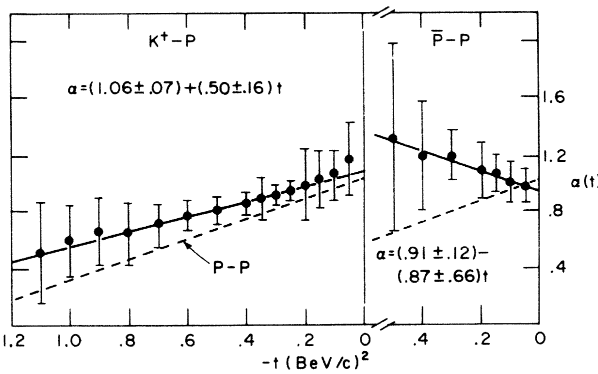


FIG. 2. $\alpha(t)$ versus $-t$; for comparison, the $p$-$p$ trajectory from reference 1 is shown.

mental data points. From a logarithmic plot of the interpolated values versus ln$s$, values of $\alpha(t)$ for a single Regge-pole representation of $K^+$ and $\bar{p}$ scattering have been obtained, using

$$\ln(d\sigma/dt) = F(t) + 2[\alpha(t) - 1]\ln s,$$

where $s$ is the square of the energy in the center-of-mass system.

As there appears to be little agreement with any specific theoretical scheme presently, the above simple representation of the data seems preferable to anything more elaborate. Values of $\alpha(t)$ thus obtained are shown in Fig. 2; the $\alpha$ curve for $p$-$p$ scattering is also shown.

From Fig. 2 as well as from the experimental cross sections, one can see that $\bar{p}$-$p$ scattering does not appear to exhibit the shrinkage observed in $p$-$p$ scattering; in fact, the best fit indicates an expansion 1.3 standard deviations from no shrinkage and 2.5 standard deviations from the $p$-$p$ shrinkage. $K^+$-$p$ scattering, on the other hand, can be described by a straight-line trajectory having a slope (66 ± 21)% that of the $p$-$p$ trajectory.

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## DEUTERON PRODUCTION IN $pp$ COLLISIONS*

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In a recent note Cocconi et al.[1] have shown that the total cross section for the reaction

$$p + p \rightarrow d + \pi^+ \qquad (1)$$

is likely to present a maximum at total c.m. energy $E^* = 2.9$ BeV, beyond the well-established maximum at $E^* = 2.16$ BeV. The above authors observed also that these values of $E^*$ correspond almost exactly to the masses of the first and fourth pion-nucleon resonances plus a nucleon mass.

It is the aim of the present note to point out that these facts, together with the nonappearance of the second and third $\pi N$ resonances, are explained by a simple model of deuteron production.

As the reaction

$$p + p \rightarrow p + n + \pi^+ \qquad (2)$$

in the same energy region is well explained by the one-pion exchange (O.P.E.) model,[2] we assume that Reaction (1) is generated by the O.P.E. mechanism followed by an interaction in the final state, which binds $p$ and $n$ into a deuteron.

This picture corresponds to the diagram shown in Fig. 1. First we show that the fact that $p$ and $n$ bind together in a deuteron freezes the three-body kinematics of the intermediate state in such a way that there is almost a one-to-one correspondence between the total c.m. energy squared

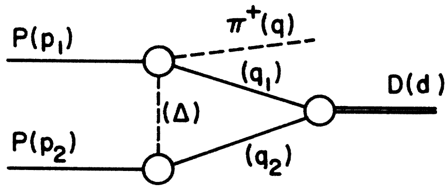


FIG. 1. The model for the deuteron production process. Near each line the corresponding four-momentum is indicated within brackets.

