The errors here represent mean square values from the processing of 7 plates. The results are in good agreement with those given by other authors[4-8] and obtained in $\beta$-spectrometers with recording by $\beta$-counters.

Thus the method of recording electrons in thick photographic emulsions proved to be entirely adaptable to $\beta$-spectroscopy. For a comparison of the exposure times necessary to darken an x-ray film appreciably, with that required by the photoemulsion method, we carried out a measurement using the same 2.65 mCu $Cs^{137}$ preparation for both. The data obtained showed that the use of the emulsion permitted the investigation of isotopes 300-500 times weaker in intensity. This increase in sensitivity of counting, together with the other advantages of the photographic method will permit the study of many short-lived isotopes and may be of value in deciding a number of questions in $\beta$-spectroscopy.

In conclusion, I would like to thank I. M. Frank and I. V. Estulin for the interest they showed and for assistance with the work.

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*It became known to the author afte the completion of the present work that a similar method had been used successfully by Pnievski[3] for investigating the $\beta$-spectra of RaD.

[1] L. V. Groshev and I. S. Shapiro, *Spectroscopy of the Atomic Nucleus*, GITTL, Moscow, 1952.

[2] E. S. Rosenblum, Phys. Rev. 72, 731 (1947).

[3] Ia. A. Pnievski, Acta Phys. Pol. 11, 215 (1953).

[4] W. C. Kelly, Phys. Rev. 85, 101 (1952).

[5] G. A. Graves, L. M. Langer, and R. D. Moffat, Phys. Rev. 88, 344 (1952).

[6] W. L. Bendel, F. J. Shore, H. N. Brown, and R. A. Becker, Phys. Rev. 87, 195 (1952).

[7] B. M. Dolishniuk, G. M. Drabkin, L. I. Orlov, and L. I. Rucinov, Dokl. Akad. Nauk SSSR 92,1141 (1953).

[8] R. E. Maerker and R. D. Birkhoff, Phys. Rev. 89, 1159 (1953).

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## Elastic Scattering of 5.4 Mev Protons by Various Nuclei

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A STUDY of the scattering of nucleons by atomic nuclei is one of the main sources of information about the form of a nucleus – the characteristics of the nuclear potential and the range of action of nuclear forces. Because of the success of the optical model for the scattering of neutrons by atomic nuclei[1] increased interest in proton scattering recently arose [2-5].

In the present work the elastic scattering of protons with initial energy of 5.4 mev by the following nuclei was studied: Be, C, F, Mg, Al, Ca, Mn, Ni, Cu and Zn. The measurements were made in the following manner. Fast protons, obtained from a linear accelerator, after going through a magnetic analyzer and a row of collimating diaphragms with diameters 2, 2.12, and 2.2 mm, were scattered by the target situated in a vacuum chamber. The scattered protons were registered by photoplates at various angles. The geometry of the experiment and the position of the photoplates are shown in Fig. 1. The angular resolution for the detectors nearest to the target was $\pm 2.5°$.

Because the photoplates, situated to the right and to the left of the beam ( see Fig. 1), were simultaneously exposed, and the intensity of the Coulomb scattering is proportional to $\sin^{-4}(0/2)$ ( where 0 is the angle of observation), the distances to the photoplates in the region of small angles were chosen in such a manner that the relationship $r \sin^2(0/2) = \text{const}$ would hold ( r is the distance from the target to the detector.)

The targets for all metals studied were obtained in the form of thin foils or films of a couple microns thickness by evaporating metal in a vacuum, with the exception of nickel whose foil was obtained by electrolysis, and carbon which was prepared as a thin free film from aquadag ( a graphite lubricant). For the study of scattering from fluorine thin films of $MgF_2$ and $Li^6F$ were used, and for calcium films of $CaF_2$.

After the exposure of the photoplates and their photochemical development, first, a study of the energy spectrum of protons which were scattered by the target at 90° and 160° angles with respect to the primary beam was made. This study was made on the paths left by protons in the photoemulsion. The energy resolution of this method

was ±3.5 %. In such a way the groups of elastically scattered protons were isolated. The number of particles, corresponding to these groups, was counted afterwards on all plates. Two segments of the angular distribution curve obtained for small and large angles, were "joined together" using data for angles 50 and 60°. This was necessary in connection with the different exposure time for the "right" and "left" plates.

