spin-orbit interaction in the nuclear potential will provide large polarizations. Finally, aside from the interest of investigating one more phase of nuclear structure, this phenomenon, because of the large diffraction cross sections, provides a relatively good source of polarized particles.

* This work was performed under the auspices of the U. S. Atomic Energy Commission.

[1] W. Heckrotte and J. V. Lepore, University of California Radiation Laboratory Report UCRL-2152, March, 1953 (unpublished), p. 32.

[2] This method has been suggested in connection with low-energy neutron scattering by R. K. Adair (private communication from K. M. Watson).

[3] Fernbach, Serber, and Taylor, Phys. Rev. **75**, 1352 (1949).

[4] For example, in the special case of real potentials the Born approximation always gives a vanishing polarization.

Production of Proton Pairs*

R. N. Thorn†
Harvard University, Cambridge, Massachusetts
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With the completion of the California bevatron in the near future it will be energetically possible to produce negative protons, if indeed they exist; and it is therefore of some interest to calculate the probability of such an occurence by nucleon collision. The production cross section has been calculated by Helstrom[1] and by Taketani and Machida,[2] using the Weizsäcker-Williams method. In addition, Taketani and Machida have made a threshold approximation of Feynman's method for the production of an antiproton by proton-proton (p,p) collision.

It is the purpose of this note to describe the results of a calculation of the cross section for pair production near threshold, an energy region just barely attainable with the bevatron. The processes treated in a perturbation calculation are:

$$p+p\rightarrow p+p+p+\bar{p},$$
$$p+n\rightarrow p+n+p+\bar{p}.$$

The nucleon field is assumed to be pseudoscalar-coupled to a symmetric pseudoscalar meson field. The threshold kinetic energy of the incident particle in the laboratory system, assuming the target particle is at rest, is $6M$ or 5.6 Bev.

The cross section is calculated in the center-of-mass system where the final particles can be treated nonrelativistically so long as the initial particle energy is not much greater than the threshold energy $2M$.

Since only neutral mesons are present in intermediate states to lowest order, the (p,p) cross section is the same for both the symmetrical and the neutral theory, and is[3]

$$\phi(p,p)=1.4\times10^{-29}(f^2/4\pi)^4[(E-2M)/M]^{9/2}\ \mathrm{cm}^2,$$

a result in disagreement with that of Taketani and Machida. Here $E-2M$ is the excess over threshold energy of an initial particle in the center-of-mass system.

The (p,p) production process is inhibited by the exclusion principle, since it is unallowable to have three final protons in a state of zero momentum. This restriction no longer applies if one of the final particles is a neutron, as in the case for antiproton production by (n,p) collision. Furthermore, in a symmetric theory there are a greater number of processes contributing because of the possibility of charged as well as neutral mesons in intermediate states. These two factors together make the (n,p) production predominant over the (p,p) production near threshold.

The (n,p) cross section is

$$\phi(n,p)=5.4\times10^{-29}(f^2/4\pi)^4[(E-2M)/M]^{7/2}\ \mathrm{cm}^2.$$

I wish to thank Professor Schwinger for having suggested this problem.

* Based on a thesis written in partial fulfillment of the requirements for a doctor's degree.

† Now at Los Alamos Scientific Laboratory, Los Alamos, New Mexico.

[1] C. W. Helstrom, Phys. Rev. **78**, 88 (1950).

[2] M. Taketani and S. Machida, Prog. Theoret. Phys. **6**, 559 (1951).

[3] Units $\hbar=c=1$ have been used, so that $f^2/4\pi$ is the usual dimensionless fine structure constant of meson theory.

Summation of γ-Ray Energies with a Single-Crystal Spectrometer

Daniel C. Lu and M. L. Wiedenbeck
Randall Laboratory of Physics, University of Michigan, Ann Arbor, Michigan
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Multi-γ coincidences were effectively observed with a simple modification of a scintillation spectrometer. This was accomplished by drilling a hole 3 mm in diameter along the axis of a cylindrical NaI(Tl) crystal from the top surface to the center. The bottom surface was coupled to a photomultiplier in the usual manner. This allowed the source to be placed outside of the crystal or at its center. With the source within the crystal, there is a reasonable probability that all prompt, cascade γ rays from a single disintegration will be absorbed and thus give a pulse corresponding to the sum of the γ energies involved. As such this device can often yield data not readily obtained with the conventional arrangement of spectrometers in coincidence.

The scheme was first tried some months ago using a crystal 1 inch thick and $1\frac{3}{4}$ inches in diameter. While this showed that the system could yield useful information, it was inadequate for higher energy γ rays. At present we use a crystal 2 inches in diameter and 2 inches thick coupled to a DuMont 6292 phototube. Pulses are observed with a single-channel discriminator.

Figure 1 shows the spectrum of γ rays following the β decay of Co^{60} taken with the source outside the crystal (with small probability for the addition of γ-ray energies) as well as the spectrum taken with the source at the center of the 2-inch crystal. Even at these relatively high energies (1.17 and 1.33 Mev) the sum peak is easily observed with this crystal.

