low-lying excited states,[14] the properties of which are not yet known.

The (n,α) reaction becomes energetically possible at a lower energy than does the (n,p) reaction, and, due to the difference in barrier penetration, the (n,α) reaction cross section is correspondingly higher for energies up to a few Mev above the (n,p) threshold. It is difficult, however, to explain the large difference in the cross sections at 8.0 Mev, at which energy both the α-particles and the protons may have energies greater than the barrier energy.

The cross sections obtained for the (n,α) and (n,p) reactions on F^{19} are of the same order of magnitude as the cross sections for reactions of this type on other nuclei.[1-9] The (n,α) reaction cross section measured at 3.9 Mev is 46±18 mb, which is in good agreement with the value 37±18 mb, obtained by Jelley and Paul[20] at this energy.

ACKNOWLEDGMENTS

The authors wish to express their appreciation of the continued assistance and encouragement given by Professor T. W. Bonner. Thanks are also due Dr. H. Bichsel for preparing and mounting the crystal.

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[20] J. V. Jelley and E. B. Paul, Proc. Phys. Soc. (London) **A63**, 112 (1950).

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K-Capture - Positron Ratios for the First-Forbidden Transitions of Rb^{84} and the Relative Probabilities of *L*- and *K*- Electron Capture*

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The radiations from Rb^{84} have been investigated by means of scintillation coincidence spectrometer techniques in order to obtain the relative intensities of the various transitions. The energies and abundances of the radiations are 0.44-Mev β^- (5%), 0.81-Mev β^+ (10%), 1.70-Mev β^+ (9%), 0.89-Mev γ (64%), and 1.91-Mev γ (0.9%). [*Note added in proof.*—The β^- has been shown to be 0.91 Mev (2.5%).] Electron capture populates the level 1.91 Mev above the ground state, competes (54%) with the 0.81-Mev β^+ to populate the level 0.89 Mev above ground, and competes (21%) with the 1.70-Mev β^+ in effecting transitions to the ground state of Kr^{84}. The ratios of *K*-capture to positron emission for the transition to the 0.89-Mev level ($\Delta I=0$, yes) and to the Kr^{84} ground state ($\Delta I=2$, yes) are 5.15±0.38 and 2.06±0.36, respectively. These values are in qualitative agreement with theory. Nucleon configurations of the several states of Rb^{84}, Kr^{84}, and Sr^{84} are discussed. In the decay to the 0.89-Mev level an L/K-capture ratio of 0.12±0.05 was obtained by use of a value, 0.65, for the fluorescence yield of krypton. Alternatively, an experimental value for the fluorescence yield, 0.62±0.03, may be computed if the theoretical L/K-capture ratio is assumed.

THE radiations emitted in the decay of Rb^{84} have been studied by a number of investigators.[1-4] According to Huddleston and Mitchell,[4] two main positron groups are observed. The maximum energies and relative abundances were stated to be 1.63 Mev (0.39) and 0.82 Mev (0.58). A gamma ray of energy 0.89 Mev was found to be in coincidence with the lower energy positron group; the higher energy positrons were shown to represent a transition to the ground state of Kr^{84}. From the shape of the Fermi plot for the 1.63-Mev group, it was concluded that the transition is of the type $\Delta I=2$, yes. Moreover, since the spin-parity assignment for the ground state of Kr^{84}, an even-even nucleus, is $0+$,[5] the ground state of Rb^{84} was given the assignment $2-$. In agreement with this $2-$ designation and with the $2+$ designation for the first excited state[5] of Kr^{84}, the Fermi plot for the lower energy positron group was found by Huddleston and Mitchell to have an "allowed shape." These authors did not observe any appreciable negative beta emission, although Beckham and Pool[2] reported that negative beta decay to Sr^{84} occurs with a probability 16 percent as great as that for positron decay. It may be noted that negative beta decay should be exoergic to the extent of ~0.5 Mev.[6] Karraker and Templeton,[3] who also observed negative electrons and positrons, reported the principal mode of decay to be electron capture; in other respects their observations are in essential agreement with those of Huddleston and Mitchell. Further, a gamma ray of energy 1.89 Mev has been observed[7] in the radiations from Rb^{84}. The best value of the half-life obtainable from the literature is 34 days.[3]

As pointed out by Huddleston and Mitchell, the

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[1] W. C. Barber, Phys. Rev. **72**, 1156 (1947).

[2] W. C. Beckham and M. L. Pool, Phys. Rev. **80**, 125 (1950).

[3] D. G. Karraker and D. H. Templeton, Phys. Rev. **80**, 646 (1950).

[4] C. M. Huddleston and A. C. G. Mitchell, Phys. Rev. **88**, 1250 (1952).

