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Stopping Power of Be, Al, Cu, Mo, Ta and Au for 28 MeV Alpha Particles

Ryutaro ISHIWARI*, Naoko SHIOMI*, Shigeko SHIRAI*,
Tokiko OHATA** and Yoshiaki UEMURA***

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The stopping power of Be, Al, Cu, Mo, Ta and Au for 28 MeV alpha particles has been measured with a silicon detector and associated electronic equipments. It has been observed that the stopping power for alpha particles devided by 4 is higher than for protons of the same velocity. The deviations are about 1.5 to 3 percent.

I. INTRODUCTION

For many years, the phenomena of penetration of charged particle in matter have been of interest in many fields of physics especially in nuclear physics. Some years ago, a compilation[1] of extensive review works was published to clarify the present status of our knowledge on these phenomena. As for the stopping power of matter for heavy charged particles, general feeling was that the existing data were insufficient to understand fully the stopping power problem. Therefore, more accurate measurements in extended energy range and atomic numbers were desired.

On such background, in our laboratory efforts have been put forth continually to obtain the accurate stopping power data of various materials for protons, deuterons and alpha particles. Some preliminary reports have been already published.[2~4]

In recent years, on the other hand, extensive measurements for protons and deuterons have been published by Andersen *et al.*.[5~8] Further, they have measured stopping power for alpha particles and He^3, and obtained very important results.[9] That is, the stopping power for alpha particles and He^3 are higher than the prediction of the Bethe theory and the deviation depends upon the particle energy.

In view of the importance of their findings, it is felt to be of use to publish our data so far obtained, although they are still insufficient because they are concerned with fixed energies.

In the present paper, the preliminary results of Be, Al, Cu, Mo, Ta and Au for 28 MeV alpha particles will be reported.

* 石割隆太郎, 塩見 直子, 白井 重子 : Department of Physics, Faculty of Science, Nara Women's University.
** 大畠トキ子 : Department of Physics, Faculty of Science, Nara Women's University, now at School of Liberal Arts and Sciences, Kyoto University.
*** 植村 吉明 : Keage Laboratory of Nuclear Science, Institute for Chemical Research, Kyoto University.

II. EXPERIMENTAL PROCEDURE

The alpha particle beam accelerated with the Kyoto University Cyclotron was used for the present measurement. The method for measuring the energy loss of alpha particles in sample foils is quite the same as described in detail in the preceding paper.[4)]

