where Eq. (27.1) of BE, *viz.*,

$$1/\lambda_1=|aR_{1n}(a)|^2/(u_{1n},u_{1n}), \tag{4.5}$$

has been applied. Equation (4.4) is in fact just the expression for β given in Eq. (24.1) of BE. The same result for the transition probability is thus obtained if the condition of resonance between the states of the two nuclei may be ignored. The results for cross sections and angular distributions quoted in the previous work may therefore be carried over directly to this treatment in the absence of resonance. If Eq. (2) were written in terms of a transformation angle $\frac{1}{2}\tan^{-1}(2A)$, the integral for the transition probability would involve $\int\frac{1}{2}(\tan^{-1}2A)dt$, instead of $\int Adt$. The difference between the two results would only be less than 2% at 10 Mev and less than 30% at 15 Mev.

It may be remarked that, by employing exact adiabatic functions but omitting the process of linearly combining them to improve convergence as done by BE, a slightly incorrect answer is obtained. On the other hand, if the inexact form listed in Eq. (2) is employed and the linear combinations are not taken, the energy matrix answer of BE is reproduced, the errors of the two approximations being of a compensating nature.

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Nuclear Levels in S^{32}, S^{34}, Cl^{35}, and Cl^{37}†

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Barium-chloride targets have been bombarded with protons accelerated by an electrostatic generator to an energy of 7.04 Mev. Charged reaction products (alpha particles and elastically and inelastically scattered protons) were observed at 90 and 130 degrees to the proton beam with a high-resolution magnetic analyzer. The following ground-state Q values have been measured: $Cl^{35}(p,\alpha)S^{32}$, $Q=1.863\pm0.008$ Mev; $Cl^{37}(p,\alpha)S^{34}$, $Q=3.026\pm0.008$ Mev. Levels were observed in S^{32} at 2.237, 3.780, 4.287, 4.465, and 4.698 Mev; in S^{34} at 2.127, 3.302, 3.915, 4.073, 4.114, 4.621, 4.685, and 4.876 Mev; in Cl^{35} at 1.221, 1.763, 2.645, 2.695, 3.006, (3.165), 4.058, 4.113, and 4.174 Mev; in Cl^{37} at 0.838, 1.728, (3.087), and (3.105) Mev.

I. INTRODUCTION

In a previous paper,[1] investigations were described of the level schemes of the nuclei S^{33}, S^{35}, Cl^{36}, and Cl^{38}. Barium-chloride targets were bombarded with deuterons, and the alpha particles and protons from the (d,α) and (d,p) reactions on chlorine were magnetically analyzed.

The same technique has been applied to the charged reaction products from the proton bombardment of these targets. This provides the level schemes of the nuclei S^{32}, S^{34}, Cl^{35}, and Cl^{37} through the (p,α) and (p,p') reactions on the chlorine isotopes Cl^{35} and Cl^{37}.

Very little was known of the Cl^{35} and the Cl^{37} level schemes; only three levels were known in S^{34}, while seven levels[2] had been found in S^{32}.

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[1] Paris, Buechner, and Endt, Phys. Rev. **100**, 1317 (1955).

[2] P. M. Endt and J. C. Kluyver, Revs. Modern Phys. **26**, 95 (1954).

II. EXPERIMENTAL PROCEDURE

Protons were accelerated to an energy of 7.037 Mev with the MIT–ONR electrostatic generator.[3] Energies of charged reaction products emitted from the target at angles of 90 or 130 degrees to the proton beam were determined with a broad-range magnetic spectrograph.[4] The preparation of $BaCl_2$ targets has been described in the Cl+d paper.[1]

Four different bombardments were performed; one on a thick target at $\theta=130°$; one on a thin target at $\theta=130°$; and two on a thin target at $\theta=90°$ with different spectrograph field settings so as to focus either the high-energy (3.8 to 9.0 Mev) or the low-energy part (2.5 to 5.8 Mev) of the secondary particles on the nuclear emulsion serving for particle detection.

The assignment of particle groups to the responsible isotope was made by observing the energy difference

[3] Buechner, Sperduto, Browne, and Bockelman, Phys. Rev. **81**, 1502 (1953).

[4] Buechner, Browne, Enge, Mazari, and Buntschuh, Phys. Rev. **95**, 609(A) (1954); Buechner, Mazari, and Sperduto, Phys. Rev. **101**, 188 (1956).