[5] G. Scharff-Goldhaber, Phys. Rev. **90**, 587 (1953).

[6] K. Way and M. Wood, Phys. Rev. **94**, 119 (1954).

[7] L. M. Langer and R. B. Duffield (private communication reported in reference 4).

assignment, 2−, for the ground state of Rb^{84} is consistent with the shell-model nucleon configurations, neutron $g_{9/2}$ and proton $f_{5/2}$. In this connection it may be noted that the measured spin of Rb^{85} is 5/2 and that the spins of Kr^{83} and Sr^{87} are 9/2.[8] Moreover, Stevenson and Deutsch,[9] from measurements of beta-gamma angular correlation, concluded that Rb^{86} has spin 2 and negative parity in accord with the nuclear magnetic moment result obtained by Bellamy.[10]

The probabilities of K-capture and positron emission for various types of transitions have been the subject of theoretical investigations.[11–14] For allowed transitions and first forbidden transitions of the type $\Delta I=2$, yes, the K-capture to positron probability ratios are independent of the nuclear matrix elements and thus of the type of interaction chosen. In the case $\Delta I=2$, yes, the K-capture to positron probability ratio is greater by a factor approximately three to six than that calculated for an allowed transition of the same energy and atomic number. However, in the cases in which $\Delta I=0$ or 1, yes, the probability ratios are dependent on the nuclear matrix elements but are not greatly different from the values to be expected for an allowed transition. Several investigations[15–17] of K-capture to positron ratios for allowed transitions have been reported and the results are in agreement with theory. On the other hand, very little experimental data exists for forbidden transitions; accurate measurements are available only for I^{126} ($\Delta I=2$, yes)[18] and As^{74} ($\Delta I=0$, yes).[19] The results for I^{126} are in good accord with theory,[12] and a careful comparison of the As^{74} value with the theoretical one is being made.[14] The study described in this paper was undertaken because Rb^{84} furnishes an opportunity for measurement of K-capture to positron ratios for first forbidden transitions of the types $\Delta I=2$ and 0.

EXPERIMENTAL METHODS AND RESULTS

Source Preparation and Purity

The Rb^{84} used in these experiments was produced by the reaction[3] $Br^{81}(\alpha,n)Rb^{84}$. The ammonium bromide target material, pressed onto the grooved face of a copper block and covered with a copper foil to degrade the energy of the helium ions, was irradiated in the external beam of the Brookhaven 60-inch cyclotron. Separation of the ammonium bromide from the rubidium activity was effected by the addition of freshly precipitated silver oxide to a water solution of the irradiated salt. The ammonium hydroxide formed was volatilized and the insoluble silver bromide, together with free silver and excess silver oxide, were removed by filtration. Precipitations of copper and zinc sulfides, ferric hydroxide, and barium sulfate were performed in order to free the rubidium from radioactive contaminants.[20] Approximately one microcurie of Rb^{84} was produced per microampere-hour of irradiation. The carrier-free rubidium activity was finally deposited on Mylar film, ~1 mg/cm² thick, and was covered with a thin layer of Zapon lacquer.

Unless otherwise stated, all the results reported in this paper and in the paper which follows were obtained with rubidium produced by the irradiation of a thick target with 14.5-Mev helium ions. The decay of one source was measured over a period of about 170 days with a proportional counter, the window of which was ~1.2 mg/cm² thick. The counter was filled to a pressure of one atmosphere with an argon-methane gas mixture. Rates were observed with the source uncovered, with a beta-stopping beryllium absorber, and with a beryllium and copper pair to stop beta particles and x-rays. The transmission of the beryllium absorber for krypton K x-radiation was determined experimentally to be 44.0% at normal incidence. The analysis of the count-rate data is shown in Fig. 1. Points labeled γ represent net rates observed through the beryllium-copper pair. The total x-ray points represent differences, corrected for the transmission of the beryllium, between the γ points and the rates observed through beryllium. The β points were computed by subtraction of the sum of the total x-ray and γ rates from the rates observed with no absorber. Although the β decay is clearly characterized by a half-life of 33.0 ± 0.2 days, the γ and total x-ray decay points show that a long-lived component was present. Subtraction from the total x-ray rates of the amount of 83-day[21] Rb^{83} component shown in Fig. 1 yields the residual 33-day x-ray decay line.

At helium-ion energies of 14.5 Mev and less it is unlikely that Rb^{83} can be produced by the reaction $Br^{81}(\alpha,2n)Rb^{83}$; small amounts of Rb^{83} are produced, however, by the reaction $Br^{79}(\alpha,\gamma)Rb^{83}$.[22] Sources prepared from material irradiated with helium ions of higher energy contained, after a period of decay, large fractions of the 83-day x- and gamma-ray emitter, Rb^{83}; the beta decay of these sources nevertheless followed a

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[8] P. F. A. Klinkenberg, Revs. Modern Phys. **24**, 63 (1952).

