Inelastic Scattering of Protons from Cl^{35} and Cl^{37}†

J. P. SCHIFFER, C. R. GOSSETT,* G. C. PHILLIPS, AND T. E. YOUNG
The Rice Institute, Houston, Texas
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The Rice Institute 180°-magnetic spectrometer was used in measuring the energies of inelastically scattered protons from targets of normal KCl and from NaCl targets enriched in Cl^{35} and Cl^{37}. Bombarding energies of 4.6, 4.7, 4.8, 5.0, and 5.6 Mev were used. One state of 1.713±0.010 Mev was observed in Cl^{37} and two states at 1.220±0.005 and 1.766±0.005 Mev are assigned to Cl^{35} for energies of excitation below 2 Mev. No state below 2.0-Mev excitation was observed in K^{39}, while the first excited state of Na^{23} was determined as 437±5 kev.

THE energies of low-lying levels in the nuclei Cl^{35} and Cl^{37} have been measured accurately by using a 180°-magnetic spectrometer,[1] in conjunction with the Rice Institute Van de Graaff generator. These nuclei were excited by inelastically scattering protons whose bombarding energies ranged from 4.6 to 5.6 Mev. The energies of the protons were determined by measuring their momenta in the magnetic field of the spectrometer. From the proton energies the Q values for the reactions were determined. In the case of inelastic scattering, the Q value is the negative of the energy of excitation of the level to which the scattering occurred. From the manner in which observed proton peaks shifted with bombarding energy, the approximate mass of the isotope responsible for the level can be determined. In this way peaks from impurities were identified. Since natural chlorine contains 75.4% Cl^{35} and 24.6% Cl^{37}, it was necessary to use enriched isotope targets to assign the levels to the appropriate isotopes.

Initial work on this reaction was done using natural

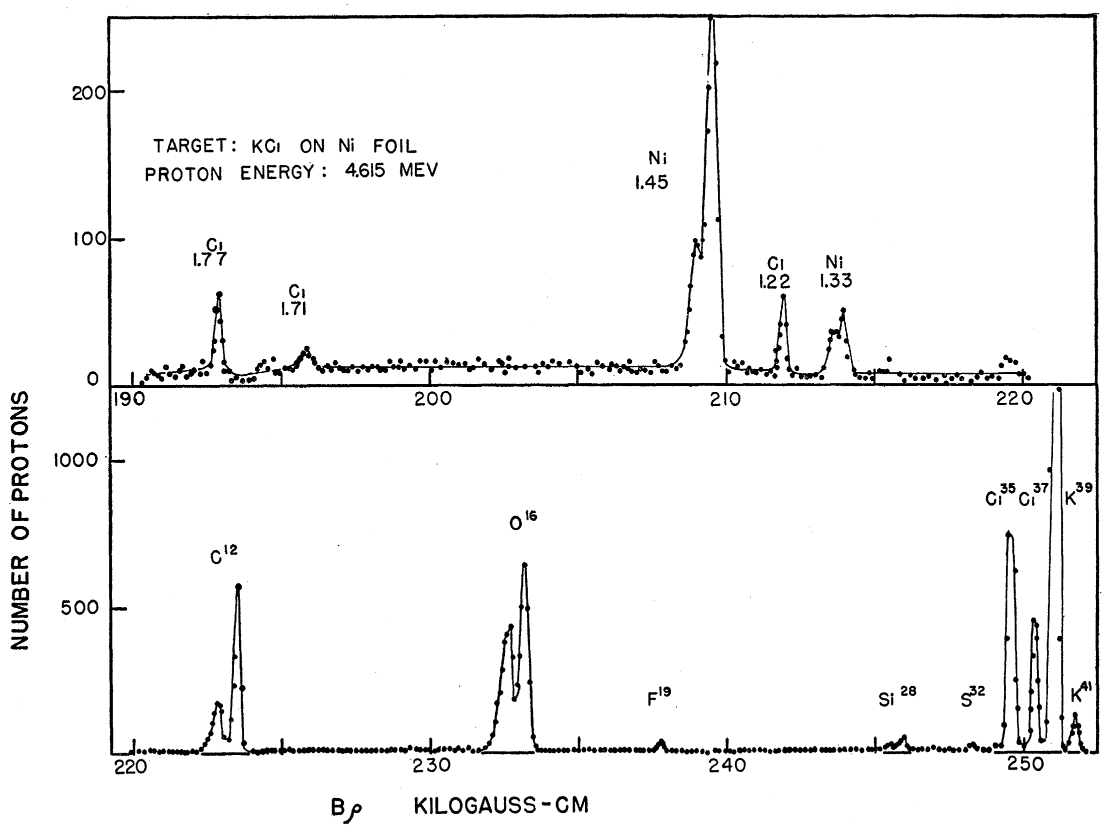

FIG. 1. Spectrum of protons scattered from a KCl target evaporated on a thin Ni foil. Levels assigned to Cl, Ni, and various contaminants are so indicated.

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* Now at Naval Research Laboratory, Washington, D. C.
[1] Gossett, Phillips, and Eisinger, Phys. Rev. 98, 724 (1955).

KCl targets evaporated on thin Ni and C foil backings. From this it was learned that three of the levels observed were due to Cl or K, as shown in Fig. 1. A repetition of the experiment under identical conditions using KI as a target indicated that none of the three levels observed corresponded to states in K^{39}, or that K^{39} did not have a state that was observed in the present work below 2.0-Mev excitation. This is in agreement with recent work by Sperduto and Buechner.[2] To obtain definite isotopic assignment of the levels in Cl, samples of NaCl with enrichment of the isotopes Cl^{35} and Cl^{37} to 95% and 67%, respectively, were obtained on a loan from the Oak Ridge National Laboratory. The assignment of the levels, to a particular isotope, was made on the basis of relative intensities.