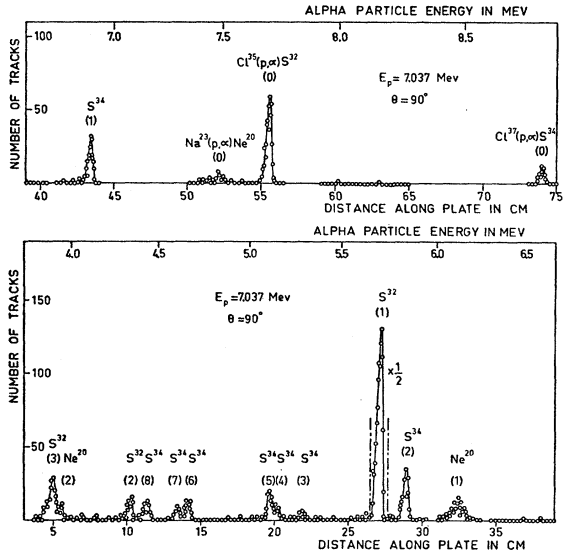

FIG. 1. Alpha-particle groups from the proton bombardment of a thin $BaCl_2$ target at $E_p=7.037$ Mev and $\theta=90°$.

of particles emitted at $\theta=90°$ and at $\theta=130°$, which depends on the mass of the initial nucleus. For instance, the $Cl^{37}(p,p')Cl^{37}$ proton groups shift, relative to the $Cl^{35}(p,p')Cl^{35}$ proton groups, by an amount varying from 13 kev (at $E_{p'}=6.5$ Mev) to 9 kev (at $E_{p'}=3.0$ Mev). For $Cl^{35}(p,\alpha)S^{32}$ and $Cl^{37}(p,\alpha)S^{34}$ alpha-particle groups, the relative energy shift is twice this amount.

III. RESULTS

The alpha-particle spectrum obtained from the thin $BaCl_2$ target at $\theta=90°$ is shown in Fig. 1. Regions where no points have been plotted have been scanned rapidly. No groups were expected in these regions, and none were found. Three groups can be assigned to the $Na^{23}(p,\alpha)Ne^{20}$ reaction. Their Q values are as to be expected from known masses and from known excitation energies in Ne^{20}. They are also found from the exposure at $\theta=130°$, showing the expected energy shift. Finally, they are definitely broader than the groups from chlorine, indicating that the sodium was present as a contaminant in the target backing.

The other alpha-particle groups have been assigned to either the $Cl^{35}(p,\alpha)S^{32}$ or to the $Cl^{37}(p,\alpha)S^{34}$ reaction. In Table I, Q values and corresponding excitation energies are given for these reactions. Groups (4) and (5) from the $Cl^{35}(p,\alpha)S^{32}$ reaction are not shown in Fig. 1, but they have been observed in two other exposures at lower spectrograph field settings.

A proton spectrum at $\theta=130°$ is shown in Fig. 2. Proton groups are found from elastic scattering by Au, Ba, Ag, Cu, K^{39}, Cl^{37}, Cl^{35}, S^{34}, S^{32}, Na^{23}, O^{18}, O^{16}, N^{14}, C^{13}, and C^{12}. The gold, silver, and copper are present in the gold foil which was used to strengthen the Formvar backing. The presence of strong sodium and sulfur contamination in the target backing gave rise also to groups of inelastically scattered protons in the expected positions. No groups were present from inelastic scattering on barium. Levels are known in Ba^{138} at 1.44, 1.90, and 2.88 Mev,[5] but the corresponding proton groups were not observed.

TABLE I. Q values from $Cl^{35}(p,\alpha)S^{32}$ and $Cl^{37}(p,\alpha)S^{34}$ and excitation energies in S^{32} and S^{34} (in Mev).