[9] D. T. Stevenson and M. Deutsch, Phys. Rev. **84**, 1071 (1951).

[10] E. H. Bellamy, Nature **168**, 556 (1951).

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[20] Details of this chemical separation are given in one of the radiochemical procedures collected and distributed by H. L. Finston, Brookhaven National Laboratory, Upton, New York.

[21] S. V. Castner and D. H. Templeton, Phys. Rev. **88**, 1126 (1952).

[22] H. Morinaga, Phys. Rev. **99**, 655(A) (1955).

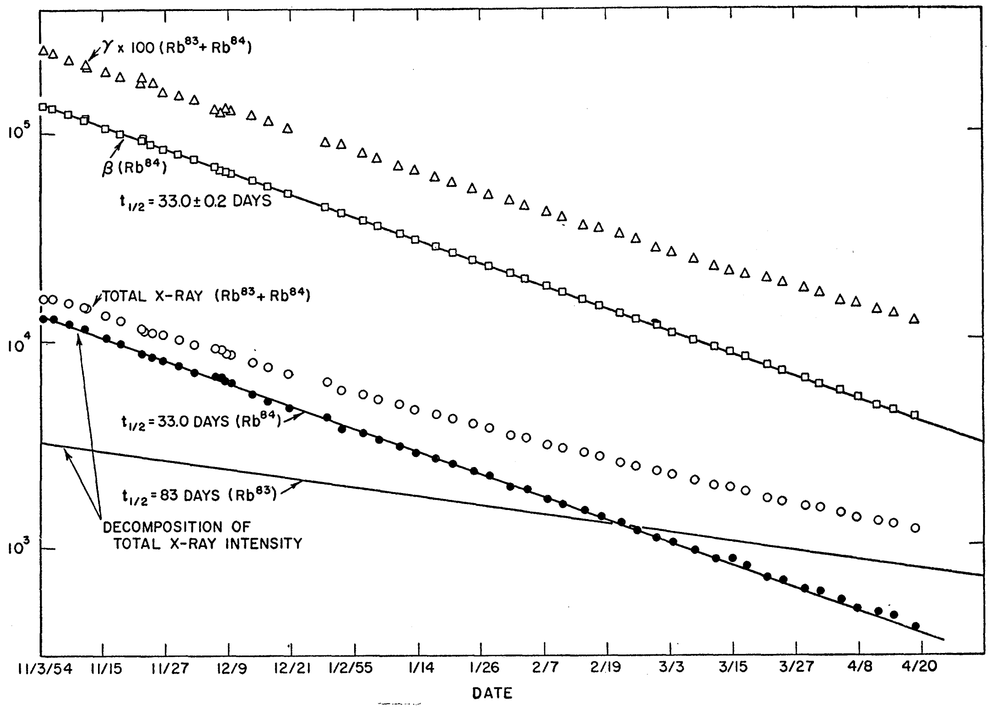

FIG. 1. Analysis of decay measurements taken with end-window proportional counter and suitable absorbers.

34-day half-life. The latter observation shows that there are very few particles emitted by Rb^{83} in agreement with the work of Castner and Templeton and with the expected decay energy.[6] The fact that no long-lived component was observed by Karraker and Templeton in rubidium sources prepared with 18-Mev helium ions is explainable; the Geiger-Müller detectors used by these authors are less sensitive to electromagnetic radiations than the end-window counter described above.

An independent determination of the relative contributions from Rb^{83} and Rb^{84} to the total x-ray intensity was made with a second source prepared from the target irradiated with 14.5-Mev helium ions. The x-ray intensity of this source, which was used in most of the experiments described below, was measured with a side-window proportional counter filled to a pressure of two atmospheres with a 95% argon-5% methane mixture. The area under the krypton K x-ray pulse-height distribution was evaluated as a function of time. Small corrections were applied to compensate for variations of the pulse-analyzer channel width between measurements. Subtraction from the experimental points of the 33-day line shown in Fig. 2 leaves residual rates which decay with an 83-day half-life. The relative x-ray intensities from Rb^{83} and Rb^{84} determined in the two ways differed by only 5%; the mean value was used in all calculations. From the work of Castner and Templeton, it is known that Rb^{83} decays at least in part to Kr^{83m}, 114-min half-life.[23] Because the sources used in this work did not emanate, as determined by test, the 83-day x-ray activity represented the sum of the contributions from Rb^{83} and from the Kr^{83m} in equilibrium with it.

