Q-Value Measurements for Phosphorus and Chlorine*

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Targets containing phosphorus and chlorine have been bombarded by protons accelerated by the ONR-Bartol Van de Graaff generator. Charged particles from nuclear reactions have been analyzed at 90° by using a 180° double-focusing magnetic spectrometer. The following ground-state Q-values have been determined: $P^{31}(p,\alpha)Si^{28}$, $Q=1.911\pm0.005$ Mev; $Cl^{35}(p,\alpha)S^{32}$, $Q=1.851\pm0.007$ Mev; $Cl^{37}(p,\alpha)S^{34}$, $Q=3.015\pm0.011$ Mev. The following level positions have been measured: P^{31}, 1.264 ± 0.004 Mev; S^{34}, 2.129 ± 0.014 Mev; Cl^{35}, 1.219 ± 0.005 Mev and 1.760 ± 0.004 Mev.

At $E_p=3.055$ Mev, a survey was made for inelastic proton groups from P^{31} corresponding to levels from 0 to 1.43-Mev excitation. Only one group ($Q=-1.264$ Mev) was observed; no other groups were observed with an intensity greater than 15% of the intensity of this group.

I. INTRODUCTION

DURING the past two years, the determination of level energies by using high-resolution magnetic analysis of charged particles from nuclear reactions has been extended to several nuclei in the region of $A>30$.[1] However, there remain many nuclei which have not been subjected to such an investigation. The nuclei P^{31}, Cl^{35}, and Cl^{37} were in this category at the time this investigation was begun.

There is also current interest in precise measurements of ground-state Q-values, particularly in the region of S to Sc, in order to extend the region of atomic masses which can be completely linked by reaction energy determinations. The ground-state Q-values of the $Cl^{35}(p,\alpha)S^{32}$ and $Cl^{37}(p,\alpha)S^{34}$ reactions had not been reported at the time the present measurements were completed.

A 180° double-focusing magnetic spectrometer has been constructed at Bartol.[2] For a first investigation using this spectrometer, it was decided to attempt to make precise measurements of a few reaction energies for P and Cl bombarded by protons. Since the completion of these measurements, the results of similar investigations made at other laboratories have become available. A preliminary report of the present measurements has been presented.[3]

II. EXPERIMENTAL PROCEDURE

The ONR-Bartol Van de Graaff accelerator, with the associated 90° deflecting magnet, provided protons in an energy range of 1.8 to 4.0 Mev for this investigation. A relative measure of the magnetic field of the deflecting magnet is obtained using a proton moment probe, which, in conjunction with the energy-defining slits, provides a beam energy reproducible to about ±3 kev for this present experiment. Normally, measurement of the $Li^7(p,n)Be^7$ threshold gives an absolute energy calibration for the deflecting magnet. However, for most of this investigation, the bombarding energy was determined by means of the magnetic spectrometer.

At a distance of 23 cm from the target, the horizontal proton beam passed through a second slit, limiting it to 2.5 mm in the vertical dimension. The horizontal dimension of the beam was limited to 1.6 mm by a slit placed 8 cm from the target. The targets were placed at an angle of 45° to the beam, being mounted on a probe which could be inserted through a vacuum interlock. For an observation angle of 90°, the particles entering the spectrometer emerged from the side of the target bombarded by the beam. After being deflected 180° in the spectrometer magnet, the analyzed particles passed through two adjustable detector slits placed at the position of focus. For most measurements, these detector slits were adjusted to accept particles over an area of 2.5 mm×7.5 mm. The detector consisted of a cleaved NaI crystal, coupled to a RCA 6342 photomultiplier.

The 180° double-focusing magnet is essentially a reproduction of the 16-inch-radius Cal. Tech. magnet.[4] This magnet has a full acceptance angle in the horizontal plane of about 3°; however, for some measurements, a tantalum collimator was inserted which reduced the acceptance angle to about 1°. The magnet is mounted on a turret, so that it can be rotated easily by hand; however, for this first investigation, all observations were made at a fixed angle of observation of $90.0\pm0.3°$. The angle of observation was measured directly by rotation of a slit from the beam direction to the position of maximum number of protons elastically scattered from the target into the spectrometer, with an acceptance angle of 1°.