$s$ and the square of the c.m. energy for $\pi N$ scattering $s_1$, where

$$s=-(p_1+p_2)^2, \quad s_1=-(q+q_1)^2;$$

the four-momenta being defined in Fig. 1. Let us neglect the deuteron binding energy and the momentum distribution of the bound nucleons. In the system $\vec{d}=0$ we take then $q_{10}=q_{20}=m$ and $\vec{q}_1=\vec{q}_2=0$. It is then easy to show that

$$\begin{aligned} s&=-(q+q_1+q_2)^2,\\ &=2(s_1+m^2)-\mu^2, \end{aligned} \tag{3}$$

where $m$ and $\mu$ are the nucleon and pion masses, respectively. A numerical calculation shows that Eq. (3) coincides with $E^*=s^{1/2}=s_1^{1/2}+m$ to within 1% (5%) if $s_1^{1/2}$ equals the first (fourth) $\pi N$ isobar mass. This result is practically unaffected by considering the true physical situation, as the deuteron wave function

$$\psi(\vec{k})\sim(\vec{k}^2+\epsilon m)^{-1}$$

$[\vec{k}=\frac{1}{2}(\vec{q}_1-\vec{q}_2)$, $\epsilon$ = deuteron binding energy] allows one to consider values of $\vec{k}^2$ of the order of $\epsilon m \ll m^2$. Therefore, we can expect a maximum in the cross section for Reaction (1) at a value of $s$ given by (3), whenever $s_1$ reaches a value corresponding to a $\pi N$ resonance.

We will now show that our model implies that the maxima corresponding to $T=\frac{1}{2}$ $\pi N$ isobars are suppressed by a factor 16 in comparison to those corresponding to $T=\frac{3}{2}$ isobars.

The isospin structure of the diagram in Fig. 1 is given by

$$\begin{aligned} &\langle 0|M_\beta|1\rangle\\ &=\langle 0|\tau_\alpha^{(1)}\{\delta_{\alpha\beta}^{(2)}A^{(+)}+\tfrac{1}{2}[\tau_\beta^{(2)},\tau_\alpha^{(2)}]A^{(-)}\}|1\rangle, \end{aligned} \tag{4}$$

where $\alpha$ and $\beta$ are the charge indices of the intermediate and emitted pions and $|I\rangle$ indicates a two-nucleon state with isospin $I$. The quantity within curly brackets in (4) is the matrix element for $\pi N$ scattering, and the plus and minus amplitudes are related to the fixed isospin amplitudes by the well-known relations

$$\begin{aligned} A^{(+)}&=\tfrac{1}{3}[A^{(1/2)}+2A^{(3/2)}],\\ A^{(-)}&=\tfrac{1}{3}[A^{(1/2)}-A^{(3/2)}]. \end{aligned} \tag{5}$$

Introducing (5) in (4), taking the linear combination of $M_\beta$'s which gives the emission of a $\pi^+$, and performing the sum over $\alpha$, we get

$$\begin{aligned} M(pp\to d\pi^+)&=\langle 0|\tfrac{1}{2}[M_1-iM_2]|1\rangle,\\ &=-\tfrac{4}{3}A^{(3/2)}+\tfrac{1}{3}A^{(1/2)}. \end{aligned} \tag{6}$$

We conclude therefore that on the cross section the $I=\frac{1}{2}$ isobars are suppressed by a factor of 16 with respect to the $I=\frac{3}{2}$ ones.[3] This makes the former practically unobservable with the present experimental accuracy. We can add that this result depends only on the isospin of the exchanged system. Thus, e.g., a $\rho$ exchange would lead exactly to the same conclusion. On the other hand, exchange of systems with zero isospin would not lead to the formation of $T=\frac{3}{2}$ isobars at all. We conclude thus that the total cross section for Reaction (1) is very sensitive to the exchanged isospin in the production step and that the present experimental evidence points to a rather strong depression of the exchange of zero-isospin systems ($\omega$, $\varphi$,$\cdots$). This result agrees with the O.P.E. model for Reaction (2).[2] The calculation of the diagram of Fig. 1 is in progress.[4]

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[4]The same model has been discussed independently by F. Turkot et al., T. Yao, and A. Stanghellini. See reference 1 for reference.