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THE REACTION $\pi^- + p \rightarrow \pi^- + \pi^+ + n$
FROM 360 TO 800 MeV

Berkeley, California

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UNIVERSITY OF CALIFORNIA
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Janos Kirz, Joseph Schwartz, and Robert D. Tripp

February 7, 1963

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Lawrence Radiation Laboratory and Department of Physics
University of California, Berkeley

February 7, 1963

In this letter we report the cross sections, angular distributions, and two-body mass spectra for the reaction



at beam energies of 360, 430, 460, 480, 555, 605, 673, and 780 MeV. At the lowest beam energies the $\pi^+ \pi^-$ mass spectra are strongly peaked near the upper kinematic limit. At higher beam energies the 3-3 π -N resonance $N^*(1238)$ is the dominant feature of the reaction. No clear evidence is found for $\pi^+ \pi^-$ resonances over the range $280 \text{ MeV} \leq M_{\pi\pi} \leq 680 \text{ MeV}$.

The Lawrence Radiation Laboratory 72-inch hydrogen bubble chamber was used in conjunction with π^- beams obtained through the channel designed for 1- to 2-BeV/c K^- mesons.¹ The 40,000 pictures analyzed yielded 300 to 600 events of reaction (1) at each of the 8 momenta.

This type of event can be easily identified on the scanning table in this energy region, because it is, essentially, the only one with two charged outgoing tracks in which the positive track is a π^+ . As the beam momentum increases, visual separation becomes somewhat less efficient. This is due to lightly ionizing fast protons from reactions



and



and also due to increasing contamination from



events.

To obtain a clean sample of events of reaction (1), the film was scanned twice, yielding an efficiency ranging from 98 % at 360 MeV to 95 % at 780 MeV; then each candidate was measured on the Franckenstein and processed on the track-reconstruction and fitting program PACKAGE. In about 15 % of the cases the program was unable to make a definite and unique fit to any one of the reactions (1), (2), or (3). However, by looking at these events on the scanning table, it was possible to reduce the number of ambiguities to 1 to 3 %.

To obtain cross sections for reaction (1), a special scan and second scan were performed on part of the film. This time, all interactions were recorded. After corrections for small-angle elastic scattering and for scanning efficiency, the total number of events found was normalized to counter measurements of the $\pi^- p$ total cross section.² This method also allows us to determine the fraction of the total cross section that yields all neutral secondaries. The results are summarized in Table I.

The three-body data may be best analyzed by using Dalitz plots, because

this method does not obscure the kinematic reflection of resonances in other pairings of final-state particles. Figure 1 shows the 360-MeV data; Fig. 2 shows the corresponding plot for 480 MeV. To facilitate quantitative observations in Figs. 3 and 4 we present projections of the Dalitz plots at each of the beam energies. These show the effective masses of the $\pi^+ - \pi^-$ and $\pi^+ - n$ systems. The curves correspond to phase-space prediction (uniform population on the Dalitz plot).

Consider first the data in terms of the dipion pairing. The most striking effect in Fig. 3 is the very significant deviation from phase space that appears strongly at the lowest beam energy. The production process favors dipions of a mass $M_{\pi\pi} \approx 400$ MeV. This behavior has been noted previously in this and other experiments.^{3,4,5} A similar effect has been observed near this beam energy in the reaction⁴ $\pi^- p \rightarrow \pi^0 \pi^0 n$ but not in the reaction⁶ $\pi^- p \rightarrow \pi^- \pi^0 p$ nor in the reaction⁷ $\pi^+ p \rightarrow \pi^+ \pi^+ n$; this leads to the conclusion that the $I=0$ state of the dipion system plays an important role in the anomaly. This view is further supported by the observation that the dipion channels, in which the effect is observed, are much more copiously produced than are the latter two channels. The simplest interpretation of this anomaly would be in terms of a strong dipion interaction or a resonance in this mass region, as suggested by other experiments.^{8,9} However, as one proceeds to the higher beam energies, the enhancement, rather than remain at the same dipion mass, continues to appear near the kinematic limit as it diminishes in strength. We have no explanation for this behavior.

