collective model. In the case of the silver isotopes, both Ag^{107} and Ag^{109} have a ground-state spin of 1/2 and therefore do not exhibit a regular rotational spectrum.[4] However, the rotational (strong coupling) model does predict that the ratio of $B(E2)$ for the 315-kev transition to that of the 418-kev transition should be 0.66. This value is considerably smaller than the one obtained from the experimental cross-section measurement and is possibly a reflection of the fact that the transition probabilities obtained from the γ-ray measurement are distorted by possible cascade decay of the 418-kev level. The nuclide Pd^{105}, with a ground-state spin of 5/2, should exhibit a regular rotational spectrum if the collective model applies rigorously to this nucleus. If the first rotational level of Pd^{105} is at 270 kev, then the second level should be at about 617 kev, which is almost 200 kev higher than the observed energy of 430 kev. The values $B(E2)$ for these two levels are also inconsistent with those which would be expected if the rotational model were strictly valid for Pd^{105}. It is possible that the 430-kev level is actually the first rotational level in this isotope. The level at 270 kev would then not be strongly excited, and the peak that appears at this energy in Fig. 4 could arise from the cascade decay of the 430-kev level. A peak at 160 kev, which should accompany such a decay, would be hidden by the bremsstrahlung background.

The authors wish to express their thanks to Dr. C. P. Keim of the Oak Ridge National Laboratory for his aid in procuring the enriched isotopes and to Dr. Caspar Borkowski, also of Oak Ridge, for calibrating the Co^{57} source. We are also indebted to Dr. G. M. Temmer and Dr. N. P. Heydenburg for sending us some of their results prior to publication, and to Professor V. F. Weisskopf and Professor S. D. Drell for many useful discussions.

PHYSICAL REVIEW VOLUME 98, NUMBER 5 JUNE 1, 1955

Radionuclides Al^{24}, P^{28}, Cl^{32}, and Sc^{40}*

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(Received January 18, 1955)

Three new short-lived positron emitters, P^{28}, Cl^{32}, and Sc,^{40} of the nuclear series $Z=2n+1$, $A=4n$ have been produced by *p-n* reactions using 20-Mev protons from the UCLA 41-in. FM cyclotron. Al^{24} has also been investigated. Al^{24} has a half-life of 2.10 ±0.04 sec and five gamma rays from 1.39 Mev to 7.12 Mev. 2-Mev alpha particles are emitted in a small fraction of the decays. P^{28} has a half-life of 0.280 ±0.010 sec, threshold of 15.6±0.5 Mev, eight gamma rays from 1.79 Mev to 7.59 Mev, and positrons of maximum energy 10.6±0.4 Mev. No heavy particles were detected in the decay. Cl^{32} has a half-life of 0.306±0.004 sec, threshold of 14.3±0.5 Mev, four gamma rays from 2.21 Mev to 4.77 Mev, and positrons of maximum energy 9.5±0.4 Mev. 2–3 Mev alpha particles are emitted in a small fraction of the decays. Sc^{40} has a half-life of 0.22±0.03 sec, threshold of 15.9±1.0 Mev, a 3.75±0.04 Mev gamma ray, and maximum positron energy of 9.0±0.4 Mev. No heavy particles were detected in the decay. Possible decay schemes can be set up which involve favored positron transitions to calculated analog levels in the daughters in the cases of Al^{24}, P^{28}, and Cl^{32}. In the P^{28} decay, the positron component to the 1.78-Mev level in Si^{28} has the same *ft* value as the negatron decay to this level from Al^{28}, thus indicating the similarity of the nuclear wave functions of P^{28} and Al^{28}.

I. INTRODUCTION

In 1950 Alvarez[1] reported the discovery of the delayed alpha-particle emitters B^8, N^{12}, and Na^{20}, all members of the nuclear series $Z=2n+1$, $A=4n$. These nuclides are positron emitters which decay, at least partially, to an excited state of the daughter which in turn breaks up into an alpha particle and a residual nucleus. The lifetime of the excited state is extremely short compared to the lifetime of the parent, hence the apparent lifetime of the alpha activity is that of the parent. Alvarez also searched for F^{16}, the member between N^{12} and Na^{20}, but concluded that it was proton-unstable. Birge[2] subsequently reported the discovery of Al^{24}, the next member of the series. Al^{24} was produced by the $Mg^{24}(p,n)Al^{24}$ reaction and was detected by means of a heavy-particle activity. Both delayed alpha particles and delayed protons are energetically possible in the Al^{24} decay and it was not determined which occurred.

