

# Measurement of electric polarizabilities of light nucleus(nucleons)<sup>\*</sup>

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**Abstract** The measurement of the electromagnetic polarizabilities have been given extensive attention, which is also a fresh field of the experimental nuclear physics. Now we will use the method - the light nucleus scattered by the heavy nucleus at energies below the Coulomb barrier to precisely and systematically measure the polarizabilities of the light nucleus. We hope we can solve the inconsistency among the results of the <sup>3</sup>He polarizabilities and extract the <sup>4</sup>He polarizabilities by our experiment. It is useful to mention that our experiment now is a supplement to the future experiment on SLEGS.

**Key words** electric polarizabilities, HI-13 tandem accelerator, coulomb barrier

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## 1 Introduction

The electromagnetic polarizabilities belong to the fundamental structure parameters of the nucleon. It can help people to understand the structure of the nucleon from the underlying theory of string interaction in terms of quark and gluon degrees of freedom. Precision measurement of electric polarizabilities of light nucleus and nucleon is a fundamental and challenging task in physics. At the same time precision measurement of electric polarizabilities can check some theoretical models, including effective field theories, lattice QCD and Generalized Parton Distributions (GPDs). Electromagnetic polarizabilities describe the medium's or particles' (molecule, nucleus, nucleons, etc) ability of being polarized in electromagnetic field. The electric polarizability is defined as

$d = \alpha \cdot E$ ,  $d$  is the dipole moment,  $E$  is electrical field strength and  $\alpha$  is the electric polarizability<sup>[1]</sup>. Magnetic polarizability has the similar definition. The measurement of the electromagnetic polarizabilities have been given extensive attention, which is also a fresh field of the experimental nuclear physics. The theoretical study of the electromagnetic polarizabilities began at the 60's last century. However no experimental results of that has been made until the 70's. From then on, physical scientists accumulated a lot of data (shown in Fig. 1). There are two different methods to measure the electromagnetic polarizabilities: Compton scattering and scattering of low energy light nuclei in the electromagnetic fields of heavy nuclei. Now the most accurate data in this field carried by Mainz laboratory<sup>[2]</sup>. Comparing with proton, we know little about neutron, thanks to the absent of

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free neutron target<sup>[3]</sup>. About deuteron's electromagnetic polarizabilities, experiment results is larger than theoretical data<sup>[4]</sup>. About <sup>3</sup>He's electromagnetic polarizabilities, experimental results has large difference<sup>[1, 5]</sup>.

In this work, we will cooperate with China Institute of Atomic Energy to measure light nucleus' electromagnetic polarizabilities by scattering of low energy light nucleus in the electromagnetic fields of heavy nucleus. Ion beam which we will use is light nucleus such as P, D, T, <sup>3,4</sup>He, <sup>6,7</sup>Li or <sup>7,9</sup>Be and target is heavy nucleus such as <sup>208</sup>Pb, <sup>56</sup>Ni, <sup>40</sup>Ca, <sup>48</sup>Ca. We can get the electric polarizabilities by using the elastic

cross section data. It is expected to get <sup>3</sup>He's electric polarizabilities to check the former results and to get <sup>4</sup>He's electric polarizabilities at first time. In addition we try to measure the deuteron's electric polarizabilities by quasi elastic scattering, which will help us to measure neutron's electric polarizabilities by quasi elastic scattering in the future. It is useful to mention that the future Shanghai Laser Electron Gamma Source (SLEGS) can provide a great opportunity to carry an experiment of the measurement of the polarizabilities by Compton scattering. So our experiment now is a supplement to the future experiment on SLEGS.

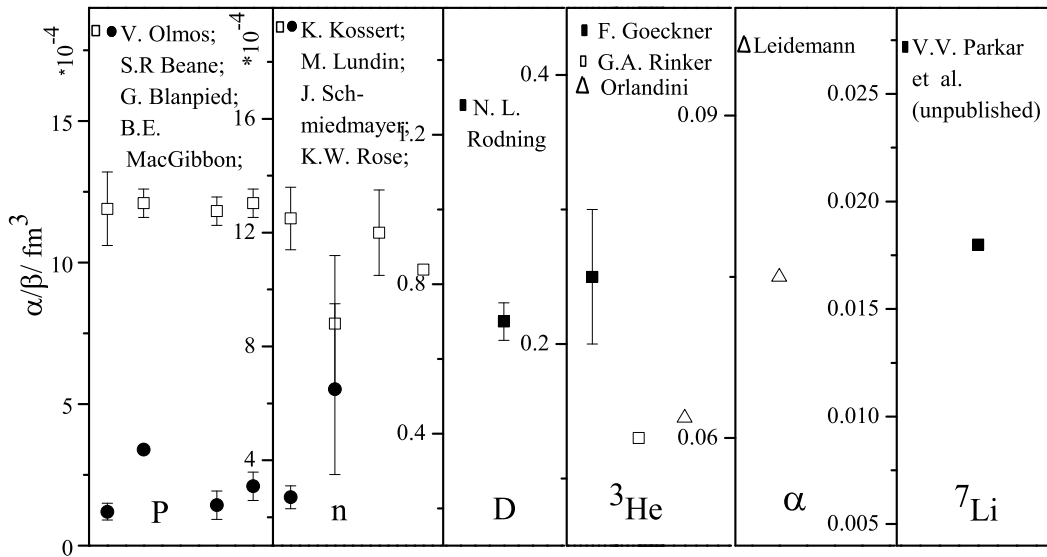


Fig. 1. • Magnetic polarizability; □ Electric polarizability (Compton Scattering); ■ Electric polarizability (elastic scattering); △ Theoretical data<sup>[6–13]</sup>.