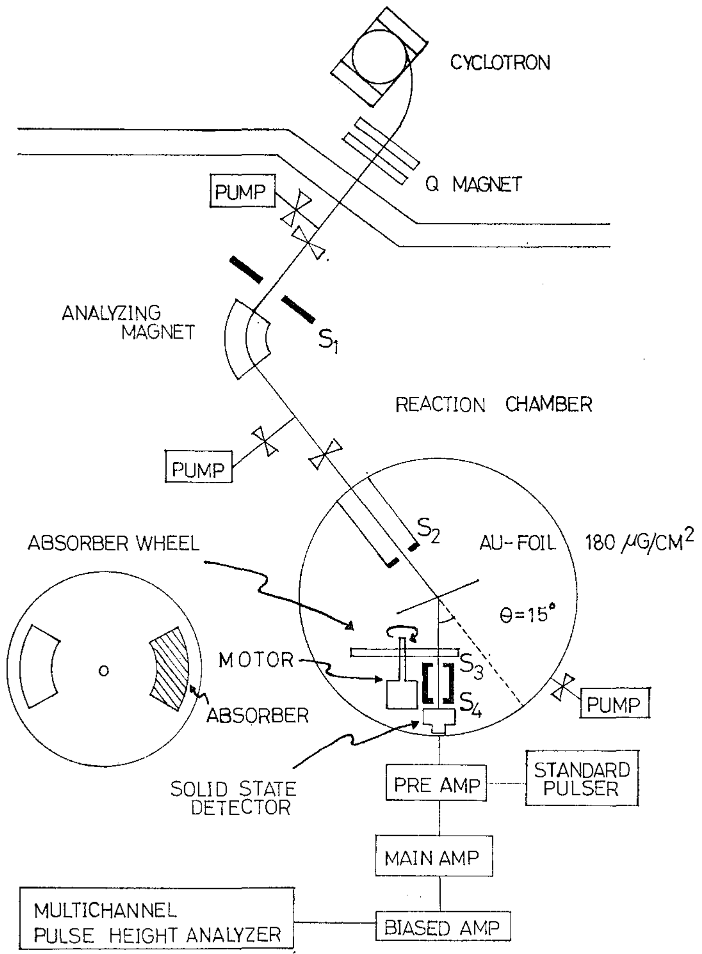


Fig. 1. The experimental set up.

Figure 1 shows the experimental set up. The absolute value of the incident energy was determined by the analyzing magnet. The beam scattered at an angle of 15 degrees by a thin gold target was used for the measurement. The absorber foil was fitted to one of the windows of the absorber wheel and the wheel was rotated in front of a silicon detector. Thus, the pulse height with and without the absorber foil was recorded by the silicon detector and associated equipments simultaneously in one exposure. The energy calibration of the detector was performed by measuring the alpha particles scattered by an aluminium target at various angles and crosschecked by a precision pulser.

The measurements were made twice for each element except for Cu.

The sample foils used are as follows:

Beryllium

Thickness: 2.4301 ± 0.0064 mg/cm^2, Stated purity: unknown but presumed to be 99 percent or up, Supplier: Brush Beryllium Co.

Aluminium

Thickness: 4.9324 ± 0.0016 mg/cm^2, Stated purity: 99.8 percent, Supplier: Toyo Aluminium Co., Ltd.

Copper

Thickness: 7.4178 ± 0.0087 mg/cm^2, Stated purity: 99.9 percent or up, Supplier: Fukuda Metal Foil and Powder MFG Co., Ltd.

Molybdenum

Thickness: 6.8050 ± 0.0029 mg/cm^2, Stated purity: 99.95 percent, Supplier: A. D. Mackay, Inc.

Tantalum

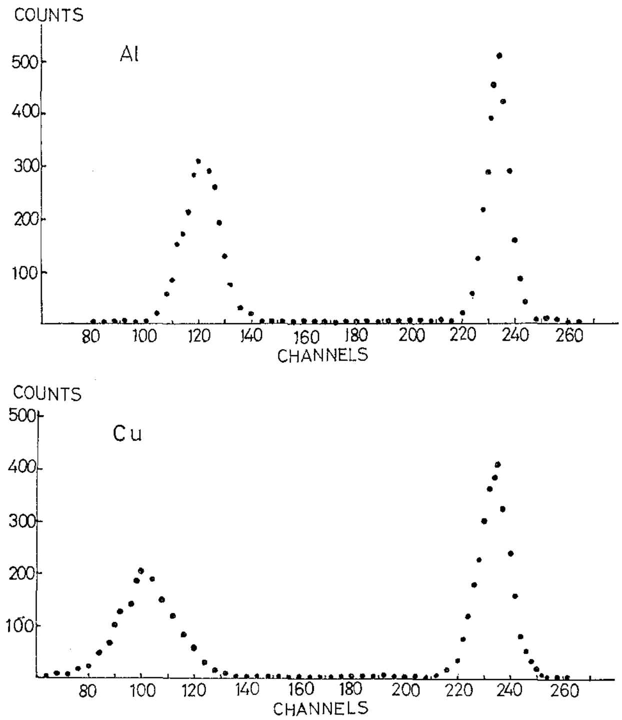
Thickness: 10.3447 ± 0.0014 mg/cm^2, Stated purity: 99.9 percent or up, Supplier: A. D. Mackay, Inc.

Gold

Thickness: 10.5060 ± 0.0005 mg/cm^2, Stated purity: 99.95 percent, Supplier: Ishifuku Metal Industry Co., Ltd.