In view of the evidence for another strong $I=0$ interaction at a mass in the vicinity of the dipion threshold (280 MeV),¹⁰ a $\pi-\pi$ cross-section calculation for $M_{\pi\pi} < 340$ MeV was made by using the one-pion-exchange model and utilizing the data in the physical region up to a momentum transfer $p^2 = 6$. Results from different beam energies ranged from 20 to 130 mb and corresponded

to an $I=0$ scattering length of 0.6 to 1.5 F . Such a lack of agreement is to be expected on the basis of evidence for more complex phenomena such as isobar production discussed below. However, our lowest beam energy is slightly below $N^*(1238)$ threshold. Here the scattering length appears smallest and we find no evidence supporting a strong dipion interaction near $M_{\pi\pi} = 280$ MeV.

Let us now turn to the π - n pairings. Effects of $N^*(1238)$ are most clearly seen from the projections of Fig. 4. Production of the negatively charged isobar can be observed at every beam energy above N^* threshold. There is no evidence for production of the positive isobar, the enhancements at other π^+n masses being a reflection of N^{*-} . For production purely through an initial $I=1/2$ state a ratio $N^{*-}/N^{*+} = 9$ is expected, although a suitable admixture of $I=3/2$ amplitude can lower or increase this ratio, depending on its relative phase. Since N^* is broad, it is difficult to estimate the fraction of pion production proceeding through isobar formation. At some energies it appears to be the dominant mechanism.

An analysis of pion production purely through isobar formation has recently been made by Olsson and Yodh.¹¹ This more complete treatment of deviations in the isobar model appears to reproduce π - N mass spectra. It also accounts for dipion mass distributions in most charge states¹² but fails to account for the $\pi^+\pi^-$ spectra observed in this experiment.

By selecting those events for which the π^-n effective mass is 1238 ± 50 MeV, we obtain a sample in which the effects of the isobar appear most strongly. For these we assume a two-body production: $\pi^-p \rightarrow N^{*-}\pi^+$. As can be seen from Fig. 5, these "isobars" prefer the backward direction below 500 MeV, whereas around 600 to 700 MeV the majority is produced in the forward hemisphere. Since this change occurs in the energy region of the second nucleon isobar, $N^*(1512)$, it may perhaps be due to an interference

between the rapidly varying resonant amplitude and nonresonant states of opposite parity.

We wish to thank Professor Luis W. Alvarez for his encouragement and advice. Theoretical consultations with Professor Gyo Takeda and Professor A. Charles Zemach have been most useful. The enthusiastic help of our data analysts, especially Jerry H. Friedman, Joe F. Hanna, C. Tom Owens, and Jack Weinberg, is gratefully acknowledged.

Table I. Cross sections.^a

T^b (MeV)	σ_T (assumed) ^c (mb)	$\sigma_{\pi^- \pi^+ n}$ (mb)	σ_{neutrals} (mb)
365	28.0	1.93 ± 0.16	15.5 ± 0.5
435	29.0	3.7 ± 0.3	12.9 ± 0.5
466	30.0	4.0 ± 0.3	12.9 ± 0.5
480	30.5	5.0 ± 0.3	11.3 ± 0.5
560	41.0	5.3 ± 0.5	14.4 ± 0.7
610	46.0	6.1 ± 0.4^d	12.9 ± 0.6
673	39.0	6.1 ± 0.6^d	12.3 ± 0.7

- a). Errors shown are statistical only.
- b). Beam energies are 5 MeV above those for the rest of the experiment because of the choice of a more restricted bubble chamber volume.
- c). See reference 2.
- d). The reaction $\pi^- + p \rightarrow \pi^- + \pi^+ + n + \pi^0$ occurs with an additional ≈ 0.5 mb at these energies, whereas its contribution below 560 MeV is less than 0.1 mb. Note that threshold for the process $\pi^- + p \rightarrow n + n$ is near 560 MeV.

