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THE DECAY SERIES Nd^{140} - Pr^{140} - Ce^{140}

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The Decay Series Nd^{140} - Pr^{140} - Ce^{140}

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The nuclide $_{60}Nd^{140}$ has been previously reported[1] as a 3.3 day K capture, and its daughter $_{59}Pr^{140}$, as a 3.4 minute K capture and β^+ emitter, with a β^+ energy, determined by aluminum absorption methods, of 2.4 Mev. We have prepared Nd^{140} by a bombardment of 300 mg of praseodymium oxide with 19 Mev deuterons on the Crocker 60-inch cyclotron followed by chemical separations by citrate elution from a Dowex-50 cation exchange resin column at 83° C.[2] The decay chain was studied on a double focusing beta ray spectrometer, a bent crystal x-ray spectrometer, and a scintillation crystal gamma spectrometer.

The Bethe and Bacher approximation was used to calculate the Fermi function employed in a Fermi plot of the Pr^{140} positron spectrum, which exhibited good linearity with an end-point energy of 2.23 ± 0.02 Mev (Figure 1). The data do not exclude the possibility of a low abundance lower energy (ca. 1 Mev) component. The e^- spectrum was investigated up to $H\rho$ values corresponding to an electron energy of 1 Mev, and showed only one discernible line, at 28.9 ± 0.5 kev, which we interpret as electrons from Auger conversion of K shell vacancies, in either praseodymium or cerium, or both, as the resolution of the line does not permit this distinction.

The gamma ray spectrum showed no lines in addition to K x-ray, annihilation radiation, and Compton radiation, in intensity as high as 10 percent of that of the K x-rays; there was a meager indication of radiation of energy 1 - 1.2 Mev.

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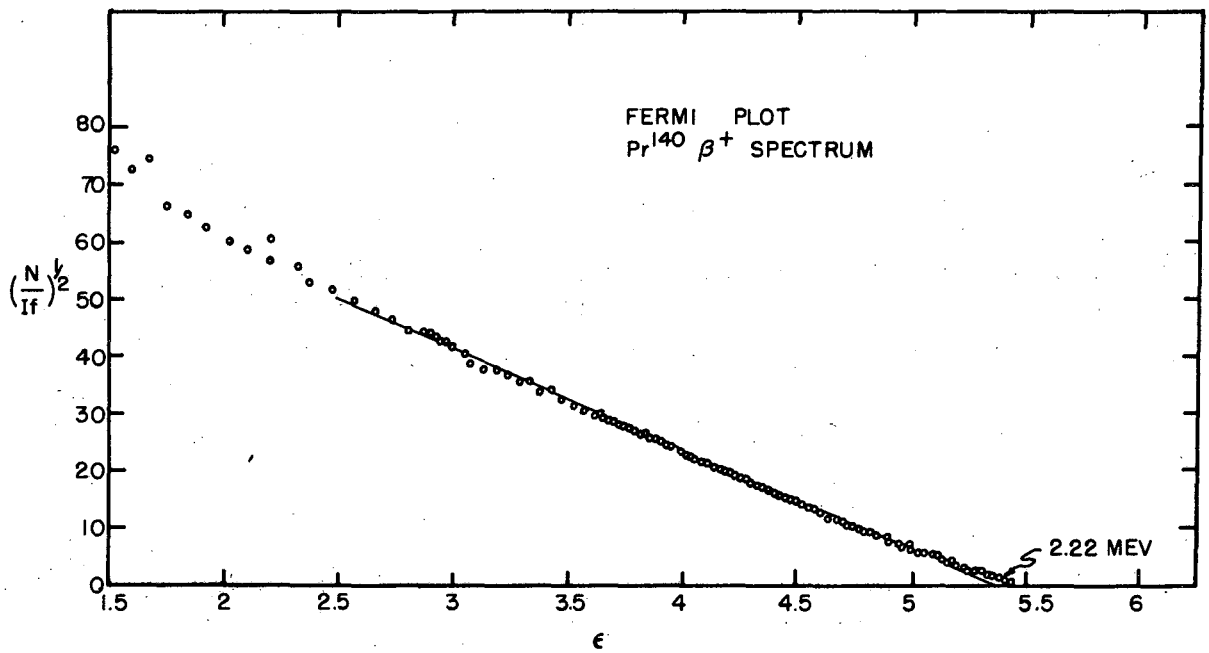
FERMI PLOT
Pr140 β+ SPECTRUM
(N/If)½
80
70
60
50
40
30
20
10
0
1.5
2
2.5
3
3.5
4
4.5
5
5.5
6
ε
2.22 MEV

FIG. 1

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The x-ray spectrum showed only the $K_{\alpha_1\alpha_2}$ (unresolved) and K_{β_1} x-rays of both praseodymium and cerium, in the following intensity ratios:

$$PrK_{\alpha_{1,2}}:CeK_{\alpha_{1,2}}:PrK_{\beta_1}:CeK_{\beta_1} = 100:50:28:11.$$

Since no sources of origin of K x-rays other than electron capture could be detected, we attribute all observed x-rays to that source, from which, if we consider only K capture, we calculate the K/β^+ ratio in Pr^{140} to be 1.0 ± 0.1.

