Inelastic Scattering of Protons from Light Nuclei

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An investigation has been made of inelastic scattering of 7.4-Mev protons at 90° from the following thin foil targets: Be, C^{12}, C^{13} (47 percent enriched), CaF_2, Ni, Al, and Na, and from the following gas targets: normal BF_3, enriched $B^{10}F_3$ (96 percent), N_2, O_2, CH_4, and Ne. The following energy levels in Mev were observed: Be^9 2.57; B^{10} 2.34; B^{11} 2.06; C^{12} 4.59; C^{13} 3.14, 4.03; N^{14} 2.35, 3.95; O^{16} none; F^{19} 1.53, 3.83; Ne 1.44, 4.36; Na^{23} 3.67; Al 1.02, 2.30, 2.89, 3.32, 4.48; Ni 1.44.

I. INTRODUCTION

THE investigation of inelastically scattered protons from light nuclei has proved useful for studying nuclear energy levels.[1,2] Although many light nuclei have been studied by inelastic scattering, no single investigation has surveyed most of these nuclei. Since the published cyclotron scattering data have not always agreed with the nuclear energy levels identified in disintegration experiments, it was believed desirable to resurvey as many of the nuclei as possible with a single technique. Furthermore, possible cyclotron energies might be expected to excite high angular momenta states in nuclei that might not appear in studies with more precise, but lower, bombarding energies available with electrostatic generators.

Consequently a study has been made of the elastic and inelastic scattering of 7.4-Mev protons at 90° to the incident beam for the stable elements through aluminum, with the exception of lithium and magnesium. In addition to the calculation of energy levels from the inelastically scattered proton groups, the relative cross sections of the groups have been determined and in the case of the gas targets, the absolute cross sections for the elastically scattered protons were obtained.

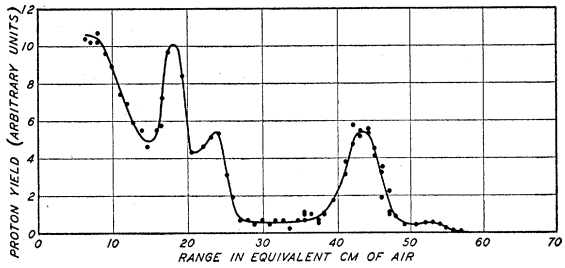

FIG. 1. Proton and deuteron groups for the reaction $Be^9(p,p)Be^{9*}$ and $Be^9(p,d)Be^8$. Ranges given in equivalent cm of air.

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II. APPARATUS AND EXPERIMENTAL TECHNIQUES

The external beam of protons from the 60-inch cyclotron at this laboratory was used to bombard the targets. Passage of the beam through the fringing field of the magnet assured considerable homogeneity of the beam energy. The target was 15 feet from the point of emergence of the beam from the electrostatic beam extractor. One-inch and $\frac{1}{4}$-inch diameter collimating aperture holes were placed in the path of the beam at distances of 8.3 feet and 10 inches, respectively, from the target position. The beam passed through the target chamber and into a Faraday cage where the collected charge was measured accurately by means of a simple current integrator consisting of a "glass-mike" condenser and an electroscope. The beam current was about 0.005 microampere.

The target chamber was formed from a brass block and was sealed with rubber gaskets to the vacuum tube passing the beam and to the Faraday cage. For the gas target experiments, the chamber was sealed on beam entrance and exit sides with brass plates having, respectively, $\frac{1}{4}$- and $\frac{3}{8}$-inch holes covered with 0.85-cm air-equivalence nickel foils. Two opposite ports at 90° to the beam direction allowed the mounting and quick removal of the thin targets supported on foils and allowed the emergence of fast particles through a nickel foil of 1.7-cm air equivalence. The particles were detected by a pair of coincidence proportional counters whose entrance port was sealed with a 1.7-cm air-equivalence nickel foil. The voltage on the counters was adjusted so that coincidences were only obtained for end-of-the-range protons. The coincidence detection was necessary because of the relatively high background near the cyclotron compared to the low counting rates for scattered protons from thin targets. Aluminum absorber foils, to measure the range of the particles, could be inserted between the 90° exit port and the counters. The foils were changed remotely by means of a wheel and selsyn system so that 24 range positions could be measured without entering the cyclotron room or interrupting the beam. The foils were weighed on a microbalance to one part in 500.

The electronic system for the counters consisted of two Los Alamos type Model 500 amplifiers of rise time 0.1 microsecond and a standard Rossi coincidence circuit

with time resolution of 0.2 microsecond. The coincidences were scaled by a scale of 64 circuit and recorded.

Targets of sodium were made by evaporating in vacuum onto 0.17-cm air-equivalent nickel foils. India ink and a solution of finely divided C^{13} (47 percent) enriched carbon were painted on similar nickel foils for the normal C and C^{13} enriched targets, respectively. The aluminum and beryllium targets were thin foils of these elements. All gas targets were at a pressure of 9 inches of mercury.