Footnotes and References

- * Work done under the auspices of the U. S. Atomic Energy Commission.
1. We wish to thank Prof. Harold K. Ticho, Dr. George R. Kalbfleisch, Dr. Janice B. Shafer, and other members of the K^- experiment for their help and use of the beam, and Prof. Frank S. Crawford, Jr., for providing the 780-MeV film.
 2. We used the data obtained by J. C. Brisson, J. F. Detoeuf, P. Falk-Vairant, L. Van Rossum, and G. Valladas, *Nuovo Cimento* 19, 210 (1961) and T. J. Devlin, B. J. Moyer, and V. Perez-Mendez, *Phys. Rev.* 125, 690 (1962).
 3. J. Kirz, J. Schwartz, and R. D. Tripp, *Bull. Am. Phys. Soc.* 7, 48 (1962); J. Schwartz, J. Kirz, and R. D. Tripp, *Bull. Am. Phys. Soc.* 7, 282 (1962).
 4. B. C. Barish, R. J. Kurz, V. Perez-Mendez, and J. Solomon, *Bull. Am. Phys. Soc.* 7, 280 (1962); R. J. Kurz, Differential Distribution of Neutrons in Inelastic π^-p Interactions at 374, 417, and 454 MeV (Thesis), Lawrence Radiation Laboratory Report UCRL-10564, Nov., 1962 (unpublished).
 5. L. I. Lapidus, in Proceedings of the 1962 International Conference on High Energy Physics at CERN, (CERN, Geneva, 1962), p. 115.
 6. B. C. Barish, A Study of the Reaction $\pi^- + p \rightarrow \pi^- + \pi^0 + p$ at 310 and 377 MeV (Thesis), Lawrence Radiation Laboratory Report UCRL-10470, Sept., 1962 (unpublished).
 7. J. Kirz, J. Schwartz, and R. D. Tripp, *Phys. Rev.* 126, 763 (1962).
 8. V. P. Samios, A. H. Bachman, R. N. Lea, T. E. Kalogeropoulos, and W. D. Shephard, *Phys. Rev. Letters* 9, 139 (1962).

9. C. Richardson, R. Kraemer, M. Mur, N. Nussbaum, A. Pevsner, R. Strand, T. Toohig, and M. Block, in Proceedings of the 1962 International Conference on High Energy Physics at CERN (CERN, Geneva, 1962).
10. N. E. Booth, A. Abashian, and K. M. Crowe, *Phys. Rev. Letters* 7, 35 (1961). N. E. Booth, Meson Production in $p + d$ Collisions and the $I=0$ π - π Interaction. IV, to be submitted to *Phys. Rev.* (UCRL-10410, 1963).
11. M. Olsson and G. B. Yodh, *Bull. Am. Phys. Soc.* 8, 68 (1963), and private communication.
12. C. N. Vittitoe, W. J. Fickinger, V. P. Kenney, J. G. Mowat, and W. D. Shephard, *Bull. Am. Phys. Soc.* 8, 67 (1963); G. B. Yodh, T. B. Day, G. Quarenzi, A. Quarenzi-Vignaudelli, R. A. Burnstein, J. Ashkin, I. Nadolhaft, and J. Oliver, *Bull. Am. Phys. Soc.* 8, 68 (1963); P. Newcomb, π^+p Scattering at 600 MeV (Thesis), Lawrence Radiation Laboratory Report UCRL-10563, Nov., 1962 (unpublished); C. P. Poirier, E. D. Alyes, Jr., H. J. Martin, C. A. Tilger, *Bull. Am. Phys. Soc.* 8, 68 (1963).

