level if both p- and f-wave alpha particles were considered, using an f/p wave amplitude ratio of 0.6, $\cos\beta=-1$, giving $W=1+7\cos^2\phi-8\cos^4\phi$. In comparing the results of the two experiments, it should be mentioned that the energy spectrum is not sensitive to the form of the angular correlation near 180 degrees, since the available solid angle is smallest there.

CONCLUSION

The alpha-alpha angular correlation at 163 kev is consistent with a pure state of spin 2 in C^{12} and 2+ but not 0+ or 4+ for the first excited state in Be^8. The nonresonant angular correlation at 290 kev cannot be explained on the basis of a pure state with spin 2− or 3+, corresponding to the 675-kev resonance, or 1−, corresponding to the 1.4-Mev resonance. The correlation is satisfactorily explained either by a mixture of these two states or by the assumption of a spin of 2+ for the 675-kev state alone.

ACKNOWLEDGMENTS

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Decay of Cr^{48}†

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The nuclide Cr^{48} has been produced by spallation of Ni. It decays by electron capture only with a half life of 23 hours and emits gamma rays of 116 kev ($M1$) and 305 kev ($E2$) of equal intensity, which are in coincidence. The genetic relationship with 16.2-day V^{48} establishes the mass assignment. The total decay energy of Cr^{48} can be estimated as 1.45±0.20 Mev. Two alternative decay schemes are proposed.

1. INTRODUCTION

THE nuclide Cr^{48} has been reported[1] as a spallation product, decaying by electron capture only, with a half-life of 23 hours. It was identified by the growth and decay of its daughter V^{48}. The radiations from Cr^{48} were detected with an end window type Geiger-Muller tube; no appreciable amount of positrons was found in Cr^{48}.

The ground state of V^{48} very probably has a spin 4 or 5 and even parity. This can be concluded from the spins of the levels in Ti^{48} and the decay properties[2] of V^{48}. The relatively short period of Cr^{48} indicates an allowed transition even for decay energies as large as 6 Mev. Now since Cr^{48} should have a ground state spin 0 with even parity, this implies that the decay goes by way of an excited state in V^{48} with spin 0 or 1 and even parity. In this mass region, low lying states with widely different spin values are known to exist in various odd-odd nuclides (Sc^{44}, Sc^{46} and Mn^{52}); presumably they arise from different couplings of the $f_{7/2}$ proton with the $f_{7/2}$ neutron.[3]

The decay of Cr^{48} should therefore be accompanied by at least one gamma ray, possibly leading to a metastable state of V^{48}.

2. SAMPLE PREPARATION

Cr^{48} can be produced in good yield by the interaction of high energy particles with a target material of considerably greater mass number (so called "spallation" reactions). For such reactions the yield is relatively independent of the mass and charge number (A,Z) of the target material chosen,[4] provided that ΔA is not too large (≤ 10 for 380-Mev protons) and that ΔZ is not too small. These considerations suggest the choice of natural nickel (68% Ni^{58}) as the target material.

It should be pointed out that in such an irradiation Cr^{49} and Cr^{51} will also be produced, the Cr^{49} in about equal yield (estimated) as Cr^{48} and the Cr^{51} in about twenty times greater yield (estimated). The Cr^{49} with only a 42-min half-life can be allowed to die, and the

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[1] Rudstam, Stevenson, Folger, Phys. Rev. **87**, 358 (1952).
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[4] E. Belmont and J. M. Miller, Phys. Rev. **95**, 1554 (1954).