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[1] For example see: Paris, Buechner, and Endt, Phys. Rev. **100**, 1317 (1955); A. Sperduto and W. W. Buechner, Phys. Rev. **100**, 961 (1955); Schiffer, Windham, Gossett, and Phillips, Phys. Rev. **99**, 655 (1955); G. M. Foglesong and D. G. Foxwell, Phys. Rev. **96**, 1001 (1954); C. M. Braams, Phys. Rev. **95**, 650 (1954); **94**, 763 (1954).

[2] The initial construction and testing of the spectrometer was done by Dr. W. D. Whitehead, now at North Carolina State College, Raleigh, North Carolina.

[3] Van Patter, Swann, Porter, and Mandeville, Bull. Am. Phys. Soc. Ser. II, **1**, 39 (1956).

[4] Snyder, Rubin, Fowler, and Lauritsen, Rev. Sci. Instr. **21**, 852 (1950); W. Whaling and C. W. Li, Phys. Rev. **81**, 150 (1951).

Relative measures of the magnetic field of the spectrometer were obtained by means of a torsion balance, placed at the 90° position of the magnet. This balance consists of a current-carrying coil mounted on a long balance arm, which is balanced on two pivots placed along the axis of the arm. The coil was located at a distance of 2.3 in. from the center of the magnetic field. A constant torque is provided by a rider arm, which can be nullified by the opposing torque exerted on the coil in the magnetic field. In order to increase the mechanical reproducibility of the balance, its angular motion is restricted to 2°. The angular position of the balance arm is indicated by means of a light beam reflected from a mirror attached to the balance arm. The position of the light beam is compared with the position of a similar light beam reflected from a fixed mirror, by means of two photoelectric cells and a balance circuit which compares their two signals. The over-all sensitivity of the system is quite satisfactory, better than 0.01%. Over a period of several weeks, the reproducibility of the torsion balance was observed to be less satisfactory, about $\pm 0.04\%$. Investigation of the effect of heating on the calibration of the torsion balance indicated that, for the highest magnet currents employed ($\sim$100 amp), the change in calibration was less than 0.03%.

Investigations of the focusing properties of the magnet were made prior to the reaction energy measurements. Using a Po-α source placed at the target position, the detector-to-spectrometer distance giving the best resolution was determined for various target-to-spectrometer distances. The results indicated a radial magnetic field varying as $r^{-0.52}$ for this magnet, rather than $r^{-0.50}$ which is expected. The momentum profile of the Po alphas was then measured as functions of the separations of the two detector slits for two source sizes. The best resolution observed corresponded to 0.08% in momentum, using a $\frac{1}{16}$-inch-diameter source, in agreement with theoretical expectation. However, for the measurements of nuclear reaction groups, the momentum resolution normally obtained was $\geqslant 0.2\%$, for reasons of intensity and finite acceptance angle of the spectrometer.

A daily calibration of the torsion balance was provided by a polonium source of the same dimensions as the beam spot which could be inserted to a position coinciding within ± 0.013 inch of the location of the beam striking the target. Hence the radii of curvature of the Po alphas and reaction particles were equal within $\pm 0.04\%$. The bombarding energy for each precise determination of a reaction energy was determined by analyzing one or more proton groups elastically scattered from the target material. A typical target backing consisted of a thin film of Formvar mounted on a $\frac{1}{2}$-inch-square wire frame, on which was evaporated a thin gold layer to improve heat conduction. A thin layer of the desired material was then deposited on the backing by evaporation in vacuum. These targets usually survived maximum beam currents of 0.2 to 1 μa (depending on the target material) over an area of 4 mm^2.

In order to obtain sufficient yields of the reaction groups for precise Q-value measurements, it was necessary to choose a bombarding energy corresponding to a resonance for the particular reaction group. Hence, rough excitation curves were measured over limited energy ranges for the purpose of locating such resonances; however, these excitation curves were not normally measured with enough detail for accurate estimates of the locations and half-widths of the resonances. A particle group of given momentum could be readily identified as a proton or alpha group from the pulse size observed from the NaI crystal, which was a factor of two greater for protons. In order to reduce background, pulses of the correct size for the desired particle were selected by means of a single-channel discriminator. Each point taken for the measurement of a momentum profile consisted of a short exposure of duration 0.1 to 5 minutes, depending on the intensity of the group being analyzed.

