the different models discussed. Thus Δ is measured in units of J^2, $\Delta'' \propto J^2\Delta$, etc.

[25]This procedure gives the correct quadratic Hamiltonian in the physically relevant limit $n \to 0$ (n is the replica index). An alternate derivation yields the correct translationally invariant form $\Delta(f_\alpha - f_\beta)^2$ as well as higher-order terms proportional to Δ such as $(f_\alpha - f_\beta)^4$, $(\nabla f_\alpha)^2(f_\alpha - f_\beta)^2$, etc. These terms would be difficult to derive by the procedure used here. All the eigenvalues and eigenvectors of Eq. (6) would have to be taken into account. However, these terms can be shown to be irrelevant, in the renormalization group sense, and will not be included here. The details of the derivation and of the renormalization group calculation will be presented elsewhere (D. Mukamel, Y. Imry, and E. Pytte, to be published).

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Measurement of the Difference in *pn* Total Cross Sections in Pure Longitudinal Spin States

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The total–cross-section difference in pure longitudinal spin states for p-d interactions has been measured at momenta from 1.1 to 6 GeV/c. Spin-dependent Glauber-type corrections and other corrections have been made to obtain $\Delta\sigma_L(pn)$ and $\Delta\sigma_L(I=0)$. These measurements are of fundamental interest and will also help in determining the existence and nature of dibaryon resonances.

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We have measured the total–cross-section difference in pure longitudinal spin states for proton-neutron interactions $[\Delta\sigma_L(pn)]$ at eleven momenta from 1.1 to 6.0 GeV/c. A polarized proton beam and polarized deuteron target were employed because polarized neutron beams of the required intensity and energy are not easily produced. These measurements were made at the Argonne National Laboratory zero-gradient synchrotron (ZGS) by the group that made previous similar measurements for proton-proton interactions in pure longitudinal spin states.

The strong energy dependence in $\Delta\sigma_L(pp)$ data,[1] together with data on the transverse-spin-state cross-section difference $\Delta\sigma_T(pp)$,[2] polarization and various two- and three-spin parameters in elastic scattering, some inelastic channels in nucleon-nucleon interactions, and π-d and p-He scattering, have led to interpretations in terms of dibaryon resonances.[3-7] Further measurements in the elastic and inelastic channels are underway at Clinton P. Anderson Meson Physics Facility, TRIUMF, Schweizerisches Institut für Nuklearforschung, and other laboratories, and data taken at the ZGS by our group and others are being analyzed.

There are several approaches to nucleon and subnucleon physics for which total nucleon cross sections in both pure spin states and pure isospin states are of fundamental interest. These include determining nucleon-nucleon scattering amplitudes, gaining information on particular exchanges in the nucleon-nucleon force and on nucleon-nucleon couplings to nucleon-isobar or isobar-isobar channels, and studying possible multiplets of multiquark resonances in order to learn about the constituent interactions.

The existence of isospin-1 dibaryons would suggest the existence of isospin-0 dibaryon states and indeed some bag models and other approaches predict many such states.[5] The isospin-0 channel is of particular interest also because this channel cannot couple to $N\Delta$ or πD channels which have been discussed in connection with the interpretation of the $pp(I=1)$ case near threshold.[8] Furthermore the thresholds for $NN^*(1400)$ and $\Delta\Delta(1236)$ are higher than 1.5 GeV/c (1.7 and 2.1 GeV/c, respectively).

The beam arrangement and general features of the transmission counters and target used for the first running period have been described previously.[1,9] A ^{3}He-^{4}He dilution refrigerator was used for the target during the second running period. The target NMR system could record both the shapes of the resonant peaks as a function of frequency and the area under the peaks with a fitted background subtracted. The target material consisted primarily of partially deuterated ethelyene glycol with two polarizable deuterons for each polarizable proton. About half the data at each energy were taken with both protons and deuterons polarized, and about half with protons selectively depolarized. Typical run-average polarizations were 90%–95% for protons when polarized and 25%–30% for deuterons. We were able to obtain both $\Delta\sigma_L(pp)$ and $\Delta\sigma_L(pd)$ from this data. The $\Delta\sigma_L(pp)$ values agree within statistics with published values, providing a check of systematics.

We measured beam polarization with a hydrogen polarimeter in our external beam line and subsequently corrected the polarization data[10] used in the published $\Delta\sigma_L(pp)$ and on-line $\Delta\sigma_L(pd)$.

In obtaining $\Delta\sigma_L(pn)$ from $\Delta\sigma_L(pd)$, we cannot simply subtract $\Delta\sigma_L(pp)$ from $\Delta\sigma_L(pd)$, but must consider Glauber-type rescattering corrections, and Coulomb-nuclear interference corrections including deuteron breakup. We have also applied corrections for real parts of amplitudes, the deuteron form factor, and the depolarizing effects of the D-wave component of the deuteron, each of which has a maximum effect of approximately 10%.

