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EVIDENCE FOR A LOW-ENERGY RESONANCE IN THE THREE-NEUTRON SYSTEM*

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A study of the double charge-exchange reaction $\pi^- + {}^3He \rightarrow \pi^+ + 3n$ indicates resonant behavior in the three-neutron system within a few MeV of threshold. The three-neutron data from this experiment are in good agreement with the resonant behavior obtained in the three-proton system in another reaction.

The three-neutron system has been the subject of a number of recent investigations, both experimental [1,2] and theoretical [3]. Although some of the earlier experimental results indicated that this system forms a bound state, more recent evidence shows that it is unbound. Similarly the theoretical results indicate that three neutrons might be bound or unbound depending on the particular assumptions made. In order to resolve some of these ambiguities we measured the three-neutron final-state interaction obtained in the double charge-exchange reaction $\pi^- + {}^3He \rightarrow \pi^+ + 3n$ at an incident π^- energy of 140 MeV.

A beam of 140 ± 3-MeV π^-, obtained at the Berkeley 4.6-m cyclotron, was incident on a liquid ^{3}He target. The beam flux was 2×10^5 particles per second consisting of approximately 65% pions, 20% muons, and 15% electrons. The positive pions were detected over the angular range of 15 to 40 deg. The direction and momentum of the outgoing π^+ were determined by a magnetostrictive wire chamber spectrometer similar to that used by Kaufman et al. [1]. The spectrometer had a maximum solid-angle acceptance of 24.8 millisteradian for a momentum of 167 MeV/$_c$ which decreased approximately linearly to 19.2 msr at 240 MeV/$_c$ and 9.7 msr at 100 MeV/$_c$. Multiple scattering in the spectrometer limited the momentum resolution to ±1 MeV/$_c$. This leads to an uncertainty of ±1 MeV in the kinetic energy of the three-neutron system, which is however still smaller than the energy spread of the beam. Other sources of uncertainty of the three-neutron kinetic energy are less than 1 MeV.

To signal an event we required that the scattered particle have a range greater than 1.25 c.m. of aluminum. This eliminated the proton background. A Monte Carlo program was used to compute the expected energy distribution of positrons. This distribution was normalized to the data in the energy region for which the range of the π^+ is less than 1.25 c.m. of aluminum and then substracted from the data. The π^- and other beam particles did not produce any background since they are negatively charged and bend in the opposite direction in the spectrometer magnet.

The measured π^+ distribution was corrected for spectrometer acceptance and π^+ decays in flight. In fig. 1 we show the differential cross section for $\pi^- + {}^3He \rightarrow \pi^+ + 3n$ as a function of the kinetic energy of the three-neutron system obtained from the measured π^+ distribution integrated over all angles.

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The abscissa is the kinetic energy of the three-neutron system, with zero corresponding to the three-neutron threshold. The indicated errors are only statistics. In addition to these there is an uncertainty of about 10% in the percentage of pions in the beam which implies an overall uncertainty of 10% in the normalization of the differential cross section. The low cross section below threshold indicates that there is no bound state of three neutrons. From this data we can set an upper limit of .03 ± .01 μb/sr for forming a trineutron with a binding energy between 0 and 15 MeV. This agrees with our previous results for the reaction $\pi^- + {}^4He \rightarrow p + 3n$ [1]. However, the distribution rises more sharply near threshold than phase-space with a shape indicating a resonant behavior. The solid line in fig. 1 is the four-particle phase space normalized to the data in the energy range of 50 to 85 MeV.

To show the characteristics of this final-state interaction more clearly we plot in fig. 2a our measured distribution divided by the phase-space curve of fig. 1. The dashed curve is a Breit-Wigner form centered at 2 MeV with a width of 12 MeV. The exact center of the curve is not well determined because of the insufficient energy resolution. In fig. 2b we plot the energy distribution, divided by the corresponding phase space, of the three-proton system obtained from the reaction ${}^3He$ (p,n)3p at 50 MeV as measured recently by Williams et al. [4]. As can be seen from the figures, the data are in good agreement allowing for the fact that the Coulomb energy causes a shift in the three-proton system of about 2 MeV.