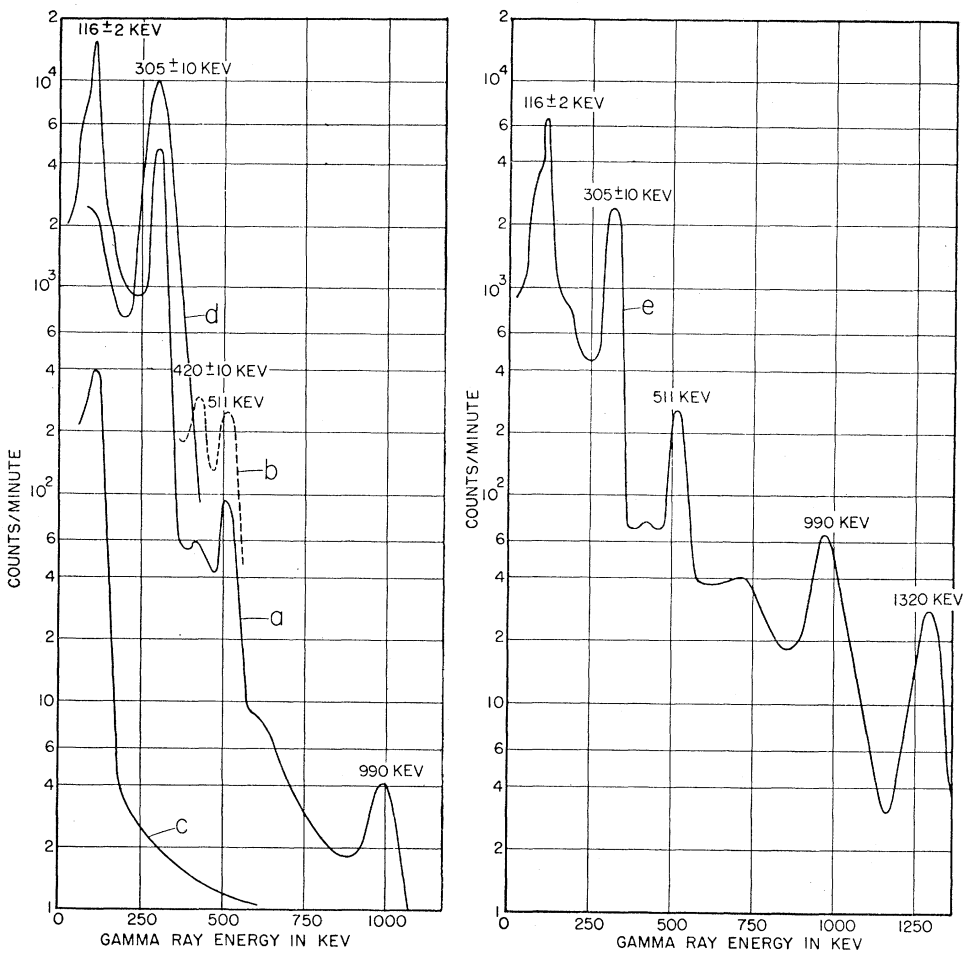

FIG. 1. Gamma spectrum of Cr^{48}. Curve *a* shows the spectrum taken with the source at $\frac{3}{4}$ in. from the detector, for curve *b* this distance is $\frac{1}{4}$ in. Curves *c* and *d* show the spectrum in coincidence with the 0.305 γ and 0.116 γ, respectively. Curve *e* was taken 2 days later and shows the characteristic radiations of V^{48} growing in.

Cr^{51}, though produced in far greater yield than the Cr^{48}, will contribute only a few percent to the total gamma activity of the sample at the end of the irradiation because of its long half-life (27 days) and particular decay scheme (electron capture with a γ ray in 10% of the disintegrations).

The targets, consisting of powdered nickel metal wrapped in thin aluminum foil, were irradiated with the 380-Mev circulating proton beam of the Nevis cyclotron for about two hours. After irradiation, the powder was dissolved in nitric acid, the chromium was oxidized to chromate with persulfate, and then was extracted as peroxychromic acid with ethyl acetate. To purify the sample it was extracted twice more. After the final extraction the chromium was reduced with hydrazine to the +3 state and precipitated as the hydroxide. For the gamma-ray spectrometer samples about 1 mg of chromium +3 carrier was added initially, while for the beta-ray spectrometer sample the procedure was followed using 50 μg of carrier and the sample mounted by evaporating the final solution to dryness on a thin film.

The high purity of the sample was shown by the fact that no annihilation radiation could be detected after sufficient time had been allowed for the decay of Cr^{49}. It is to be expected that any impurity would be on the neutron deficient side of the stability line because of the relatively low neutron number of Ni^{58}.

3. GAMMA-RAY SPECTRUM

The gamma ray spectrum of the chemically separated Cr fraction was studied with an energy- and efficiency-calibrated single-channel scintillation spectrometer (resolution 9% at 661 kev). For periods up to a few hours after the end of the bombardment the spectrum showed an appreciable amount of annihilation radiation decaying with a half-life of the order of 1 hour. The same short period was also found in the decay curve followed with an end window Geiger-Muller counter. It is attributed to the presence of 42-min Cr^{49}.

Curve *a* of Fig. 1 shows the gamma-ray spectrum at ~8 hours after the end of the bombardment. Prominent peaks are evident at 116±2 (γ_1) and at 305±10 kev (γ_2), there is a much smaller peak at 420±10 kev and a small annihilation peak. No other gamma rays are seen in the decay of Cr^{48}; the bump at the low-energy side of γ_1 is at the correct energy for the associated escape peak. This run was taken with the source at a distance of

$\frac{3}{4}$ inch from the crystal. The dotted curve *b* shows the region above 350 kev with the source at only $\frac{1}{4}$ inch distance. This demonstrates that the peak at 420 kev arises mainly from pile up of the two strong gamma rays.

