effects occur in regions of substantial smooth-curve yields. In $U^{235}(n,f)$, the effect at mass 100 (mass spectrometric yield determination) is more prominent than that at mass 101. In the next two entries in Table IV, the mass 101 effect seems to be small, but for these and $U^{238}(d,f)$ mass 100 data are not available. The rapid fall of yields for thermal-neutron fission and spontaneous fission on approaching symmetrical fission[1,22] tends to minimize effects of the 50-proton shell.

Attempts have been made to define an empirical yield enhancement curve for closed-shell species which would be a function of smooth-curve independent yields. Such a treatment serves to support the correlations of Table IV, but is at present on too speculative a basis for detailed confidence. The accumulation of more experimental data on independent fission yields in selected cases should help ground such treatment. Treatment at the level presented in this paper predicts a relatively large separation in the $U^{233}(d,f)$ curve for the spikes complementary to $N=82$ (masses 97–99) and complementary to $Z=50$ (masses 103–105).

The statistical theory of Fong[23] provides one mechanism for selectivity of closed-shell species in the fission process. The enhanced stability of closed-shell configuration in one of the two fragments implies greater internal energy in the fission mode, thus giving higher statistical weights and fission yields for these modes. This enhancement should be slowly diluted out with increasing energy in the fission process.

Sincere thanks are expressed to the operating staffs of the M.I.T. Cyclotron and Linear Accelerator. Of these, Dr. John Winhold and Messrs. Earl White and Frank Fay have been particularly generous with their time. Mrs. Charleen Vanelli and Mrs. Grace Rowe have assisted greatly in the preparation of the manuscript, which was kindly proofread by J. W. Winchester and R. C. Fix.

The authors express their gratitude to the United States Atomic Energy Commission for supplying nearly pure U^{235}, which led directly to the discovery of the 50-proton effect.

[23] P. Fong, Ph.D. Thesis in Physics, University of Chicago, 1953 (unpublished); and P. Fong, Phys. Rev. 89, 332 (1953).

PHYSICAL REVIEW VOLUME 96, NUMBER 3 NOVEMBER 1, 1954

γ Rays from the $C^{13}(p,\gamma)N^{14}$ and $Na^{23}(p,\gamma)Mg^{24}$ Reactions

B. Hird, C. Whitehead, J. Butler, and C. H. Collie
Clarendon Laboratory, Oxford, England
(Received July 14, 1954)

The γ rays from the 554-kev resonance of $C^{13}(p,\gamma)N^{14}$ and the 310-kev resonance of $Na^{23}(p,\gamma)Mg^{24}$ have been measured with a three-crystal pair spectrometer. Energies and intensities were measured and cascades detected by coincidence measurements. The 5.7-Mev γ-ray from $C^{13}(p,\gamma)N^{14}$ is 0.7 ± 0.6 percent of the intensity of the main 8.05-Mev radiation. The most intense radiation from $Na^{23}(p,\gamma)Mg^{24}$ was the 1.38-Mev line, and no 2.76-Mev radiation was observed.

THE three-crystal pair spectrometer[1,2] is well suited to measure weak γ rays in the presence of more intense radiation of higher energy. We have used it to investigate the γ rays from the 554-kev resonance of the $C^{13}(p,\gamma)N^{14}$ and the 310-kev resonance of $Na^{23}(p,\gamma)$-Mg^{24} reactions.

$C^{13}(p,\gamma)N^{14}$

The pair pulse-height energy distribution curve is shown in Fig. 1. The energy calibration is based upon RdTh (2.62 Mev) and Po—Be (4.45 Mev) and the assumption that the main component has an energy of 8.05 Mev.[3] The intensities of the lines, obtained from the pair cross section values of Mann, Meyerhof, and West,[4] was found to be:

Energy (Mev)	8.05	5.7 ± 0.15	4.05 ± 0.05	2.35 ± 0.02	1.66 ± 0.03
Relative intensity	100	0.7 ± 0.6	12.5 ± 2	15 ± 5	17 ± 4.

The shape of the pair peak was estimated for each energy. The asymmetrical shape of the peaks arises partly because of bremsstrahlung and electron escape and partly because all the triple coincidences do not correspond to pair formation in the central crystal. It is possible to obtain a triple coincidence when the Compton-scattered γ ray is captured in one side crystal and the bremsstrahlung from the Compton electron is captured in the other. The assumptions made in calculating the shape of pair spectrum peaks were checked by comparison with the measured shape of the known γ rays from the $F^{19}(p,\gamma)O^{16}$ and the $B^{11}(p,\gamma)C^{12}$ reac-

[1] B. Hird and C. Whitehead, Proc. Phys. Soc. (London) 67, 644 (1954).
[2] H. I. West and L. G. Mann, Rev. Sci. Instr. 25, 129 (1954).
[3] F. Ajzenberg and T. Lauritsen, Revs. Modern Phys. 24, 321 (1952).
[4] Mann, Meyerhof, and West, Phys. Rev. 92, 1481 (1953).

tions. The relative intensities of the observed γ rays can easily be obtained by quadrature once the shape of the peaks is known.

