but a scalar potential survives between outer particles and any subgroup coupled to zero total spin, there is no simple reason to expect the mixture of forces in the perturbation to be independent of A. However, with the exception of Co^{58} all of the nuclei can be fitted with a value of α between $\frac{1}{6}$ and $\frac{1}{4}$.

With regard to Nordheim's rules, we now see that their validity is not as general as was first indicated in the case of one odd proton and one odd neutron. Certainly for one less than a filled shell of both neutrons and protons they are equally valid; and the "strong" rule,

$$J=|j_p-j_n|,\quad \text{for } j_p+j_n+l_p+l_n \text{ even},$$

is still good when n_1 and n_2 are both more or both less than half of a filled shell. However, in general, the situation is more complicated, especially as it is unsafe to rely on the constancy of the mixture of forces.

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The Decay Scheme of Zr^{95}†*

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The decay scheme of Zr^{95} has been studied using the techniques of beta-ray spectroscopy and beta-gamma angular correlation. The decay of Zr^{95} is found to proceed by three beta gamma cascades. Two of the beta transitions are allowed and proceed to Nb^{95} levels at 722.0 kev and 754.4-kev. The third beta transition is to a 235-kev level in Nb^{95}. From K-conversion coefficient determinations and shell theory the 722-kev and 754.4-kev levels are both assigned even parity and a spin of 5/2 or 7/2.

THE radiations originating from the decay of Zr^{95} have been studied by a number of investigators with somewhat divergent results. A recent paper by Cork *et al.*,[1] published after the completion of this study, contains an excellent survey of the previous work.

In the present investigation, beta-ray spectrometer studies were made of the Zr^{95} spectra and gamma ray conversion lines. In addition, the angular correlation between the Zr^{95} beta and gamma rays in cascade to the ground state of Nb^{95} was measured.

BETA-RAY SPECTROMETER STUDIES

The beta-ray spectrometer used in this investigation was a double-focusing, high-resolution spectrometer patterned after that of Kurie, Slack, and Osaba.[2] In most of the runs reported here it was operated at a resolution of 0.2 percent. The electron detector used for studies of the shape of the beta spectrum was an end-window Geiger counter with a 0.6-mg/cm² rubber hydrochloride window. Later studies of conversion lines and of the high-energy end of the beta spectrum employed an end-window counter with a 3-mg/cm² mica window.

The magnetic field in the spectrometer was measured using a double-coil monitor with a temperature-stabilized permanent magnet supplying the reference field. The magnetic field could be kept constant to within 1 part in 20,000 for extended periods of time.

The source material used in all of the experiments consisted of a $Zr^{95}-Nb^{95}$ oxalate mixture obtained from Oak Ridge National Laboratory. The Oak Ridge analysis indicated that the radiochemical purity of the source material was better than 99 percent and that the source initially consisted of 40 percent Zr^{95} and 60 percent Nb^{95}.

The source for the spectrometer study of the spectrum shape was prepared by laying down the source material in the form of a line 3 mm wide by 1 inch high on a thin formvar film on which a film of gold had been vacuum evaporated. The areal density of the source backing was less than 125 μg/cm². The areal density of the source material was approximately 50 μg/cm².

Figure 1 shows the Kurie plot obtained with this source. It will be noted that the plot has an "allowed" shape from the end point of the Nb^{95} spectrum at 160 kev out to approximately 360 kev. At the high-energy end of the spectrum the 900-kev branch of the Zr^{95} decay is in evidence but the source was too weak to make significant measurements on it. The K conversion line resulting from the 235-kev isomeric transition in Nb^{95} is also in evidence in this figure.

The conversion lines from the gamma ray transitions in Nb^{95} and Mo^{95} were examined with a stronger source. This source was prepared by ruling a line 1 mm wide and