Mass estimates of possible additional members of the series, P^{28}, Cl^{32}, and Sc^{40}, placed them on the borderline of proton instability. A search for these nuclides and an investigation of their properties, and a further investigation of Al^{24}, has been carried out in this laboratory. The nuclides were produced by *p-n* reactions using 20-Mev protons generated in the UCLA 41-inch frequency-modulated cyclotron. Some earlier results of this investigation have been published.[3]

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* Work supported by joint program of Office of Naval Research and U. S. Atomic Energy Commission. Part of a thesis submitted by N. W. Glass to the Graduate Division, University of California, Los Angeles, California, in partial fulfillment of requirements for the Ph.D. degree in Physics.

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[1] L. W. Alvarez, Phys. Rev. **80**, 519 (1950).

[2] A. C. Birge, Phys. Rev. **85**, 753(A) (1952).

[3] Glass, Jensen, and Richardson, Phys. Rev. **90**, 320 (1953); N. W. Glass and J. R. Richardson, Phys. Rev. **93**, 942 (1954).

II. APPARATUS AND METHOD

Since the activities were expected to have short half-lives, a sample carrier in a pneumatic tube was used to transport the sample from the bombarding position in the internal beam of the cyclotron to the exterior where measurements were made. A schematic sketch of the tube and carrier is shown in Fig. 1. The balsa sample carrier fits into a $\frac{1}{2}$ in.×$\frac{1}{2}$ in. square tube. The carrier is moved from bombarding to counting position, and vice versa, by atmospheric or higher pressure on one side, and low pressure provided by a vacuum cleaner system on the other. The delayed valve is closed by an interval timer just before the carrier reaches the end of its travel, and it is cushioned to a stop by compressing the residual air between itself and the needle valve. The sample is then held in counting position by the positive pressure on the rear of the carrier. The machinery was cycled automatically by a master sequence timer, which also gated the cyclotron beam and the detectors. The transit time of the carrier was of the order of one-tenth second.

A. Gamma-Ray Measurements

The activities reported on in this paper were all first detected in this laboratory by means of the relatively high-energy gamma radiation associated with their decay. The gamma rays were detected and measured with a $\frac{7}{8}$ in.×$\frac{7}{8}$ in. cylindrical NaI(Tl) crystal in conjunction with a RCA 5819 photomultiplier. The pulses were fed through a preamplifier to a linear amplifier containing a delay line clipper compensated to provide a flat top pulse. The pulses were then displayed on a high stability oscilloscope and the resulting pulse-height distribution was photographed. The oscilloscope was designed and built by Dr. H. K. Ticho of the UCLA Physics Department Staff.

Different exposures and gain settings were used to accentuate the different areas of the pulse-height distributions. For an average case with full gain on the scope face, about 100 000 pulses were required. With continuous cycling of the samples, longer-lived components built up large lower-energy backgrounds, hence, for the lower-lying gamma rays, it was necessary to wait between bombardments for a sufficiently long time to prevent this buildup. The possible appearance of peaks in the longer-lived background activities was checked by making exposures for various lengths of time after the activity of interest had decayed. Densitometer traces of the film density distributions were made, and positions of the peaks were determined from the traces. Many measurements of each spectrum were taken to check the consistency of the energy measurements, and the consistency of appearance of some of the less easily distinguished peaks.

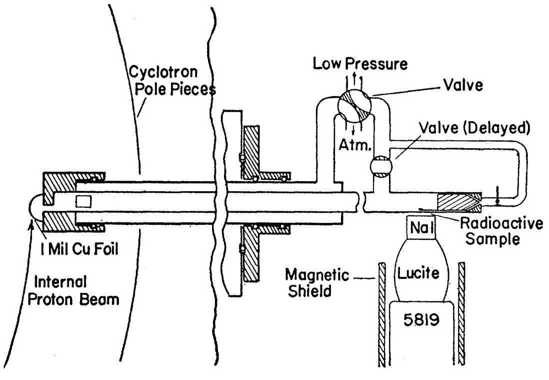

FIG. 1. Schematic of the pneumatic tube and sample carrier. Closing the delayed valve causes the sample carrier to be cushioned to a stop at the end of its travel.

