Experiment 351: Proton Scattering Experiment – Aura 2 Laboratory

Aim

The aim of the experiment is to study the scattering of 2 MeV and 4 MeV protons from aluminium and to compare the scattering cross-sections, as a function of angle, with the predictions of the Rutherford scattering formula. An additional feature of interest is that, at 4 MeV, not all the particles emitted from the target are from elastic scattering, or indeed are necessarily protons.

References

1. E. Rutherford "The scattering of α and β particles by matter and the structure of matter" Phil. Mag. vol.21, p.669, (1911)
2. R.T. Beyer "Foundations of Nuclear Physics" Dover Publications (539.7 B57)
3. R.D. Evans "The Atomic Nucleus" McGraw-Hill
4. R. Eisberg & R. Resnick "Quantum Physics of Atoms, Molecules etc" McGraw-Hill
5. A.C. Melissinos "Experiments in Modern Physics" Academic Press
6. W.E. Burcham "Nuclear Physics" Longmans
7. P.M. Endt & C. Van der Leun "Energy Levels in A=21-44 Nuclei (VI)" Nuclear Physics, vol.A310, p.206 (1978)

Rutherford's paper (Ref. 1) is reprinted in Ref. 2. Refs 3−6 cover the nuclear physics aspects of the experiment. Nuclear energy levels can be found in Ref. 7. Refs. 3, 5 & 6 are available in the Advanced Laboratory and 2, 4 & 7 can be found in the Science Library. A copy of Ref. 7 is also available in AURA2.

Summary

The charged particle detector, the electronics and the multi-channel analyser used in the experiment are similar to those used in the first part of the "Radiation Detectors" experiment. The mono-energetic incident beams of protons come from the AURA2 electrostatic accelerator. The scattering, detection, etc., take place in a vacuum of around 10^{-5} Torr, (10^{-8} atmosphere). All the calibration and experimental spectra should be stored on the MCA hard disk.

Procedure

(1) Check the linearity and zero-offset of the detector/amplifiers/MCA combination using a precision pulser.

(2) Calibrate the detector/amplifiers/MCA combination, in keV/channel, using a source of ^{241}Am (the principal group has $E_\alpha = 5.486$ MeV).

(3) Using a beam of 2 MeV protons and the thin aluminium target, take spectra of the scattered particles at angles from 30° to 140°. The aim is to be able to work out the scattering cross-section as with an accuracy of a few percent.

   (a) The number of target nuclei/cm^2 can be worked out from a knowledge of the areal density. Ask the AURA2 technical staff for a sample of the aluminium foil used.

(b) The total number of incident protons is obtained by realising that:-

i. essentially all the protons pass through the target,

ii. they can be monitored electrically by letting them hit an insulated metal plate further downstream, and

iii. the number can be got by integrating this current in a "current integrator".

(c) "Dead-time" in the detection electronics due to non-zero count rates should not be greater than 10%, and should be corrected for using a pulser. Your demonstrator will explain the technique. The count-rate and dead-time are regulated by adjusting the beam current. The AURA2 technician will do this when asked.

(d) The MCA, current integrator and dead-time pulser should all be controlled from a master timer, so that the accumulated spectrum, the integrated charge and the pulser totals correspond to each other.

(e) At some scattering angles the plane of the target holder will obscure the detector, so the target will have to be rotated. The easiest way is to have it at either 45° or 135° to the incident beam, so spectra at forward angles are taken in "transmission" and those at backward angles in "reflection". Take the 90° scattered spectrum in each target orientation, as a check.

(4) Do the same for 4 MeV protons. Observe that there are several peaks in the spectra, particularly at back-angles. Take one spectrum at around 90° with good statistics and plot it using the MAC2. Ask someone how to do it.

(5) Run the kinematics program "kin" on one of the PC's to tell you $E(\text{out})$ vs $\theta(\text{lab})$ for whatever reactions you reckon you may have seen. You can do this later by arrangement if you want.

Write-up

The write-up should include:

1. Raw and processed data for the two elastic angular distributions, and plots of the differential cross-sections vs angle. This is most easily represented as plots of $(\mathrm{d}\sigma/\mathrm{d}\omega)_{\text{exp}} / (\mathrm{d}\sigma/\mathrm{d}\omega)_{\text{Ruth}}$ vs θ_{lab}. Obviously you should comment on the features apparent in your graphs.

2. The identification of as many of the peaks in the 4 MeV 90° spectrum as you can. What reactions are possible given the beam-target combination and the input energy? Look up the Q-values in the Endt and Van der Leun reference (Ref. 7). The response of the detector to p's and α's is not exactly the same, so it may be better to take a proton energy calibration for the non-elastic peaks from the position of the elastic peak in the spectrum and the energy it is supposed to have according to the program "kin". If your data is good enough you could plot angular distributions for some of the non-elastic peaks.

3. The answers to the following questions:

   (a) What is the Coulomb barrier height in MeV for protons on aluminium and on tantalum? Comment in the context of the present experiment where the target is aluminium and the beam and detector collimators are tantalum.

   (b) How much energy is lost by the protons as they pass through the aluminium foil?

   (c) Account for the obvious difference in the proton peaks in the 90° spectra in "transmission" and "reflection". Is this in accord with your answer to question (b)?

   (d) Estimate the size of the aluminium nucleus using conclusions gained from the differing scattering behaviour at 2 and 4 MeV.

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