III. RESULTS AND DISCUSSION

Aluminum

In order to test the performance of the spectrometer, several charged particle groups from the proton bombardment of thin Al targets on Formvar were analyzed. The results of one survey are shown in Fig. 1, for which a target 9 kev thick for the $Al^{27}(p,p)$ group was used, at a bombarding energy of 3.633 Mev corresponding to a resonance for the $Al^{27}(p,\alpha)Mg^{24}$ group. The acceptance angle of the spectrometer was limited to 1° for this survey. The elastically scattered proton group from Al^{27}, and inelastic groups corresponding to the first two states of Al^{27} are indicated. In addition, elastically scattered groups from C^{12} and O^{16} nuclei in the Formvar backing appear. The highest energy group corresponds to the $Al^{27}(p,\alpha)Mg^{24}$ ground-state group; the increased half-width of this group is caused by target thickness.

In order correctly to determine the location of each group, a detailed analysis of the various contributions to the momentum profile of each group was necessary. The various groups from Al were observed for targets 2 and 9 kev thick, with the full acceptance angle of the spectrometer, and with the acceptance angle limited to 1°. A comparison of the various momentum profiles permitted the estimation of the target thicknesses, acceptance angles, and spectrometer resolution. The following procedure for analysis of succeeding observations of particle groups was adopted. For each momentum profile, the locations of the maximum and the high-energy cutoff were determined. Appropriate corrections for the effect of target thickness, acceptance angle, and spectrometer resolution were then applied to each of the two determinations. No corrections were made for the effects of possible layers of contamination,

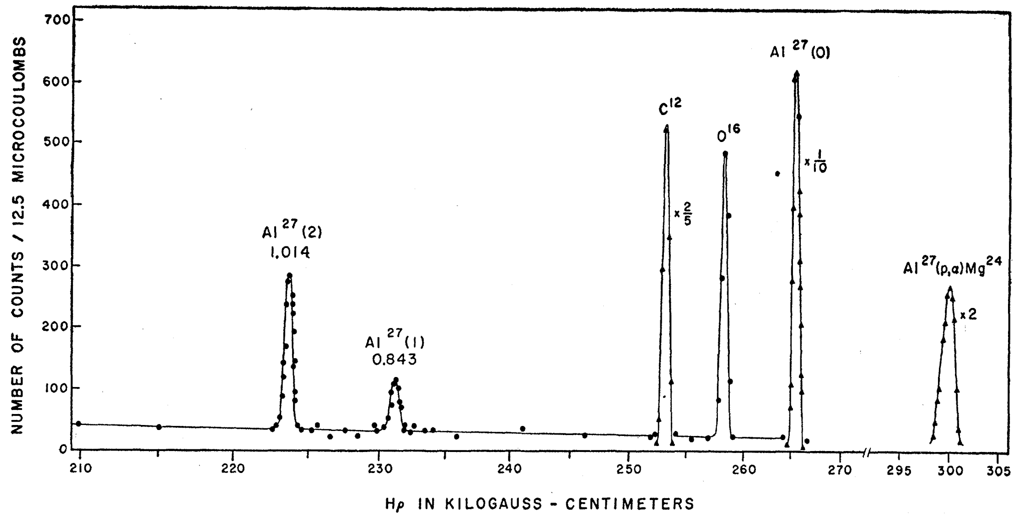

FIG. 1. Charged particle groups from a 9-kev Al target at $E_p=3.633$ Mev and $\theta=90°$.

since no effect resulting from contamination build-up was observed. In most of the precision Q-value measurements, freshly prepared targets were used.