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* This work was reported at the 1953 Washington meeting of the American Physical Society.
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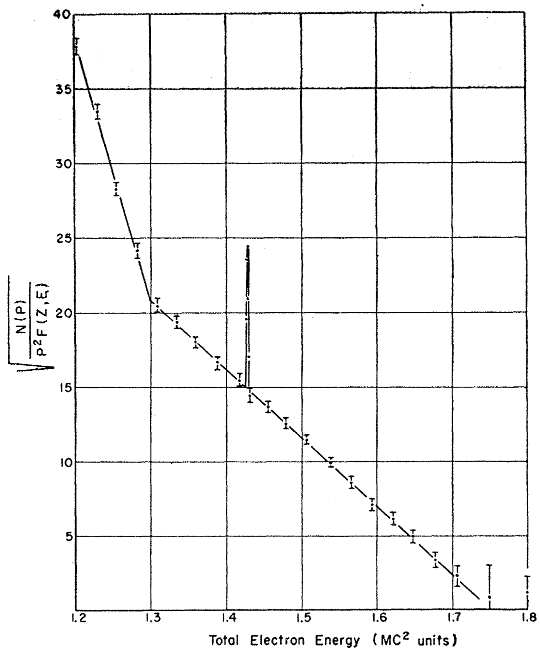

FIG. 1. Fermi plot of the beta spectrum from a mixed $Zr^{95}-Nb^{95}$ source.

1 inch high on 2.7-mg/cm² aluminum foil. The areal density of the source material was approximately 300 μg/cm². Preliminary examinations of the conversion lines indicated the presence of three gamma rays in the 700-kev region. Previous investigations had indicated that only two gamma rays were to be expected in this region, one from an excited state of Nb^{95} at 708 kev and a second from an excited state of Mo^{95} at 760 kev. To determine the origin of the third conversion line, careful studies were made of the K and L conversion lines with the result shown in Fig. 2. In this figure can be seen the three K lines with their associated L and M lines. The energy differences between the K and L lines for each of the three sets

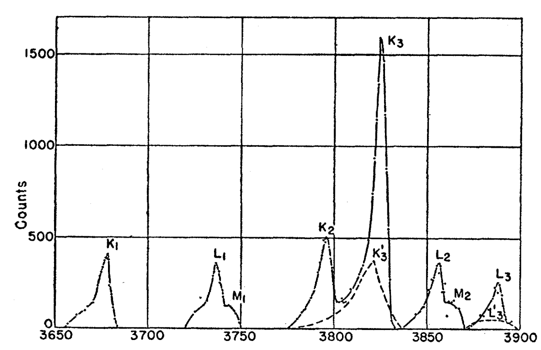

FIG. 2. High-energy internal conversion lines from a mixed $Zr^{95}-Nb^{95}$ source. Counting times for K_1, K_2, and K_3 were three minutes per point; for L_1, L_2, M_1, and M_2, twenty minutes; for L_3, four minutes.

of conversion lines are compared in Table I to the energy differences possible for conversion in Nb^{95} and for conversion in Mo^{95}. It can be seen that gamma rays No. 1 and No. 2 are to be associated with conversion in Nb^{95} and gamma ray No. 3 with conversion in Mo^{95}.

To verify the element assignments, a source rich in Nb^{95} was made. This source was prepared by precipitating Nb^{95} from a solution of $Zr^{95}-Nb^{95}$ oxalate in *10N* HNO_3 by $KMnO_4$ following the method of Connick and McVey.[3] The precipitate containing the Nb^{95} was dissolved in H_2O_2 and laid down as a line source on 2.7-mg/cm² aluminum. The conversion lines obtained with this source are labelled K_3' and L_3' on Fig. 2. It will be noted that the position of K_3' coincides with K_3 in agreement with the previous element assignment of the three gamma rays.

The energies of the gamma rays were determined by making up a mixed $Cs^{137}-Zr^{95}-Nb^{95}$ source on aluminum. Assuming that $H\rho=3380.5\pm3$ gauss-cm for the Ba^{137} conversion line, according to Langer and Moffat,[4] the energies of the three gamma rays are $\gamma_1=722.0\pm1.4$ kev, $\gamma_2=754.4\pm1.4$ kev, $\gamma_3=764.0\pm1.4$ kev.

The presence of two high-energy gamma rays in the decay scheme of Zr^{95} suggested the possibility that there might be two beta branches in the Zr^{95} decay differing in end-point energy by approximately 32 kev. To examine this possibility, a study was made of the high-energy portion of the Zr^{95} beta spectrum using the source prepared for the conversion line studies.

Figure 3 shows the total Zr^{95} beta spectrum near its end point with the 900-kev beta branch subtracted. The total spectrum of Fig. 3 clearly indicates the presence of two partial spectra. Since the energy difference between the two Zr^{95} gamma rays could be determined more precisely than the difference in beta energies from a partial spectrum analysis of the data, the 32-kev energy difference between γ_1 and γ_2 was used as a criterion for drawing the best partial spectra lines to fit the beta spectrum data. These two lines are designated B and C in Fig. 3 with end points at 364 and 396 kev, respectively. Extrapolating the resolved spectra back to zero electron kinetic energy the branching ratio could be determined. The average of two such determinations yielded a value 1.38 ± 0.1 for the ratio of the intensity of the low-energy branch to that of the high-energy branch.