In comparing these two experiments, it is plausible to assume that these resonances among three nucleons are corresponding members of an I = 3/2 multiplet, with the other members of the multiplet being possible excited states of ^{3}He and ^{3}H [4].

We would like to acknowledge the help of D. Hunt in constructing the ^{3}He target, and of J. Vale and the crew for the efficient operation of the cyclotron.

FOOTNOTE

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FIGURE LEGENDS

Fig. 1. Differential cross section for the reaction $\pi^- + {}^3He \rightarrow \pi^+ + 3n$ as a function of the kinetic energy of the three-neutron system. The solid line represents four-body phase space normalized to the data in the energy range of 50 to 85 MeV.

Fig. 2. Differential cross section divided by phase space (a) for the reaction $\pi^- + {}^3He \rightarrow \pi^+ + 3n$. The dashed curve is a Breit-Wigner form centered at 2 MeV with a width of 12 MeV (b) for the reaction ${}^3He(p,n)3p$ as measured by Williams et al. [4].

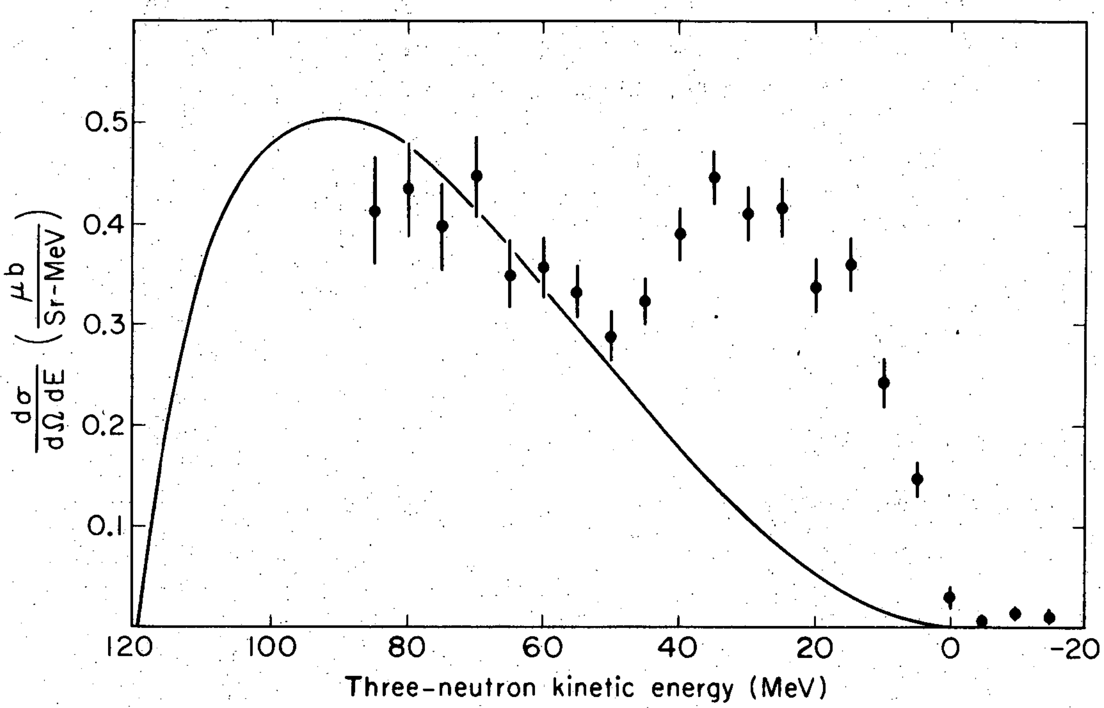
0.5
0.4
0.3
0.2
0.1
$\frac{d\sigma}{d\Omega\, dE}$ $\left(\frac{\mu b}{\text{Sr-MeV}}\right)$
120
100
80
60
40
20
0
-20
Three-neutron kinetic energy (MeV)
XBL703-2489

