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Rutherford Scattering

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Abstract

These experiments studies the Rutherford scattering of protons on atomic nuclei. Energetic 400 keV protons were generated using a Van de Graaff accelerator and directed onto thin metal foils of Au/C, LiF, B, and Al and the scattering cross section of the target atoms was measured as a function of the scattering angle in the range xx to 160 degrees. The cross section showed a clear angular dependency as ....., as expected. The thickness of the target layers Au/C were determined from the stopping power of the layers to be ..... The nuclear reactions of protons with boron were demonstrated by ... Mere is den dur bla bla bla ... In conclusion ...

1 Introduction

Almost all of our knowledge in the field of nuclear and atomic physics has been discovered through scattering experiments, and the theory of scattering underpins one of the most ubiquitous tools in physics. Even more, in low energy physics, scattering phenomena provide the standard tool to explore solid state systems. Historically, this was used as a first step towards our current understanding of the atom.

This paper examines the Rutherford scattering of a beam of 400 keV protons with a Au/C solid target. To limit the extend of the paper, and to keep our discussion simple and relevant, we will only examine elastic collisions in the semi-classical regime, governed by the Sommerfeld critcriterion for classical scattering. (Paetz gen Schleck, 2014, p. 14)

This is usually fine for low energy physics, in which internal energies remain constant and no further particles are created or annihilated. For our experiment, which involves a single Van-de-Graaff accelerator with energies of the order of 400 keV, this will be a very fine approximation.

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2 Materials and Methods

Experimental Setup

To obtain energies in the order of a 400 keV, a single Van-de-Graaf accelerator (see fig. 10) was used. The variety of incomming beam particles was limited by the source (a flask of hydrogen gas connected to the accelerator tank). Therefore, we only concider incomming ions H^+ and $H_2{}^+$, as the source was stationary, and not changed.

The accelerator ionized the hydrogen gas which could escape in a narrow beam. The particles kinetic energy was controllable on the dashboard. The particles entered a big electromagnet which makes a magnetic field that controls the angle of deflection of the beam. By adjusting the field one could control which particles, depending on the mass and charge, could enter the beamline and thus

interact with the target.
From the beamline the particles were directed toward a chosen target material, where they got scattered on atomic nuclei of the target. A detector was placed at a movable position around the target, such that scattering angles up 160 degrees could be measured. The detector was coupled to a digitizer with a time resolution of 123 and connected to a computer. During measurements the digitizer started a clock inside it. When the detector was hit by a particle, the digitizer translated the measured energy into a digital number and sent the number and the corresponding time stamp to the computer. The program Mc2Analyzer was used to handle the data. The digital number is an arbitrary number called a channel number. It is translatable to the actual energy by a linear factor plus an offset. In order to convert these channel numbers to correct energies of the scattered particles a calibration was done.

FiXme: HUSK DETTE!

Calibration

The measured energy of a scattered particle is given as a digital output called a channel number. A calibration is necessary to convert these channel numbers to the actual particle scattering energies. Assuming a linear relationship between the energy and the channel number the energy can be found as

$$E = \alpha(k - k_0), \tag{1}$$

where k is the channel and k_0 and α are parameters. The parameters in the relation is determined by varying the incoming energy and writing down the corresponding values of energy and channel number. The constants are determined from a linear fit of the energies as function of channel numbers. With the Van de Graff accelerator the magnetic field can be adjusted to deflect either H^+ or ${H_2}^+$ into the beamline. For each of these a data point of energy related to channel number can be found. By considering energy and momentum conservation for elastic scattering in two dimensions the energy of the scattered particles E_f can be found from the incident proton energy and the scattering angle as:

$$E_f = \left(\frac{m_p \cos\theta + \sqrt{{m_t}^2 - {m_p}^2 \sin^2\theta}}{m_p + m_t} \right)^2 E_i, \tag{2}$$

where E_i is the energy of the incident beam particles, m_p and m_t are the masses of the incident protons and the target particles, respectively, and θ is the angle between the direct outgoing non-scattered beam and the scattered particles - also called the scattering angle.
Unfortunately, this only give two data points one from H^+ and another from ${H_2}^+$. Nonetheless, the incline from the linear fit to these data points is still useful. However, another method is used to determine the zero-amplitude constant k_0. Different energies are generated using a pulse generator by changing the amplitude (corresponding to a change of resistance). For each fixed amplitude, a normal distribution of counts around a certain mean channel is obtained. The mean channel (also called the centroid) is determined from a Gaussian fit to the distribution.
fig. 1 shows the count distribution as function of channels for the amplitude fitted with gaussian function. The data clearly follows a gaussian distribution and the data points are, within uncertainty, well described by a gausian distribution.

