where $\partial\mu/\partial\rho$ is taken along an adiabatic path. One is tempted first of all, to substitute this expansion into Eq. (12). If this is done, the results are interesting. For example, it shows that the b which is measured from absorption differs from the b that is measured by the Eckart and Liebermann method. Since this correction does not affect Δ but only $2\mu+\lambda$, it implies the existence of a method to distinguish between the viscosity effects and the relaxational effects. The correction is small for water and mercury but in general is not small unless $2\mu+\lambda\ll\Delta$.

In other words, one would conclude that there is a fundamental difference between evaluating b by absorption and by means of streaming. This conclusion disagrees with Fox and Herzfeld. Unfortunately, the data of Liebermann are inconclusive on this point.

Actually this approach to the problem which starts with Eq. (12) seems incorrect to the author. One should return to the definition of the revised stress tensor and there assume Eq. (32). The problem seems quite complicated and therefore will not be attempted at present.

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Excited States of P^{32} from the $P^{31}(d,p)P^{32}$ Reaction*

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The $P^{31}(d,p)P^{32}$ reaction has been investigated by means of magnetic analysis of the protons emitted from thin targets containing phosphorus bombarded by 1.8- and 2.0-Mev deuterons. Sixteen of the proton groups observed have been assigned to the $P^{31}(d,p)P^{32}$ reaction, corresponding to the ground state and fifteen excited states of P^{32}, in a region of excitation from zero to 4.3 Mev.

The position of the first excited state of P^{32} has been measured as 77.0±1.7 kev. Three other pairs of closely spaced levels were observed. These occurred at 2.2-, 2.7-, and 3.3-Mev excitation with spacings of 50±2, 92±7, and 59±3 kev, respectively. Because of the presence of contaminant groups, it is possible that some $P^{31}(d,p)P^{32}$ groups were missed, corresponding to states in a region of excitation from 3.3 to 4.3 Mev. The nucleus P^{32} appears to have a large number of low-lying states, with the first level very near to the ground state.

I. INTRODUCTION

UNTIL recently, very little was known about the excited states of the nucleus P^{32}, although transitions to the ground state had been found with several reactions. The ground-state $P^{31}(d,p)P^{32}$ proton group was observed by Pollard[1] using 3.3-Mev deuterons, with a Q-value of 5.9±0.3 Mev measured by range methods. The ground-state transition of the $S^{32}(n,p)P^{32}$ reaction was found by Huber[2] to have a Q-value of −0.93±0.10 Mev, in agreement with the value of −0.929±0.005 Mev, which can be calculated from the beta-decay of P^{32}. The characteristic 14.5-day period of P^{32} was found by King *et al.*[3] after bombarding quartz with 16-Mev alpha-particles. This was attributed to the $Si^{29}(\alpha,p)P^{32}$ reaction, for which a reaction energy of −2.45±0.01 Mev may be calculated.

Prior to 1950, the only evidence for an excited state of P^{32} was the measurement by Metzger *et al.*,[4] who found an alpha-particle group with Q-value of 0.44 ±0.20 Mev from the neutron bombardment of chlorine, which they attributed to the $Cl^{35}(n,\alpha)P^{32}$ reaction. Since the ground-state Q-value of this reaction can be calculated to be 1.11±0.07 Mev from masses,[5] this group evidently corresponds to an excited state in P^{32} at 0.67±0.21 Mev.

At present, no levels in the compound nucleus P^{32} have been reported. Fields and his co-workers[6] measured the total neutron cross section for P^{31} in an energy region from 0.2 to 0.8 Mev and found no resonances. However, since they measured at only a few selected neutron energies, it is possible that some resonances were missed. Additional measurements of the total neutron cross section for P^{31} have been compiled by Adair.[7]

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Recently, Allen and Rall[8] studied the proton groups emitted at zero and 90 degrees from phosphorus targets bombarded by 3.76-Mev deuterons. Using range measurements, they observed eight groups which they attributed to transitions to the ground state and seven excited states of P^{32} in a region of excitation from 0 to 3.3 Mev. They measured the Q-value of the ground-state $P^{31}(d,p)P^{32}$ group as 5.52 ± 0.10 Mev.

