MEASUREMENTS OF THE ELASTIC SCATTERING CROSS-SECTION OF ALPHA PARTICLES ON THE HEAVY AND MEDIUM WEIGHT NUCLEI IN THE VICINITY OF THE COULOMB BARRIER IN A WIDE ANGULAR RANGE

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The measurements of differential cross-section of the elastically scattered alpha particles with energies 23.5 and 27.7 MeV on Nb, Pd, Ag, In, Sn, Ta, Pt, Au, Pb and Bi targets, made of natural elements, were performed in a wide range of angles. The experimental procedure and the results are presented. It was observed that the oscillatory structure of $\frac{\sigma(\theta)}{\sigma_R}$ disappears continuously when energy is lowered from higher to lower values and approaches the Coulomb barrier. The slope of $\frac{\sigma(\theta)}{\sigma_R}$ and the cross-section values, obtained at backward angles, varies more rapidly with energy in the vicinity of the Coulomb barrier.

1. *Introduction*

The interaction of alpha particles with the atomic nuclei in the elastic channel is usually described by the optical model potential. It is known that there exist several sets of the phenomenological optical model parameters fitting eqally well the experimental data. A few years ago it was suggested [1, 2] that one of the possibilities of reducing the number of potential sets is a careful analysis of the dependence of elastic scattering and total reaction cross-sections on energy near to the Coulomb barier. The measurements of these two quantities were performed in the Institute of Nuclear Physics in Cracow.

The present paper accounts for the measurements of the differential cross-sections of the elastically scattered alpha particles. The results of the total reaction cross-section

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measurements will be published later. Instead of changing the energy, our approach to the problem was to vary the target nuclei maintaining the energy (properly chosen) constant. The energy of incident alpha particles and the target nuclei were chosen in such a way that the ratio of the energy to the Coulomb barrier varied from 2.02 to 1.06.

2. *Experimental arrangement and procedure*

The collimated beam of alpha particles, obtained from the 120 cm cyclotron of the Institute of Nuclear Physics in Cracow, was focused on the self-supporting target placed in the centre of the large scattering chamber [3]. After passing through the target the beam was collected in the Faraday cup connected with the current integrator. The intensity of the beam was independently monitored by a semiconductor counter viewing the target at a fixed angle of 20 degrees.

Three silicon surface barrier counters mounted on a rotable arm inside the scattering chamber were used as detectors. The angular distance between each two neighbouring counters on the arm was 5 degrees and their solid angles were approximately equal $8 \cdot 10^{-5}$ sterad. The accuracy of angle setting was better than ± 0.1 degree. The pulses from the detectors, after amplification, were registered by the 512-channel analyser whose memory was split into four 128-channel parts. The overall energy resolution for the thin target was about 350 keV.

During the experiment the energy of the beam was checked frequently by means of the absorption method [4]. Additionally the energy measurements were verified kinematically [5], determining the angle at which the alpha peaks from two independent sources coincided (one corresponding to the elastic scattering of the alpha beam on carbon and the second from radioactive decay of ^{211}At). For this purpose the Bi+C target was used in which the ^{211}At nuclei were formed in Bi(α, 2n) reaction. The energy of the incident beam was then calculated from the value of the scattering angle. The accuracy of the measurement of the absolute value of energy was estimated to be ± 150 keV. Corrections were made for energy loss in the targets.

In the tables presenting the results (see Ref. [24]), the exact energies of the incident α-particles at half target thickness are given.

The angular distribution measurements were performed in 2.5 degree steps, starting from 10 degrees and extended in most cases up to 175 degrees in the lab. system.

The absolute values of cross-sections for all targets except the lightest ones were determined by normalization of the experimental data, taken at relatively small angles, to the Rutherford cross-section. This procedure made it possible to avoid the errors due to inaccuracies in the beam intensity, the solid angles of counters, and the target thickness measurements.

