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Radiations from P^{30}, Cl^{34}, and K^{38}†

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Results are reported on the measurement of the radiations from the 2.55-min activity in P^{30}, the 32.40 ± 0.04 min activity in Cl^{34} and the 7.7-min activity in K^{38} by means of a large double-lens spectrometer and a NaI scintillation spectrometer. P^{30} has a simple positron spectrum with end point at 3.24 ± 0.04 Mev and no gamma rays or conversion electrons. Cl^{34} has a complex positron spectrum with end points at 4.50 ± 0.03 Mev 2.48 ± 0.07 Mev, and 1.33 ± 0.10 Mev. K^{38} has a simple positron spectrum with end point at 2.68 ± 0.04 Mev and no conversion electrons. These results indicate an *ft* value for the ground ($T=1$) state of Cl^{34} of 3160 ± 120 sec, and indicate that the ground states of P^{30} and K^{38} are probably the $T=0$ states.

THE odd-odd $N=Z$ nuclei are of special interest in nuclear structure consideration because they have more than one T value among their low-lying states.[1–5] In addition, they furnish examples of positron transitions of the type $0 \rightarrow 0$ (no). This paper reports experimental measurements[6] on the beta and gamma radiations from three of these nuclei, P^{30}, Cl^{34}, and K^{38}.

EXPERIMENTAL TECHNIQUES

A magnetic split-lens spectrometer[7] utilizing a variable-width ring focus was used in these investigations. Sources were prepared by evaporating solutions on 0.0005-inch aluminum foil before bombardment in the UCLA FM cyclotron and had an average areal density of about 10 mg/cm². All activities from the aluminum died out in less than a minute. This type of source preparation was necessary for the short-lived activities, particularly for the study of the 2.5-min P^{30} activity. Checks were made to be certain that the thickness of the source was not great enough to affect appreciably the shape of the β-ray spectra in the region of interest here. The instrument was calibrated with conversion electrons from gamma rays of widely differing energies: the 0.6616-Mev gamma ray from Ba^{137*}, the 1.278-Mev gamma ray from Ne^{22}, and the 4.43-Mev gamma ray from C^{12}. The latter radiation was furnished by a RaD-Be source. The Ba^{137*} gamma ray was internally converted; the other two were externally converted in thorium foils. The calibration constant of momentum *vs* coil current was found to be indeed constant within the uncertainty in the energy of the C^{12} gamma ray (0.02%). A scintillation spectrometer[8] was used to investigate the gamma-ray spectra of P^{30} and K^{38}.

P^{30}

The most recent measurements on P^{30} are those of Koester[9] who found a half-life of 2.55 ± 0.02 min and a positron end point from absorption of 3.23 ± 0.07 Mev.

In this experiment P^{30} was produced by the $P^{31}(p,pn)P^{30}$ reaction in sources made by evaporation of water solutions of P_4S_3 on $\frac{1}{2}$-mil aluminum foil backings. Chemical separation after bombardment was impractical with this isotope because of its short half-life. Therefore a number of runs with the magnetic spectrometer set at different currents were made to determine whether conflicting half-lives were present. The activity was pure enough so that half-life runs extending over periods of at least six half-lives were possible. The average of five runs gives a value of 2.56 ± 0.15 minutes which is in good agreement with the best value mentioned above.

Data were taken on the positron spectrum of this isotope, using the magnetic spectrometer. The mean value of the positron end point obtained from Kurie plots of the four best runs is 3.24 ± 0.04 Mev.

As part of the general investigation of this isotope, a prolonged and careful search was made for a conversion line. This search was unsuccessful, which was to be expected in the light of calculations made by Kofoed-Hansen.[1]

The first excited state of Si^{30} lies 2.32 Mev above the ground state and so the possibility of beta decay to this state from P^{30} was investigated by looking for a gamma ray of this energy, using the scintillation spectrometer. No gamma ray was found, indicating that there is no appreciable branching in the beta decay from the ground state of P^{30}.

Cl^{34}

Ruby and Richardson[7] using a spectrometer found three positron components in the 33-min decay of Cl^{34}, with end point energies of 4.45, 2.58, and 1.3 Mev. Three gamma rays accompanied the decay, with

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TABLE I. Beta spectrum from Cl^{34}.