In order to use the observations on the groups from Al^{27} for absolute energy calibrations, it was necessary to know the bombarding energy, which in this case must be taken from the calibration of the 90° deflecting magnet. The absolute energy calibration of the deflecting magnet was primarily obtained from an accurate observation of the $Li^7(p,n)Be^7$ threshold assumed to be 1.8811 ± 0.0005 Mev.[5] Also, the linearity of the magnetic field *versus* the proton moment probe frequency was substantiated to better than $\pm0.05\%$, at three higher proton energies up to $E_p=3.4$ Mev, from observations of resonances in the $P^{31}(p,p')$ and $Al^{27}(p,\alpha)$ reactions. It was then possible by taking the known Q-values of the Al^{27} groups to calculate the momentum of each group, and the corresponding calibration constant $K=H\rho\times R$, where R is the reading of the torsion coil current. Q-values of 1.594 ± 0.002,[6] -0.843 ± 0.002,[6] and -1.014 ± 0.005[7] Mev were assumed for the $Al^{27}(p,\alpha)Mg^{24}$ ground-state group and the $Al^{27}(p,p')$ groups corresponding to the first two levels of Al^{27}.

During the course of the experiment, two additional absolute energy calibrations were made. At a proton bombarding energy corresponding to the $Li^7(p,n)$ threshold, elastically scattered protons were observed from a target of Au on Formvar. At $E_p=3.246\pm0.003$ Mev, corresponding to a resonance in the $P^{31}(p,p')$ reaction,[8] elastic proton groups from a zinc phosphide target were analyzed. Finally, the daily observation of the Po alpha group, assuming Wapstra's momentum value of 331.65 ± 0.06 kilogauss-cm,[9] provided the highest energy absolute calibration.

Each of the points plotted in Fig. 2 represents one absolute energy calibration, with its associated uncertainty. The dashed lines indicate the estimated uncertainty for this absolute curve. In Fig. 2, the percentage change in the calibration constant K is plotted as a function of the particle momentum $H\rho$, normalized to the value of K taken for Po alphas. It would be expected ideally that K should be independent of $H\rho$, or of the magnetic field. The observed departure from constancy can be explained if the magnetic field sampled by the coil of the torsion balance were not proportional to the average magnetic field felt by the analyzed charged particles. Evidently the torsion balance coil was located too close to the edge of the pole faces, so that saturation of the pole tips could cause this nonlinearity. A further symptom of this effect was an

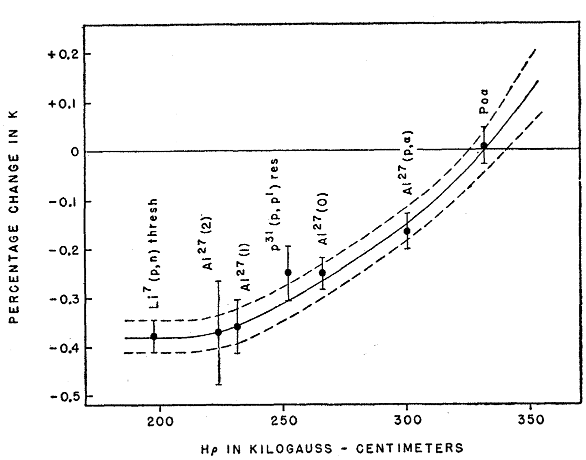

FIG. 2. Absolute energy calibration curve.

[5] Jones, Douglas, McEllistrem, and Richards, Phys. Rev. **94**, 947 (1954).

[6] Donahue, Jones, McEllistrem, and Richards, Phys. Rev. **89**, 824 (1953).

[7] Browne, Zimmerman, and Buechner, Phys. Rev. **96**, 725 (1954); H. Daniel and W. Bothe, Z. Naturforsch. **9a**, 402 (1954).

[8] J. W. Olness and H. W. Lewis, Phys. Rev. **99**, 654 (1955), and also private communication.

[9] A. H. Wapstra, Physica **21**, 367 (1955).