The conversion line studies yielded the number of conversion electrons for each gamma ray. Associating the 754-kev gamma ray with the low-energy beta branch and the 722-kev gamma ray with the high-energy beta branch, the K-conversion coefficient for the 722-kev gamma ray is $1.38\pm0.2\times10^{-3}$ and that of the 754-kev gamma ray is $1.14\pm0.17\times10^{-3}$. According

[3] R. E. Connick and W. H. McVey, J. Am. Chem. Soc. **71**, 3182 (1949).
[4] L. M. Langer and R. Moffat, Phys. Rev. **78**, 74 (1950).

to the tables of Rose, Goertzel, and Perry,[5] these values for the K conversion coefficient are consistent with either $E2$ or $M1$ transition for each of the gamma rays.

BETA-GAMMA ANGULAR CORRELATION MEASUREMENTS

Preliminary to the spectrometer studies of the Zr^{95} beta spectrum, the beta-gamma angular correlation of the beta-gamma cascades in Zr^{95} had been studied.

The radioactive source was mounted in the center of a brass vacuum chamber 5 in. in diameter, 5 in. high and $\frac{1}{8}$ in. thick. A 2 in.-diameter brass tube opening into the vacuum chamber contained the beta detector which consisted of an RCA 5819 photomultiplier with a $\frac{1}{8}$ in. thick anthracene crystal mounted on its photocathode. The crystal was set 5 in. from the source. An 80-mil aluminum disk with a 1 in. diameter hole in its center, mounted in the tube between the source and the crystal, served to prevent electrons, scattered from the main vacuum tank and from the tube wall, from reaching the beta detector. A second 5819 photomultiplier fitted with a $\frac{3}{4}$ in. thick anthracene crystal was mounted outside the vacuum chamber and served as the movable gamma detector. The crystal of this detector was shielded with at least 1 in. of lead on all sides and with 0.1 in. of lead in the direction of the source. The output of each photomultiplier was fed to a cathode follower pre-amplifier and then to a Hewlett-Packard wide band amplifier and finally into a fast coincidence circuit (resolving time 5×10^{-8} sec). Coincidence pulses from the coincidence circuit were amplified in a Model 100 amplifier and recorded on a binary scalar.

Preliminary studies of the angular correlations of the beta-gamma cascades in Co^{60} and Rb^{86} were made with this apparatus. Assuming that the counting rate as a function of the angle θ between the beta and gamma detectors is given by

$$\omega(\theta)=a+b\cos^2\theta,$$

the value of b/a was determined to be 0.00 ± 0.02 for Co^{60} and 0.13 ± 0.05 for Rb^{86}. These values are in good agreement with the work of many investigators for Co^{60},[6–9] and with the work of Stevenson and Deutsch for Rb^{86}.[9]

For the study of the Zr^{95} angular correlation a source composed of 40 percent Zr^{95} and 60 percent Nb^{95} was used. The source consisted of a drop of the $Zr^{95}-Nb^{95}$ oxalate mixture evaporated to dryness on a thin, gold plated, formvar film (mass density 100 $\mu g/cm^2$). The source strength was approximately 70 microcuries and the source density about 300 $\mu g/cm^2$. To eliminate the effect of the Nb^{95} beta-gamma cascade 12 mg/cm^2 aluminum was placed in front of the beta detector.

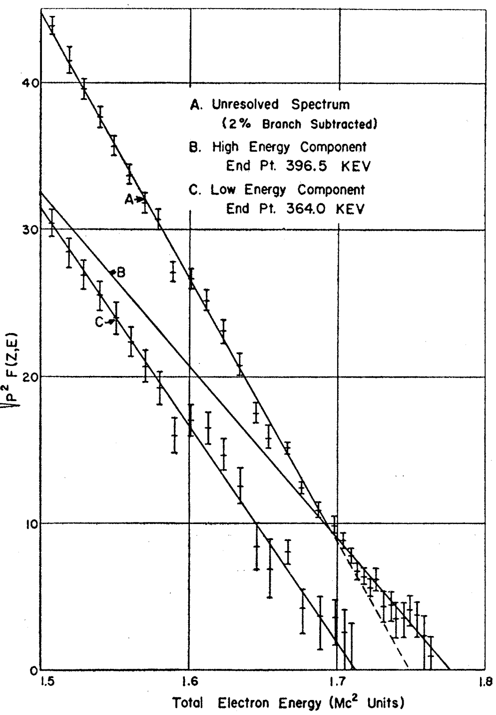

FIG. 3. Fermi plot of the high-energy end of the Zr^{95} beta spectrum.