Figure Legends

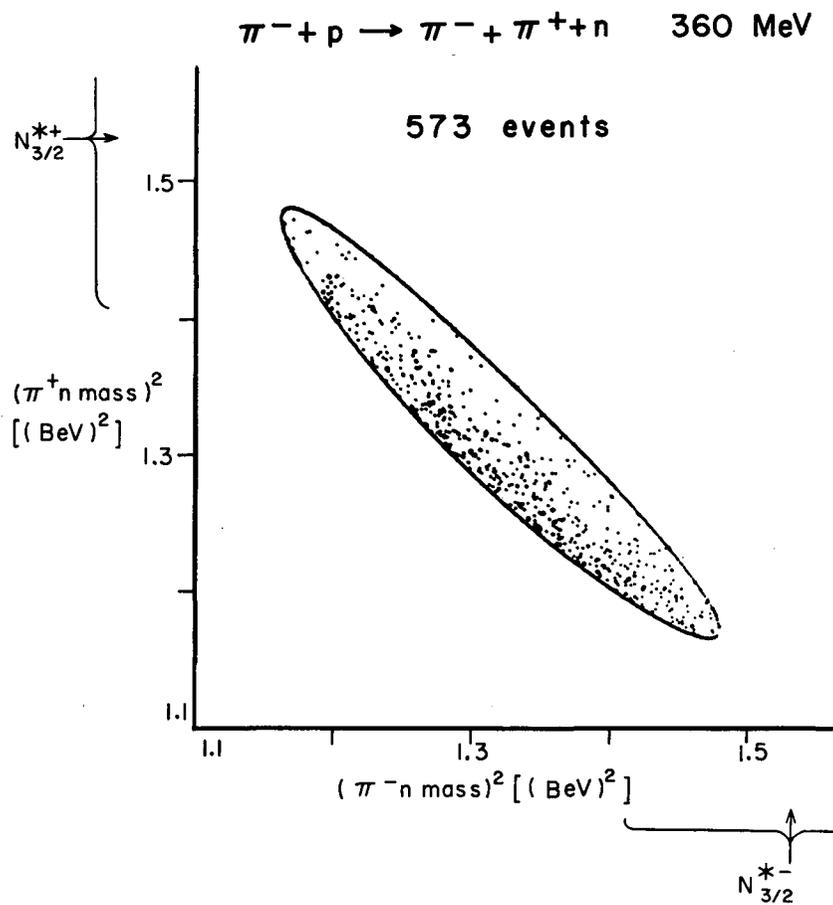
Fig. 1. Dalitz plot for reaction (1) at 360-MeV beam energy. The position and width of $N^*(1238)$ are indicated in both charge states.

Fig. 2. Dalitz plot for reaction (1) at 480-MeV beam energy. The position and width of $N^*(1238)$ are indicated in both charge states.

Fig. 3. $\pi^+ \pi^-$ effective-mass distribution at each beam energy. The dashed curves represent phase space.

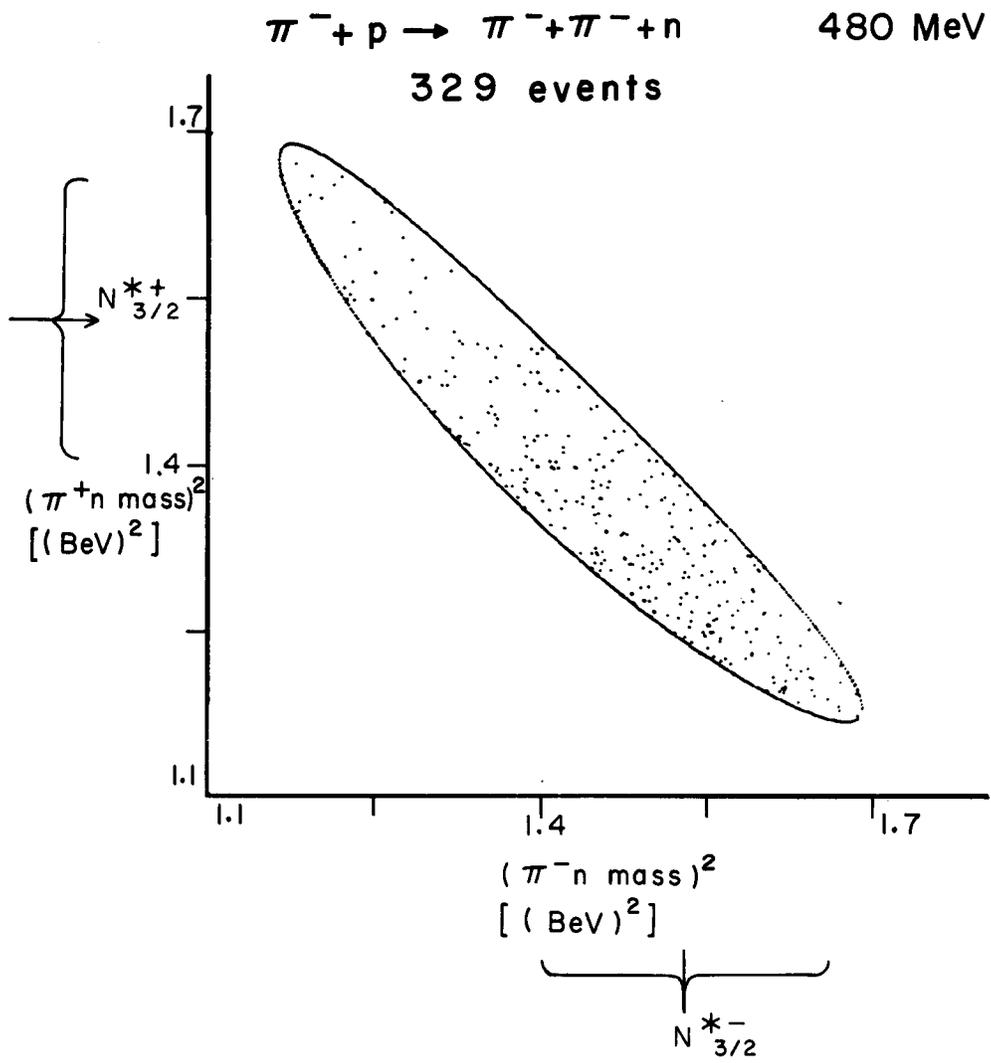
Fig. 4. $\pi^+ n$ and $\pi^- n$ effective-mass distribution at each beam energy. The dashed curves represent phase space. The arrows point to the position of the N^* mass of 1238 MeV.