III. RESULTS

The typical pulse height spectra are shown in Fig. 2. In Table 1, the pulse



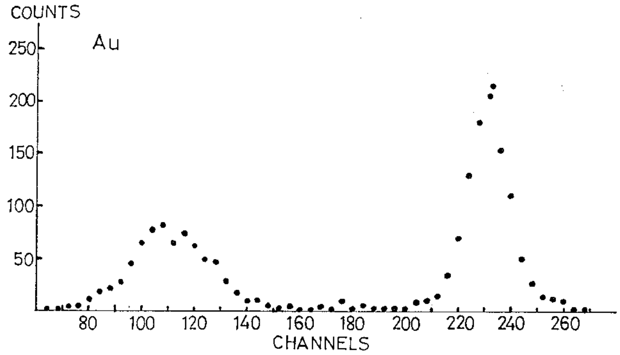


Fig. 2. Typical pulse height spectra.

Table 1. The Pulse Height Difference. The Error Attached to the Average Value is the Standard Error.

Element	Pulse height difference (channel)		Average (channel)
	Run 1	Run 2	
Be	60.05±0.29	59.92±0.15	59.99±0.07
Al	112.45±0.13	112.94±0.13	112.70±0.25
Cu	131.48±0.18		
Mo	108.11±0.17	107.67±0.17	107.89±0.22
Ta	123.52±0.23	124.18±0.26	123.85±0.33
Au	121.20±0.29	121.41±0.32	121.31±0.11

height difference are tabulated.

In case of Cu the measurement was made only once because of the time limitation of the experiment. The energy calibration are shown in Fig. 3. By assuming the linear relation between the pulse height and the particle energy, the slope was determined by the method of least squares as 7.806±0.074 keV/channel.

Table 2 shows the stopping power obtained in the present study. The

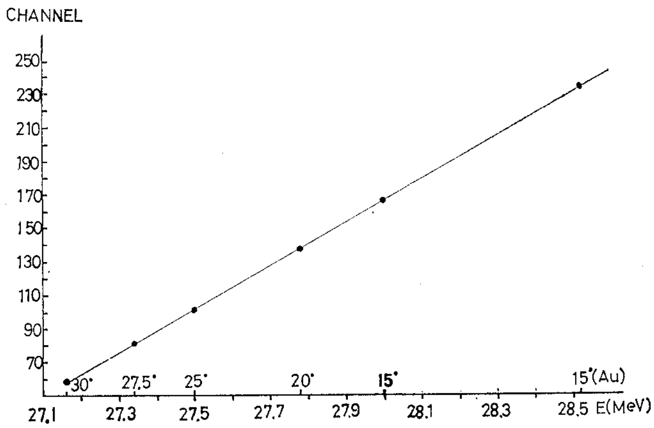


Fig. 3. The energy calibration.

Table 2. The Stopping Power Data.

Element	$\bar{E}$ (MeV)	$\bar{E}'$ (MeV)	$\Delta E/\Delta x$ (keV/mg cm^{-2})	$(\Delta E/\Delta x)\times 1/4$ (keV/mg cm^{-2})	Andersen (keV/mg cm^{-2})	Fractional Difference (%)
Be	28.4527 ± 0.0128	7.1622	192.70 ± 1.92	48.17 ± 0.48	49.42 ± 0.15	−2.53 ± 1.01
Al	28.0783 ± 0.0076	7.0680	178.36 ± 1.74	44.59 ± 0.44	44.48 ± 0.13	+0.25 ± 1.03
Cu	28.1737 ± 0.0135	7.0920	138.37 ± 1.33	34.59 ± 0.33	34.79 ± 0.10	−0.57 ± 0.98
Mo	28.2658 ± 0.0132	7.1152	123.76 ± 1.21			
Ta	28.2035 ± 0.0135	7.0995	93.46 ± 0.93	23.37 ± 0.23	23.45 ± 0.07	−0.34 ± 1.02
Au	28.2134 ± 0.0134	7.1022	90.13 ± 0.86	22.53 ± 0.22	22.47 ± 0.07	+0.27 ± 1.02

incident energy was 28.5182±0.0062 MeV for Al and 28.6869±0.0126 MeV for other elements. In the second column average energies are given. In the third column, proton energies which correspond to the velocities same as average alpha energies are given. The present result was devided by 4 and compared with Andersen's data. For the sake of reference standard, the fractional difference was obtained by deviding the difference by Andersen's value.

