sent upper limits, since the cross section integrated over all angles and energies yields 0.378 barn for carbon, while the observed inelastic cross section for neutrons of 270 Mev is only 0.144 barn.[7] The theoretically expected distribution for single collisions with a degenerate Fermi gas[15] is shown in Fig. 1, curve (A). Curve (B) represents the theoretical distribution expected on the basis of the momentum distribution deduced by Chew and Goldberger[10] from the deuteron pick-up process.[11] Curve (C) was calculated like (B) with the additional empirical assumption of a cut-off in the momentum distribution at 72 Mev. The rectangles indicate the experimental values multiplied by 2.2. Within the accuracy of the experiment some distribution such as that leading to curve (C) adequately represents the data, except for the very high energy points discussed above.

The differential diffraction scattering cross section for carbon at 90° is about 4×10^{-29} cm²/steradian when calculated according to the model of Fernbach *et al.*[16] It is planned to extend measurements into the region of elastically scattered protons in order to look for this contribution.

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* Work performed under the auspices of the AEC.
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Calculations Concerning the Measurement of the Energy of Charged Particles by Small Angle Scattering*

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A COMMON method for determining the energy of particles in photographic emulsions is to measure the mean absolute angle between successive chords on a track. For the papers by Snyder and Scott[1] and by Scott and Snyder[2] various tables of distribution functions were computed and relations determined from which one can find the relationships among the mean absolute angle $\bar{\alpha}$ between successive chords on a track, the momentum p of the particle, the velocity v of the particle, the chord length s, and the composition of the matter through which the particle is passing. Defining the scattering constant K, which is a function of $s_0=s/\beta^2(\beta=v/c)$, by

$$K(s_0)=\bar{\alpha}pv/s^{\frac{1}{2}}, \tag{1}$$

one obtains

$$K(s_0)=\sqrt{2}(\bar{\alpha}'/z^{\frac{1}{2}})(\eta_0 pv/\lambda^{\frac{1}{2}}), \tag{2}$$

in which $\bar{\alpha}'=\alpha/\eta_0$ is a function of z. The quantities z, λ, and η_0 are

TABLE I. Calculated values of the scattering constant $K(s_0)$.

z	s_0	$\bar{\alpha}'/z^{\frac{1}{2}}$	$K(s_0)$
100	0.0801	0.912	22.96
400	0.3205	1.001	25.20
1600	1.282	1.085	27.32
6400	5.128	1.153	29.02
25600	20.51	1.219	30.69

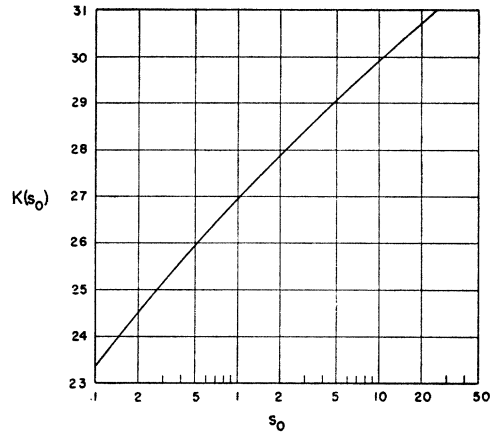

FIG. 1. Graph of $K(s_0)$ against s_0 on a semilogarithmic scale. The scattering constant K is given in units of Mev-deg/(100μ)$^{\frac{1}{2}}$. The quantity $s_0=s/\beta^2$ is given in units of 100μ.

defined by

$$z=2s/\lambda, \tag{3}$$

$$1/\lambda=(4\pi/\beta^2)(\hbar/mc)^2\sum N_i Z_i^{4/3}, \tag{4}$$

and

$$\eta_0^2 p^2 v^2/\lambda=4\pi e^4\sum N_i Z_i^2. \tag{5}$$

The meanings of the symbols in these equations are given in the above-mentioned papers. For the values of $\sum N_i Z_i^2$ and $\sum N_i Z_i^{4/3}$ the composition of a standard Ilford emulsion was used, and the corresponding values were found to be 3.704×10^{25}/cm³ and 3.33×10^{24}/cm³. Substituting numerical values in Eqs. (2) and (3), one obtains[3]

$$z=1248s_0 \tag{6}$$

if s_0 is measured in units of 100μ, and

$$K(s_0)=25.18\bar{\alpha}'/z^{\frac{1}{2}} \tag{7}$$

if K is measured in units of Mev-deg/(100μ)$^{\frac{1}{2}}$. The values of $\bar{\alpha}'$ were computed for various values of z from tables available at Brookhaven National Laboratory. The results of this calculation are given in Table I. These values of $K(s_0)$ are also plotted against s_0 on a semilogarithmic scale in Fig. 1.

From these values of K and measured values of $\bar{\alpha}$, one can obtain by use of Eq. (1) the value of pv (in Mev) for the particle.

* Research carried out under contract with the AEC.
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[3] The relation (6) among z, s, and β is valid only for large β, approximately for $\beta>\frac{1}{2}$, because the Born approximation was used in determining the effect of screening on the mean free path, λ. If a better value of λ is used, then Eq. (3) should be used to determine z. Since K is a function of z only, a graph of K as a function of z enables one to determine the appropriate value of the scattering constant for any given case. Actually, a precise value of λ is not very important, since a change in λ by a factor of four changes the scattering constant by about five percent.

Neutron Deficient Europium and Gadolinium Isotopes*

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A STUDY has been made of the light europium and gadolinium isotopes produced by bombardment of samarium and europium oxides with energetic protons, deuterons, and helium ions. In addition to the natural oxides, electromagnetically concentrated isotopes of samarium were used as target materials.[1] In some of the bombardments chemical separations of the target

TABLE I. Observed radiations.