Our notation is as follows: P is polarization, $\mathcal{P}$ is probability, p is proton, $p_{\rm lab}$ is momentum, $\mathrm{Im}(\alpha_n) = 2mp_{\rm lab}\sigma^{\rm tot}(pn)$, $\mathrm{Im}(\epsilon_n) = 2mp_{\rm lab}\Delta\sigma_L(pn)$, etc.[11] We assume eikonal-type corrections only and isospin independence in the strong interaction.

If the energy dependence of the amplitudes is ignored in integrating over the form factor one obtains the formulas of Sorenson[12] and Albert *et al.*[13] which include charge exchange and the D wave in this approximation:

$$\begin{aligned}\Delta\sigma_L(pd) = {}& (2/2mp_{\rm lab})[\mathrm{Im}(\epsilon_p)+\mathrm{Im}(\epsilon_n)](1-\tfrac{3}{2}\mathcal{P}_D)\\ &+(1/16\pi m^2 p_{\rm lab}^2)R_L\{2\,\mathrm{Re}(\epsilon_p)\,\mathrm{Re}(\alpha_n)-2\,\mathrm{Im}(\epsilon_p)\,\mathrm{Im}(\alpha_n)+2\,\mathrm{Re}(\epsilon_n)\,\mathrm{Re}(\alpha_p)-2\,\mathrm{Im}(\epsilon_n)\,\mathrm{Im}(\alpha_p)\\ &-\mathrm{Re}(\alpha_p)\,\mathrm{Re}(\epsilon_p)+\mathrm{Im}(\alpha_p)\,\mathrm{Im}(\epsilon_p)-\mathrm{Re}(\alpha_n)\,\mathrm{Re}(\epsilon_n)+\mathrm{Im}(\alpha_n)\,\mathrm{Im}(\epsilon_n)\},\end{aligned}$$

where $\mathcal{P}_D$ is the D-wave probability. R_L is similar to $\langle 1/r^2\rangle$ for the deuteron but can include effects of the D-wave and t dependence in the form-factor integral, which makes it differ from $\langle 1/r^2\rangle$ by perhaps 15% for $\Delta\sigma_L$ (Ref. 13).

Noting that a formula of this type is linear in ϵ_n, Grein and Kroll[14] show how to obtain the correction corresponding to real parts of amplitudes by using the equation in a dispersion relation. They have further developed a closed-form approach to this problem.

Given the strong energy dependence of $\Delta\sigma_L(pp)$, one cannot ignore the energy dependence of the amplitudes in integrating over the form factor. For the present analysis we wish to consider only the first-order correction due to the effect of the form factor with D wave.[15-17]

Even this approach would be difficult if we did not ignore the correlation between proton and neutron motion in the deuteron. This assumption may be justified after the fact by noting that ϵ_n has an energy dependence which may be considered negligible compared to that of ϵ_p.

The form-factor integral was done numerically as

$$\int dq_z\,\epsilon_p(E_{\rm c.m.}(q_z))\int dq_x\,dq_y\,\mathcal{P}_p(\vec{q})P_p(\vec{q}),$$

where q_z is the z component of Fermi momentum of the proton.

After beam-polarization[10] and target-polarization corrections, the actual physics correction procedure was as follows: The measured value of $\Delta\sigma_L(pd)$ (Table I) was corrected for both elastic and breakup Coulomb-nuclear interference.[14] It was sufficient in the present experiment to do this with an additive correction at $t=0$ rather than correcting the asymmetry of each transmission counter before extrapolation to $t=0$ because the t dependence in the pp case was known.

TABLE I. $\Delta\sigma_L(pd)$.

Momentum	Raw $\Delta\sigma_L(pd)$ (mb)	Corrected $\Delta\sigma_L(pd)$ (mb)
1.10	-17.60 ± 0.97	-17.37 ± 0.97
1.20	-15.40 ± 2.30	-15.36 ± 2.30
1.30	-17.14 ± 0.58	-17.25 ± 0.58
1.43	-19.62 ± 0.50	-19.66 ± 0.50
1.47	-18.70 ± 0.40	-18.74 ± 0.40
1.62	-17.03 ± 0.36	-16.97 ± 0.36
1.75	-15.91 ± 0.98	-15.77 ± 0.98
2.0	-12.30 ± 0.49	-12.11 ± 0.49
2.25	-9.00 ± 0.30	-8.82 ± 0.30
2.75	-3.65 ± 0.30	-3.49 ± 0.30
6.00	-0.24 ± 0.35	-0.19 ± 0.35