At the same time, an independent investigation of the $P^{31}(d,p)P^{32}$ reaction was made at this laboratory, using magnetic analysis.[9] Several proton groups were found that were identified with the $P^{31}(d,p)P^{32}$ reaction. The highest energy group had a measured Q-value of 5.704 ± 0.009 Mev, as reported in a later publication.[10] This result was communicated to Kinsey and his collaborators, who were in the process of measuring the gamma-rays from the capture of thermal neutrons by phosphorus, using a pair spectrometer. Upon further investigation, they found a high energy gamma-ray[11] of energy 7.94 ± 0.03 Mev, corresponding to a direct transition to the ground state of P^{32}. After subtraction of the deuteron binding energy of 2.23 Mev, a value of 5.71 ± 0.03 Mev may be calculated for the $P^{31}(d,p)P^{32}$ reaction, in excellent agreement with the measured value of 5.704. Kinsey *et al.* have detected a total of twenty gamma-rays from the $P^{31}(n,\gamma)$ reaction, many of which can be correlated with the known levels of P^{32}.

The results of the first preliminary survey of the $P^{31}(d,p)P^{32}$ reaction,[9] made at 1.8-Mev bombarding energy, indicated that several contaminants were present, which made the identification of the observed proton groups subject to uncertainty. In addition, the yield of the proton groups from phosphorus was considerably lower than that observed from lighter nuclei, which also contributed to the uncertainty of the assignment. It was decided to repeat the experiment using different targets and also to make surveys at both 1.8- and 2.0-Mev bombarding energy in order to obtain a more positive identification of the proton groups.

II. EXPERIMENTAL PROCEDURE

The essential details of the experimental equipment and methods of analysis have been described previously.[10,12] The protons from the phosphorus targets were analyzed at 90 degrees to the incident deuteron beam by means of a 180-degree focusing magnet and registered on nuclear-track plates. The use of nuclear-track plates permitted the observation of extremely low counting rates for charged particles. For example, it was possible to detect a high energy proton group containing only ten tracks, after exposing the plate for a period of one hour or longer and to measure the Q-value of the group to better than 15 kev. The background between proton groups with energies greater than that for the $C^{12}(d,p)C^{13}$ ground-state group was nearly zero for such an exposure.

The targets used for the present investigation consisted of thin layers of copper phosphate and zinc phosphide evaporated in vacuum onto platinum backings. The targets varied in thickness from 2 kev to 12 kev for the $P^{31}(d,p)P^{32}$ ground-state group. Deuteron bombarding energies of 1.81 and 2.00 Mev were used. It was necessary to run the electrostatic generator at the highest voltage that could be reliably maintained, since the yield of the $P^{31}(d,p)P^{32}$ groups was observed to increase rapidly with bombarding energy. In addition, it was desirable to observe the $P^{31}(d,p)$ groups at more than one bombarding energy in order to observe the resulting change in proton energy. A change in bombarding energy of 200 kev was found to be sufficient to distinguish between the proton groups caused by phosphorus and those which were due to the usual contaminants of carbon, nitrogen, and oxygen.

The spectra of protons observed were obtained by exposing a series of nuclear-track plates successively over a wide range of analyzing-magnet field strengths. These field strengths were chosen so as to give considerable overlapping of the data obtained from successive plates. A total of fifteen exposures was necessary to obtain a spectrum of proton energies from 3.0 to 7.5 Mev. For each exposure, the deuteron bombarding energy was determined to an accuracy of ±4 kev. For a deuteron bombarding energy of 2.0 Mev, proton groups with energies less than 4.0 Mev were recorded in the presence of deuterons elastically scattered from the target backing by covering the nuclear-track plates with aluminum foils sufficiently thick to stop the scattered deuterons.