The calibration of the energy scale was always made on the same film as the pulse-height distribution being measured. Sources of Na^{22} and Na^{24} provided calibration points corresponding to photopeaks at 0.51, 1.28, 1.37, and 2.75 Mev, and a RaD-Be source furnished the pair peak of the 4.44-Mev gamma ray from C^{12}. The pair peak of the 7.639-Mev gamma ray from neutron capture in iron[4] found in the normal cyclotron background provided a high-energy calibration point.

Gamma-ray intensities were estimated from differential discriminator runs over the spectra. The areas under the peaks of each gamma ray were estimated after subtraction of the Compton distribution of higher-energy gamma rays, and the intensities were then determined from the absorption coefficients for the various absorption processes in NaI.

B. Positron Energy Measurements

Since the estimated positron energies were in the vicinity of 10 Mev, it seemed that information at least on the high-energy end point could be gotten by direct measurements with a scintillation crystal even in the presence of the high-energy gamma rays. This proved to be true except for the case of Al^{24}.

Since there are very few high-energy beta sources suitable for calibration purposes, a $\frac{7}{8}$ in.×$\frac{7}{8}$ in. cylindrical NaI crystal was used for the positron measurements, and gamma-ray peaks used for calibration. The positrons entered the crystal through a collimating

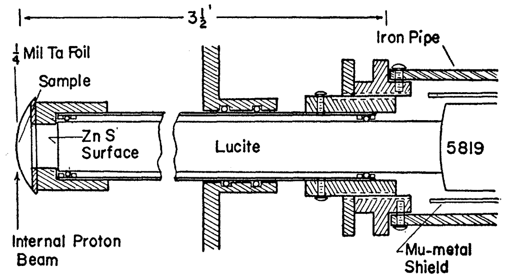

FIG. 2. Probe for measurement of heavy particle emissions.

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[4] B. B. Kinsey and G. A Bartholomew, Phys. Rev. 89, 375 (1953).

TABLE I. Experimental data on Al^{24}, P^{28}, Cl^{32}, and Sc^{40}. The alpha particles emitted in the decay of Al^{24} and Cl^{32} occur to the order of one per several thousand disintegrations.

	p-n threshold (Mev)	Half-life (sec)	Alpha particles (Mev)	Mass value (aMU)	Gamma rays Energy (Mev)	Gamma rays Estimated intensity	Positrons Energy (Mev)	Positrons Log*ft*	Positrons Branching ratio
Al^{24}	15.4±0.3[a]	2.10 ±0.04	~2	24.0076	1.39±0.03	40%	~8½	···	Weak
				±0.0003	2.73±0.06	32%			
					4.22±0.10	15%			
					5.35±0.10	6%			
					7.12±0.10	7%			
P^{28}	15.6±0.5	0.280±0.010	···	28.0006	1.79±0.02	75%	10.6±0.4	4.9±0.1	0.47±0.15
				±0.0004	(2.6 ±0.2)				
					4.44±0.05	10%			
					(4.93±0.08)				
					6.14±0.10				
					6.70±0.12	10%			
					7.04±0.10				
					7.59±0.15	5%			
Cl^{32}	14.3±0.5	0.306±0.004	2–3	31.9960	2.21±0.03	70%	9.5±0.4	4.6±0.1	0.48±0.15
				±0.0004	2.77±0.08	10%	~7½	···	···
					or 3.79				
					4.27±0.08	7%			
					4.77±0.04	14%			
Sc^{40}	15.9±1.0	0.22 ±0.03	···	39.9901	3.75±0.04	···	9.0±0.4	4.1	100% assumed
				±0.0004					

[a] See reference 2.

hole in a ⅜-in. brass disk. The positron spectra were measured with a single channel discriminator with a two volt window and with the end point of the spectrum corresponding to about 100 volts. A separate counter and channel were used to monitor the source intensities. In all cases except that of Al^{24} the gamma contribution, determined by covering the collimating hole, was small compared with the positron contribution, hence the error introduced by subtraction of the gamma contribution was small. The capture of 0.51-Mev quanta from the annihilation of the positrons in the crystal produces a tail at the high end of the spectrum. A correction was applied for this effect and also for the effect of resolution on the end point. Check runs were made on the positron spectrum of Cl^{34}. The end point of the Cl^{34} high-energy component was measured as 4.40±0.2 Mev. This is in good agreement with the reported value of 4.50±0.03 Mev.[5] The deviation from a straight line on the Kurie plot was consistent with the presence of the 28 percent branch with 2.58-Mev end point.