IV. DISCUSSION

In the present experiment, the operational condition of the cyclotron was much worse than the previous experiments.[4] It took from 30 to 60 minutes to make one exposure. Correspondingly the stability of the analyzing magnet was also bad but kept constant within 5 parts in 10^4.

As is seen from Table 2, the uncertainty of the present experiment is barely ±1 percent. Nevertheless, comparing the results for Al, Cu and Au, the common elements with the previous experiment[4], with Andersen's values[6], it can be seen that the stopping power for alpha particles devided by 4 is higher than for protons, because our proton data are lower than Andersen's by 1 to 2.5 percent.

In order to compare our alpha data directly with our proton data, as in the previous paper it was assumed that the stopping power is proportional to $\ln v^2/v^2$ in a narrow velocity range. The proton results obtained in the preceding paper[4] were reduced to the values corresponding to the present alpha velocities.

Table 3. Comparison of the Alpha Data with our Proton Data Reduced to the Alpha Velocities.

Element	Al	Cu	Au
$(dE/dx)_\alpha \times 1/4$	44.59±0.44	34.59±0.33	22.53±0.22
$(dE/dx)_p$	43.27±0.25	34.02±0.18	22.15±0.18
Difference (%)	3.05±1.18	1.68±1.12	1.72±1.26

The comparison is shown in Table 3.

It is seen that the stopping power for alpha particles is generally higher than that for protons of the same velocity. Unfortunately, however, the uncertainty of the present results is as large as 1 percent. The deviations are not quite significant statistically except for Al. So that, it is difficult to discuss the problem more in detail from the present results. However, the present results offer the positive evidence of the deviation which was found by Andersen *et al.*.[9] One thing to say is that in our data the deviation is largest for Al while in Andersen's the deviation should disappear at our energies.

In the next series of experiments on alpha particles, more positive evidences have been obtained and the results will soon be published.

The present experiment is reported here as a preliminary report of the following more complete experiment.

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REFERENCES

(1) Natl. Acad. Sci.-Natl. Res. Council Publ. 1133 (1964).
(2) K. Hosono, R. Ishiwari and Y. Uemura, *Bull. Inst. Chem. Res., Kyoto Univ.* **43**, 323 (1965).
(3) R. Ishiwari, N. Shiomi, Y. Mori, T. Ohata and Y. Uemura, *Bull. Inst. Chem. Res., Kyoto Univ.*, **45**, 379 (1967).
(4) R. Ishiwari, N. Shiomi, S. Shirai, T. Ohata and Y. Uemura, *Bull. Inst. Chem. Res., Kyoto Univ.*, **49**, 390 (1971).
(5) H. H. Andersen, A. F. Garfinkel, C. C. Hanke and H. Sørensen, *Kgl. Danske Videnskab. Selskab, Mat.-Fys. Medd.*, **35**, No. 4. (1966).
(6) H. H. Andersen, C. C. Hanke, H. Sørensen and P. Vajda, *Phys. Rev.*, **153**, 338 (1967).
(7) H. H. Andersen, C. C. Hanke, H. Simonsen, H. Sørensen and P. Vajda, *Phys. Rev.*, **175**, 389 (1968).
(8) H. H. Andersen, H. Simonsen, H. Sørensen and P. Vajda, *Phys. Rev.*, **186**, 372 (1969).
(9) H. H. Andersen, H. Simonsen and H. Sørensen, *Nucl. Phys.*, **A 125**, 171 (1969).