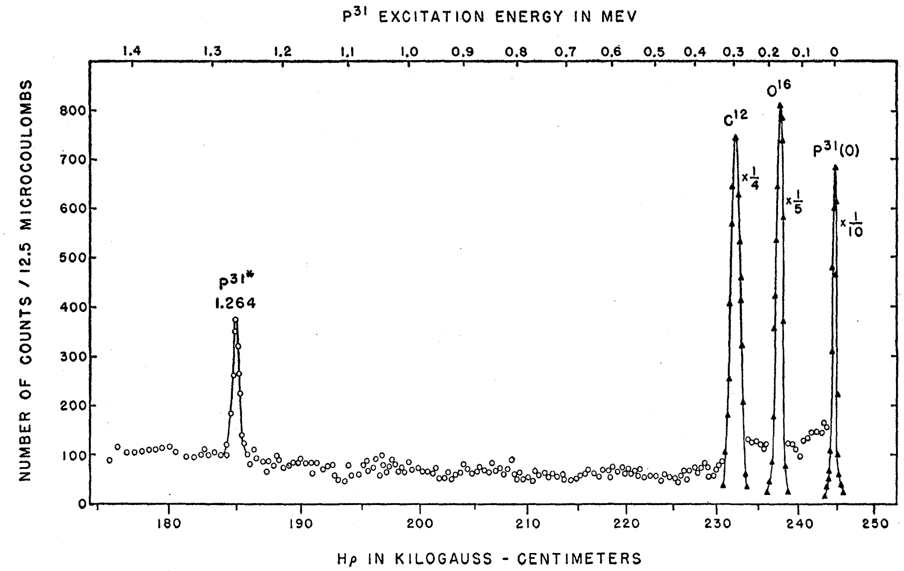

FIG. 3. Proton groups from a 2-kev Zn_3P_2 target at $E_p=3.055$ Mev and $\theta=90°$.

observed hysteresis (0.07%) of the torsion balance reading which appeared only at the highest currents used. For future investigations, it is hoped to reduce this saturation effect considerably by moving the coil one inch closer to the center of the magnetic field, with the disadvantage of added interference of the coil with the analyzed particles. It may be noted that the $Cl^{37}(p,\alpha)S^{34}$ ground-state group, with a momentum of 352 kilogauss-cm, was the only reaction group measured where extrapolation of this absolute calibration curve was necessary.

Having established an absolute energy calibration curve, the Q-value for each reaction group could be calculated using the relativistic Q-equation, and the total error for each group could be estimated. Estimates were made of the uncertainties associated with (a) the location of each particle group, (b) daily calibration of the torsion balance, (c) calculated corrections to the momentum profiles for target thickness, acceptance angle, and resolution, (d) angle of observation, and (e) absolute energy calibration. The total uncertainty for the energy of the bombarding and reaction particles was separately calculated, and the two combined to give the total error for each reaction energy measurement. In the case of error (e), the errors separately assigned to the bombarding and reaction particles were treated as being independent, in order to provide a generous allowance for the uncertainty of the shape of the curve of Fig. 2. The final Q-value quoted represents a weighted average of from two to seven separate measurements. However, the final error assigned represents the error associated with one typical measurement; it was not reduced because several measurements were made.

PHOSPHORUS

(1) Levels of P^{31}

For the investigation of charged particle groups from P^{31}, zinc phosphide targets 2 to 14 kev thick for the $P^{31}(p,p)$ group were used. Even when the maximum beam current was limited to 0.2 μa, these targets often did not survive when exposed to lengthy beam bombardments, and had to be replaced several times during the course of the experiment. In Fig. 3, the results are shown for a survey made at $E_p=3.055$ Mev corresponding to a broad resonance in the yield of the one inelastic proton group observed, with a measured $Q=-1.264\pm0.004$ Mev. No additional proton groups were observed with an intensity greater than 15% of the intensity of this group, for a region of excitation from 0 to 1.43 Mev, except for the regions obscured by the intense elastic groups from C^{12} and O^{16}. The increased half-widths of the C^{12} and O^{16} elastic groups are due to the energy spread accepted by the full acceptance angle of the spectrometer, which was used for this survey. It can be seen that the observation of weak inelastic groups was limited by the continuous background, which is considered to be primarily caused by slit-edge scattering of the bombarding proton beam. This background should be appreciably reduced by an improved collimating system with proper provision for antiscattering slits.

This investigation of the inelastic scattering from P^{31} was aided considerably by the results of Olness and Lewis[10] concerning the energies and excitation curves of gamma rays from the proton bombardment of P^{31}. Limited excitation curves for the $P^{31}(p,p')$ group with $Q=-1.264$ Mev were taken, and resonances were

[10] J. W. Olness and H. W. Lewis, Phys. Rev. **99**, 654 (1955), and private communication.