III. RESULTS

The proton groups with energies of 2.9 to 7.6 Mev observed from a 12-kev target of copper phosphate are shown in Fig. 1. In the upper curve are shown the results for a bombarding energy of 1.81 Mev; in the lower curve, the results for 2.0-Mev bombarding energy are presented. In these curves, a total of thirty-two proton groups can be distinguished. Sixteen of these groups are assigned to contaminants of D^2, C^{12}, C^{13}, N^{14}, O^{16}, and Si^{28}. The contaminant Si^{28} contributes eight groups, for which the Q-values are accurately known.[13] In all cases the measured Q-values of the contaminant groups agreed within ±5 kev with the previously measured values. The remaining sixteen groups, numbered (0) through (15), are assigned to the $P^{31}(d,p)P^{32}$ reaction.

Some reservation must be made concerning the assignment of group (11). The yield of this group was

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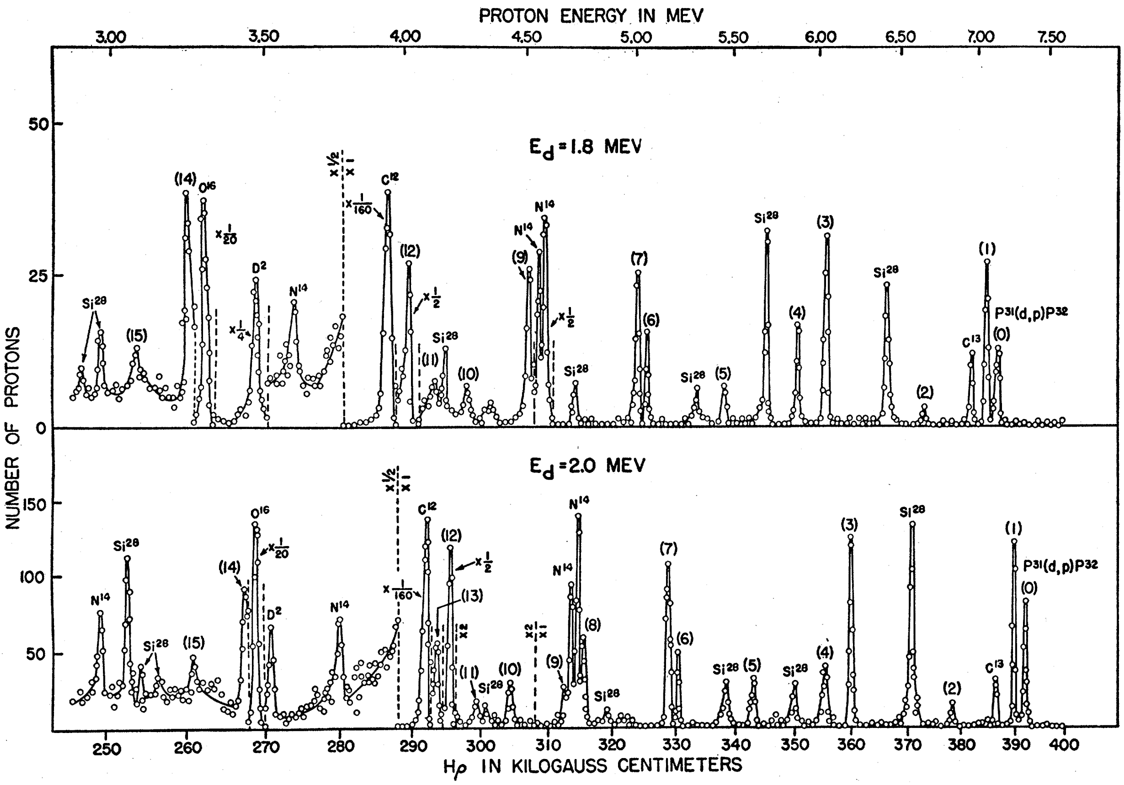

FIG. 1. Spectra of proton groups observed from a copper-phosphate target bombarded by 1.81- and 2.00-Mev deuterons.

so low that it could barely be detected. Although this group has been observed from two different targets containing phosphorus, its yield was not sufficient for positive identification.