Beta energy (Mev)	Branching ratio
4.50±0.03	0.47
2.48±0.07	0.26
1.33±0.10	0.26

TABLE II. Results on the high-energy positron limit of Cl^{34}. E_0 is the beta end-point total energy expressed in units of mc^2.

Source No.	E_0	Deviation
1	9.824	0.008
2	9.847	0.031
3	9.803	0.013
4	9.788	0.028

energies of 0.145, 2.13, and 3.30 Mev and the 0.145-Mev line was strongly internally converted. Ticho[8] used a scintillation spectrometer to measure the gamma rays more accurately, and found them to be 2.10 and 3.22 Mev, respectively. He also found a new gamma ray with an energy of 1.16 Mev. Stähelin[2] was able to produce by (γ,n) reaction a 1.58-sec energetic positron activity which had to be assigned to Cl^{34} and which from the previous work he deduced must be the ground state characterized by 0+ and $T=1$ with positron upper limit presumably the 4.45-Mev component mentioned above. It followed that the 0.145-Mev line was $M3$ radiation corresponding to a transition in Cl^{34} from the (3+) 33-min isomer to the 0+ ground state and the experimental results of Ruby and Richardson then yield an internal conversion coefficient of 0.14 which is in reasonably good agreement with the theoretical value for $M3$ radiation.

Cl^{34} was produced by the Cl^{35}(p,pn)Cl^{34} reaction. The half-life and beta spectrum were investigated with the magnetic spectrometer using aluminum foil-backed sources on which water solutions of NaCl were evaporated. Repeated half-life runs were made and analyzed by the method of least squares. Some of these runs extended over a period of eight half-lives. The mean value was measured to be 32.40±0.04 min. Results on positron component end points and branching ratios were in good agreement with those of Ruby and Richardson; they are summarized in Table I.

In an effort to check the constancy of the ft-values of 0→0 transitions, the Cl^{34} high-energy positron end point was redetermined in the following fashion. Four samples of pure NaCl were evaporated over hot tantalum filaments in vacuum on $\frac{1}{2}$-mil aluminum foil backings covered by masks with a $\frac{1}{8}$-in. hole to define the target. Different targets were bombarded instead of rebombarding a single target, in order to see whether target thickness could influence the Kurie plot of the high-energy component. A least-squares analysis was made on each of the four Kurie plots. The results are summarized in Table II.

The average of these values and the mean square deviation is 9.816±0.022, which, expressing the kinetic energy in Mev is 4.504±0.010. Making allowance for possible systematic errors, we consider that the end-point energy with an estimated maximum error may be written as 4.50±0.03 Mev. The Kurie plot for the upper part of the positron spectrum was found to be a straight line from 3.0 to 4.5 Mev using the allowed Fermi function $F_0(Z,E)$.

K^{38}

This isotope was produced by the K^{39}(p,pn)K^{38} reaction. The magnetic spectrometer was used to investigate the half-life and positron spectrum. Sources were made by evaporating water solutions of KI on aluminum foil backings. No conflicting activities were encountered. Half-life runs over periods of about seven half-lives were made at different energies in the spectrometer, and gave a mean result of 7.7±0.3 min.

The positron spectrum was investigated and one component with a straight-line Kurie plot was found. The average of the eight best runs gives a value for the end point of 2.68±0.03 Mev.

A careful search for an internal conversion line gave negative results. This search was prompted by the fact that a very weak radiation above the 2.68-Mev energy seemed to be present with the 7.7-min half-life, indicating that perhaps a $J=0$, $T=1$ level is really the ground state of K^{38}, as in the case of Cl^{34}. Theoretical estimates indicate that the 0—0 transition from such a level would have an end-point energy of about 4.9 Mev. An upper limit for the branching ratio of the two components was experimentally determined on this basis as 0.006:1. This observation, together with the fact that no conversion line can be found indicates that such a level must lie either above the $J=3$ level or not more than about 80 kev below it. This reasoning is based upon the assumptions that $M3$ radiation would be involved and that the transition probability would differ from that in Cl^{34} by the seventh power of the transition energy.

The very small counting rate above the 2.68-Mev energy beta end point may be due to gamma-ray leakage through the spectrometer. Naturally, this leakage would have the same half-life as the 2.68-Mev positron spectrum.