Gamma-Ray Spectra

The gamma radiations were examined with a gray-wedge spectrometer and NaI(Tl) detectors. Various gamma-ray standards[23] were used to calibrate the energy scale. In addition to the K x-ray photoline, photopeaks were observed at energies 0.51, 0.89±0.02, and 1.91 ±0.05 Mev. Peaks at these energies were to have been expected on the basis of previously published information; it was found, however, that the intensity of the 0.51-Mev peak relative to that of the 0.89-Mev photoline increased as the fractional amount of Rb^{83} increased. Since there is no positron emission from Rb^{83}, it was concluded that a gamma ray of very nearly the same energy as annihilation radiation is associated with the decay of this nuclide.[24] It was observed that the ratio of the intensities of the 0.89- and 1.91-Mev photopeaks is independent of the source composition; therefore, the 1.91-Mev radiation is characteristic of Rb^{84}.

The pulse-height spectra shown in Figs. 3A and 3B

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[23] *Nuclear Data*, National Bureau of Standards Circular 499 and Supplements (U. S. Government Printing Office, Washington, D. C., 1950).

[24] The decay scheme of Rb^{83} is discussed in detail by M. L. Perlman and J. P. Welker, following paper [Phys. Rev. **100**, 81 (1955)].

were obtained with a sliding channel pulse-height analyzer, a NaI(Tl) detector 1.5 inches in diameter and 1 inch long, and a source covered on both sides with beta-stopping beryllium absorbers. From the areas under the photopeaks and from the relative photopeak-efficiency curves of Bell,[25] the intensities of the 1.91- and 0.89-Mev gamma rays were calculated to be in the ratio (0.0135±0.001)/1.

Beta Spectra

Beta-ray spectra were investigated with a small anthracene scintillation detector only slightly greater in thickness than the range of the most energetic particles. A photograph of the pulse distribution from this detector as displayed by the gray-wedge spectrometer is given in Fig. 4. Three beta groups are seen to be present; the maximum energies are 1.70±0.07, 0.81 ±0.05, and 0.44±0.05 Mev. The energy scale was calibrated by means of beta-ray standards[23]: P^{32} (1.701 Mev), Tl^{204} (0.765 Mev), and Na^{22} (0.542 Mev). There is no indication in the photographs of any internal-conversion electron line. The 0.81-Mev beta group was displayed alone in experiments in which coincidences with the 0.89-Mev gamma rays were required. It may be noted that the energy difference between the two higher energy groups agrees well with the observed gamma-ray energy, 0.89 Mev.

Experiments with a crude magnetic spectrometer indicated the presence of negative electrons, in abundance of the order one-fifth that of the positrons. On the basis of the coincidence results described in the next section of this paper, it is established that the two higher energy beta groups are positrons. Because the intensity of conversion electrons from the 0.89-Mev transition is expected to be approximately 1/200 that of the observed negative electrons, the negative particles must be the 0.44-Mev beta group. The abundance of these negative betas relative to that of the positrons was determined quantitatively by comparison of the rubidium source with a Na^{22} source. For the two sources in a defined geometry, the particle count rates were measured with an end-window proportional counter and the areas under the 0.51-Mev photopeaks were determined. The 0.51-Mev rubidium peak area was corrected

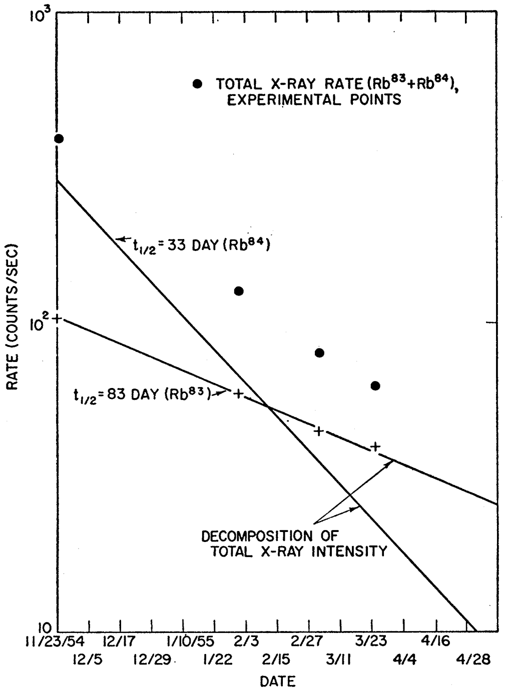

FIG. 2. Analysis of the decay of the *K* x-ray pulse distribution as observed with a proportional counter spectrometer.