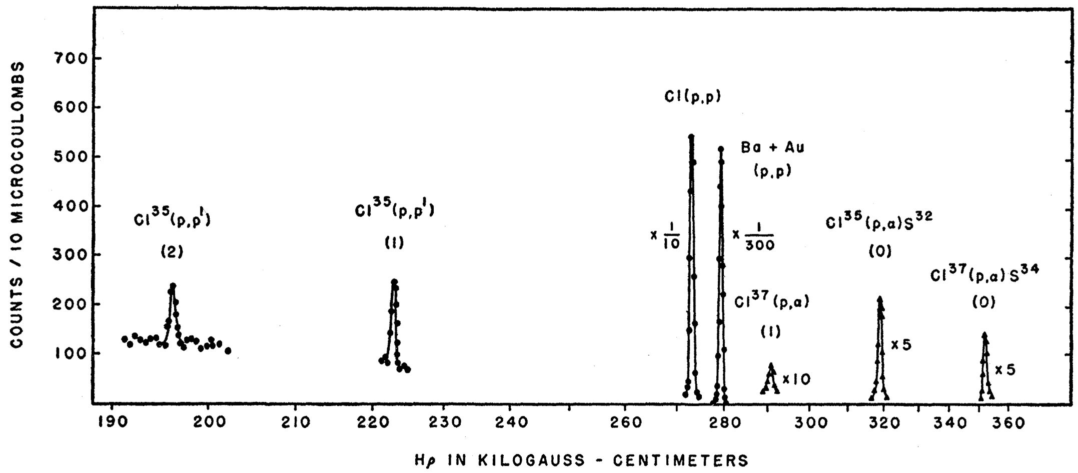

FIG. 4. Charged particle groups from a 2-kev $BaCl_2$ target at $E_p=3.770$ Mev and $\theta=90°$.

observed at energies consistent with the resonance energies for production of a 1.265±0.015 Mev γ ray at $E_p=3.060$ and 3.246 Mev, reported by Olness and Lewis. These observations definitely verify their assignment of this gamma ray to a P^{31} level. A rough excitation curve of the $P^{31}(p,p')$ group was also measured using a 6 kev target in the region $E_p=3.57$ to 4.00 Mev, which indicated the presence of many unresolved resonances, with pronounced resonances at 3.58, 3.73, and 3.79 Mev.

For the region of excitation below 2.5 Mev, there have been reports of levels in P^{31} at about 0.4, 0.9, 1.4, and 2.3 Mev from measurements of the $Si^{30}(d,n)P^{31}$ and $Si^{28}(\alpha,p)P^{31}$ reactions, as summarized by Endt and Kluyver.[11] However, Olness and Lewis[10] observed only gamma rays of energies 1.265 and 2.21 Mev which could be assigned to P^{31} levels. No indication of any levels below the 1.264-Mev level was found in the present investigation. More recently, an investigation of gamma-ray spectra from the $Si^{30}(p,\gamma)P^{31}$ reaction[12] has not revealed any low-lying states in addition to levels at 1.26 and 2.23 Mev. In addition, the low-lying levels of the mirror nucleus S^{31} have been studied by means of the $P^{31}(n,p)S^{31}$ reaction,[13] and the first two levels reported occurred at 1.13±0.2 and 2.23±0.15 Mev. Hence there has been no confirmation in any of the recent experiments of low-lying states in P^{31} at 0.4 and 0.9 Mev, and it is likely that the first two levels occur at 1.264 and 2.22 Mev. It would be worthwhile to extend the survey of the $P^{31}(p,p')$ reaction to the region above 1.4-Mev excitation, which is planned in the near future.

Scherrer *et al.*[14] observed γ rays of energies 1.00±0.05, 1.24±0.05 (strong), 1.60±0.07, 1.75±0.08, and 2.05 ±0.18 Mev from the bombardment of P^{31} by 3.2-Mev neutrons. From the present knowledge of the level schemes of P^{31} and Si^{31}, the 1.24 and 2.05 Mev γ rays can be assigned to the first two levels of P^{31}. Some of the remaining γ-rays (such as the 1.75-Mev γ ray) probably arise from the $P^{31}(n,p)Si^{31}$ reaction[11]; however, there is not sufficient information to definitely assign these γ rays to either P^{31} or Si^{31}.