The peak at 305 kev is not due to Cr^{51}. The intensity is too high by about an order of magnitude, the energy compared to that of the 0.325 line in pure Cr^{51} consistently turned out to be lower by about 20 kev and its intensity relative to γ_1 did not change appreciably over the first few days. The 325-kev line due to the Cr^{51} contamination was seen only after a few days.

The relative intensities of γ_1 and γ_2 were determined within 12 hr after the end of the bombardment by comparison with Se^{75}. In the region above 250 kev the relative efficiency of the scintillation spectrometer was determined by a method described in an earlier paper.[5] The intensity of γ_1 is $90\pm15\%$ of that of γ_2. It is also possible to give an upper limit of 2% for any positrons in the decay of Cr^{48} and a rough upper limit of 2% for a cross over gamma ray of 420 kev.

For one of the sources used the evolution of the scintillation spectrum was followed for a period of three weeks. The characteristic radiations of V^{48} were seen to grow in (compare Fig. 1, curve *e*). The height of the various peaks was compared to those of standard sources of Se^{75}, Cr^{51}, Na^{22}, Bi^{207}, and Co^{60}. After the peak heights of γ_1 and γ_2 are corrected for the Compton contributions due to the other gamma rays, their decay yielded a half-life of 23 ± 1 hour for Cr^{48} over a period of 6 half-lives. The growth and decay of the peaks due to V^{48} over a period of three weeks was compatible with the expected genetic relationship between γ_1 and γ_2 on the one hand and the 0.511-, 0.99-, and 1.32-Mev lines on the other hand.

The occurrence of a strong sum pulse at 420 kev (see Fig. 1) in contrast to the absence of a sum pulse at 230 kev, indicates that γ_1 and γ_2 are probably in cascade. A coincidence experiment, using the selective coincidence scintillation spectrometer described in an earlier paper,[5] was performed. Curve *c* and *d* of Fig. 1 show that γ_1 and γ_2 are indeed in coincidence and the dropping off of the counting rate at higher energy shows that there are no other coincident gamma rays. In addition the coincidence spectrum of Se^{75} was studied under the same conditions. From a comparison of the results of these two coincidence experiments the intensity of γ_1 is $95\pm10\%$ of that of γ_2. Since the resolving time of the coincidence apparatus is $\sim10^{-7}$ sec, it is clear that the delay between γ_1 and γ_2 is certainly less than 10^{-6} sec.

TABLE I. Decay properties of Cr^{48}.

	23 ± 1 hour No $\beta^+(0.511\gamma<1\%)$		ϕ 16.2-day V^{48}	
	Energy	Rel. int.	α	
γ_1	116 ± 2 kev	95 ± 10	0.02 ± 1	$M1$
γ_2	305 ± 10 kev	100	0.006 ± 3	$E2$
	γ_1 and γ_2 are in coincidence No other γ's			

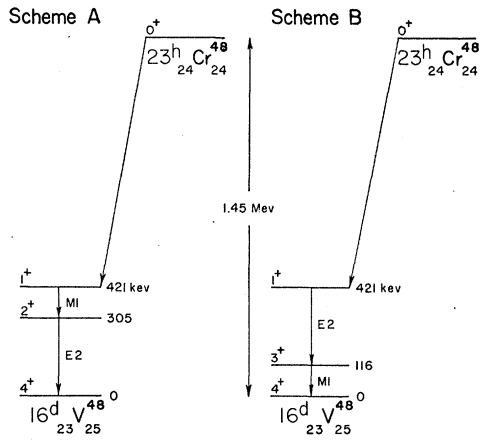

FIG. 2. Proposed decay schemes for Cr^{48}.

4. CONVERSION ELECTRON SPECTRUM

The conversion electron spectrum, studied in the Columbia solenoidal spectrometer, showed peaks corresponding to γ_1 and γ_2, but no other peaks of comparable intensity. The intensities of these two conversion peaks were compared to that due to the well-known 0.56-Mev gamma transition in Bi^{207}. The same two sources of Cr^{48} and Bi^{207} were then compared for their gamma intensities with the efficiency-calibrated scintillation spectrometer. This comparison gave conversion coefficients of $\alpha=0.02$ for the 116-kev transition and $\alpha=0.006$ for the 305-kev transition, the uncertainty amounting to 50%. This is only compatible with a dipole transition for γ_1 and a quadrupole for γ_2.

5. DISCUSSION

Taking the experimental lower limit of ~50 for the ratio of electron capture to positron emission and using the graphs by Feenberg and Trigg,[6] an upper limit of 1.25 Mev can be placed on the energy difference between the initial and final states in the capture process. Assuming $\log(2J_f+1)ft\geq4.5$ for an allowed capture process (a super-allowed transition is not expected in this case), a lower limit of 0.85 Mev is found for this same energy difference.