The γ-ray spectra following the β decay of Cs^{134} is indicated in Fig. 2. The main sum peaks are due to triple "coincidences" be-

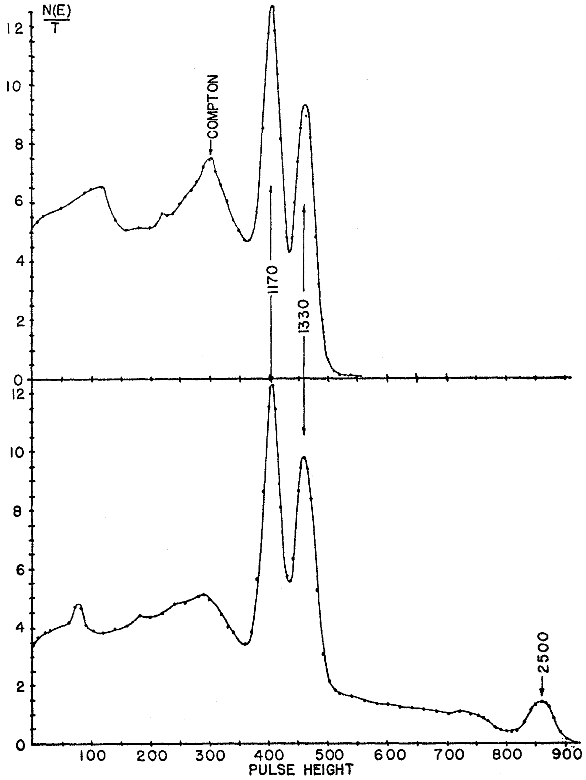

Fig. 1. Gamma-ray spectra of Ni^{60}. Energies in kev indicated at the top of peaks. Upper curve with sample 3 in. from top of crystal. Lower curve with sample inside crystal. The peak representing the sum of the two gamma energies is seen at 2.5 Mev.

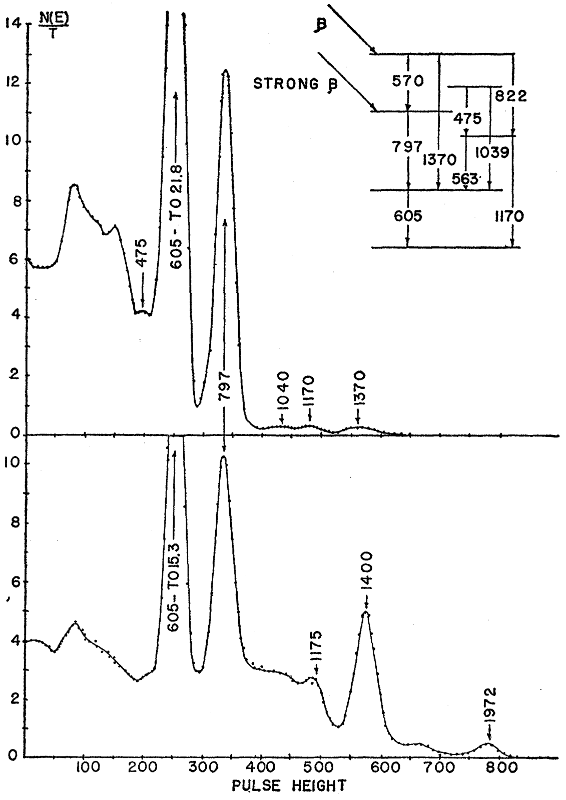

FIG. 2. Gamma-ray spectra of Ba^{134}. The upper curve is the ordinary spectrum. The lower curve shows several peaks due to the addition of two or three gamma rays. Energies are in kev.

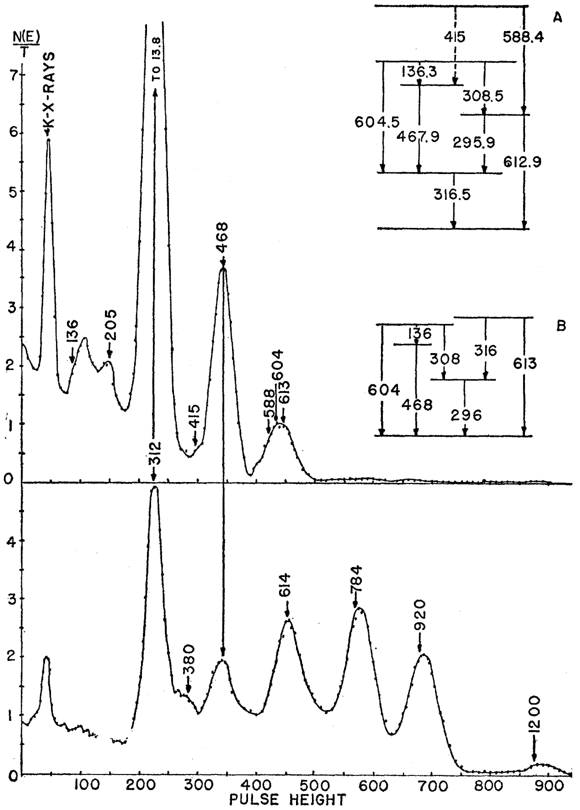

FIG. 3. Gamma spectra of Pt^{192} with proposed decay schemes. The present data favor the scheme *A*. Energies are in kev.

tween the lines of 570, 797, and 605 kev as well as to double "coincidences" of the strong 797- and 605-kev lines and the 605-kev line with the weak 570-kev line.

From the precise energy measurements of the gamma rays following the decay of Ir^{192}, two possible decay schemes have been proposed.[1,2] (See Fig. 3.) The spectrum was investigated with the source outside the crystal as well as inside. It is evident that the highest sum peak corresponds to 1.2 Mev and peaks are also found at 920 and 794 kev. In addition the peak at 614 kev is greatly augmented. It is clear that these data are in agreement with decay scheme *A* but not with *B*.

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[1] Cork, LeBlanc, Stoddard, Childs, Branyan, and Martin, Phys. Rev. **82**, 258 (1951).

[2] Muller, Hoyt, Klein, and DuMond, Phys. Rev. **88**, 775 (1952).