## 2 Experiment setup

The different light nuclei beams, to collide with heavy nuclei target, can be provided by the HI-13 tandem accelerator in China Institute of Atomic Energy. We set a pair detectors symmetrically at forward setting angle  $60^\circ$  and after the impact angle  $140^\circ$ . The thickness of target is so thick that we spread target material over Carbon flake. About the particle energy points, for different target, we choose the lowest energy point at  $1/4$  Coulomb barrier and the highest energy point at bigger than the Coulomb barrier several MeV. In our experiment we intend to use the silicon surface barrier detector. It is worth mentioning that from the former experiment we know  $R(E)$

is not sensitive to scattered angle, so we do not need position-sensitive detector<sup>[3, 4]</sup>. Because of the limit of the DAQ, one detector can accept about 1000/s particles at most. We solve this problem by changing the distance between detectors and target or changing the beam intensity.

## 3 Measure $\alpha$

Light nuclei will be elastic scattered by the target when its energy lower than the Coulomb barrier. When particle in the target's Coulomb field with electric polarizabilities  $\alpha$ , it has polarize potential:

$$V_{\text{pol}} = -\frac{1}{2}\alpha \frac{Z^2 e^2}{R^4}, \quad (1)$$

where  $Z$  is the charge of the target, and  $R$  is the distance between particle and target.  $V_{\text{pot}}$  is so little that

we can see it as perturbation interaction. Therefore, if we can get the difference between the total cross section and pure Coulomb scattering cross section, we can measure this perturbation interaction. And then the electric polarizabilities  $\alpha$  can be obtained easily. But this difference is so little that we can not measure it directly. So we will measure the cross section ratio between one energy point and the referenced energy point:

$$R(E, \theta) = \frac{\sigma(E, \theta)}{\sigma(E, \theta_{\text{ref}})} \bigg/ \frac{\sigma(E_{\text{ref}}, \theta)}{\sigma(E_{\text{ref}}, \theta_{\text{ref}})}, \quad (2)$$

where  $E_{\text{ref}}$  and  $\theta_{\text{ref}}$  is referenced energy and referenced angle. To get the yield  $N$ , which is usually obtained in the experiment, the ratio can be change as:

$$R(E, \theta) = \frac{N(E, \theta)}{N(E, \theta_{\text{ref}})} \bigg/ \frac{N(E_{\text{ref}}, \theta)}{N(E_{\text{ref}}, \theta_{\text{ref}})}, \quad (3)$$

$N(E, \theta)$  is the yield when the particle energy is  $E$  and angle is  $\theta$ . In our experiment we will measure the yield at referenced point  $N(E_{\text{ref}}, \theta)$  and  $N(E, \theta_{\text{ref}})$  at the same time. Then we can get the ratio and reduce uncertainty from that.

#### 4 Cross section, yield, scattering particle energy

In order to measure the ratio  $R(E, \theta)$  exactly and then get the electric polarizabilities  $\alpha$ , we set  $\theta_{\text{ref}} = 60^\circ$  and the measure angle at  $140^\circ$ . If the particle energy is under the Coulomb barrier, the scattered cross section can be deduced by:

$$\frac{d\sigma_{\text{Ruth}}}{d\Omega} = \left(\frac{a_0}{2}\right)^2 \sin^{-4} \frac{\theta}{2}, \quad (4)$$

$a_0 = a_c/2E$ . For each particle we calculate the cross section of the particles with four targets ( $^{208}\text{Pb}$ ,  $^{56}\text{Ni}$ ,  $^{40}\text{Ca}$ ,  $^{48}\text{Ca}$ ) at two angle ( $60^\circ$  and  $140^\circ$ ). Fig. 2 shows the cross section of  $^3\text{He}$  with four targets at two angle. The yield can be written as:

$$N = \frac{d\sigma}{d\Omega} \times d_{\text{target}} \times N_A \times \Delta\Omega \times I \times \frac{1}{e}, \quad (5)$$

To  $^3\text{He}$  case study, in our experiment the density of the target is  $d_{\text{target}} = 160 \mu\text{g}/\text{cm}^2$  and the beam intensity is 100 nA respectively. We change distance between detector and target to satisfy the request of detector and DAQ. Fig. 3 shows yield of  $^3\text{He}$  with four targets at  $60^\circ$  and  $140^\circ$ .