C. Half-Life and Threshold Measurements

The half-lives of the activities were measured by means of a Sanborn Twin-Viso Recorder. The output of a decimal scaler was fed to the galvanometer coil of the recorder pen. At every tenth, hundredth or thousandth count, depending on the scale factor used, a pip was marked on the recorder tape. The tape speed was calibrated timewise by means of a one second marker provided with the Sanborn unit.

Threshold measurements were made by moving the probe assembly in to smaller cyclotron radii by small increments until the activity under scrutiny no longer appeared. Comparison was made with the threshold of Al^{24} measured by Birge[2] for the absolute energy calibration. The slope of a previously determined proton energy *vs* radius curve was then used to determine the energy threshold.

D. Heavy-Particle Search

Heavy-particle emission was reported[2] in the decay of Al^{24} and is energetically possible in the P^{28}, Cl^{32}, and Sc^{40} activities; hence a search was made for such emissions. Since negative results were gotten by viewing the bombarded sample in the pneumatic tube by a ZnS phosphor, a more sensitive arrangement in respect to counting rates and minimum particle energy was used. This consisted of a long Lucite light pipe with RCA type 33-*Z*-16*A* ZnS phosphor on the end which viewed the sample inside the cyclotron as shown in Fig. 2. A thin film of the sample to be bombarded was coated on the inside of the 0.25-mil tantalum foil. The phosphor was kept about an inch away from the target so that the cyclotron magnetic fields prevented the large number of positrons emitted from the target from reaching the phosphor and Lucite. This spacing also reduced the number of protons scattered into the phosphor which excited long-lived components in the luminescent decay of the phosphor.

Measurements were made by simply gating the cyclotron on and off and visually observing the resulting decay pulses on an oscilloscope. Unmistakable large pulses consistent with the respective half-lives were observed in the decay of Al^{24} and Cl^{32}. Threshold

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[5] D. Green and J. R. Richardson, Phys. Rev. **96**, 858(A) (1954).

checks were also made and the activities disappeared below the respective thresholds. The number of pulses observed was about 4–8 per bombardment for Al^{24} and $\frac{1}{2}$ to 1 per bombardment for Cl^{32}. A rough pulse-height calibration was obtained by bombarding Bi powder in the probe and observing the maximum pulse height of the 4.86-Mev alpha particles from Po^{209}. The Al^{24} particles appeared to be $\sim$2 Mev and the Cl^{32} particles 2–3 Mev. Since both alpha particle and proton emission are energetically possible in these activities, an absorption check was made to determine which occurred. Aluminum foil absorbers of 0.15 mg/cm^2, 0.60 mg/cm^2, and 1.7 mg/cm^2 were in turn placed between the target and phosphor. For both Al^{24} and Cl^{32} the results were consistent with a 2–3 Mev alpha particle range in aluminum but clearly not with the proton range.

III. EXPERIMENTAL RESULTS

A. Aluminum-24

Al^{24} was produced by the $Mg^{24}(p,n)Al^{24}$ reaction by using a Mg foil of thickness about 5 mils as the target. The half-life was measured as 2.10 ± 0.04 seconds in agreement, within experimental error, with that reported by Birge.[2] The gamma-ray spectrum was found to be quite complex, with five gamma rays identified with certainty as listed in Table I. The 1.39-Mev and 2.73-Mev gamma rays were calibrated with respect to the 1.37- and 2.75-Mev gamma rays from Na^{24}, and there is no doubt that they arise from the same level transitions in Mg^{24} as the Na^{24} gammas.

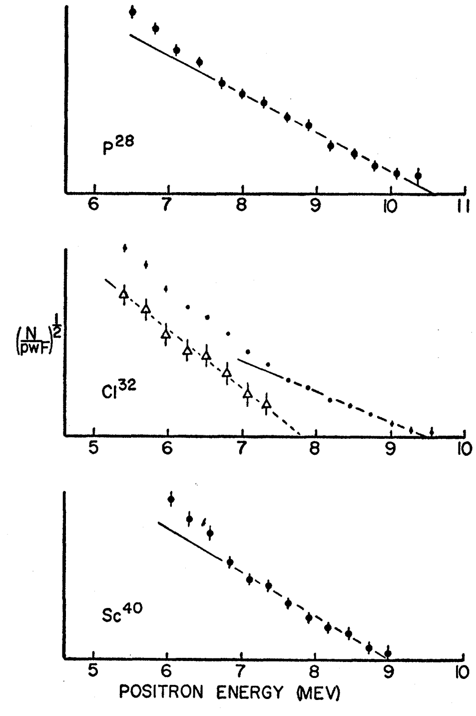

FIG. 3. Kurie plots of the high-energy positrons from P^{28}, Cl^{32}, and Sc^{40}. The Cl^{32} plot shows a first subtraction indicating a positron component to the region of $7\frac{1}{2}$ Mev.

