-up threshold. Other Li isotopes, such as ^{6}Li, ^{7}Li, ^{8}Li

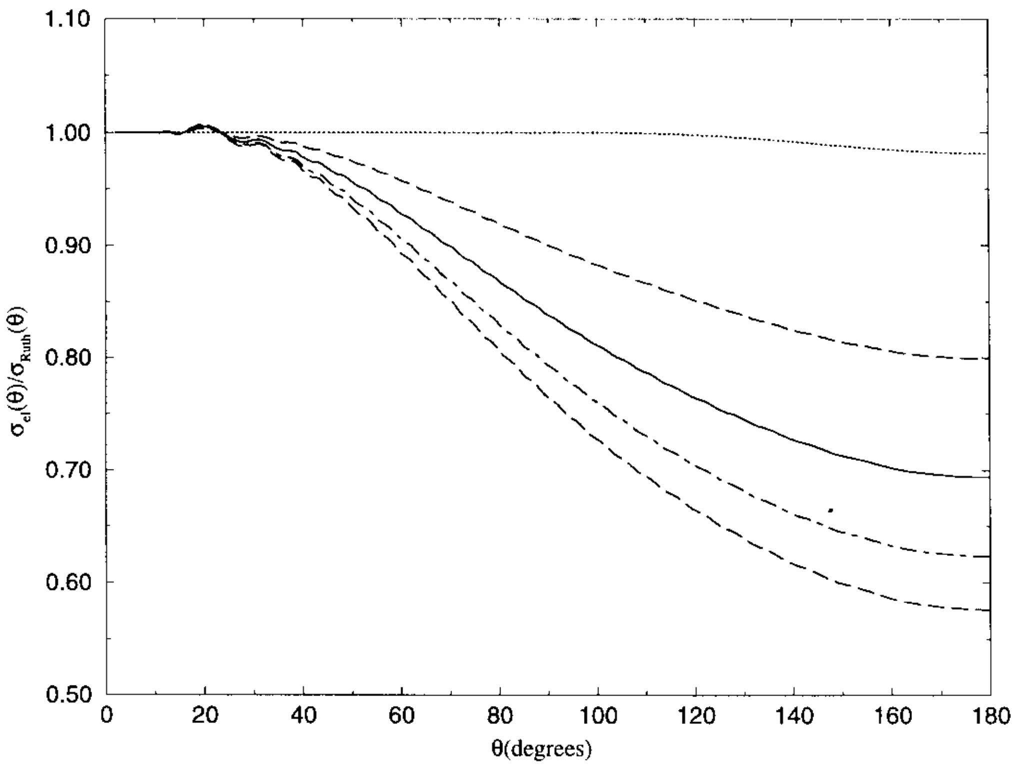

Figure 1: Elastic cross section of ^{11}Li on ^{208}Pb divided by the Rutherford cross section at 24 MeV. The dotted line ignores dipole polarizability effects. The effect of dipole polarizability are obtained using three B(E1) distributions consistent with the measurement of Zinser et al: high polarizability (lower dashed line), medium polarizability (full line), and low polarizability (upper dashed line). The dot-dashed line corresponds to a theoretical calculation of the B(E1) distribution [10].

and ^{9}Li, should present only minor diferences to the Rutherford cross section at energies below the barrier. In fact, the scattering of ^{6}Li and ^{7}Li on ^{208}Pb at energies around and below the barrier has been studied in detail at Daresbury Laboratory using unpolarized [11] and polarized beams [12]. The effect of dipole polarizability for the elastic scattering of ^{7}Li on ^{208}Pb at 27 MeV was recently investigated [8], and we found that the reduction on the elastic cross sections is about 1%, much smaller than for ^{11}Li.

A systematic study of the cross sections of Li isotopes could be illuminating. At energies well below the barrier (2.2 MeV/u), the scattering cross sections for ^{6}Li, ^{7}Li, ^{8}Li and ^{9}Li should be accurately described by the Rutherford formula, while that of ^{11}Li should display an important reduction in the cross sections at backward angles.

