Test of Isotopic Spin Conservation from an Experiment Limit on $\sigma(d+d \to He^4+\pi^0)$†

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The reaction $d+d \to He^4+\pi^0$, which is forbidden by isotopic spin conservation, has been looked for at the 184-in. cyclotron. A beam of deuterons of 460 Mev kinetic energy was scattered from an extended target filled with deuterium gas at 25 atm pressure and at liquid-nitrogen temperature. The differential cross section in the center-of-mass system at $\theta_{c.m.}=90$ deg was measured and a value of $(18\pm2.3)\times10^{-34}$ cm²/sr was obtained. We consider this value to be an upper limit for the reaction; the data are consistent with no π^0 production. From a comparison of this upper limit with the theoretical prediction of the cross section for this reaction if isotopic spin need not be conserved, we conclude that isotopic spin is at least 93.5% conserved.

THE reaction

$$d+d \to He^4+\pi^0 \qquad (1)$$

has been looked for at the 184-in. cyclotron at Berkeley. This reaction is of interest because it is forbidden by the conservation of isotopic spin, I, since the three heavy particles all have isotopic spin=0 and the isotopic spin of the ordinary $\pi_1{}^0$ (member of the isotopic spin triplet $\pi_1{}^+$, $\pi_1{}^0$, $\pi_1{}^-$) is 1. Therefore reaction (1), which is a strong interaction, would require a change in isotopic spin of +1. The incident deuteron kinetic energy in the laboratory system for this experiment was 460 Mev. Previous efforts at observing reaction (1) have obtained upper limits for the total cross section of 7×10^{-32} cm² at 460 Mev,[1] and 2×10^{-32} cm² at 400 Mev.[2]

We obtain an apparent center-of-mass system differential angular cross section of $(18\pm2.3)\times10^{-34}$ cm²/sr at $\theta_{c.m.}=90°$. For reasons given below, we consider this value to be an upper limit for reaction (1); the data are consistent with no π^0 production. Within the limits of the impulse approximation used to calculate the expected cross section for (1) if isotopic spin need not be conserved,[3] we conclude that isotopic spin is at least 93.5% conserved. We also looked for the reaction

$$d+d \to He^4+\gamma. \qquad (2)$$

An apparent cross section for (2) is $(48\pm10)\times10^{-34}$ cm²/sr at $\theta_{c.m.}=65°$. This also is to be treated as an upper limit; our data are consistent with no γ production from reaction (2).

Figure 1 shows the laboratory-system kinematics for reaction (1) for incident deuterons of 460 Mev kinetic energy and $M(\pi^0)=135.0$ Mev. The kinematics for reaction (2) are also shown, dashed. Slits of lead were placed between the target and the first quadrupole to fix the lab angle of the alpha particle at $8.7\pm0.6°$ (indicated in Fig. 1) and to prevent the magnetic channel from seeing the deuteron beam as it passed through the windows of the gaseous target.

Two alpha momentum settings were used: 1275 ± 75 Mev/c, which was sensitive to the production of a neutral particle with a mass of 120–155 Mev, and 1427 ± 40 Mev/c, which was sensitive to a mass of 0–110 Mev. The momentum intervals quoted above were defined by the deliberately broad magnetic channel acceptance (±6%) and by the energy loss in the deuterium target.

Figure 2 shows the experimental arrangement used to focus and identify the alpha particles. The target

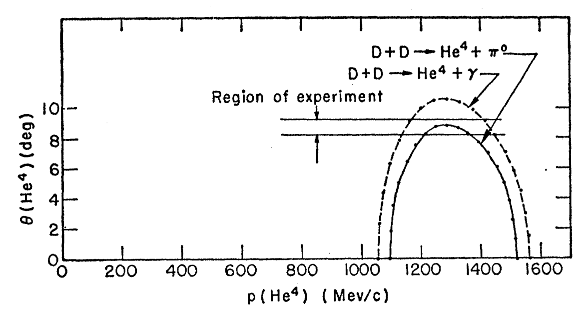

FIG. 1. Angle vs momentum of He⁴ (lab).

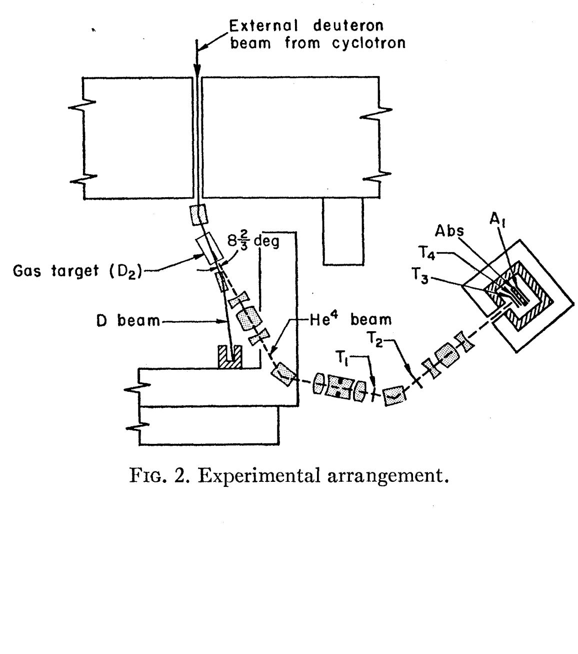

FIG. 2. Experimental arrangement.