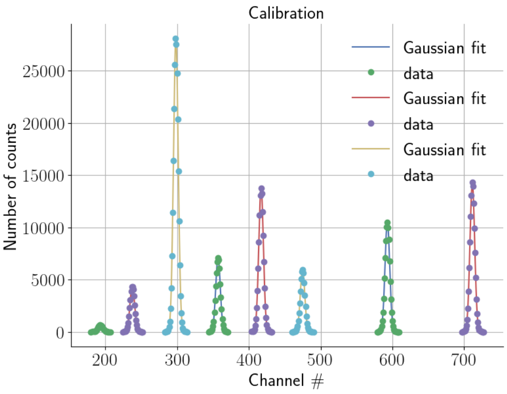

Figure 1: Gaussian fit of all data values. This was used to estimate the mean bin number (channel number), and the uncertainty of this bin number, in the energy-calibration.

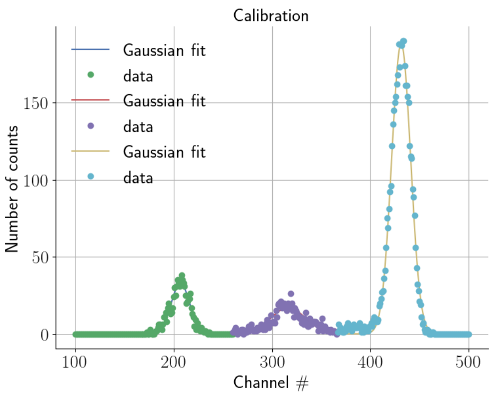

Figure 2: Gaussian fit of all data values. This was used to estimate the mean bin number (channel number), and the uncertainty of this bin number, in the energy-calibration.

Procedure

First thing, the Van-de-Graaf. To accelerate the beam of incomming particles, one has to generate a hugh potential. Turning on the Belt, one hears the mechanical rhumming. This will generate a potential difference as described further in Krane, 1987, p.xx.

Figure 3: The belt

Now adjust the terminal voltage patiently towards to wanted energy. Our lab instructor advised us to wait for each step, before going to the next.

Figure 4: terminal voltage

Turn on the electromagnet. Remember to calculate the wanted B-field for given element. Look on Faraday cup for received current of particles. Maximize with fine grid (small adjustments).

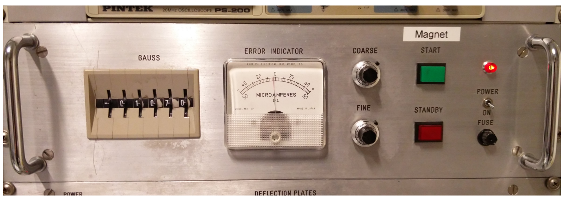

Figure 5: terminal voltage

When signal is good, set the voltage supply to ...

Figure 6: terminal voltage

Figure 7: process5

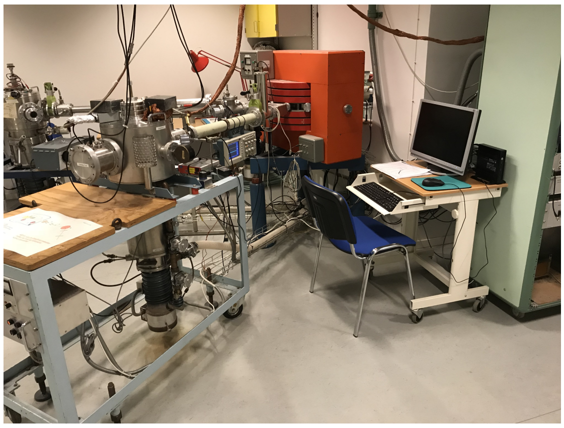

Figure 8: something to do with setup1

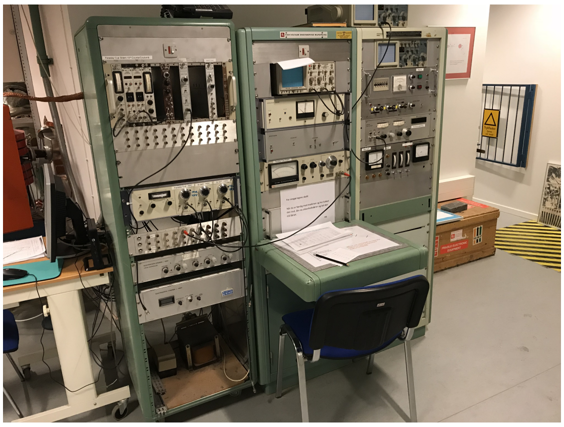

Figure 9: something to do with setup1

Figure 10: something to do with setup1

3 Angular dependency of the Rutherford cross section

4 Angular dependency of the proton energy

5 Target dependency of the Rutherford cross section

6 Thickness of the target layers

7 Nuclear reactions of protons with boron

8 Discussion

References

Krane, K. S. (1987). *Introduction to nuclear physics*. John Wiley & Sons.

Paetz gen Schleck, H. (2014). *Nuclear reactions: An introduction*. Springer.