The ranges, as calculated by means of the weighed aluminum absorbers, were checked by observing proton groups from the reaction $B^{10}(d,p)B^{11}$. For this experiment the apparatus was installed on the electrostatic generator and a thin target of evaporated boron (enriched to 96 percent B^{10} and supplied by the Isotopes Division AEC, Oak Ridge) was bombarded by 1-Mev deuterons. The Q-values calculated for the four longest range groups from the range data agreed with those reported by Buechner and Van Patter.[3]

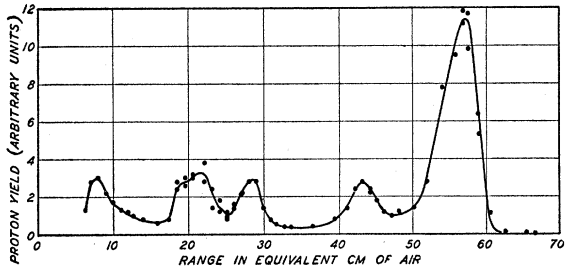

FIG. 2. Proton groups for the reaction $Al^{27}(p,p)Al^{27*}$. Ranges given in equivalent cm of air.

III. RESULTS AND CONCLUSIONS

Range curves of the charged particle groups are shown in Figs. 1, 2, and 3 for beryllium, aluminum, and neon, respectively. These curves are representative of those taken for foil and gas targets. Probable errors have not been indicated on the experimental points; however, the points of the group peaks represent several hundred counts.

The extrapolated ranges of the proton groups were measured in terms of the accurately weighed aluminum absorber foils by using an air equivalence of 1.52 mg/cm^2 per cm of air. The part of the range in the target gas (for gas targets only), the part in air, the part in the two nickel foils, and the average range in the counters, was added. Corrections for the variation of aluminum stopping power with range, corrections for range straggling, and angular straggling were applied and the energy of the proton groups obtained.[4]

The beam energy at the target was measured in each case by the elastically scattered groups. For the foil

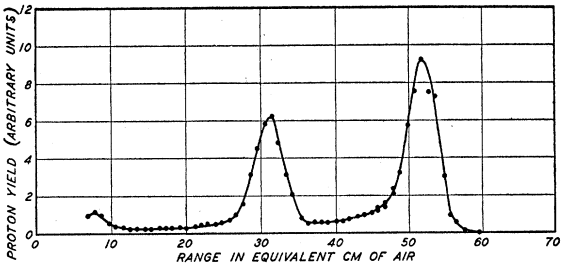

FIG. 3. Proton groups for the reaction $Ne^{20}(p,p)Ne^{20*}$. Ranges given in equivalent cm of air.

targets this energy was 7.37±0.10 Mev, while for the gas target it was 7.17±0.10 Mev.

The Q-values are presented in Table I as excited levels of the assigned nuclei. In the case of groups of uncertain origin the most reasonable reaction was tried and the Q-value calculated. The Q-values reported in the review articles by Hornyak *et al.*,[5] Alburger and Hafner,[6] and Reilley *et al.*[2] are included for comparison.

For the gas targets several integral type range curves were obtained on the elastic scattered proton groups. These data allowed the calculation of absolute cross sections for these reactions. The relative intensities of the shorter range groups were compared to the longest range group by graphical integration under the peaks of the range curves. These data are also given in Table I.

Most of the proton groups corresponded to previously

TABLE I. Summary of energy level values.

Nucleus	Target	Energy level (Mev)	Reported values (Mev)	Y_i/Y_e[a]	Cross section in barns
Be^9	Be^9 foil	2.57	2.42[b]	1.36	
B^{10}	$B^{10}F_3$ gas	0			0.44
B^{10}	$B^{10}F_3$ gas	2.34	2.14[b]		
B^{11}	normal BF_3 gas	0			0.44
B^{11}	normal BF_3 gas	2.06	2.14[b]		
C^{12}	india ink on Ni foil	4.59	4.47[b]		
C^{12}	CH_4	0			0.84
C^{13}(47%)	soot on Ni foil	3.14	3.10[b]		
		4.03	3.70[b]		
N^{14}	N_2 gas	0			0.54
N^{14}	N_2 gas	2.35	2.3[b]	0.05	0.027
N^{14}	N_2 gas	3.95	3.9[b]	0.13	0.070
O^{16}	O_2 gas	0			0.61
O^{16}	O_2 gas	no levels observed			
F^{19}	BF_3 gas	0			0.36
F^{19}	$B^{10}F_3$ and $^{19}BF_3$ gas	1.49	1.4[b]	0.30	0.11
F^{19}	$B^{10}F_3$ and BF_3 gas	3.90	not reported	0.07	0.025
Ne^{20}	neon gas	0			0.48
Ne^{20}	neon gas	1.44	1.5[b]	0.63	0.30
Ne^{20}	neon gas	4.36	4.2[b]	0.04	0.019
Na^{23}	Na on Ni foil	3.67	3.45[c]		
Al^{27}	Al foil	1.02	0.985[d]	0.13	
Al^{27}	Al foil	2.30	2.25[d]	0.11	
Al^{27}	Al foil	2.89	2.57[d]	0.11	
			3.04		
Al^{27}	Al foil	3.32	3.377[d]	0.05	
Al^{27}	Al foil	4.48	4.46[d]	0.10	
Ni	Ni foil	1.44	1.475[d]	0.12	

[a] Relative yield of inelastic to elastic scattered groups.
[b] See reference 5.
[c] See reference 6.
[d] See reference 2.