The value of ft of the Pr^{140} decay was calculated from the theoretical values of Feenberg and Trigg[3] for $(f_+ + f_k)$ to be 2×10^4, which leads to the conclusion that the transition is allowed, and if we take the TAM (total angular momentum) of Ce^{140} as 0, the ΔI must be, by Gamow-Teller selection rules, unity. The ratio of f_k/f_+ is given by Feenberg and Trigg to be 1.0, in good agreement with the value for K/β^+ given above. If L capture is taken into consideration, the experimental value for K/β^+ in Pr^{140} is changed somewhat. An internally consistent solution based upon Rose's[4] theoretical L/K ratios, our data, and theoretical values for f_k leads to the conclusion that Nd^{140} decays 26 percent by L capture and 74 percent by K capture; that Pr^{140} decays 58 percent by β^+ emission, 37 percent by K capture, and 5 percent by L capture; that the ratio of β^+/K in Pr^{140} is 1.5/1, and that the decay energy of Nd^{140} is 105 ± 40 kev.

The ground state of Ce^{140} is very probably S_0, so that the state of Pr^{140}, by Nordheim's[5] rule that $\Delta L = 0$ for an allowed transition, must be S_1. Both the odd nucleons in Pr^{140} fall into the shell $50 < N \leq 82$, with possible states, by the Mayer model, of $g_{7/2}$, $d_{5/2}$, $d_{3/2}$, $S_{1/2}$, and $h_{11/2}$. Since the TAM is low, Nordheim's[5] rule 9 should apply to Pr^{140}, leading to six possible combinations of these states as describing the odd neutron and the odd proton. However, the TAM of Pr^{141} is known to be 5/2, and that of $_{56}Ba^{137}$ as 3/2, suggesting the

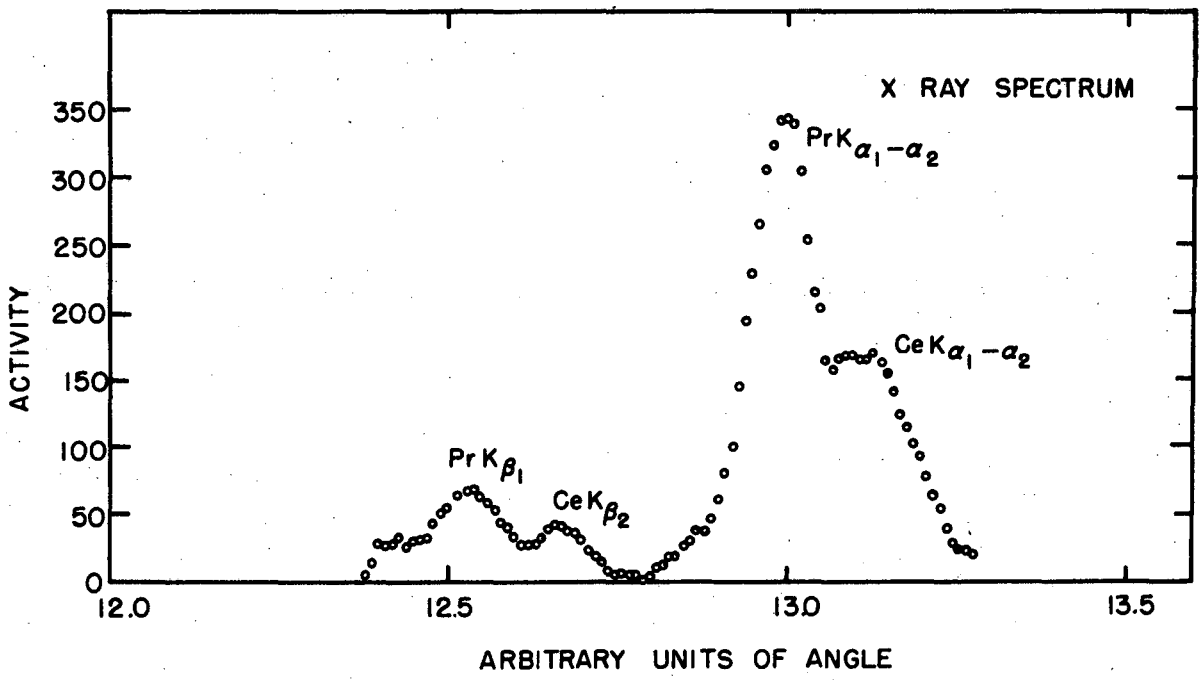
X RAY SPECTRUM
ACTIVITY
350
300
250
200
150
100
50
0
12.0
12.5
13.0
13.5
ARBITRARY UNITS OF ANGLE
Pr K$\alpha_1 - \alpha_2$
Ce K$\alpha_1 - \alpha_2$
Pr Kβ_1
Ce Kβ_2

FIG. 2

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probable choice of $d_{5/2}$ as the state of the proton, and $d_{3/2}$ as that of the neutron, which is one of the combinations admitted by Nordheim's rule. If, then, the angular momenta couple antiparallel, as Nordheim implies, the resulting over-all state of Pr^{140} would be S_1, in agreement with the conclusion reached earlier.

We have also integrated the β^+ and e^- spectra, and find a ratio of β^+/e^- of approximately 300, leading to a K/e^- ratio of 600. Such a value leads to a very high figure (.99+) for the mean K fluorescent yield at Z = 58 and 59. Considering that an error of a factor of 10 (a very high estimate indeed) due to self-absorption, back-scattering, etc., in the e^- spectrum would reduce the value of W_K only to some .98, it seems likely that W_K in this region is at least 0.95.

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5. L. W. Nordheim, Phys. Rev. 78, 294 (1950).