An attempt was made to measure the positron energy of Al^{24}, but the high-energy positron branch is of fairly weak intensity and not a great deal higher in energy than the high-energy gamma ray. About all that can be said is that there appears to be a fairly low intensity positron branch with end point of around $8\frac{1}{2}$ Mev.

Delayed alpha particles of energy $\sim$2 Mev with a branching ratio of the order of one in several thousand disintegrations were observed.

B. Phosphorus-28

P^{28} was produced by the $Si^{28}(p,n)P^{28}$ reaction. Silicon metal targets were used for the gamma ray measurements and powered silicon metal mixed with polystyrene binder pressed between $\frac{1}{4}$-mil Ta foil for the positron measurements. No contributions from the Ta or polystyrene were observed in the energy regions measured. The gamma-ray spectrum was found to be very complex. Since some of the peaks are not easily distinguishable, many runs were made to check the consistency of appearance of these peaks. Table I lists the measured gamma-ray energies and other data. The gamma ray of energy 4.93 Mev is not completely certain, since its pair peak falls on the position of a small peak arising from the pair energy plus a single annihilation quantum capture of the more intense 4.44-Mev gamma ray. However, this peak appears to be quite consistently more intense than would be expected from annihilation capture effect. Weak peaks in the vicinity of 2.6 Mev appeared on some of the spectra. Because of the complexity of the spectrum, there is a distinct possibility of other weak gamma rays existing in the decay.

Figure 3 shows a Kurie plot of the corrected P^{28} positron spectrum. The end point from three such runs is 10.6 ± 0.4 Mev. The consistency from run to run was better than the quoted error would indicate but since a long extrapolation from the calibration points is necessary, the quoted error is felt to be a safer limit. In the three runs, the plots deviate from a straight line in the region of $7\frac{1}{2}$ Mev.

The *ft* value of the high-energy component is found from the slope of the Kurie plot, normalized by determining the total number of counts in the entire positron distribution compared with the counts in the monitor channel. The total number of counts was determined from an analysis of the decay of all the activities present as they appeared on the pen recorder tape. In this manner the *ft* value of the 10.6 Mev component is found to be $(8\pm2)\times10^4$ sec or $\log ft=4.9\pm0.1$. No heavy-particle activity was detected. If present, it is less than an estimated one out of 30 000 disintegrations, or less than $\frac{3}{4}$ Mev in energy.

C. Chlorine-32

Cl^{32} was produced by the $S^{32}(p,n)Cl^{32}$ reaction. Sulfur powder wrapped in $\frac{1}{4}$-mil Ta foil was used for gamma-ray measurements. Positron sources were made by pressing sulfur powder mixed with polystyrene binder between $\frac{1}{4}$-mil Ta foil. Four gamma rays are identified in the spectrum as listed in Table I. It is not certain whether the peak at 2.77 Mev is a pair peak or a photoelectric peak, but it is probably a pair peak corresponding to a gamma ray of 3.79 Mev.

Figure 4 shows a Kurie plot of the corrected Cl^{32} positron spectrum. A fairly reasonable first subtraction can be made as shown which indicates a component in the region of $7\frac{1}{2}$ Mev. The log*ft* value of the high-energy component is 4.6±0.1, corresponding to a 0.48±0.15 branching ratio.

Alpha particles of 2–3-Mev energy were detected in the Cl^{32} decay. These occurred to the order of one out of several thousand disintegrations.

D. Scandium-40

Sc^{40} was produced by the $Ca^{40}(p,n)Sc^{40}$ reaction by using calcium pounded into a thin sheet as the target material. The measurements on Sc^{40} were more difficult than those of the other activities since the competing activities were of shorter half-life and of higher energy, and the activity itself was weak. The experimental data are given in Table I. Only one gamma ray of energy 3.75±0.04 Mev was identified in the spectrum. There are numerous weak peaks which also appear in the background spectra. Hence, the possibility of weak peaks in the Sc^{40} decay occurring and falling near peaks in the background cannot be eliminated. However, if such peaks do occur, they are weak compared to the 3.75-Mev gamma.