Group	Q value present work	E_x present work	Q value[a]	E_x [b]
	$Cl^{35}(p,\alpha)S^{32}$			$S^{32}(p,p')S^{32}$
(0)	1.863±0.008	0	1.865±0.015	0
(1)	−0.374±0.008	2.237±0.008		2.25±0.02
(2)	−1.917±0.008	3.780±0.008		3.81±0.02
(3)	−2.424±0.008	4.287±0.008		4.32±0.02
(4)	−2.602±0.010	4.465±0.010		4.50±0.02
(5)	−2.835±0.010	4.698±0.010		4.74±0.02
	$Cl^{37}(p,\alpha)S^{34}$			$Cl^{34}(\beta^+)S^{34}$ [c]
(0)	3.026±0.008	0	3.015±0.015	0
(1)	0.899±0.008	2.127±0.008		2.10±0.03
(2)	−0.276±0.008	3.302±0.008		3.24±0.03
(3)	−0.889±0.008	3.915±0.008		3.9
(4)	−1.047±0.008	4.073±0.008		
(5)	−1.088±0.008	4.114±0.008		
(6)	−1.595±0.008	4.621±0.008		
(7)	−1.659±0.008	4.685±0.008		
(8)	−1.850±0.008	4.876±0.008		

[a] Almqvist, Clarke, and Paul, Phys. Rev. **100**, 1265(A) (1955).
[b] Arthur, Allen, Bender, Hausman, and McDole, Phys. Rev. **88**, 1291 (1952).
[c] See reference 2, and E. Bleuler and H. Morinaga, Phys. Rev. **99**, 658(A) (1955).

TABLE II. Excitation energies in Cl^{35} and Cl^{37} from $Cl^{35}(p,p')Cl^{35}$ and $Cl^{37}(p,p')Cl^{37}$.

Group	$Cl^{35}(p,p')Cl^{35}$ E_x (in Mev)	Group	$Cl^{37}(p,p')Cl^{37}$ E_x (in Mev)
(1)	1.221±0.005	(1)	0.838±0.005
(2)	1.763±0.005	(2)	1.728±0.005
(3)	2.645±0.005	(3)	(3.087±0.008)
(4)	2.695±0.005	(4)	(3.105±0.008)
(5)	3.006±0.005		
(6)	(3.165±0.008)		
(7)	4.058±0.005		
(8)	4.113±0.005		
(9)	4.174±0.005		

Conspicuous is the large intensity of all $Cl^{35}(p,p')Cl^{35}$ inelastic groups, which was between 20 and 50% of the intensity of the elastic group. The $Cl^{37}(p,p')Cl^{37}$ inelastic groups reach at most 5% of the corresponding elastic group. The large intensity of the $Cl^{35}(p,p')Cl^{35}$ groups and of the alpha-particle group from the $Cl^{35}(p,\alpha)S^{32}$ reaction, leading to level (1) in S^{32}, would most naturally be explained by the assumption that $Cl^{35}+p$ shows a resonance for the bombarding energy used, corresponding to an excitation energy in A^{36} of 15.35 Mev. This is above the threshold for breakup into A^{35} and a neutron, but only by about 0.7 Mev.

Excitation energies in Cl^{35} and Cl^{37} are collected in Table II. Groups (7), (8), and (9) assigned to Cl^{35}

[5] Hollander, Perlman, and Seaborg, Revs. Modern Phys. **25**, 469 (1953).

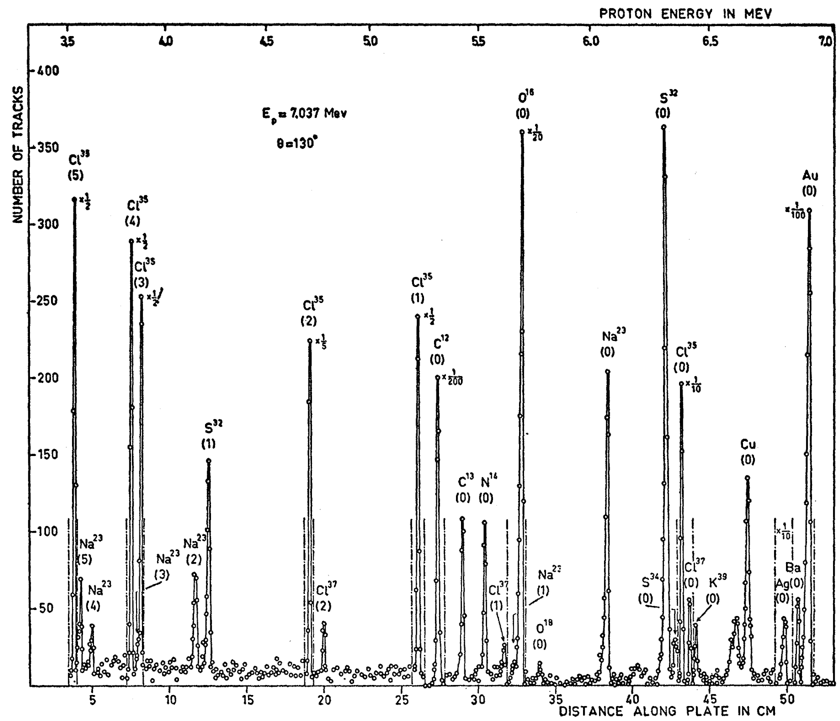

FIG. 2. Proton groups from the proton bombardment of a thin $BaCl_2$ target at $E_p=7.037$ Mev and $\theta=130°$.