Fig. 1

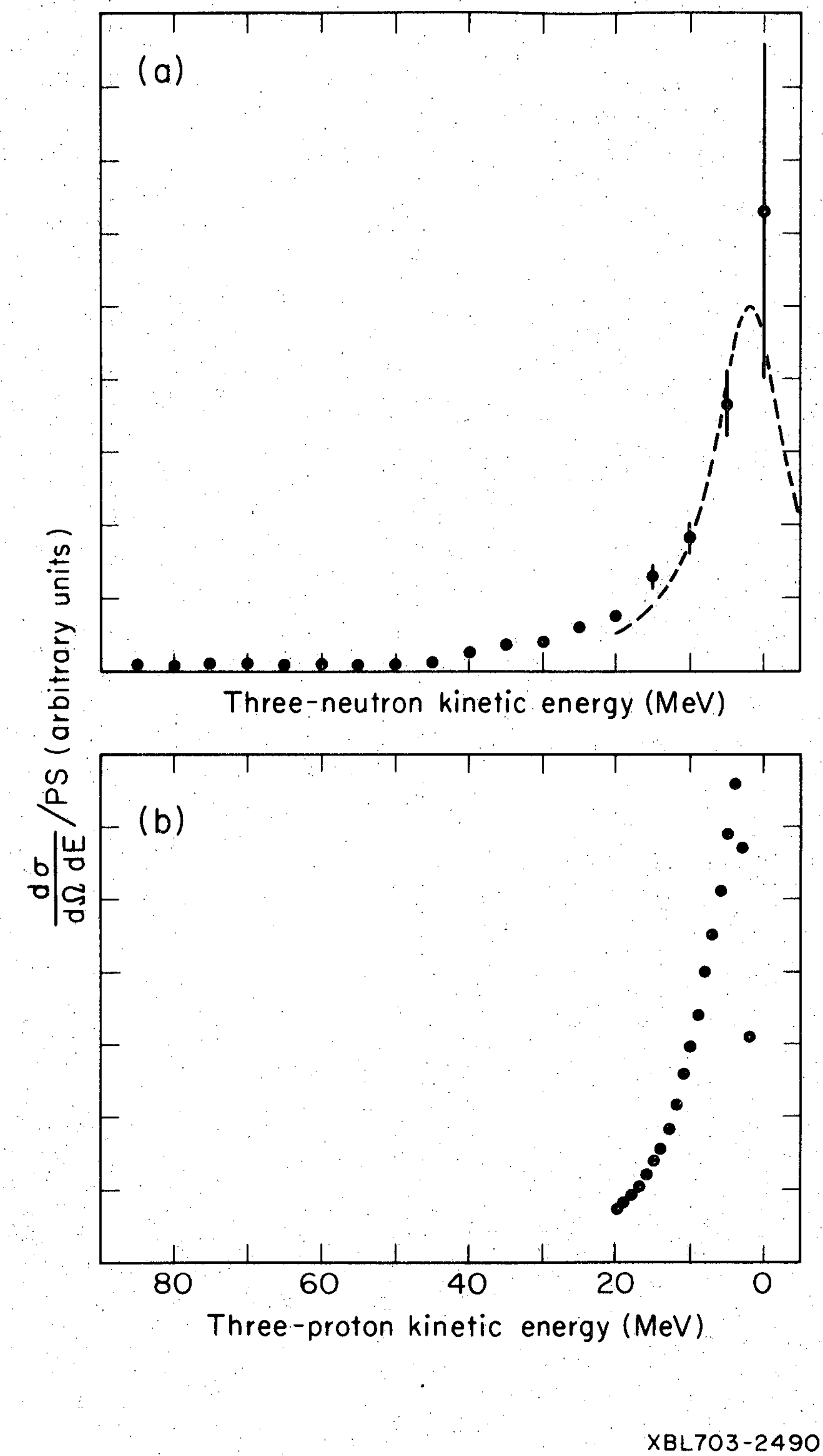
(a)
Three-neutron kinetic energy (MeV)
$\frac{d\sigma}{d\Omega\, dE}$/PS (arbitrary units)
(b)
80
60
40
20
0
Three-proton kinetic energy (MeV)
XBL703-2490

Fig. 2

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