Figure 3 shows a Kurie plot of the Sc^{40} positron distribution. No heavy-particle activity was detected.

IV. DISCUSSION OF RESULTS

From the comparison of measured threshold values and maximum positron energies, it is evident that none of the positron emissions goes to the ground state. The differences between maximum positron energies available and those measured correspond to positions of known levels in the daughter nuclei, and to gamma rays associated with decay of the nuclei. The occurrence of gamma rays corresponding to the energies of the first excited states of the daughter nuclei in the cases of Al^{24}, P^{28}, and Cl^{32}, and to the second in that of Sc^{40}, is confirmation of the correct assignment of the activities. The masses of P^{28}, Cl^{32}, and Sc^{40} are found from a weighted mean of the positron-gamma ray and threshold energies, using the mass values of Li[6] and Johnson.[7] These masses would indicate that P^{28}, Cl^{32}, and Sc^{40} are proton-stable by 2.5 Mev, 1.0 Mev, and 0.5 Mev respectively.

A. Analog Levels and Isobaric Spin

The charge multiplet theory,[8] which results from the assumption of charge-independent nuclear forces and the treatment of the Coulomb energy as a small perturbation, predicts that the energy levels of the members for which $T_z=(N-Z)/2=\pm1$ of an isobaric triad will have corresponding, or "analog," levels in each other and in the member for which $T_z=0$. N and Z are the numbers of neutrons and protons, respectively, which make up the nucleus. The levels in $T_z=0$ not having analogs in $T_z=+1$ and $T_z=-1$ are considered to belong to a state of total isobaric spin $T=0$, or an isobaric spin singlet state. Those having analogs belong to a state of $T\geqq1$, constituting an isobaric triplet or higher multiplet. Thus, with the difference in Coulomb energy and the neutron proton mass difference taken into account, the ground states of the $T_z=+1$ and $T_z=-1$ members of the triad should have the same energy, and the $T_z=0$ member should have an analog state corresponding to these ground states. Actually, the levels in $T_z=+1$ and $T_z=-1$ should have analog levels in each other if *p*-*p* forces are equal to the *n*-*n* forces. However, the existence of the analog levels in the $T_z=0$ member requires the complete charge independence of nuclear forces.

Since each of the nuclides reported in this paper is the $T_z=-1$ member of an isobaric triad and decays by positron emission to the $T_z=0$ member, it is possible to see whether some aspects of the decay are consistent with the predictions of the charge multiplet theory. In each case, the properties of the $T_z=+1$ member are quite well known. Thus, some further evidence regarding the charge independence of nuclear forces might be available. The isobaric triads $C^{10}-B^{10}-Be^{10}$ and $O^{14}-N^{14}-C^{14}$ have been studied[9] and the results shown to be consistent with the theory. The triads under consideration here are heavier and the charge effect considerably greater, hence the theory might not be expected to hold so well.

TABLE II. Values of r_0 calculated from energy differences of $T_z=-1$ and $+1$ members of $A=4n$ triads, and resulting position of analog levels in $T_z=0$ members.

	T_z		$r_0\times10^{13}$ (cm)	Analog level in $T_z=0$ (Mev)
-1	0	$+1$		
Al^{24}	Mg^{24}	Na^{24}	1.38±0.04	9.5
P^{28}	Si^{28}	Al^{28}	1.43±0.05	9.0
Cl^{32}	S^{32}	P^{32}	1.33±0.04	7.1
Sc^{40}	Ca^{40}	K^{40}	1.38±0.05	7.5

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[6] C. W. Li, Phys. Rev. **88**, 1038 (1952).

[7] W. H. Johnson, Jr., Phys. Rev. **88**, 1213 (1952).

[8] J. M. Blatt and V. F. Weisskopf, *Theoretical Nuclear Physics* (John Wiley and Sons, Inc., New York, 1952), p. 254.

[9] Sherr, Muether, and White, Phys. Rev. **75**, 282 (1949); R. Sherr and J. B. Gerhart, Phys. Rev. **91**, 909 (1953).