The combined gamma (95 ± 10) and conversion electron intensities (2 ± 1) of γ_1 are practically equal to the total intensity of the 305-kev transition (101). The approximate equality of the two cascading gamma rays indicates that there is no appreciable electron capture to the intermediate level. This excludes an allowed transition to the intermediate state. Since only even parity states are expected in V^{48}, the intermediate level can therefore be populated only by a second or higher forbidden electron capture transition. This indi-

[5] Koerts, Macklin, Farrelly, van Lieshout, and Wu, Phys. Rev. 98, 1230 (1955).

[6] E. Feenberg and G. L. Trigg, Revs. Modern Phys. **22**, 399 (1950).

cates that the electron capture takes place to the 421-kev level exclusively. From this, it follows that the mass difference between Cr^{48} and V^{48} lies between 1.25 and 1.65 Mev, compatible with the predictions of beta decay energy systematics in this region.[7] The various decay properties of Cr^{48} are listed in Table I.

The conversion coefficients limit the multipolarity of γ_1 to fairly pure $M1$ and that of γ_2 to $E2$. The order of emission of γ_1 and γ_2 is not known, but in either case rather severe restrictions can be placed on the possible spin values of the various states.

The total angular momentum carried away by the allowed electron capture process and by the gamma cascade is $J \leq 4$. This fixes the ground state spin of V^{48} as 4 and the spin of the 421-kev level as 1; spins 2 or 3 can be chosen respectively for the intermediate level for case A or case B (see Fig. 2). The branching ratio of the two posssible γ transitions from the 421-kev level can be calculated using the nomogram published by Montalbetti[8] which is based on the formulas of Blatt and Weisskopf. For scheme A, the upper limit on the intensity of the cross over relative to the 116-kev transition is $\sim 1 \times 10^{-8}$, for scheme B its upper limit relative to the 305-kev transition is $\sim 1 \times 10^{-6}$. Neither of the two excited states is expected to have a half life of over 10^{-7} sec; thus the decay of Cr^{48} does not seem to lead to a metastable state of V^{48}.

From our data for the various gamma-ray intensities, it follows that for a 380-Mev proton bombardment of Ni the cross section for the production of 27-day Cr^{51} is 18 ± 2 times the cross section for the production of 23-hour Cr^{48} (assuming 10% K capture to the 0.32-Mev level in V^{51}).

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Excitation Function for the Reaction $Be^9(N^{14},\alpha n)F^{18}$

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The cross section for the production of F^{18} by nitrogen bombardment of beryllium was measured as a function of energy. The cross section varies from 100 to 200 millibarns at energies from 15 to 30 Mev. Below the barrier, the cross section falls off with decreasing energy in a manner which indicates a barrier penetration by the entire nucleus.

A SURVEY of nitrogen-induced nuclear reactions produced in light elements by 26-Mev nitrogen ions from the Oak Ridge National Laboratory 63-Inch Cyclotron was made by Reynolds, Scott, and Zucker.[1] The excitation functions of three nitrogen-induced reactions in carbon which result in radioactive residual nuclei were reported previously.[2] In this paper the excitation function of the reaction $Be^9(N^{14},\alpha n)F^{18}$ is reported for energies from 6 to 29 Mev.

The experimental method is similar to that described previously.[2] Thick targets of beryllium metal were bombarded in the deflected nitrogen beam at various maximum nitrogen energies. The energy of the incident beam was varied by placing nickel foils in front of the targets. Bombardments were made in two ways. In the first method, a disk with twelve holes on the periphery, eleven of which contained beryllium and appropriate absorbers, was rotated through the beam at approximately 5 rpm. A Faraday cup was placed beyond the disk so that for each rotation of the disk the current passing through the empty hole was measured and integrated, thus determining the number of particles striking each target. Fluctuations in beam intensity were averaged out since bombardments lasted for 30 minutes or longer. After bombardment the targets were removed and the amount of 112-minute F^{18} activity was measured with shielded Geiger counters which were calibrated by standard procedures.[2]

In the second method, targets were bombarded individually inside the Faraday cup. The energy absorbers were placed inside the cup to avoid making corrections for electron charge exchange in the foils. The results from the two methods are in good agreement, as shown by the yield curve in Fig. 1. The points indicated by dots were obtained with the rotating disk while the crosses represent data obtained from the direct bombardments in the Faraday cup. The probable error in

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[2] H. L. Reynolds and A. Zucker, Phys. Rev. **96**, 1615 (1954).