Part of the observed 2.35-Mev radiation was due to N^{13}, but this could be accurately estimated since it continued after the beam had been switched off.

The difficulty in interpretation caused by the fact that the 4.05-Mev γ ray has very nearly the same energy as the crossover radiation from the 2.35-Mev and 1.66-Mev cascade can be resolved by coincidence measurements.

The 4.05-Mev, 2.35-Mev, and 1.66-Mev lines were found to be in coincidence. This enables the 4.01-Mev crossover transition of the 2.35, 1.66-Mev γ-ray cascade to be distinguished from the 4.05-Mev radiation. Its intensity was found to be 5 ± 5 percent of the 2.35, 1.66-Mev cascade.

Our results are in agreement with the energy level scheme discussed by Ajzenberg and Lauritsen[3] (Fig. 1, inset).

Our crossover intensity is less than that found by Woodbury, Day, and Tollestrup[5] in an investigation using a single-crystal spectrometer. Our intensity for the 5.7-Mev radiation agrees with that found experimentally in a single crystal measurement by Clegg and Wilkinson,[6] and we can exclude their alternative explanation that it was due to a 5.08-Mev line. We have discussed the point with Dr. Beghian,[7] who is now in agreement with our results.

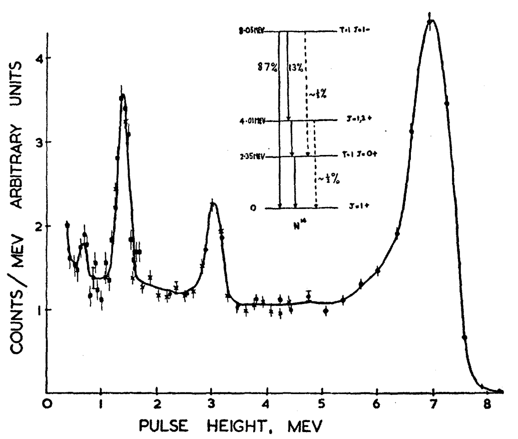

FIG. 1. Pair spectrometer pulse-height distribution of the γ rays from the $C^{13}(p,\gamma)N^{14}$ reaction.

[5] Woodbury, Day, and Tollestrup, Phys. Rev. **92**, 1199 (1953).
[6] A. B. Clegg and D. H. Wilkinson, Phil. Mag. **44**, 1269 (1953).

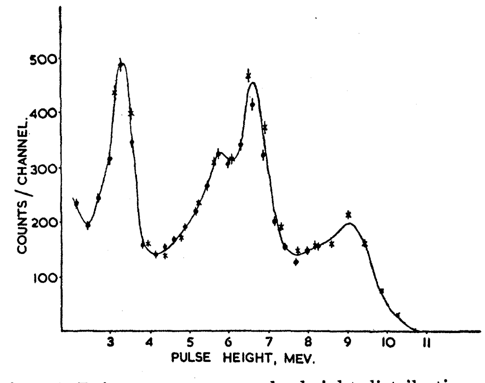

FIG. 2. Pair spectrometer pulse-height distribution of the γ rays from the $Na^{23}(p,\gamma)Mg^{24}$ reaction.

$Na^{23}(p,\gamma)Mg^{24}$

Thick targets of NaCl and Na_2SO_4 were bombarded with about 100 μa of protons.

The observed pulse-height distribution is shown in Fig. 2. The energies and relative intensities obtained were:

Energy (Mev)	10.6 ± 0.2	7.67 ± 0.1	6.7 ± 0.2	4.11 ± 0.05	1.38 ± 0.02
Relative intensity	72 ± 10	75 ± 10	13 ± 3	57 ± 6	105 ± 20.

The 6.7-Mev peak had the correct shape when the background due to the two higher lines was subtracted. The relative intensities were determined by the method already described, except for the 1.38-Mev line, all the measurements on which were made with a single-crystal spectrometer.

These results are in good agreement with the recent measurements of Carlson, Geer, and Nelson,[8] and show that the 1.38-Mev line is not fed from the well-known 4.14-Mev level of Mg^{24}. The peak at 4.11 Mev was found to be significantly broader than would be expected from a single γ ray. This provides further evidence in support of the decay scheme suggested by Carlson, Geer, and Nelson,[8] according to which this line is a superposition of two lines of approximately the same energy.

[7] Hicks, Husain, Sanders, and Beghian, Phys. Rev. **90**, 163 (1953).
[8] Carlson, Geer, and Nelson, Phys. Rev. **94**, 1311 (1954).