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[1] Norman E. Booth, Owen Chamberlain, and Ernest H. Rogers, Lawrence Radiation Laboratory Report UCRL-8944, 1960 (unpublished).

[2] Yu. K. Akimov, O. V. Savchenko, and L. M. Soroko in *Proceedings of the 1960 International Conference on High-Energy Physics at Rochester* (Interscience Publishers, Inc., New York, 1960).

[3] K. R. Greider, following paper [Phys. Rev. **122**, 1919 (1961)].

TABLE I. Counts per 10^{13} incident deuterons.

$p(He^4)$	D_2	H_2	Target empty
1275 Mev/c (π^0)	31.4 ± 0.85	22.7 ± 0.73	16.5 ± 1.08
1427 Mev/c (γ)	33.9 ± 1.07	24.2 ± 0.88	

had $\frac{1}{32}$ in.-thick aluminum entrance and exit windows 6 in. in diameter. It was filled to a gas pressure of 25 atm at liquid-nitrogen temperatures. Hydrogen and deuterium fillings were alternated during the experiment. The alpha-particle beam passed entirely through a vacuum, except for regions near the target and in the vicinity of the counters.

The counters were constructed of 0.020 in.-thick plastic scintillator to minimize energy loss and multiple scattering. Alpha particles were identified by means of time of flight and range (i.e., $T_1T_2T_3T_4\bar{A}_1$) and dE/dx (i.e., lower-level discrimination of the pulse height on T_3 and T_4). All counter pulses were recorded on a four-gun oscilloscope. The electronics was tuned up by means of an alpha-particle beam from the cyclotron, and consistency checks were made periodically through the run.

The cross section for deuterons on carbon,

$$(d\sigma/d\Omega)(d+\mathrm{C}\rightarrow \mathrm{He}^4+\mathrm{residue}),$$

was also measured by using the CH_2-H_2 subtraction technique. The result is 2.3×10^{-30} cm^2/sr-Mev/c for alpha particles of 1060 Mev/c momentum (lab) and an angle of $8\frac{2}{3}°$. With the CH_2 target we could show that our electronics did not saturate even though the production cross section for alpha particles and the background of deuterons were larger than with the deuterium target in place.

Our data runs were cycled among four settings: He^4 momentum set at 1275 Mev/c to observe reaction (1) and then at 1427 Mev/c to observe reaction (2), first with a deuterium target and then with a hydrogen target.

Table I presents our data with their statistical errors. Since no alpha particles can come from d-p collisions, the hydrogen data were treated as background and subtracted from the deuterium data to yield the net He^4 signal from d-d collisions. This signal is now to be considered as an upper limit because any contamination of the deuteron beam with alpha particles would give us a net positive yield. This was shown by using an alpha-particle beam from the cyclotron under the conditions listed in Table I. At both momenta the α-d inelastic scattering yielded 1.48 ± 0.03 times as many alpha counts as did α-p scattering. Alpha contamination of the deuteron beam could explain the observed net positive difference in alpha-particle yield between the deuterium and hydrogen targets. Further data (not shown in Table I) at different momenta give us additional information on the background. These data are consistent with zero yield from reaction (1), but the errors are large. We find, therefore, no evidence of the nonconservation of isotopic spin.

To get a firm upper limit for reaction (1) we assumed that the counts in Table I for D_2 target minus those from H_2 target were due entirely to reaction (1). The limit for the differential scattering cross section in the center-of-mass system obtained in this manner is $d\sigma_{\mathrm{c.m.}}/d\Omega<(18\pm2.3)\times10^{-34}$ cm^2/sr at 90° (c.m.). To get a lower limit for isotopic spin conservation, we compare this with the theoretical prediction[3] for the cross section, $d\sigma^T/d\Omega=(380\pm50)\times10^{-34}$ cm^2/sr, which is computed with the assumption that isotopic spin need not be conserved. From this ratio, increased by two standard deviations, we find that isotopic spin is at least 93.5% conserved. The standard deviation of 0.9% was a composite of experimental errors quoted here plus errors on experimental quantities as reflected in the calculation of reference 3. The limit obtained for reaction (2), mentioned previously, was obtained in this same manner from the data in Table I.

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