The presence of the intense $N^{14}(d,p)N^{15*}$ doublet indicated that there was considerable nitrogen contamination on the copper-phosphate target. At 1.8-Mev bombarding energy, these groups obscured the $P^{31}(d,p)P^{32}$ group (8). However, at 2.0-Mev bombarding energy, the energy of proton group (8) was sufficiently greater than that of the nitrogen groups to permit the resolution of group (8).

Group (13) has been observed only at 2.0-Mev bombarding energy, because at 1.8-Mev bombarding energy, it is obscured by the $C^{12}(d,p)C^{13}$ ground-state group. However, it has been observed from targets of both copper phosphate and zinc phosphide with the same intensity relative to group (12).

The region of proton energies below the $C^{12}(d,p)C^{13}$ ground-state group was largely obscured by various contaminant groups. It is quite possible that some $P^{31}(d,p)P^{32}$ groups were missed, particularly between groups (13) and (14). However, two groups (14) and (15), which evidently could be attributed to a target mass in the region of P^{31}, were observed in this region, as indicated by their shift in energy from 1.8- to 2.0-Mev bombarding energy relative to the contaminant groups. A further check was provided by the observation of these groups from a 2-kev zinc-phosphide target, where the groups were more clearly resolved, with approximately the same intensities relative to group (12). In addition, groups (14) and (15) can be closely correlated to $P^{31}(n,\gamma)$ gamma-rays observed by Kinsey *et al.*, indicating that the assignment of these two groups is correct.

The measured Q-values of the proton groups assigned to the $P^{31}(d,p)P^{32}$ reaction are listed in Table I, together with the resulting energy levels for the P^{32} nucleus. The relative intensities of the groups observed at 90 degrees at 1.8- and 2.0-Mev bombarding energies are also given. In the case of groups (8), (9), and (15), which were not completely resolved from contaminant groups, these relative intensities cannot be relied upon to better than a factor of 2. It is interesting to note that the intensity of nearly all the groups increased a factor of 2 when the bombarding energy was increased from 1.8 to 2.0 Mev.

In Table I and in Fig. 2, the P^{32} levels observed by Allen and Rall[8] are compared with the present results. For the range of excitation covered in their experiment, the agreement between the two sets of results is within the stated errors. However, additional structure has been found in the present experiment because of the higher resolution provided by magnetic analysis. It is noted that levels at 3.00 and 3.14 Mev were not found by Allen and Rall.

TABLE I. Q-values for $P^{31}(d,p)P^{32}$ groups and energy levels in P^{32}.

Group	The $P^{31}(d,p)P^{32}$ reaction Present results Relative intensity 1.8 Mev	2.0 Mev	Q-value (Mev)	Calculated Q-value Kinsey *et al.*	Levels in P^{32} $P^{31}(d,p)P^{32}$ reaction Present results	Allen+Rall	Reaction Kinsey *et al.*
(0)	1.0	2.2	5.704±0.008	5.71±0.03	0	0	0
(1)	1.7	2.7	5.627±0.008	5.62±0.05	0.077±0.002	—	0.08±0.05
(2)	0.3	0.5	5.189±0.010	5.19±0.03	0.515±0.005	0.50±0.05	0.51±0.03
(3)	1.8	4.7	4.550±0.007	4.53±0.03	1.154±0.007	1.10±0.03	1.17±0.03
(4)	0.7	2.0	4.388±0.007	—	1.316±0.008	1.36±0.05	—
(5)	0.4	1.4	3.954±0.007	3.91±0.03	1.750±0.009	1.71±0.04	1.79±0.03
(6)	0.6	1.0	3.527±0.008	—	2.177±0.009 }	2.22±0.04	—
(7)	1.2	4.	3.477±0.008	3.48±0.03	2.227±0.009 }		2.22±0.03
(8)	~0.5	1.6	3.054±0.006	3.04±0.03	2.650±0.008 }	2.72±0.03	2.66±0.03
(9)	~0.8	—	2.962±0.006	—	2.742±0.008 }		—
(10)	0.4	0.5	2.705±0.008	2.69±0.03	2.999±0.010	—	3.01±0.03
(11)	0.2	0.2	(2.563±0.010)	—	(3.141±0.012)	—	—
(12)	4.8	8.	2.445±0.006	2.45±0.03	3.259±0.009	3.27±0.04	3.25±0.03
(13)	—	1.8	2.386±0.006	—	3.318±0.009	—	—
(14)	4.2	—	1.672±0.005	1.69±0.03	4.032±0.009	—	4.01±0.03
(15)	~0.7	~1.3	1.497±0.008	—	4.207±0.010	—	4.20±0.03