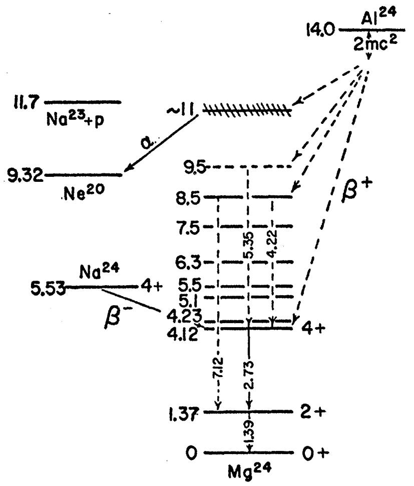

FIG. 4. Known Mg^{24} energy levels and possible Al^{24} decay scheme. The dotted line at 9.5 Mev is the calculated position of the analog level corresponding to the ground states of Na^{24} and Al^{24}.

Assuming that the Coulomb energy of a nucleus is given by $\frac{1}{2}Z(Z-1)(6/5)(e^2/r_0A^{\frac{1}{3}})$, r_0 can be calculated from the ground state energy differences of the $T_z=+1$ and $T_z=-1$ members of the triads, and the position of the analog level in the $T_z=0$ member determined. Table II lists these calculated values. The calculated r_0's are in quite reasonable agreement with the values from the mirror nuclei in this mass region.[10] In Si^{28} there is a measured level at 9.16 Mev[11] which could correspond to this analog level. In the other three cases, these regions have not been completely surveyed.

A test for the similarity of the wave functions of the ground states of the $T_z=+1$ and -1 members of a triad can be gotten from the comparison of the ft values for the beta decay to the same level of the $T_z=0$ member. As it turns out, the $A=28$ triad is the only one for which a quantitative comparison can be made. In the P^{28} decay the high-energy positron component goes to the same excited level of Si^{28} as does the negatron emission from Al^{28}. The logft value of this P^{28} component is measured as 4.9 ± 0.1. This is in good agreement with the value of log$ft=4.92$ found in the Al^{28} negatron decay.[12]

Assuming the equality of the ft values to the same state gives results consistent with those found in the other three cases. In the Al^{24} decay, the Na^{24} value[13] of log$ft=6.11$ would give about a 10 percent branch to the 4.14-Mev level of Mg^{24}. This is consistent with the observed results. In the Cl^{32} decay, no positron branch to the S^{32} ground state is observed, which is consistent with the P^{32} logft value of 7.90.[13] The same thing is true of the Sc^{40} decay.

Hence the energies of the ground states of the $T_z=-1$ nuclei reported in this paper are quite well accounted for by the charge effect, and the positron decay is consistent with the negatron decay of the $T_z=+1$ member of each triad. Thus, according to this picture, the ground state of the $T_z=-1$ member in each case should have the same spin and parity as the corresponding $T_z=+1$ member. If the analog state exists in the $T_z=0$ member, it should also have this same spin and parity.

B. Possible Decay Schemes

Although the decay schemes cannot be uniquely determined from the data reported here, it is interesting to note that decay schemes can be set up which are consistent with the known energy levels of the daughter nuclei, with the assumed presence of analog levels at the calculated positions, and with the estimated intensities of the positron and gamma-ray branches.

Aluminum-24.—Possible transitions which account for the positron and gamma ray activity are shown by the dotted lines in Fig. 4. From this scheme, a level at 9.49 Mev would be required which is very close to the calculated analog level. The gamma-ray intensities would indicate a logft of 3.8 to this level which is consistent with the expected favored transition. An alpha-particle emission ratio of 1/5000 gives a log$ft=5.5$ to a level around 11 Mev which indicates an allowed positron transition to that level.

Phosphorus-28.—In this decay there are measured[11] energy levels which could correspond to every gamma ray, as shown in Fig. 5. However, the 1.79-Mev gamma ray appears more intense than would be expected from the positron branching ratio to this level, so that other gamma rays are probably in cascade with the 1.79-Mev gamma. A positron transition to an analog level

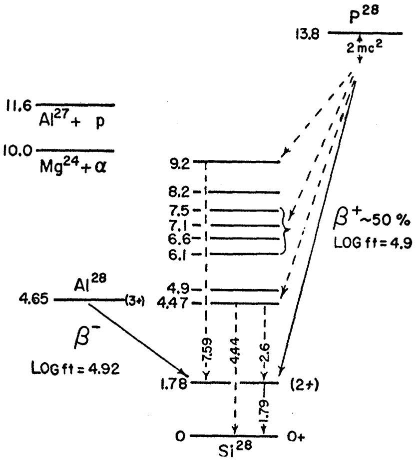

FIG. 5. Known Si^{28} energy levels and possible P^{28} decay scheme. The level at 9.2 Mev may correspond to the analog of the ground states of Al^{28} and P^{28}. The equality of the ft values for the β^- and β^+ components to the 1.78-Mev level indicates the similarity of the P^{28} and Al^{28} wave functions.