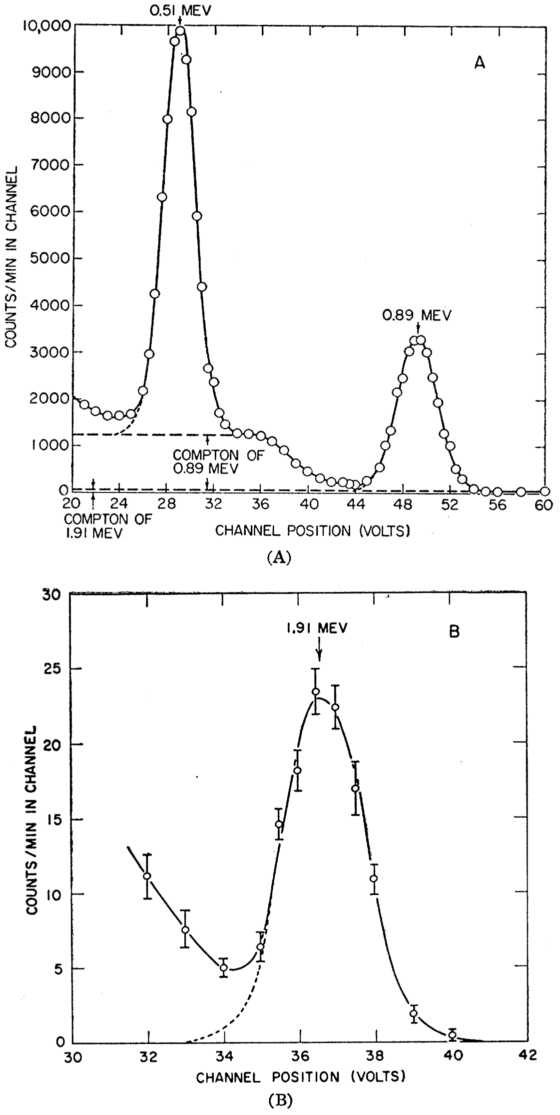

FIG. 3. Gamma rays emitted in the decay of Rb^{83} and Rb^{84}. Pulse-height distributions measured with a sliding channel scintillation spectrometer: A (high gain); B (low gain).

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[25] P. R. Bell (privately circulated data).

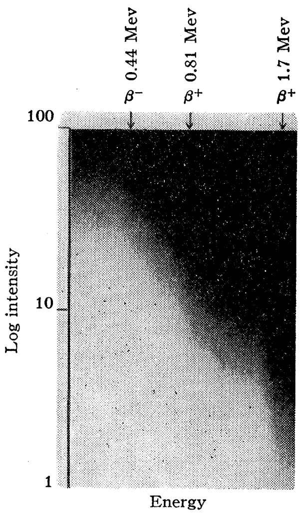

FIG. 4. Gray-wedge spectrometer record of beta-ray distributions from Rb^{84} (see reference 28).

for the amount of 0.525-Mev Rb^{83} radiation by means of a method described in the next section of this paper. It was found that the particle count rate per unit of corrected 0.51-Mev peak area is 1.25 times as great for Rb^{84} as for Na^{22}; or, in other words, the negatron-to-positron intensity ratio for Rb^{84} is 0.25±0.10.

Coincidence Studies

Coincidence investigations were carried out with a gray-wedge coincidence spectrometer and pairs of scintillation detectors appropriate for the various radiations. The geometrical arrangements of the detectors and sources and the nature of the absorbers used were varied to suit the individual experiments. The coincidence resolution time was 0.1 microsecond. In Table I the results of these qualitative experiments are summarized.

From the experimental results presented so far, it may be deduced that the disintegration scheme for Rb^{84} is that shown in Fig. 5. A few comments on the qualitative features of the scheme follow. Positron emission and electron capture compete to populate the first excited state of Kr^{84} and should also compete in the ground-state transition. The observations of the radiations in coincidence with the 0.89- and 1.91-Mev gamma rays show that these two gammas represent transitions to the ground state of Kr^{84}. Positron emission to the 1.91-Mev level is energetically impossible. Because all observed gamma rays are accounted for in the $Rb^{84} \rightarrow Kr^{84}$ decay, it follows that the 0.44-Mev negative beta rays decay to the ground state of Sr^{84}.

In order to determine the relative abundances of the various transitions associated with the decay of Rb^{84}, several quantitative comparison coincidence measurements were performed. The intensity of the 0.525-Mev gamma rays of Rb^{83} relative to that of the annihilation quanta from Rb^{84} was determined by an experiment in 180° geometry in which the net number of (0.511, 0.511)-Mev coincidences per 0.511(0.525)-Mev quantum was compared with the number of (0.511, 0.511)-Mev coincidences per annihilation quantum from a Na^{22} source. Two NaI(Tl) scintillation detectors with sliding channel pulse-height selectors were used. One crystal and channel were kept fixed with respect to the source; with the other the areas under the "singles" and coincidence photopeaks were scanned. The result obtained on 12–17–54 for the intensity ratio of 0.525-Mev gamma rays to annihilation quanta, 0.77±0.04, was then used together with the known half-lives of Rb^{83} and Rb^{84} to compute the relative amounts of these two radiations at other times. It is readily calculated that a negligible error is introduced into the Na^{22} measurement by the occurrence of coincidences of annihilation quanta with Compton events associated with the 1.28-Mev gamma ray.