Previously, using this method, the angular distribution of protons scattered by gold and platinum was determined, and it was found that the distribution corresponded to the Rutherford formula within the limits of experimental error; this was to be expected since the nuclei had a greater potential barrier than the energy of incident protons.

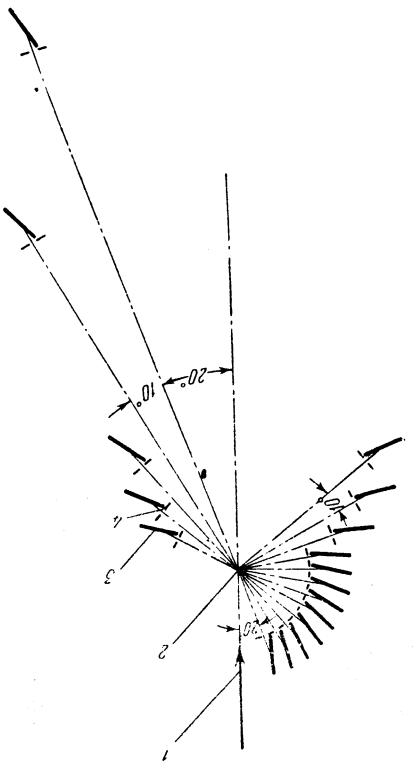


FIG. 1. *1*-proton beam, *2*-target, *3*-photoplate, *4*-diaphragm

The results obtained by us are shown in Fig. 2, where $N(\theta)$ is the number of protons scattered into the angle $\theta$, $N(20^\circ)$ is the number of protons scattered into the angle of 20°, $\theta_c$ is the angle in the center-of-mass system. Scattering from fluorine was obtained by excluding the effect of scattering from magnesium in $MgF_2$. Analogously,

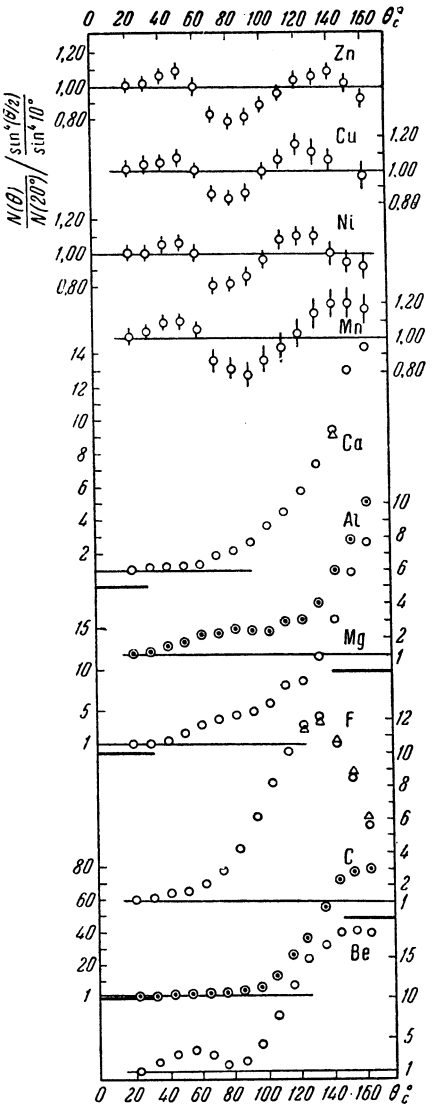


FIG. 2.

data was obtained for Ca from scattering by $CaF_2$. The qualitative trend of the angular distribution of protons scattered by fluorine into big angles was also measured using a thin film of $Li^6F$. The energy spectrum of protons, scattered from this compound, showed that for 110° it is already possible to safely divide the groups of protons elastically scattered by fluorine and $Li^6$. The data obtained in this way, and normalized for 110° are shown in figure 2 (the triangles). It was possible to safely separate the protons scattered by Ca and F from the target consisting of $CaF_2$ only for the angles of 140, 150 and 160° (the corresponding data is also shown by triangles).