It is possible to fit at least twelve of the twenty $P^{31}(n,\gamma)$ gamma-rays observed by Kinsey *et al.*, to the level scheme of P^{32} established by the present experiment, as indicated in Table I and in Fig. 2. In the case of nine of these gamma-rays, very good agreement is obtained by assuming that they represent transitions from the capturing state at 7.93 Mev to various excited states. In this case, the gamma-ray energies can be compared with the Q-values of the $P^{31}(d,p)$ groups corresponding to the same excited states by subtraction of the deuteron binding energy of 2.23 Mev. As can be seen in Table I, the calculated values agree with the measured $P^{31}(d,p)P^{32}$ Q-values within 40 kev in all cases.

In addition, the energies of three $P^{31}(n,\gamma)$ gamma-rays agree within 40 kev with the established positions of three P^{32} levels, indicating that these gamma-rays may well represent direct transitions to the ground state. It is noted that the 3.00-Mev level of P^{32} can be associated with two gamma-rays in cascade. However, no verification has been found for the doubtful level at 3.14 Mev, which makes the assignment of proton group (11) more uncertain.

The present experiment has revealed the existence of four pairs of closely spaced levels in P^{32} at approximate excitations of 0.1, 2.2, 2.7, and 3.3 Mev. In the case of three of these "doublets," it was possible to make a rather precise estimate of the level spacing, since both members could be recorded on the same nuclear-track plate. The measured level spacings were 77.0±1.7, 50±2, 92±7, and 59±3 kev, respectively. The spacing of the proton groups (8) and (9), corresponding to levels at 2.7-Mev excitation, could not be determined so accurately because of the presence of the $N^{14}(d,p)N^{15*}$ doublet.

IV. CONCLUSIONS

An investigation of the $P^{31}(d,p)P^{32}$ reaction using magnetic analysis has revealed the presence of fourteen and possibly fifteen excited states of the nucleus P^{32}, of which seven have not been previously reported. The range of excitation covered was 0 to 4.3 Mev. A level diagram for P^{32} incorporating these results is shown in Fig. 3.

The positions of the P^{32} levels found from these measurements are in agreement with the recent results of Allen and Rall[8] for the $P^{31}(d,p)P^{32}$ reaction using range measurements. However, because of the increased resolution provided by magnetic analysis, considerably more structure has been found in the present experiments. The average spacing for levels in P^{32} up to 3.3-Mev excitation is approximately 260 kev. As can be seen in Fig. 3, the level density appears to be increasing up to 3.3-Mev excitation. Between 3.3- and 4.3-Mev excitation, it is probable that some levels were missed because of the presence of contaminant groups in the observed $P^{31}(d,p)P^{32}$ spectrum.

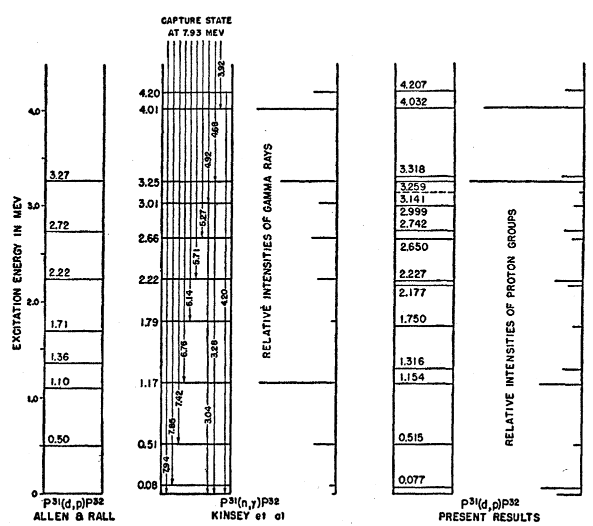

FIG. 2. Comparison of the results of various experimenters concerning the energy levels of P^{32}.