In order to ascertain the fraction of the positrons which is followed by the 0.89-Mev radiation, the number of (0.511, 0.89)-Mev coincidences per 0.511 (0.525)-Mev quantum was compared with the number of (1.12, 0.89)-Mev coincidences per 1.12-Mev quantum from a Sc^{46} source. It is known that the two cascading Sc^{46} gamma radiations are of equal intensity.[23] In this experiment the geometry of the sources with respect to the detector for the 0.89-Mev radiations was maintained constant. The result, corrected for the 0.525-Mev gamma-ray intensity present at the time of measurement, is $I_{0.81\beta^+}/I_{\text{total}\beta^+}=0.505\pm0.026$.

The fraction of the 0.89-Mev gamma transitions which is associated with positron emission was determined by comparison of the number of (0.511, 0.89)-Mev coincidences per 0.89-Mev quantum with the number of (0.511, 1.28)-Mev coincidences per 1.28-Mev quantum from a Na^{22} source. The result, $I_{0.81\beta^+}/I_{0.89\gamma}$

TABLE I. Results of coincidence experiments with $Rb^{83,84}$ mixture.

Selected event	Events observed in coincidence with selected event	Remarks[a]
Kr *K* x-ray	0.525-, 0.89-, 1.91-Mev γ's	0.525-Mev γ is associated with Rb^{83}
0.511(0.525)-Mev γ's[b]	*K* x-ray, 0.511-, 0.89-Mev γ's; 0.81-, 1.70-Mev β^+ spectra[c]	no γ's other than 0.89 Mev in coinc.; no [0.511, 0.511(0.525)]-Mev coinc. out of 180° geometry
0.89-Mev γ	*K* x-ray, 0.511-Mev γ; 0.81-Mev β^+ spectrum	no indication of coinc. with 1.02-Mev γ (stopover) or any γ other than annihil.
1.91-Mev γ	*K* x-ray	

[a] A detector-source-detector angle of ~135° was employed whenever necessary to eliminate (0.511, 0.511)-Mev annihilation coincidences.

[b] The photopeak distributions from these two radiations were not resolved from each other.

[c] Huddleston and Mitchell, reference 4, showed that the 1.70-Mev β^+ group is not in coincidence with a nuclear gamma ray and therefore represents a transition to the ground state of Kr^{84}.

$=0.150\pm0.011$, is based upon the fact that in the decay of Na^{22}, 90.0 ± 0.5 percent[17] of the 1.28-Mev quanta are associated with positrons.

To determine the fraction of the krypton K x-rays which is followed by the 0.89-Mev transitions, the number of K x-ray, 0.89-Mev gamma coincidences per K x-ray was compared with the number of (1.12, 0.89)-Mev coincidences per 1.12-Mev gamma quantum observed with a Sc^{46} source. A thin NaI(Tl) detector was used for the x-rays, and a thick NaI(Tl) scintillator was used for the 1.12-Mev gamma rays; however, the same crystal and geometry were employed for the detection of the 0.89-Mev radiations from both sources. The K x-ray "singles" rate was corrected for the intensity of 83-day x-rays present at the time of measurement. It should be noted that the result,

$$I_{\text{x-ray to 0.89 level}}/I_{\text{x-ray}}=0.71\pm0.03,$$

represents, independently of the fluorescence yield, the fraction of all electron capture which proceeds to the 0.89-Mev level, provided only that the ratio of L to K capture is the same for the various capture branches.

Most of these quantitative coincidence measurements were made twice; the errors attached to the above results were computed from errors assigned to the individual experiments. In all cases the differences between duplicate experiments were less than the combined individual errors.

INTERPRETATION OF Rb⁸⁴ RESULTS

Transition Intensities

From the results of the quantitative coincidence experiments, from the ratio of negatrons to positrons, and from the intensity ratios of the gamma radiations, the intensities of all the transitions associated with Rb^{84} were computed. An L-capture to K-capture probability ratio of 0.10 is assumed.[13] The value for the fluorescence yield of krypton does not enter into these calculations. The transition intensities, together with the measured transition energies, were then used to compute the logft values (Table II).

TABLE II. Abundances and comparative half-lives of the radiations from Rb^{84}.