(2) $P^{31}(p,\alpha)Si^{28}$ Reaction

The $P^{31}(p,\alpha)Si^{28}$ ground-state group was observed, with a measured Q-value of 1.911±0.005 Mev, using two acceptance angles for the spectrometer, and three bombarding energies. This result is in excellent agreement with the previously reported MIT value of 1.910±0.010 Mev[15] (as corrected by Wapstra),[9] and the value of 1.913±0.011[9,15] obtained from the difference of the MIT Q-values for the $P^{31}(d,\alpha)Si^{29}$ and $Si^{28}(d,p)Si^{29}$ reactions.

The excitation curve of the $P^{31}(p,\alpha)Si^{28}$ ground-state group was measured over limited energy ranges. The resonances at 1.892 and 2.030 Mev reported by the Chalk River group[16] were observed. Resonances were also observed at energies approximately corresponding to the resonances at $E_p=2.658$, 2.827, and 2.860 Mev for a 1.78-Mev γ ray from $P^{31}+p$ measured by Olness and Lewis.[10] No broad resonance was found at $E_p=2.733$ Mev for the $P^{31}(p,\alpha)Si^{28}$ group. This resonance was found by Olness and Lewis for the 1.265-Mev γ ray from $P^{31}+p$, but not for the 1.78-Mev γ ray. These observations confirm their assignment of the 1.78-Mev γ ray to the first level of Si^{28} excited by the $P^{31}(p,\alpha)Si^{28*}$ reaction.

[11] P. M. Endt and J. C. Kluyver, Revs. Modern Phys. **26**, 95 (1954).
[12] Paul, Bartholomew, Gove, and Litherland, Bull. Am. Phys. Soc. Ser. II, **1**, 39 (1956).
[13] Rubin, Ajzenberg, and Reynolds, Phys. Rev. **98**, 1185 (1955).
[14] Scherrer, Allison, and Faust, Phys. Rev. **96**, 386 (1954).
[15] Van Patter, Sperduto, Endt, Buechner, and Enge, Phys. Rev. **85**, 142 (1952).
[16] Clarke, Almqvist, and Paul, Phys. Rev. **99**, 654 (1955), and private communication.

CHLORINE

(1) Levels in Cl^{35} and Cl^{37}

For the investigations of charged particles from natural chlorine (75.5% Cl^{35} and 24.5% Cl^{37}), targets of barium chloride were used, bombarded by protons in the energy range 3.63 to 3.83 Mev. The relatively low intensities of the reaction groups necessitated the use of the full acceptance angle of the spectrometer. The results of a survey limited to the observation of a few groups[17] from a 2-kev $BaCl_2$ target at $E_p=3.770$ Mev are shown in Fig. 4. In Fig. 4, elastic proton groups from chlorine and (barium+gold) are indicated. In order to obtain a more precise determination of the bombarding energy, the group from chlorine was decomposed into two groups corresponding to Cl^{35} and Cl^{37}, with the correct energy spacing and with the maxima assumed to be in the ratio of the isotopic abundances.

The results of Fig. 4 indicate two inelastic groups, which have been assigned to the Cl^{35} isotope, corresponding to excited states at 1.219±0.005, and 1.760 ±0.004 Mev. The identification of the groups with the Cl^{35} isotope was initially based on the results of Endt *et al.*[18] concerning inelastic scattering from Cl^{35} and Cl^{37}. However, a recent study of the $A^{35}(\beta^+)Cl^{35}$ decay[19] revealed γ rays of 1.19±0.04 and 1.73±0.04 Mev, which definitely confirms the assignment of these two inelastic groups. In Table I, the present measurements for two levels of Cl^{35} are compared with two similar independent measurements, indicating excellent agreement. These are evidently the same levels which have been reported at 1.1 and (1.7) from a recent study of the $S^{32}(\alpha,p)Cl^{35}$ reaction.[20] A weighted average has been calculated for each energy determination, in the same manner as described by Van Patter and Whaling.[21]

A level in Cl^{37} has been measured at 1.728±0.005 Mev by Endt *et al.*[18] and 1.713±0.010 Mev by Schiffer *et al.*[22] An inelastic proton group corresponding to this level should have occurred at $H\rho=199$ kilogauss-cm in the survey of Fig. 4; however, the continuous proton background was too large to permit observation of this group. The inelastic group corresponding to a Cl^{37} level at 0.838 Mev, observed by Endt *et al.*, was not investigated in this survey.