Isotope	Type of radiation	Half-life	Radiation characteristics	Produced by	Bombarding particle energy	Chemical separation
Eu^{145}	EC, e^-	5±1 days	0.2 Mev e^-	recoil nuclei from α-decay of Tb^{149}	—	—
				$Sm^{147}(p, 3n)Eu^{145}$	50 Mev	ion exchange column
Eu^{146}	EC, e^-	38±3 hrs	0.4 Mev e^-	$Sm^{147}(d, 3n)Eu^{146}$	19 Mev	no
				$Sm^{144}(\alpha, 2n)Gd^{146}$ $(\alpha, pn)Eu^{146}$	25 Mev	no
Eu^{147}	EC, e^-, no β^+	24±2 days	2.88±0.1 Mev α 0.2 Mev e^- $\alpha/EC\sim10^{-5}$	$Sm^{147}(p, n)Eu^{147}$	8.5 Mev	ion exchange column
Eu^{148}	EC, e^-, γ no β^+	50±2 days	0.38 Mev e^-	$Sm^{148}(p, n)Eu^{148}$	8.5 Mev	no
Eu^{149}	—	<1 hr or >50 days	—	$Sm^{149}(p, n)Eu^{149}$	8.5 Mev	no
Gd^{149}	EC, e^-, α, γ	9±1 days	3.0±0.15 Mev α 0.35 Mev e^-	$Eu^{nat}(p, 3n)Gd^{149}$	28–32 Mev	sodium amalgam
				$Sm^{147}(\alpha, 2n)Gd^{149}$	28–30 Mev	no
				$Sm^{nat}(\alpha, xn)Gd^{149}$	36 Mev	sodium amalgam

materials were not considered necessary because of restrictions on the number of possible isotopes produced due to the use of low energy bombarding particles and enriched isotopes. When necessary, separations of europium and samarium were made using a cation exchange resin column (Dowex-50, pH of citrate=3.3–3.5) at elevated temperatures as described in a recent article by Thompson, *et al.*[2] Separations of europium and gadolinium were made using a sodium amalgam reduction method[3] to overcome the difficulty of their separation in a cation exchange column. The conversion electron energies were determined from aluminum and beryllium absorption data. A search for positron emission in most of the nuclides studied here was made using a 180° beta-ray spectrometer of low resolution (see Table I).

The decay of europium isotopes with mass numbers 147 and 148 was observed after proton bombardments of enriched samarium isotopes (see Table I). The (p, n) reaction is probably virtually the only nuclear reaction induced by 8.5-Mev protons on samarium. The threshold of the $(p, 2n)$ reaction is estimated to be 9–10 Mev for $Sm^{147-149}$ using neutron binding energies calculated from the semi-empirical mass equation[4] and estimated electron capture decay energies. This assumption is borne out by the experimental observation that when rare earth samples consisting of a single relatively pure isotope are bombarded with 8.5-Mev protons, only one radioactive species is produced in high yield. The decay of Eu^{149} formed in a proton bombardment of Sm^{149} has not been observed, thus making it possible to set limits on the half-life of Eu^{149}. Our assignment of the 50-day activity to Eu^{148} is in disagreement with the assignment of a 53-day activity to Eu^{147} by Marinsky and Glendenin,[5] who based their assignment on calculations using the Bohr-Wheeler equations. Eu^{147} showed rare alpha-decay branching[6] ($\alpha/EC\sim10^{-6}$) with a particle energy of 2.88±0.1 Mev as measured with the differential alpha-pulse analyzer.[7]

Another isotope of europium, Eu^{145}, was observed as recoil nuclei from the alpha-decay of Tb^{149}. The terbium was produced in a 150-Mev proton bombardment of gadolinium oxide and isolated using a cation exchange column separation. The Eu^{145} has also been produced in a 50-Mev proton bombardment of $Sm_2{}^{147}O_3$.

The radionuclide, Eu^{146}, was observed after a helium ion bombardment of $Sm_2{}^{144}O_3$. A series of samarium oxide targets were placed between a series of stacked platinum foils which degraded the energy of the helium ions through a range from 36 Mev to 13 Mev. Decay of the samples showed the 38-hour activity was formed in greatest abundance with 25-Mev helium ions. At this approximate energy an (α, pn) reaction or $(\alpha, 2n)$ reaction followed by electron capture decay was considered the predominant mechanism for the production of the nuclide.[8] The 38-hour period was also observed after a 19-Mev deuteron bombardment of enriched $Sm_2{}^{147}O_3$, thus ruling out a possible assignment to Gd^{146} but consistent with an assignment to Eu^{146}.

A gadolinium isotope, Gd^{149}, has been observed as a product in a number of different bombardments. Natural europium oxide was bombarded with protons in a stacked foil arrangement which produced a proton energy range from 32 Mev to 8 Mev. The Gd^{149} was produced in largest yield with 28- to 32-Mev protons, and therefore, a $(p, 3n)$ reaction was assumed as the predominant mechanism in the production of this isotope. This 9-day period, belonging to Gd^{149}, was also produced in a helium ion bombardment of enriched $Sm_2{}^{147}O_3$ also placed between stacked platinum foils. The helium ion energy range through the target was 36 Mev to 13 Mev. The 9-day activity was produced in largest yield with 28- to 30-Mev helium ions, and an $(\alpha, 2n)$ reaction was assumed as the predominant mechanism for the production of this isotope. Measurements with the differential alpha-pulse analyzer gave indication of alpha-branching of this isotope with a particle energy of 3.0±0.15 Mev.

This work is being continued and a more complete report will be published at a later date.

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