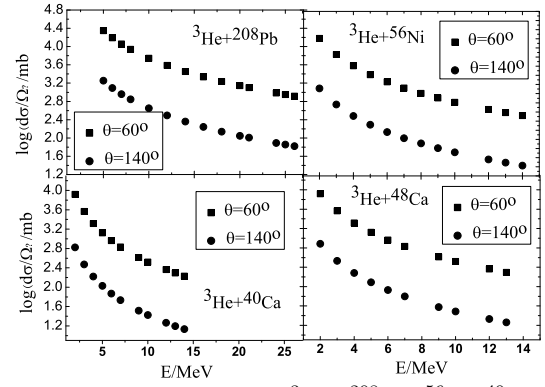


Fig. 2. Cross section of  $^3\text{He}+^{208}\text{Pb}$ ,  $^{56}\text{Ni}$ ,  $^{40}\text{Ca}$  and  $^{48}\text{Ca}$  at  $60^\circ$  and  $140^\circ$ .

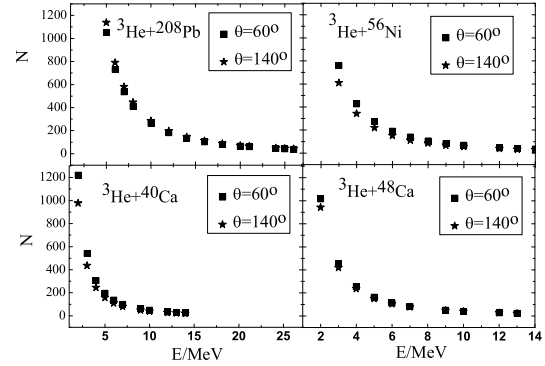


Fig. 3. Yield of  $^3\text{He}+^{208}\text{Pb}$ ,  $^{56}\text{Ni}$ ,  $^{40}\text{Ca}$  and  $^{48}\text{Ca}$  at  $60^\circ$  and  $140^\circ$ .

The energy of scattered particle at different angle is also simulated. The energy of scattered particle in reaction  $^3\text{He}$  with  $^{208}\text{Pb}$  at different angle is shown in Fig. 4.

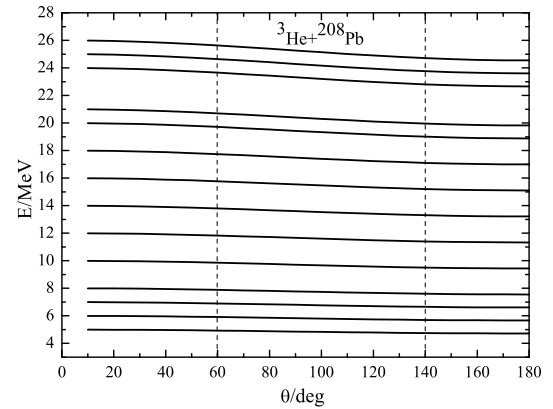


Fig. 4. Scattering particle energy at different angle of  $^3\text{He}+^{208}\text{Pb}$ .

#### 5 Error analysis

In our experiment, the system error is relate to the yield. For the ratio  $R(E, \theta)$ , it's relative error can be write as Eq. (6) and  $R(E, \theta) \approx 1$ . At same measuring time, the three behind term much small than than the first term in Eq. (6). So the ratio's relative

system error lie on the  $N(E, \theta)$ 's relative error. And then, the ratio's relative system error lie on the reaction time. To  ${}^3\text{He}+{}^{208}\text{Pb}$  case study, if we want to let the ratio's relative system error small than 0.15%, the reaction time should be longer than 51 h.

## 6 Summary and concluding remarks

We will measure electric polarizabilities of light nuclei(particle) on HI-13 tandem accelerator in China Institute of Atomic Energy and hope get accurate result. Especially for  ${}^3\text{He}$ , the large difference results

are obtained between different experiment laboratory, which is necessary to check it further in our experiment. In addition, we will set up Shanghai Laser Electron Gamma Source (SLEGS), which can provide the experiment of measuring the polarizabilities by Compton scattering. Besides P,  ${}^3\text{He}$  and other light nuclei, we will measure heavy nuclei which have no experiment data now! In our experiment we will choose different target to check our result. We will measure the proton's electric polarizabilities by quasi elastic scattering, witch is the foundation of measuring neutron' electric polarizabilities in the future.

$$\frac{\delta R(E, \theta)}{R(E, \theta)} = \sqrt{\left(\frac{\delta N(E, \theta)}{N(E, \theta)}\right)^2 + \left(\frac{\delta N(E, \theta_{\text{ref}})}{N(E, \theta_{\text{ref}})}\right)^2 + \left(\frac{\delta N(E_{\text{ref}}, \theta)}{N(E_{\text{ref}}, \theta)}\right)^2 + \left(\frac{\delta N(E_{\text{ref}}, \theta_{\text{ref}})}{N(E_{\text{ref}}, \theta_{\text{ref}})}\right)^2}. \quad (6)$$

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