Fig. 5. The ratio $(F-B)/(F+B)$ for events with $1188 \leq M_{\pi n} \leq 1288$. F stands for the numbers of events for which the πn system is produced forward in the reaction center of mass, B for those produced backward.



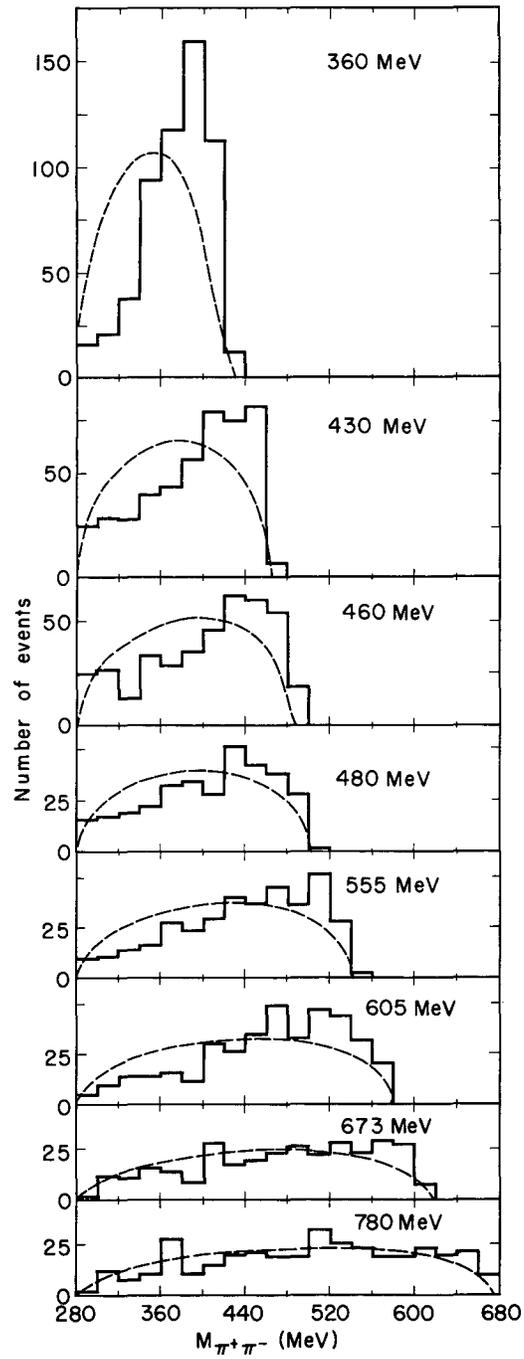
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Fig. 1.