The value of b/a resulting from this investigation was 0.005 ± 0.03. In the light of the later spectrometer studies, it should be noted that two distinct beta-gamma cascades were being detected and therefore the value of this measurement is open to question.

DISCUSSION AND CONCLUSION

In the light of the above experimental results, the decay scheme of Fig. 4 is proposed for Zr^{95}. This decay scheme is in good agreement with that proposed by Cork *et al.*[1]

The spin and parity assignments of the ground states of Zr^{95} and Nb^{95} and of the first excited state of Nb^{95}

TABLE I. Comparison of experimentally determined $K-L$ energy differences with values determined from critical x-ray absorption energies.[a]

Experimental $(K-L)$ energy differences (kev)	Possible $K-L$ differences (kev) Conversion in Nb^{95}	Conversion in Mo^{95}
Gamma No. 1 16.38±0.4	$(K-L_1)$ 16.286	$K-L_1$ 17.134
Gamma No. 2 16.20±0.4	$K-L_2$ 16.519	$K-L_2$ 17.373
Gamma No. 3 17.13±0.4	$K-L_3$ 16.614	$K-L_3$ 17.478

[a] Hill, Church and Mihelich, Rev. Sci. Instr 23, 523 (1952).

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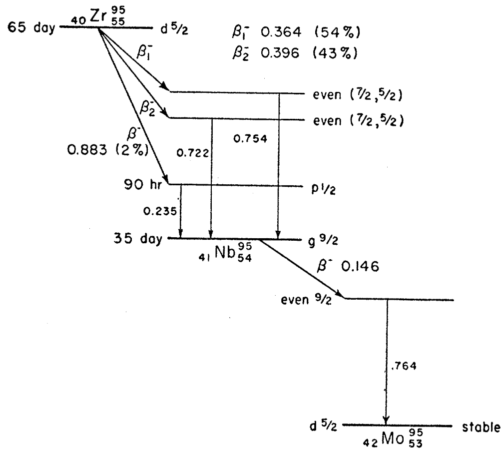

FIG. 4. Proposed decay scheme of Zr^{95}.

are those proposed by Goldhaber and Hill[10] from shell model considerations. Assuming these to be valid, the two highly excited states of Nb^{95} must have even parity. This follows from the identification of the gamma ray transitions to the ground state from these levels as either $E2$ or $M1$. Furthermore the spin of the excited states can be either 7/2 or 5/2. Assignment of 9/2, 11/2, or 13/2 to these levels is ruled out since the Zr^{95} beta transition would be second or higher forbidden in contradiction to the experimental evidence. Using the tables of Feenberg and Trigg,[11] the ft value for the 396-kev branch is 6.9 and that for the 364-kev branch is 6.7. These can at most be associated with once forbidden transitions. Actually the proposed spin and parity assignments indicate that both beta transitions are allowed. Such high ft values for $\Delta I = 0,1$ (no) transitions have been reported for Y^{87}, Zr^{89} and other isotropes by Goldhaber and Hill,[10] and are discussed in detail by de-Shalit and Goldhaber.[12]

The proposed spin and parity assignments are in agreement with the fact that the gamma ray transition to the 235-kev level of Nb^{95} is weak or nonexistent. They also lead to the conclusion that the 32.4-kev transition between the two Nb^{95} levels should be very weak.

Since the 754-kev and 722-kev levels of Nb^{95} may be many particle states, no specific orbitals have been assigned. However, the shell model[13] predicts that the next excited levels above $g_{9/2}$ should be $g_{7/2}$ and $d_{5/2}$ and that these should differ only slightly in energy. This prediction is in very good agreement with the proposed level assignment.

The beta-gamma angular correlation work is not in disagreement with the proposed level assignments. The lack of angular correlation implies an allowed shape for the beta spectra[14] and, as noted above, this is predicted by the level assignment and observed in the experiments.

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