The angular distribution of protons obtained by us differs very much from the Coulomb distribution and is not the same for various nuclei. Qualitative similarity in scattering by neighboring nuclei is observed. Thus, for Be and C a large scattering in the region of the angles 150-160° is obvious; however, the numerical value of the ratio for carbon is almost 4 times bigger than for beryllium. Apparently this is connected with the formation of the intermediate nucleus of $N^{13}$, which in this region of energies has an excitation level which gives rise to the resonant scattering of protons. Note that for an energy of 10 mev for carbon and for beryllium for 5.4 mev, a maximum at 50° [6] is observed. The curve for fluorine has a maximum for 140°. There is no data for scattering of protons from fluorine. but its neighbor – oxygen, has a big scattering maximum in the region of 120° for 9.6 mev.[5]

Scattering by magnesium and aluminum is similar, with a somewhat greater absolute value of the ratio for Mg. The angular distribution for Ni, Cu and Zn, within the experimental errors is alike in the magnitude of their ratios and in the position of maxima and minima. Similar curves for Cu were obtained by Goldman [7] for a proton energy of 6.5 mev; and by Schneider, Martin et al[8] for energies of 6, 6.5 and 7 mev. For Mn, qualitatively the curve for angular dependence is analogous to the preceding elements, but a displacement of the position of the minimum and second maximum in the direction of greater angles is observed, and the maximum is somewhat bigger. An unexpectedly large magnitude for the ratio for Ca was obtained, especially for big angles. It is possible that this was obtained as a result of two types of operation, which we were forced to do in these experiments; however, the fact is not excluded that this large effect is caused by a characteristic of the nucleus of $Ca^{40}$. The interesting fact is that, in spite of the small value of the ratio measured by us for heavier nuclei, the interference character of elastic scattering from these nuclei appears more clearly than for light nuclei.

Our attempts to explain the obtained results by the optical model have been as yet unsuccessful. It is possible, that the optical model in its present state is only a rough approximation for consideration of proton scattering, for which one must take into consideration a complex dependency on the potential of the nucleus, whose form can change. Obviously, further study of proton scattering at various energies and from a number of nuclei is necessary. Especially important is further study on free protons, which we are undertaking.

In conclusion the authors consider it their duty to express great thanks to Prof. K. D. Sinelnikov for discussion and constant interest in our work, and also to P. M. Seidlitz for his great attention which helped in the completion of work.

1 H. H. Barschall, Am. J. Phys., 22, 517 (1954).
2 B. L. Cohen and R. V. Neidigh, Phys. Rev. 93, 282 (1954).
3 I.E. Dayton, Phys. Rev. 95, 756 (1954).
4 R. D. Woods and D. S. Saxon, Phys. Rev. 95, 577 (1954).
5 Y. Fujimoto and A. Hossain, Phil. Mag. 46, 542 (1955).
6 G. E. Fischer, Phys. Rev., 96, 704 (1954).
7 L. M. Goldman, Phys. Rev. 89,349 (1953).
8 H. Schneider, M. Martin, M. Sempert and J. Saladin Helv. Phys. Acta, 27, 170 (1954).

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## Photoconductivity and Luminescence of Polycrystalline CdS(Cu)

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POLYCRYSTALLINE cadmium sulfide[1] with just a trace of a foreign metal represents a very convenient specimen for investigating the laws of photoconduction and luminescence. The results are summarized here of a preliminary investigation of the stationary (steady-state) and relaxation laws of a series of CdS specimens with just a trace of copper, and also copper and iron. The CdS (Cu) series consisted of 9 specimens (several of each) with various concentrations C (gms/gm) (see table)

Specimen number 10, CdS (Cu, Fe) had concentrations of Cu and Fe of $10^{-3}$ and $10^{-5}$ grams/gram, respectively.

**1. Stationary (steady-state) photoconduction.** The dependence of stationary photoconductivity $\Delta\sigma_0$ on the level of intensity of light E in specimens with small concentration (SC) of copper appears typical of photoconduction of the "hyper-