A scintillation spectrometer with an integral discriminator was used in an additional effort to determine whether positrons with an end point higher than 2.68 Mev are emitted with the 7.7-min half-life. The discriminator was set to accept pulses corresponding to energies of 3.0 Mev and above, and a half-life run was made. Enough time elapsed between the end of the cyclotron bombardment and the start of the half-life run to insure that none of the 0.95-sec activity discovered by Stähelin was present. The half-life obtained was 4.6±0.4 min. The sample decay was followed down to the background counting rate, and no longer half-life was evinced. It was concluded that the half-life obtained was due to pileup of pulses with lower energy; such pileup should display a half-life of one-half the 7.7-min half-life.

The lack of an observed internal conversion line indicates that the 0+, $T=1$ level[2] probably lies above the $J=3$, $T=0$ level. This would require a positron end point for the 0.95-sec activity in K^{38} of energy ≥ 4.84 Mev. In any case the above argument indicates that the energy of the transition is greater than 4.76 Mev.

CONCLUSIONS

The experimental results reported in this paper together with the half-life measurement of Kline and Zaffarano[10] lead to an ft value for the ground ($T=1$) state of Cl^{34} of 3160 ± 120 sec. This is in reasonably good agreement with the result for the other accurately measured $0\rightarrow0$ (no) transition in O^{14}, namely $ft=3275\pm75$ sec.[11]

In the other two cases (P^{30} and K^{38}), the experimental evidence indicates that the ground state is probably not the $J=0$, $T=1$ state. The $\log ft$ values in these cases are 4.8_4 for P^{30} and 4.9_6 for K^{38} corresponding to transitions from the $T=0$ states.

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Mass-Ratio Method Applied to the Measurement of *L*-Meson Masses and the Energy Balance in Pion Decay*

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We report a comprehensive series of measurements made on the masses of *L*-mesons produced by the 184-inch cyclotron. A general ratio principle of measurement is employed which largely eliminates systematic errors. The particular method that we have developed is described in detail. The theory of nonequilibrium particle orbits in the cyclotron field is worked out to provide formulas from which momenta may be calculated, and to obtain the momentum distribution functions determined by the target and detector dimensions. The energy-loss processes in nuclear track emulsion, which is used as a stopping material and detector, are studied and the range-momentum exponent q is found. Several small corrections to the mean range are made. A number of range straggling effects are evaluated. The theoretical distribution of the quantity Rp^{-q} (R being the range and p the momentum) is studied, and the first three moments of the distribution are calculated explicitly. The distribution is found to be closely gaussian. From the theory of the distribution of Rp^{-q}, the best estimate and the statistical uncertainty of the mass ratio (e.g., of meson to proton) are evaluated. A number of effects influencing the ratio are studied, but all the corrections found are very small. The measurement of the momentum acquired by the muon when a pion decays has also been treated. Several important relations connecting this quantity with the particle masses are then introduced. Apparatus developed for the application of the ratio principle is described. A number of experiments in which mesons and protons of similar velocities were detected in the same nuclear track plate are reported. Each experiment was repeated a number of times. The measurements of particle ranges and orbit parameters, the magnetic field measurements, the dimensional tolerances, the calculations, and other important details are discussed.

The following mass ratios are reported: $\pi^+/\text{proton}=0.1488_7\pm0.00011$, $\pi^-/\pi^+=0.998\pm0.002$, $\pi^+/\mu^+=1.321\pm0.002$. The center-of-mass momentum acquired by the muon in positive pion decay was measured as 29.80 ± 0.04 Mev/c and its energy, 4.12 ± 0.02 Mev. All the results are consistent if the rest mass of the neutral particle in the pion decay is zero. With this assumption, the measurements further imply that the positive pion-muon mass difference is 66.41 ± 0.07 electron masses. The derived masses, in units of the electron mass, are: $\pi^+=273.3\pm0.2$, $\pi^-=272.8\pm0.3$, $\mu^+=206.9\pm0.2$.

I. INTRODUCTION

THE determination of pion and muon masses presented special problems which slowed the convergence of the numerous early measurements.[1] One of the various reasons that precision is difficult to attain is that no known comparison particles with approximately the same specific charges as those of *L*-mesons are available, so that we cannot utilize doublets analogous to those of atomic mass spectrometry. Therefore, absolute measurements of quantities determining the mass usually were employed.

It was noticed,[2–11] however, that the mass normalizes a number of measurable quantities so that when divided by the mass, they become functions of the velocity

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