Radiation	Abundance (percent)	log ft[a]	log f_1t[b]
EC to ground state	$21\ \pm3$	7.8	
EC to 0.89-Mev level	54.3 ± 0.7	7.1	
EC to 1.91-Mev level	$0.9^{+0.3}_{-0.1}$	8.1	
0.81-Mev β^+	9.6 ± 0.7	7.3	
1.70-Mev β^+	9.4 ± 0.9	8.8	8.7
0.44-Mev β^- [c]	4.7 ± 2.0	7.7	6.6
	Total 100		
0.89-Mev γ	64		
(1.02-Mev γ)	<0.3[d]		
1.91-Mev γ	0.9 ± 0.1		

[a] The log ft values were computed from the monographs of S. A. Moszkowski, Phys. Rev. 82, 35 (1951), and from the graphs given by E. Feenberg and G. Trigg, Revs. Modern Phys. 22, 399 (1950).

[b] The log f_1t values for the unique transitions were calculated by the method of J. P. Davidson, Phys. Rev. 82, 48 (1951).

[c] See reference 28.

[d] This upper limit was estimated from Fig. 3.

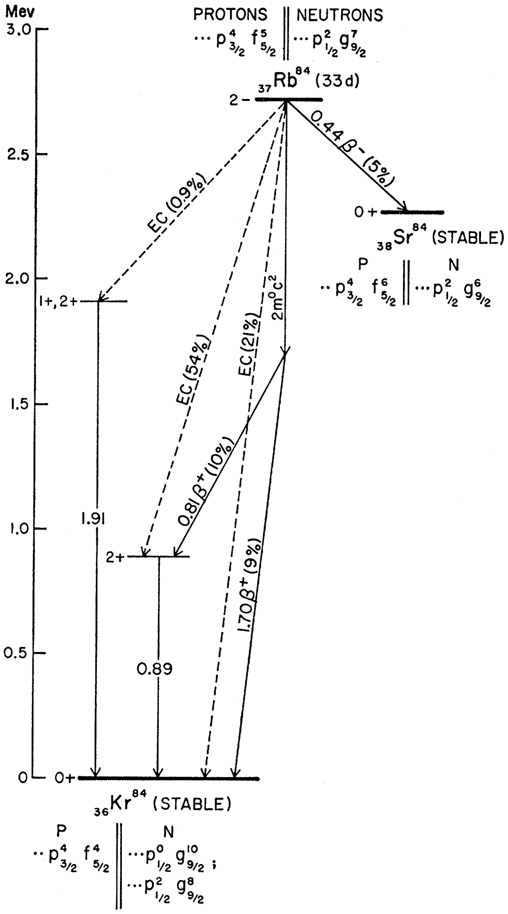

FIG. 5. The decay scheme of Rb^{84} (see reference 28).

K-Capture - Positron Ratios

For the transition to the 0.89-Mev level, which is characterized by spin change zero and parity change, the measured K-capture to positron-emission probability ratio is 5.15 ± 0.38. This result is to be compared with the value, 3.1, computed for an allowed transition of the same energy. For the ground-state transition, which is of the type $\Delta I=2$, yes, the K-capture to positron ratio observed is 2.06 ± 0.36; if the transition were an allowed one, the ratio would be 0.28. In both cases the measured ratios are larger than those computed for allowed transitions, and the increases are in agreement with the qualitative theoretical expectations for first forbidden transitions.[11–13] Quantitative comparisons will be made[14] on completion of the theoretical calculations for Rb^{84}.

Characterization of the Levels

According to King and Peaslee,[26] for first forbidden transitions in which $\Delta I=0$ and Δj, the nucleon spin change, is greater than ΔI, the log ft values average 7.55 ± 0.47. The transitions to the first excited state of Kr^{84} at 0.89 Mev above ground are of this type, and the logft values for the positron and electron-capture branches are 7.3 and 7.1, respectively. King and Peaslee have pointed out further that, for first forbidden transitions characterized by $\Delta I=2$, the average value for logf_1t is 8.5 ± 0.5. The logf_1t value, 8.7, for the positron decay to the ground state of Kr^{84} is in good agreement with this average; however, for the negative beta-decay branch to the ground state of Sr^{84}, logf_1t is 6.6. Arguments based on the nucleon configurations[27] of the three ground states involved may be employed to explain the relatively high transition probability for negative beta decay, and a set of tenable shell-model proton and neutron configurations is presented in Fig. 5.[28]

In a recent survey of even-even nuclei Scharff-Goldhaber and Weneser[29] have pointed out that the ratio of the energies of the second and first excited states is approximately 2.2 for neutron numbers below eighty-eight. The designation of the 0.89- and 1.91-Mev levels as the first and second excited states of Kr^{84} is in agreement with this general observation. The logft value, 8.1, for the transition to the 1.91-Mev level, considered together with the low probability of the stopover gamma transition as compared with that of the crossover transition, would seem to favor the designation 1+ for the second excited state. However, the designation 2+, which characterizes more than half of the second excited states investigated,[29] cannot be excluded.