1.2 Inclusive break-up cross sections of ^{11}Li

The reduction in the elastic cross sections of ^{11}Li at backward angles is due to the combined effect of the real, attractive part of the polarization potential, which is caused by the reduction of the Coulomb repulsion, and the imaginary, absorptive potential, which is due to the effect of the Coulomb break-up. This latter effect can be investigated by looking at the fragments of ^{11}Li, in particular to the ^{9}Li fragments. This fragment can be differentiated from the ^{11}Li nuclei just by taking into account that they will have approximately 9/11 of the energy of ^{11}Li. Thus, the ratio of ^{9}Li to ^{11}Li events will be a complementary measurement of the effect of dipole polarizability, which depends on the imaginary part of

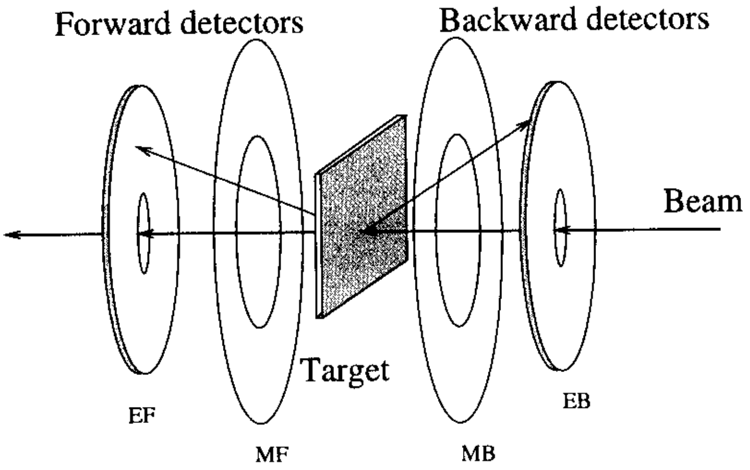

Figure 2: Experimental detector set-up

the polarization potential, while the reduction in the elastic cross sections of ^{11}Li depends both on the real and imaginary parts of the polarization potentials.

2 Proposed experiment

The proposed experiment consists in measuring the elastic differential cross section of ^{11}Li on ^{208}Pb at 2.2 MeV/u laboratory energy at the REX-ISOLDE facility. This will be complemented with the detection of the ^{9}Li fragments coming from break-up, and from a systematic study of the scattering of the other isotopes ^{6,7,8,9}Li at the same energy per nucleon. We expect to detect and quantify the reduction of the differential cross sections at backward angles for ^{11}Li, compared to the Rutherford cross sections expected for the other lithium isotopes.

The main limiting factor for this experiment is the intensity of the ^{11}Li beam. We will make the conservative assumption that we can achieve an intensity of 125 ^{11}Li per second interacting with the ^{208}Pb target. This estimate assumes a production rate of 10.000 pps, a transmission of 10% through REX-ISOLDE with a cost of 3 half lives due to cooling, breeding, and transport of the ^{11}Li nuclei. To compensate for this very small value, we require to have the solid angle of the detector as large as possible, and the target as thick as possible. We propose to use a detector setup as shown in figure 2. It contains four annular detectors, covering all the azimuthal angles and a range of scattering angles from $\theta=5^o$ to 45^o for the end forward detector (EF), from 50^o to 70^o (MF), from 110^o to 130^o (MB) and from $\theta=135^o$ to 175^o for the end backward detector (EB). Uncertainties in the solid angles of the detectors could be avoided determining in the same way the ratio of forward to backward counts for an stable isotope such as ^{6}Li. Further, as the set-up is symmetric, systematic differences in detectors and electronics can be tested by rotating the full detector set-up 180^o around the target, and again determining the above mentioned ratio.

Assuming that the incident beam is pure ^{11}Li, after the collision with the target one will get elastically scattered ^{11}Li, as well as break-up fragments. Of these, the most important fragment will be ^{9}Li coming from the removal of the halo neutrons. It is very important that ^{11}Li events are separated from the fragments, mainly the ^{9}Li events. This can be done considering that, while the backward scattered ^{11}Li would have an energy of about 20 MeV, the ^{9}Li, having lost the neutrons, would have an energy of about 17 MeV. The separation of ^{9}Li and ^{11}Li events puts a limit on the target thickness. The stopping