[3] W. W. Buechner and D. M. Van Patter, Phys. Rev. **79**, 240 (1950).
[4] M. S. Livingston and H. H. Bethe, Rev. Modern Phys. **9**, 245 (1937).
[5] Hornyak, Lauritsen, Morrison, and Fowler, Revs. Modern Phys. **22**, 291 (1950).
[6] D. E. Alburger and E. M. Hafner, Revs. Modern Phys. **22**, 373 (1950).

reported Q-values. For Be^9 only the one level at 2.57 Mev was observed. Levels higher than this might have been masked by a strong alpha-group appearing at ranges shorter than the proton group. The deuteron group from the $Be^9(p,d)Be^8$ reaction was observed between the inelastic and elastic proton groups with comparable intensity.

The C^{13} groups corresponding to reported levels at 3.10 and 3.70 Mev were observed but were very weak.

There were no groups in O^{16} for the energy region covered (to 4.6 Mev).

A new level at 3.90 Mev was found for fluorine in addition to the previously reported level at 1.4 Mev. This group appeared for both the BF_3 and CaF_2 targets.

Only natural neon gas was used, so the two observed levels were assigned to the most abundant isotope Ne^{20} (90 percent).

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A Study of the Electron Traps in Zinc Sulfide Phosphor

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The thermoluminescence characteristics of a hexagonal zinc sulfide phosphor, copper activated, were measured as a function of the wavelength of the exciting light. The glow curve had maxima at 120, 220, and 280°K. It was found that the heights of these maxima at saturation varied with the wavelength of the exciting light, reaching the greatest values at 4270A for the 120°K maximum, 4400A for the 220°K maximum, and 4500A for the 280°K maximum. When the sample was irradiated with 4400A light for a definite time interval and then irradiated with monochromatic radiation of either shorter or longer wavelength for another time interval, it was found that the subsequently measured glow curve showed a decrease in the heights of the maxima from that with 4400A light alone. Since the glow curve can be interpreted as a process of emptying electrons from traps, the above results are interpreted to mean that light which is capable of filling the traps is also capable of stimulating electrons out of the traps. There is a long wavelength limit beyond which irradiation does not affect electrons present in traps. It is 0.7 micron for the trap represented by the 280°K maximum.

INTRODUCTION

THERMOLUMINESCENCE experiments have been used to characterize phosphors.[1–4] In these experiments a phosphor is excited with radiation for a definite period of time, the exciting light is removed, the material is heated at a constant rate, and the light output is measured as a function of the temperature of the phosphor. The glow curve so obtained is often characterized by the presence of peaks which can be interpreted in the following way: The position of the peaks on the temperature scale is a measure of the energy depth of trapped electrons in the solid, while the area under the peak often indicates the number of electrons transferred into these traps by the exciting light. It is the purpose of this investigation to study the the process of the filling and the emptying of the electron traps in a hexagonal zinc sulfide, copper activated, as a function of the wavelength of the exciting light.

EXPERIMENTAL PROCEDURE

The phosphor used in these studies was a copper-activated hexagonal zinc sulfide obtained from Leverenz of the RCA Laboratories. The phosphor was settled with ethanol in a layer about 1 mm thick on a flat-bottomed glass tube. This tube was suspended in a cavity in a copper cylinder which in turn was suspended in a Dewar flask. The phosphor could be maintained at the temperature of liquid air or heated at a rate of about 0.017°K. The temperature of the phosphor was measured by means of a chromel alumel thermocouple buried in the phosphor layer.

The phosphor was excited by monochromatic light either from a carbon arc, 100-candlepower Point-o-lite lamp or a globar. Either a Gaertner glass monochromator or a rock salt monochromator (Wadsworth mounting) was used to give monochromatic light. The current from the photomultiplier tube was amplified by means of a dc amplifier and recorded on a Brown potentiometer. No filter was used in measuring the light output of the phosphor since the emission band in the samples used was exclusively in the green region. Attempts to detect the blue band, which sometimes occurs in these phosphors, by spectral isolation with a 35D Wratten filter were unsuccessful.

RESULTS AND DISCUSSION

A typical glow curve for the phosphor sample used in these experiments is shown in Fig. 1. The important features are the three peaks at about 115°K, 225°K, and 280°K and the shoulder at about 180°K. Under

* AEC Predoctoral Fellow, 1949–50.
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