have only been observed in the $\theta=90°$ exposure with low spectrograph magnetic field. The assignment, however, must be regarded as unambiguous, because their intensity is as large as that of the other inelastic Cl^{35} groups, and also because they cannot be identified with known contaminant inelastic groups. Group (6) assigned to Cl^{35} and groups (3) and (4) assigned to Cl^{37} appear in the $\theta=90°$ exposure with low spectrograph field and in the $\theta=130°$ thick-target exposure. They certainly result from inelastic scattering on chlorine, but the observed energy shift is not accurate enough to determine the responsible isotope uniquely; nor is the intensity of group (6), which is about 10% of the Cl^{35} elastic group, as large as that of the other Cl^{35} inelastic groups.

IV. DISCUSSION

The ground-state Q values found for the $Cl^{35}(p,\alpha)S^{32}$ and $Cl^{37}(p,\alpha)S^{34}$ reactions have also been measured recently by Almqvist, Clarke, and Paul.[6] Their data have been included in Table I. The $Cl^{35}(p,\alpha)S^{32}$ Q value can also be computed from that of the $Cl^{35}(d,\alpha)S^{33}$ reaction[1] and from the $S^{33}-S^{32}$ mass difference given by Li.[7] This yields 1.858 ± 0.014 Mev, in very good agreement with the value of 1.863 ± 0.008 Mev measured in this work, and with the value of 1.865 ± 0.005 Mev given by Almqvist *et al.*

The known data on the S^{32} level scheme have been reviewed by Endt and Kluyver.[2] The excitation energies found from inelastic scattering of 8-Mev protons on sulfur by Arthur, Allen, Bender, Hausman, and McDole[8]

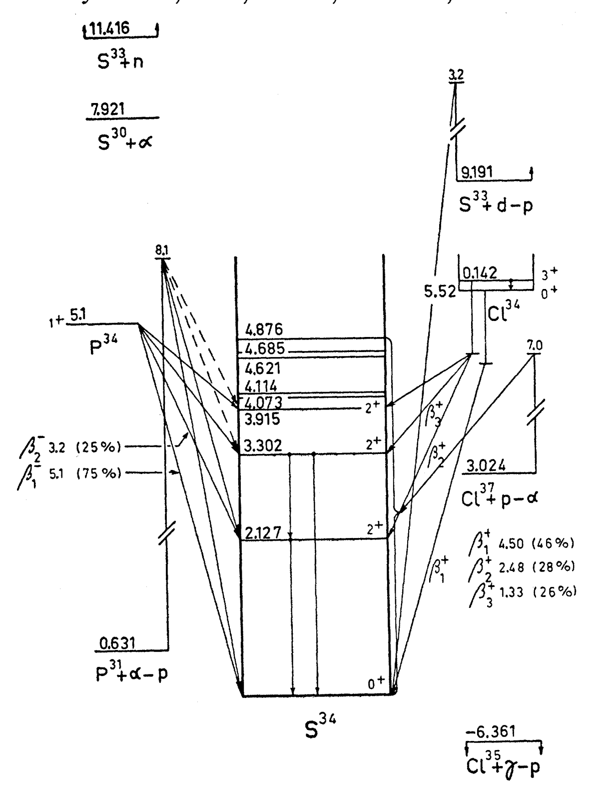

FIG. 3. Level scheme of S^{34}.

[6] Almqvist, Clarke, and Paul, Phys. Rev. **100**, 1265(A) (1955).
[7] C. W. Li, Phys. Rev. **88**, 1038 (1952).
[8] Arthur, Allen, Bender, Hausman, and McDole, Phys. Rev. **88**, 1291 (1952).