[17] We are indebted to Dr. P. M. Endt *et al.* for the communication of their preliminary results concerning inelastic proton scattering from Cl^{35} and Cl^{37}.

[18] Endt, Paris, Sperduto, and Buechner, Bull. Am. Phys. Soc. Ser. II, **1**, 223 (1956).

[19] Kistner, Schwarzchild, and Rustad, Bull. Am. Phys. Soc. Ser. II, **1**, 30 (1956).

[20] Pieper, Stanford, and von Herrmann, Phys. Rev. **98**, 1185 (1955).

[21] D. M. Van Patter and W. Whaling, Revs. Modern Phys. **26**, 402 (1954).

[22] Schiffer, Gossett, Phillips, and Young, Bull. Am. Phys. Soc. Ser. II, **1**, 95 (1956).

TABLE I. Q-value measurements.

Excited states of Cl^{35}	E_1 in Mev	E_2 in Mev
Utrecht—M.I.T.[a]	1.221±0.005	1.763±0.005
Rice Institute[b]	1.220±0.005	1.766±0.006
Present work	1.219±0.005	1.760±0.004
Average	1.220±0.003	1.762±0.003
$Cl^{35}(p,\alpha)S^{32}$	Q_0 in Mev	
Chalk River[c]	1.865±0.015	
Utrecht—M.I.T.[a]	1.863±0.008	
Present work	1.851±0.007	
Average	1.857±0.005	
$Cl^{37}(p,\alpha)S^{34}$	Q_0 in Mev	Q_1 in Mev
Chalk River[c]	3.015±0.015	...
Utrecht—M.I.T.[a]	3.026±0.008	0.899±0.008
Present work	3.015±0.011	0.886±0.009
Average	3.021±0.006	0.893±0.006
Excited states of S^{34}	E_1 in Mev	
$Cl^{34m}(\beta^+,\gamma)S^{34}$ [d]	2.10 ±0.03	
Utrecht—M.I.T.[a]	2.127±0.008	
Present work	2.129±0.014	
Average	2.127±0.007	

[a] See reference 18.
[b] See reference 22.
[c] See reference 23.
[d] See reference 24.

(2) (p,α) Reactions for Cl^{35} and Cl^{37}

The survey included the observation of three alpha-groups, shown in Fig. 4, at bombarding energies of 3.77 and 3.82 Mev. The most intense group was assigned to the ground-state $Cl^{35}(p,\alpha)S^{32}$ reaction with a measured $Q=1.851\pm0.007$ Mev. The remaining two groups were assigned to the $Cl^{37}(p,\alpha)S^{34}$ reaction with measured Q-values of 3.015±0.011 and 0.886±0.009 Mev, corresponding to the ground state of S^{34} and an excited state at 2.129±0.014 Mev. The increased error for the ground-state Q-value is caused by the uncertainty in the absolute energy calibration for this group, as indicated in Fig. 2. These results are compared with the results of other recent measurements[18,23,24] in Table I, which indicates agreement within the stated errors. Contrary to reports for a level of S^{34} at about[20,25] 0.8 Mev from the $S^{33}(d,p)S^{34}$ and $P^{31}(\alpha,p)S^{34}$ reactions, the results of Endt *et al.*[18] indicate that the state at 2.127 Mev is the first excited state of S^{34}, as is also indicated from studies of the $Cl^{34m}(\beta^+,\gamma)S^{34}$ decay.[11,24]

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[23] Almqvist, Clarke, and Paul, Phys. Rev. **100**, 1265 (1955).

[24] H. K. Ticho, Phys. Rev. **84**, 847 (1951).

[25] P. W. Davison, Phys. Rev. **75**, 757 (1949).