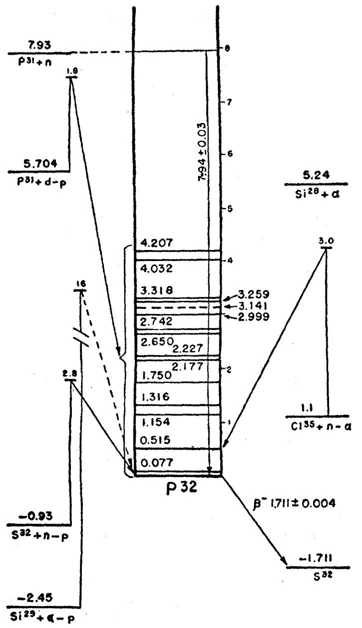

FIG. 3. Energy-level diagram for P^{32}.

The pattern of the established P^{32} levels is quite distinctive. Of particular interest is the discovery of the first excited state at 77.0±1.7 kev. This state has been verified by Kinsey *et al.*,[11] who found two high energy $P^{31}(n,\gamma)P^{32}$ gamma-rays, evidently corresponding to the ground state and an excited state at 80±50 kev. In this region of the periodic table, the only other known case for such a low-lying level is Al^{28}, where the first excited state occurs at 31 kev.[14]

In addition to this ground-state doublet, there are three other pairs of closely spaced levels at excitations of 2.2, 2.7, and 3.3 Mev, with spacings of 50±2, 92±7, and 59±3 kev, respectively. At present, none of these doublets has been verified by other workers.

The present results for the $P^{31}(d,p)P^{32}$ reaction can be closely correlated with the results of Kinsey and co-workers for the $P^{31}(n,\gamma)P^{32}$ reaction, as indicated in Table I. The measured energies of twelve of the $P^{31}(n,\gamma)$ gamma-rays agree to 40 kev or less with the established P^{32} levels, when assigned to the transitions indicated in Fig. 2. Except for the case of the ground-state doublet, the relative intensities of the observed gamma-rays have generally the same pattern as the relative intensities of the $P^{31}(d,p)P^{32}$ proton groups.

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The Interpretation of Image Transitions in Beta-Decay Theory*†

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The allowed favored beta-transitions are studied in relation to problems of nuclear structure and beta-decay theory. These problems include (1) the influence of deviations from *L-S* coupling on the beta-decay matrix elements of the light nuclei, (2) the relation between the observed magnetic moments, simple nuclear models and deviations from *L-S* coupling, (3) determination of the ratio of Fermi to Gamow-Teller type coupling constants, and (4) determination of the absolute magnitudes of the coupling constants.

The analysis of all available data yields two mutually supporting conclusions: (a) a substantial Fermi-type component is present in the beta-decay interaction and (b) deviations from *L-S* coupling are an important factor in the interpretation of nuclear magnetic moments.

I. INTRODUCTION

THE theoretical interpretation of beta-decay data is made difficult by two complicating factors: (a) the possibility of linear combinations of the five covariant formulations of the theory and (b) the occurrence of unknown nuclear matrix elements in the derived formulas. Under (b) the difficulties are particularly formidable when two or more nuclear matrix elements are involved in a transition probability.

Because of these general complications the testing of the theory outside of the allowed range has been largely dependent on the occurrence of transitions subject to special selection rules for which only one nuclear matrix element appears in the theoretical transition probability.[1,2] The study of such transitions (especially $\Delta I=\pm 2$, yes) proves the need for a tensor or axial vector component in the general linear combination, but does not exclude the presence of other components (scalar, polar vector, and pseudoscalar).

In allowed transitions the tensor and axial vector components are responsible for the Gamow-Teller

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