	N(EF)/h	N(MF)/h	N(MB)/h	N(EB)/h	N(EB)×22 shifts
Rutherford	2 565	12.65	1.35	0.839	148
Low Pol.	2 565	12.14	1.14	0.671	118
Medium Pol.	2 565	11.64	1.01	0.587	103
High Pol.	2 565	11.22	0.886	0.503	87

Table 1: Number of counts expected per hour in the different detectors of our experimental setup, as a function of the various values assumed for the dipole polarizability.

power of a target of ^{208}Pb for a ^{11}Li beam at 24 MeV is 0.4 MeV per mg/cm^2. Taking into account that part of the backward scattered particles will cross the target twice, in order to maintain the energy separation of ^{11}Li and ^{9}Li, this thickness should not be larger than 2.5 mg/cm^2. We plan to use 2 mg/cm^2 in our set-up. With this value, ^{9}Li events can be separated from ^{11}Li events in all the detectors except in the MF detector.

The expected count rate for the different detectors, assuming different values of the dipole polarizability, and using a target thickness of 2 mg/cm^2 of Pb, is shown in table 1.

The number of break-up events gives complementary information to the elastic cross sections, in order to determine the break-up mechanism. A very rough estimate is to assume that the break-up events observed in each detector will just be the difference of Rutherford events to the actual elastic events observed. The data presented in table 1 shows that the break-up cross section can be measured in this experiment within an accuracy of 10%.

It is useful to define ratios which are independent from geometric factors, and which only depend on the polarizability. If we scatter ^{6}Li from ^{208}Pb below the barrier, we expect to find pure Rutherford scattering. For the Li isotopes, we can define the following ratios, where D is the detector (MF, MB, EB), and A represents the mass of each measured isotope $A = 7, 8, 9, 11$:

$$R(D, A) = \frac{N(D, A)N(EF, 6)}{N(EF, A)N(D, 6)}$$

Note that in this ratio, any uncertainty associated to the solid angle, the efficiency of the detector or the intensity of the beams disappears. For the isotopes ^{7,8,9}Li, the value of this ratio should be 1, showing that the effect of dipole polarizability is small, at all scattering angles. However, for ^{11}Li, the ratio should be significantly smaller than one, and thus one will see a systematic change in the behavior of ^{11}Li with respect to the rest of the isotopes, which is yet another manifestation of the halo structure of this nucleus.

3 Goals of the Experiment

We will consider an experimental situation as previously described. We expect to achieve the following objectives:

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

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. This can be achieved by comparing the number of observed elastic events with the predictions in table 1.

c) To see whether the dipole dynamic polarization potential (DDPP) is sufficient to describe the elastic differential cross section distribution, or, on the contrary, a more accurate treatment of the reaction mechanism is required. It should be considered that, even if the nuclear potential by itself is unimportant at energies so much below the barrier, Coulomb-nuclear interference effects may play a significant role. We expect that the effect of these Coulomb-nuclear interference terms will lead to a further reduction of the elastic cross sections at backward angles. If the ratios of the number of counts in the EB detector to the MF or MB detectors is not consistent with the patterns shown in table 1, it would be an indication of nuclear-Coulomb interference playing a role.

4 Summary and Beam-time request

We propose to study the effect of dipole polarizability by the elastic scattering of ^{11}Li on ^{208}Pb at 2.2 MeV/u using the REX ISOLDE installation. Based on an expected beam intensity of 125 ions/s of ^{11}Li interacting in our target, the number of shifts requested has been calculated to get 100 events recorded in the end backward detector (EB) assuming the polarizability expected from the B(E1) distribution of [9]. In this way one would be able to determine the predicted effect of dipole polarizability of ^{11}Li within a statistical accuracies of 10%. We also need to study the other Li-isotopes, therefore we request:

- A 2.2 MeV/u beam of ^{11}Li for **22** shifts.
- A 2.2 MeV/u beam of ^{8,9}Li for **1** shift.
- A 2.2 MeV/u beam of ^{6,7}Li for **1** shift.

We also request 3 shifts of stable beam to align and adjust our experimental setup at the end of REX-ISOLDE. The target to be used is a Ta-foil target optimized for high lithium yield and fast release time. We also request the use of the ISOLDE Data acquisition System.

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