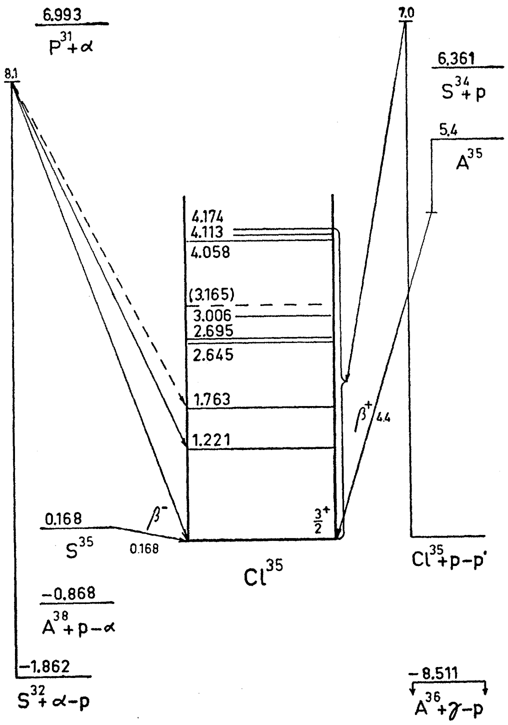

FIG. 4. Level scheme of Cl^{35}.

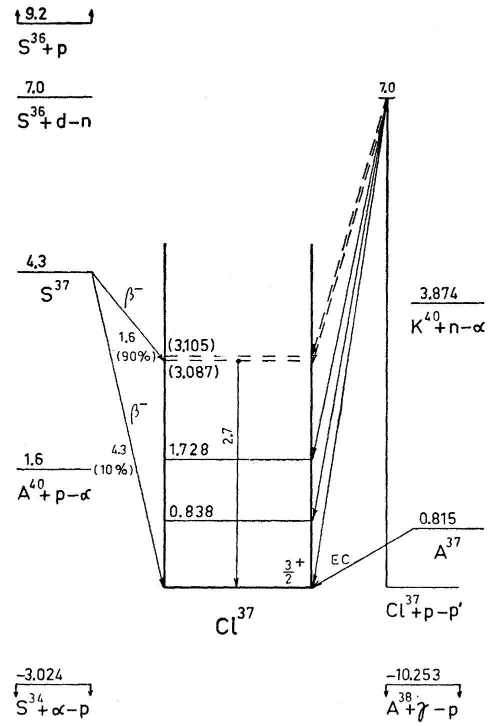

FIG. 5. Level scheme of Cl^{37}.

have been included in Table I. Their values are in general agreement with those found in the present work. The excitation energy of the first level in S^{32}, as found from the $S^{32}(n,n'\gamma)S^{32}$ reaction, has been given by Day[9] as 2.23 ± 0.02 Mev. In recent work at MIT, an excitation energy of 2.233 Mev has been measured in inelastic proton scattering studies.

The three lower levels found in S^{34} have also been observed from the $Cl^{34}(\beta^+)S^{34}$ decay (see Table I) and from the $P^{34}(\beta^-)S^{34}$ decay.[10] Levels at (0.7), 2.1, (3.0), and (3.6) Mev are found from the $P^{31}(\alpha,p)S^{34}$ reaction.[11] A level at 0.82 Mev has also been reported from the $S^{33}(d,p)S^{34}$ reaction.[12] No alpha-particle group corresponding to this excitation energy has been observed in the present work. although the region of the spectrum where such a group could be expected has been counted with care.

Levels in Cl^{35} are reported at (0.7), 1.1, and (1.7) Mev from the $S^{32}(\alpha,p)Cl^{35}$ reaction.[11] The doubtful level at 0.7 Mev has not been observed in the present work, while the levels at 1.1 and 1.7 Mev agree with those of Table II at 1.221 and 1.763 Mev. No accurate measurements exist of excitation energies of levels in Cl^{37}.

The level schemes of S^{34}, Cl^{35}, and Cl^{37} are given in Figs. 3, 4, and 5, in which the present results and those of others have been incorporated.

[9] R. B. Day, *International Conference on Peaceful Uses of Atomic Energy*, Geneva, 1955 (to be published).
[10] E. Bleuler and H. Morinaga, Phys. Rev. **99**, 658(A) (1955).
[11] Pieper, Stanford, and Von Herremann, Phys. Rev. **98**, 1185(A) (1955).
[12] P. W. Davison, Phys. Rev. **75**, 757 (1949).