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[10] E.g., D. C. Peaslee, Phys. Rev. **95**, 171 (1954); P. Stahelin, Phys. Rev. **92**, 1016 (1953).

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around 9 Mev giving rise to the 7.59 Mev or 7.04-Mev gamma ray in cascade with the 1.79-Mev level would require a log*ft* of 3.4–3.7 which would indicate a favored transition, if it occurs. The deviation from linearity of the P^{28} positron plot is consistent with a branch to the 4.47-Mev level from which the 4.44-Mev gamma probably arises. Casson[14] has reported work which also indicates a 2.7-Mev gamma from this level in cascade with the 1.8-Mev level.

Chlorine-32.—Figure 6 shows the measured[15] energy levels and calculated analog level position for S^{32}. The intensity of the 2.21-Mev gamma ray appears somewhat greater than would be expected from the positron branch to this level, indicating possible cascade gammas through this level. The sum of energies of the 2.21 Mev and 4.77 Mev gammas is 6.98 Mev as compared with 7.1 Mev for the calculated energy of the analog level. If the 4.77 Mev does arise from a 7-Mev level, then the necessary positron branch to this level would have a log*ft* of 3.6, indicating a favored transition. An alpha-particle energy of 2–3 Mev and branching ratio of 1/5000 gives a log*ft* of about 4.9–5.5 for positron emission to a level at 9–10 Mev. This indicates an allowed transition to a level in this region.

Scandium-40.—Harvey[16] reports a level at 3.8 Mev in Ca^{40}, and Braams *et al.*[17] report levels at 3.35, 3.74, 3.90, and 4.49 Mev. The 3.75-Mev gamma ray probably arises from the 9.0-Mev positrons to the 3.74-Mev level. No strong lines appear which would indicate a transition to an analog level in the region of 7.5 Mev. Unfortunately, the appearance of several gamma-ray peaks in the longer-lived background leaves the possibility of one or more additional weak peaks appearing in the Sc^{40} decay.

CONCLUSION

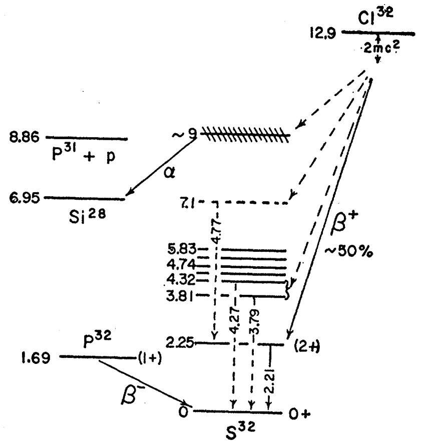

FIG. 6. Known S^{32} energy levels and possible Cl^{32} decay scheme. The dotted line at 7.1 Mev shows position of the calculated analog level corresponding to the ground states of P^{32} and Cl^{32}.

During the course of this work and subsequent to the publication[3] of initial results on Al^{24}, P^{28}, and Cl^{32}, it was learned[18] that workers at McGill University, Montreal, had independently discovered the P^{28} and Cl^{32} activities and had made gamma-ray measurements on these and Al^{24}. Their results (half-lives, thresholds, and gamma rays) were in quite good agreement with those reported here. They listed several more gamma rays than we have been able to identify with certainty in P^{28}, and ascribe the 2.77-Mev peak in Cl^{32} to a 3.79-Mev gamma ray.

In conclusion, then, three new activities belonging to the nuclear series $Z=2n+1$, $A=4n$ have been discovered and further measurements made on a fourth. From the results reported herein, it is seen that these results appear to be consistent with those of the charge multiplet theory. In the case of P^{28}, comparison of the positron decay to the first excited state of Si^{28} with the negatron decay of Al^{28} gives additional evidence for the charge symmetry of nuclear forces.

We wish to express our appreciation for the help and interest of many present and former members of the Cyclotron Laboratory, particularly Professor Byron T. Wright, Dr. Louis K. Jensen, Dr. Harry E. Handler, Mr. Steve Plunkett, and Mr. Bowman C. Collins. Special thanks are also due by one of us (N.W.G.) to Professor R. Sherr of Princeton University for some very interesting discussions.

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