3. *Results and discussion*

Figures 1 and 2 show two examples of the measured spectra of scattered alpha particles. As is seen from these figures, the energy resolution was insufficient to seperate in each case the elastic and inelastic groups of alpha particles. When the level spacing between the ground and the first excited state was less than 700 keV the inelastic groups could contribute to the elastic one. However, cross-sections of the inelastic scattering of alpha particles on heavy nuclei, *i. e.* Ta, Pt and Au, are expected to be in our case vanishingly small owing to the high Coulomb barrier. This conclussion is supported by the results of measurements of inelastic scattering processes on these nuclei by the authors of Refs [6, 7, 8]. In the case of the two remaining heavy elements, *i. e.* Pb and Bi, the inelastic groups were easily seperated.

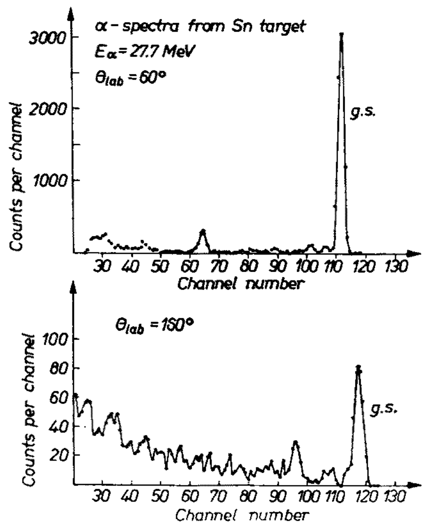

Fig. 1. The measured spectra of alpha particles scattered on the Sn target

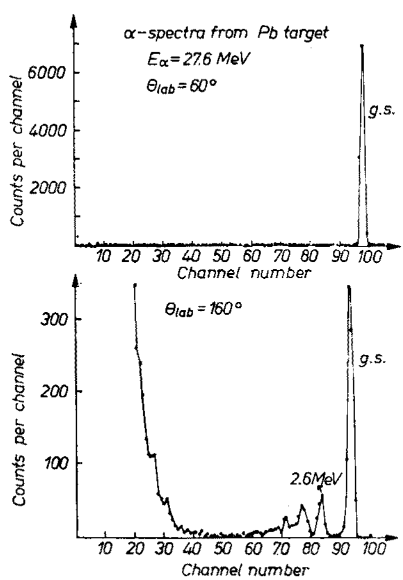

Fig. 2. The measured spectra of alpha particles scattered on the Pb target

In Table I are given the values of the Coulomb barrier for alpha particles scattered on the nuclei under study.

The Coulomb radii used for calculation of the Coulomb barrier, were found from the relation

$$\frac{d}{dr}\left[\frac{z_1 z_2}{r} - \frac{u_0}{\left[1+\exp\left(\frac{r-r_0\sqrt[3]{A}}{a}\right)\right]}\right] = 0$$

where U_0 is the depth of the real potential and r_0 and a are the nuclear radius and diffuseness parameters respectively.

TABLE I

Element	The hight of the Coulomb barrier for alpha particles of elements with weighted average atomic mass
Nb	13.7 MeV
Pd	14.8 MeV
Ag	14.9 MeV
In	15.3 MeV
Sn	15.5 MeV
Ta	20.1 MeV
Pt	21.1 MeV
Au	21.3 MeV
Pb	21.9 MeV
Bi	22.1 MeV

The optical model parameters were taken from preliminary fits of the four parameter optical model to the measured differential cross-sections. It is to be noticed that the Coulomb radii, found in this way, are not sensitive to the ambiguity in optical model parameters.

In the case of the lighter elements under investigation, *i. e.* Nb, Pd, Ag, In and Sn, the unresolved contribution from inelastic channels may change the shape of the measured angular distribution, especially at the backward angles. This problem has to be examined in details.

It must be mentioned that only the odd mass isotopes, if they are abundant, might provide some admixture from the inelastic scattering to the elastic peak. The even mass isotopes usually have the first excited state sufficiently high.