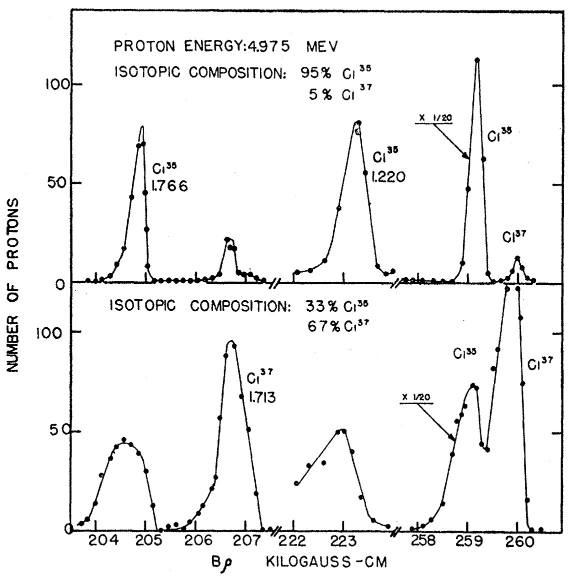

FIG. 2. Partial spectra of protons scattered from NaCl targets enriched in the Cl isotopes, per 500 microcoulombs of protons. The two peaks on the right are due to elastically scattered protons, while the three peaks on the left are due to inelastic scattering from Cl. The peak intensities were not in the exact ratio of the relative enrichments, because of the effects of resonances in the compound nucleus and the difference in target thickness for the two targets.

As is shown in Fig. 2, two of the levels, at 1.220 and 1.766 Mev, can definitely be assigned to Cl^{35} while the 1.713-Mev state is assigned to Cl^{37}. The fact that the ratio of observed intensities in Fig. 2 is not exactly the same as the ratio of isotopic abundances can probably be explained by a strong resonance in the compound nucleus. Many resonances are observed in the similar reaction of inelastic scattering on Ni, where intensity changes by factors of 5 are often observed in energy intervals of 2 kev. The isotopic assignment is based upon the data shown in Table I.

[2] A. Sperduto and W. W. Buechner, Phys. Rev. **100**, 961(A) (1955).

TABLE I. Observed energy levels.

Energy of excitation (Mev)	Isotope assigned	Proton bombarding energy (Mev)	Target material[a]	Intensity ratio[b]
1.219	Cl^{35}	4.615	KCl	
1.210		4.713	$NaCl^{35}$	
1.221		4.839	$NaCl^{37}$	
1.223		4.630	$NaCl^{35}$	
1.221		4.977	$NaCl^{35}$	
				3:1
1.221		4.975	$NaCl^{37}$	
Av = 1.220±0.005				
1.760	Cl^{35}	5.604	KCl	
1.762		4.615	KCl	
1.762		4.839	$NaCl^{37}$	
1.769		4.713	$NaCl^{35}$	
				3:1
1.778		4.711	$NaCl^{37}$	
1.767		4.977	$NaCl^{35}$	
				2:1
1.762		4.975	$NaCl^{37}$	
Av = 1.766±0.005				
1.700	Cl^{37}	4.615	KCl	
1.700		5.604	KCl	
1.726		4.839	$NaCl^{37}$	
1.716		4.711	$NaCl^{37}$	
				1:8
1.711		4.713	$NaCl^{35}$	
1.724		4.975	$NaCl^{37}$	
				1:5
1.720		4.977	$NaCl^{35}$	
Av = 1.713±0.010				
0.441	Na^{23}	4.415	NaCl	
0.431		4.713	NaCl	
0.439		4.711	NaCl	
Av = 0.437±0.005				

[a] Target material designated $NaCl^{35}$ was an evaporated layer of NaCl with the Cl enriched to 95% Cl^{35}, while the target material designated $NaCl^{37}$ had the Cl enriched to 67% Cl^{37}.
[b] The intensity ratio is the ratio of the numbers of protons inelastically scattered to a particular excited state, from two targets of identical chemical composition and mass per unit area, but of differing isotopic composition. In this case, the ratio is the ratio of the number of protons inelastically scattered from a target enriched in Cl^{35} to the number scattered from an equivalent target enriched in Cl^{37}.

Pieper, Stanford, and Herrmann[3] report states in Cl^{35} as 0.7, 1.1, and 1.7 Mev from the reaction $S^{32}(\alpha,p)Cl^{35}$. While the upper two states are in rough agreement with the present work, the inelastic proton scattering experiments showed no evidence for the state at 0.7 Mev. However, the two levels in Cl^{35} reported here are in almost exact agreement with those reported recently by Van Patter *et al.*[4]

No level in the region of 1.713 Mev of excitation of Cl^{37} had been reported previously. The S^{37} beta decay only shows evidence for a state in Cl^{37} at 3.1 Mev.[5] The first excited state found for Na^{23} is in good agreement with that reported by Donahue, Jones, McEllistrem, and Richards[6] by electrostatic analysis.

[3] Pieper, Stanford, and Herrmann, Phys. Rev. **98**, 1185(A) (1955).
[4] Van Patter, Swann, Porter, and Mandeville, Bull. Am. Phys. Soc. Ser. II **1**, 39 (1956).
[5] E. Bleuler and W. Zünti, Helv. Phys. Acta **19**, 137 (1946); H. Morinaga and E. Bleuler, Bull. Am. Phys. Soc. Ser. II **1**, 30 (1956).
[6] Donahue, Jones, McEllistrem, and Richards, Phys. Rev. **89**, 824 (1953).