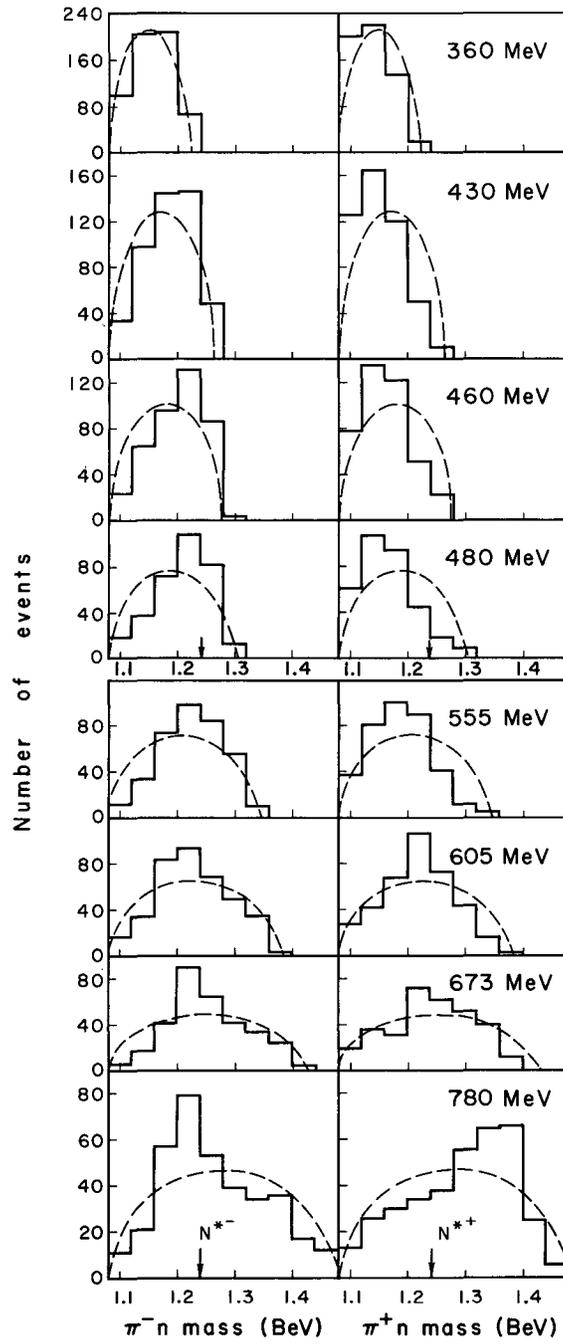
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Fig. 2.



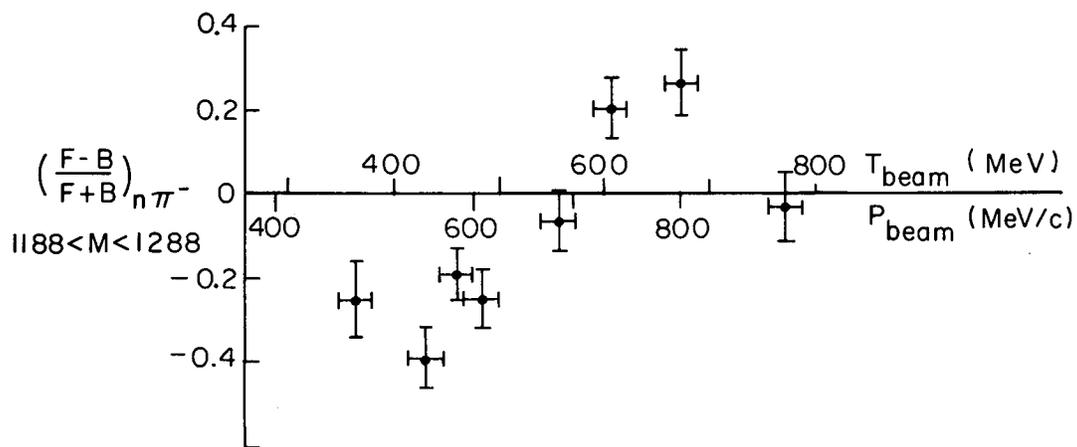
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Fig. 3.



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Fig. 4.



MU-29070

Fig. 5.

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