TABLE I. The concentration of copper atoms and holes in germanium containing radioactive copper.

Sample	Cu atoms per cc	Holes per cc	Ratio Cu/holes
1	2.0×10^{15}	1.7×10^{15}	1.2
2	9.0×10^{14}	8.8×10^{14}	1.0
3	3.6×10^{14}	3.9×10^{14}	0.9

had been hot only briefly. The material was all n-type, according to measurements of the thermal emf.

In another experiment the crystal was grown to the halfway point, and was removed from the crystal growing machine. The partly-grown crystal was immersed briefly in pure water (doubly distilled in Pyrex), which was allowed to evaporate from the surface of the germanium. The crystal was then returned to the machine and was held in contact with the melt for 30 minutes, whereupon the growth was resumed as above. Again there was no evidence of conversion. Nor was there any conversion in a similar experiment in which the partly-grown crystal was exposed to the air for 15 hours, instead of being immersed in pure water.

Fuller had observed[2] that conversion occurred when copper salts were present on the surface of a cut and lapped germanium wafer prior to heating. Hence the present experiment on an uncut crystal was performed using a dilute solution of copper sulfate (0.001 atomic percent) in pure water, followed as before by heating for 30 minutes in contact with the melt. Extensive conversion, with resistivity as low as 4 ohm-cm along the growth axis, occurred in that part of the crystal which had been heated, but no conversion occurred in the part subsequently grown. It was found that for sufficiently dilute copper sulfate solutions (somewhat more dilute than 0.001 atomic percent), the degree of conversion depended upon the concentration of the solution and the time that the crystal was immersed. This suggests that a surface reaction with the germanium is a necessary step in conversion.

In a similar experiment, using a solution containing the radioactive isotope Cu^{64}, copper was found to have entered the germanium. Tracer measurements of the copper concentration, performed by Struthers, and resistivity measurements indicate the following relation between copper concentration and hole concentration in three specimens from the same crystal,[4] (Table I).

The calculation of hole concentrations from resistivity measurements involved use of the value 1700 cm^2/volt-sec for the hole mobility. The aggregate experimental error was probably about 30 percent.

These results, together with the studies by Fuller and Struthers[5] on the diffusion of copper, are in keeping with the proposition that thermal conversion may be associated with the rapid diffusion of copper into the germanium.

[1] H. C. Theuerer and J. H. Scaff, J. Metals 191, 59 (1951).
[2] Unpublished studies.
[3] G. K. Teal and J. B. Little, Phys. Rev. 78, 647 (1950).
[4] Similar values for the ratio of copper concentration to hole concentration have been found by J. A. Burton in germanium crystals grown from a melt containing radioactive copper.
[5] C. S. Fuller and J. D. Struthers, Phys. Rev. 87, 526 (1952).

Decay Scheme of $_{21}Sc^{48}$

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THE decay scheme of $_{21}Sc^{48}$ is of interest because in the jj-coupling shell model this nucleus is a particularly simple configuration. It represents the coupling of a single $1f_{7/2}$ proton with a single $1f_{7/2}$ neutron-hole. Calculations with product wave functions and static central-force interactions between nucleons indicate that in such cases the ground state has a spin that is either the maximum possible or one unit less than this.[1] Maximum spin, $I = j_1 + j_2$, results from use of an infinite range spatial de-
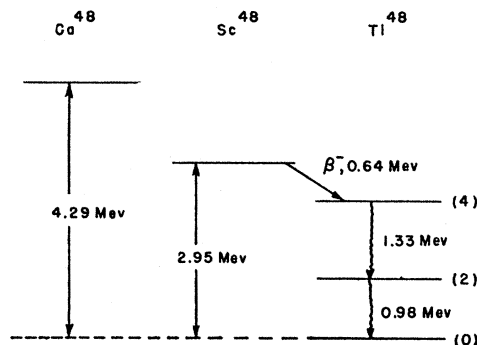

FIG. 1. Experimental energy differences at mass number 48. Probable spins of the Ti^{48} levels are given in parentheses.

pendence in the interaction, while the use of a delta-function range dependence gives $I = j_1 + j_2 - 1$. The competing levels will cross somewhere between these limits, the indication from the measured spins of the analogous cases $_{17}Cl^{36}$ and $_{19}K^{40}$ being that the delta-function result is more likely.

Therefore the spin of Sc^{48} is expected to be 6 or possibly 7, which is also in agreement with the prediction of Nordheim's rules[2] for odd-odd nuclei. The decay scheme of Sc^{48} shows an allowed beta decay ($\log ft \sim 5.4$) followed by two gammas in cascade as in Fig. 1. The spin assignments of the levels of Ti^{48} are probably the same as in the isotope Ti^{46} where gamma-gamma correlation[3] is consistent with the assignments $I = 0, 2, 4$. Therefore, the fact that the beta-decay is allowed is not inconsistent with the assignment of 6 (or 7) for the spin of Sc^{48}.

However, recent measurements[4] of the masses of Ca^{48} and Ti^{48} give a difference in mass of 4.29 ± 0.15 Mev, which means that if the decay scheme of Sc^{48} is correct, Ca^{48} should be unstable to negative beta decay to Sc^{48} with an energy of 1.35 ± 0.2 Mev as indicated in Fig. 1. This fact has been pointed out recently,[5] and a search for this beta-activity led to negative results with a lower limit of 2×10^{16} years for the lifetime. From calculation and comparison with the similar isotopes $_{21}Sc^{44}$ and $_{21}Sc^{46}$ which have low-lying isomeric states, one would expect that Sc^{48} has an excited state of low spin, to which Ca^{48} could readily decay, within 0.5 Mev of the ground state. The fact that no activity is found even though 1.35 Mev is available is puzzling.

If, on the other hand, there were another gamma-ray of sufficient energy present in cascade with the known gammas in the decay scheme of Sc^{48}, the situation could be understood. For then the spin of 6 (or 7) would not be inconsistent with the allowed beta followed by three gammas; and simultaneously there would be very little energy left for the decay involving Ca^{48}, as a result of which the large spin change present would lead to such a long lifetime that observation would be extremely difficult.

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Gamma-Rays from Sc^{48}

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AS indicated in the preceding Letter,[1] the question of a missing amount of energy (1−1.5 Mev) in the Ca^{48}, Sc^{48}, and Ti^{48} masses and decay schemes may be resolved by finding a beta process in Ca^{48} or by finding a third gamma-ray in the Sc^{48} scheme. We have looked for and found the latter.