Numerous investigations of inelastic processes on Nb, In and Sn [11–23] showed that the low-lying levels of these nuclei are not excited to any great extent. This fact is due to their single particle nature, which is unfavoured in the inelastic scattering. Some admixture of alpha particles scattered inelastically may be present in the elastic peak for the case of Pd target [9, 12] and Ag target [10, 16] owing to the low energy spacing between the ground and the first excited states. Therefore in all cases when the contribution from the inelastic to the elastic scattering was expected to be appreciable and could not be seperated, the measurements ranged only to 130 or 150 degrees.

The Nb target was contaminated by a small percentage of tantalium. This contamination was determined by chemical analysis. For angles larger than 90 degrees the peaks of alpha particles scattered elastically on Nb and Ta were well seperated. For smaller angles the contribution of alpha particles scattered on tantalium to the elastic scattering on Nb was calculated on the basis of Ta data and then subtracted.

The results of the experiment are presented in Figs 3 and 4. Numerical values of the measured cross-sections are available [24]. The error of the absolute value of the cross-

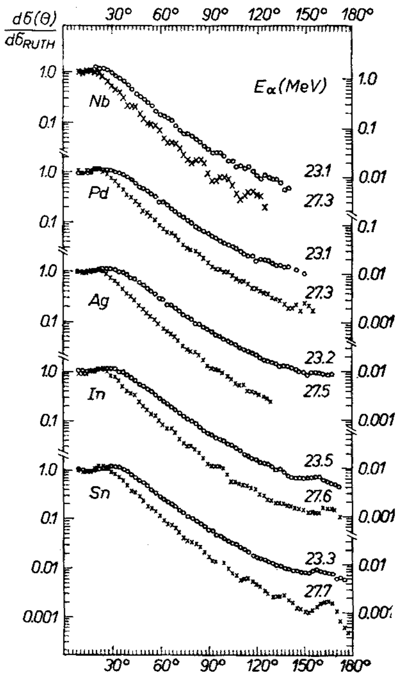

Fig. 3

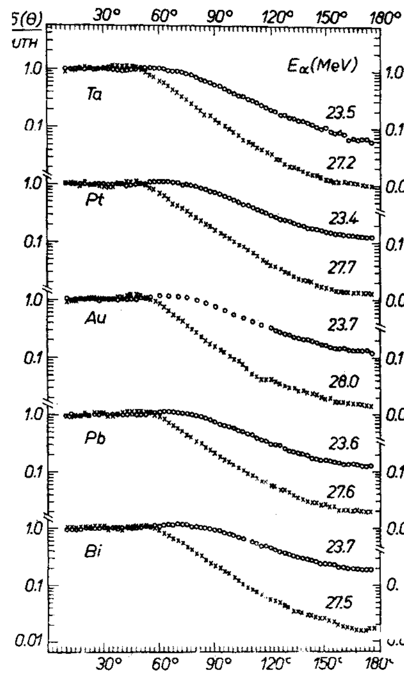

Fig. 4

Fig. 3. The measured differential cross-sections (normalized to the Rutherford cross-sections) for alpha particles elastically scattered on medium weight nuclei

Fig. 4. The measured differential cross-sections (normalized to the Rutherford cross-sections) for alpha particles elastically scattered on heavy nuclei

-section was evaluated individually, taking into account the possible energy fluctuation of the beam.

Some general observations can be made from the study of the systematics of the data:

(*i*) with decreasing energy of alpha particles the oscillatory structure of differential cross-section divided by the Rutherford cross-section becomes more and more damped, vanishing completely at the Coulomb barrier, (*ii*) the slope of $\frac{\sigma(\theta)}{\sigma_R}$ increases with increasing energy,

(*iii*) the values of cross-sections measured at backward angles and the slope of $\frac{\sigma(\theta)}{\sigma_R}$ vary by approaching the Coulomb barrier more rapidly than in the other energy region.

Further studies of these effects by measuring the total reaction cross-section for all these elements and subsequent analysis of the differential and total reaction cross-section by means of the optical model interaction are in progress.

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