RELATIVE PROBABILITY FOR THE CAPTURE OF *L*- AND *K*-ELECTRONS; THE FLUORESCENCE YIELD OF KRYPTON

The theory for the relative capture probability of L and K electrons has been thoroughly developed[13] for both allowed and forbidden transitions. The L/K-capture branching ratio for A^{37}, measured by Pontecorvo, Kirkwood, and Hanna,[30] is in agreement with theory; however, the results of Langevin[31] for Ge^{71}, 0.30 ± 0.02, and of Langevin and Radvanyi[32] for Kr^{79}, 0.25 ± 0.03, disagree with the theoretical predictions, 0.10 and 0.09, respectively. Because of the paucity of the experimental data, a measurement of the L/K-capture ratio for the transition to the 0.89-Mev level in Kr^{84} was undertaken.

Evaluation of the L/K-capture ratio depends on the relation,

$$[(EC_L+EC_K)/EC_K](f_x/\omega_K)+f_{\beta^+}=1, \qquad (1)$$

where EC_L and EC_K refer to the probabilities of L- and K-electron capture, ω_K is the K-fluorescence yield of krypton, f_{β^+} designates the fraction of the 0.89-Mev level population that is supplied by positron emission, and f_x the fraction supplied by K-capture processes accompanied by fluorescence. Population of the 0.89-Mev level by gamma radiation from the 1.91-Mev state ($<0.5\%$) is neglected. The value for f_{β^+}, 0.150 ± 0.011, was obtained as described earlier in this paper. The value for f_x, 0.48 ± 0.02, was determined from a measurement of the number of K x-ray, 0.89-Mev coincidences per 0.89-Mev quantum and from the absolute efficiency of the thin NaI(Tl) detector for krypton K x-rays. The latter efficiency is made up of several factors which were evaluated experimentally: the solid angle subtended by the detector at the source in the coincidence geometry, the fraction of the krypton x-ray pulse distribution accepted by the single channel analyzer, the transmission of the thin aluminum crystal cover, and the transmission of the beryllium beta-stopping absorber. The geometrical factor was determined by comparison of the x-ray count rate in the coincidence geometry with the count rate at a source-to-detector distance such that the solid angle subtended by the detector at the source could be accurately evaluated by mensuration. If, from the analysis of the experimental data carried out by Broyles, Thomas, and Haynes,[33] the value, 0.65, is taken for ω_K, then EC_L/EC_K is computed to be 0.12 ± 0.05. This result is in good agreement with the theoretical result, 0.10. It may be noted, that in order to obtain an L/K ratio about 0.27, an average of the values for Ge^{71} and Kr^{79}, ω_K would have to be 0.73, an unreasonably large value.

Conversely, Eq. (1) may be used to compute the krypton K-fluorescence yield if the theoretical L/K-capture ratio is assumed. The value thus obtained for ω_K is 0.62 ± 0.03.

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[28] *Note added in proof.*—The authors are indebted to Dr. C. S. Wu and Miss N. Benczer, who has kindly informed them that unpublished results obtained in her laboratory with a magnetic lens spectrometer show that the negative beta radiations of Rb^{84} have a maximum energy of 0.910 Mev and an abundance $\frac{1}{8}$ that of the positrons. The small break in Fig. 4 which was interpreted to represent the end point of the negative beta spectrum is therefore probably spurious. The values obtained by Wu and Benczer change the negative beta abundance in the decay scheme from the quoted value, $4.7\%\pm2\%$, to 2.4%; and electron capture to the 0.89-Mev level increases from 54.3% to 55.5%. Other abundance changes are completely negligible. The value for logf_1t for the negative beta transition becomes 8.7 in excellent agreement with the value for the ground-state positron transition; and thus no special configuration arguments are required.

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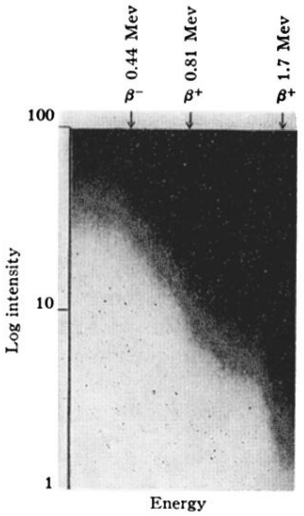

FIG. 4. Gray-wedge spectrometer record of beta-ray distributions from Rb^{84} (see reference 28).