The spin-dependent Glauber corrections from imaginary parts of amplitudes, including charge exchange, along with the deuteron wave-function effects (Fermi motion and nucleon polarization) were then applied following Sorensen and Alberi *et al.* A detailed study was made comparing corrections done in two ways. One with one specific wave function which determined the nucleon polarization at each value of projected Fermi momentum so that the corrections for energy dependence of amplitudes and for the energy dependence of nucleon polarization were done properly within the context of this wave function. We then found that essentially the same results were obtained with a simple scale factor indicating the amount of D wave (5.3% assumed) along with a smearing of $\Delta\sigma_L$ with any reasonable wave function ignoring spin.[18-20] The actual form of this correction was

$$\Delta\sigma_L(pn) = [\Delta\sigma_L(pd)_{\rm corr} - A\,\Delta\sigma_L(pp)_{\rm smear}]/B,$$

where

$$A = (1 - \tfrac{3}{2}\mathcal{P}_D) - (1/2\pi)R_L[\sigma(pn)^{\rm tot} - \tfrac{1}{2}\sigma(pp)^{\rm tot}],$$

$$B = (1 - \tfrac{3}{2}\mathcal{P}_D) - (1/2\pi)R_L[\sigma(pp)^{\rm tot} - \tfrac{1}{2}\sigma(pn)^{\rm tot}],$$

and $(1/2\pi)R_L = 0.006$ mb^{-1} which is larger than the conventional $(2/4\pi)\langle 1/r_d^2\rangle$ but not quite as large as an example in Ref. 13.

We then applied the spin-dependent Glauber corrections due to real parts of amplitudes with use of the method of Grein and Kroll.[14] The real parts of amplitudes used were obtained by them from the partially corrected data of the previous step by using dispersion relations. The dispersion-relation solutions were constrained as in Ref. 21.

The energy dependence of $\Delta\sigma_L(pd)$, $\Delta\sigma_L(pn)$, and $\Delta\sigma_L(I=0)$ is shown in Fig. 1. There is an overall energy-independent uncertainty of 12% in the values of $\Delta\sigma_L(pd)$ due to beam and target polarization. The pn data are consistent with the absence of energy dependence between 1.1 and 2 GeV/c. Note that any narrow structure in $\Delta\sigma_L(pn)$ would be smeared to about 80-MeV/c full width at half maximum by Fermi motion in the deuteron. The limit from the error bars on the strength of such a structure is about 200 mb MeV/c [one tenth the strength of the proposed $^3F_3$ resonance $(I=0)$] except at 1.2 GeV/c where the error bars are larger.

The structure in $\Delta\sigma_L(I=0)$ around 1.5 GeV/c is essentially a reflection with smaller magnitude of the structure in $\Delta\sigma_L(pp)$ since $\sigma(I=0) = 2\sigma(pn) - \sigma(pp)$.

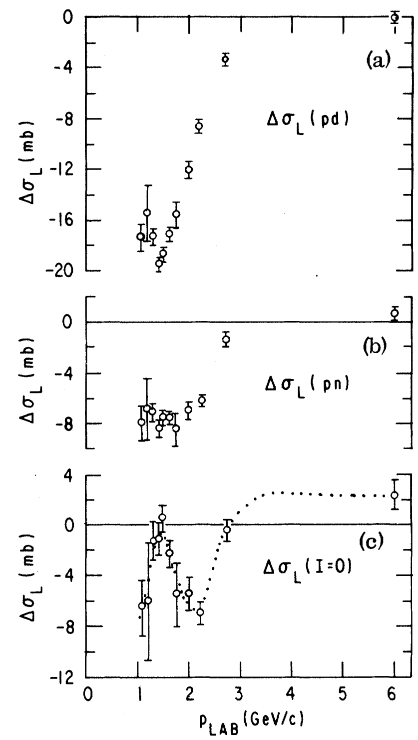

FIG. 1. Cross-section differences obtained in this experiment. Error bars are statistical only except for the 1.2 GeV/c point (see text). (a) $\Delta\sigma_L(pd)$. (b) $\Delta\sigma_L(pn)$ obtained from (a) by using spin-dependent Glauber-type corrections and corrected $\Delta\sigma_L(pp)$ data. (c) $\Delta\sigma_L(I=0)$. Note—(b) and (c) are smeared by Fermi motion of the neutron inside the deuteron.

The energy dependence around 1.2 GeV/c is not clear in $\Delta\sigma_L(I=0)$. The reflection of the structure in $\Delta\sigma_L(pp)$ around 1.2 GeV/c is moderated by the variation in $\Delta\sigma_L(pd)$, by the Fermi-motion smearing, and by the rescattering corrections. Also, the error bars on the 1.2-GeV/c point are large because of an uncertainty in the target polarization during operation of a new target.

There is an observed structure in $\sigma^{\rm tot}(pn)$ around 1.4 GeV/c,[22] and an apparent lack of structure in $\Delta\sigma_L(pn)$. This is complementary to the situation of no obvious fine structure in $\sigma^{\rm tot}(pp)$ but clear structure in $\Delta\sigma_L(pp)$. There is the additional degree of freedom of isospin in the pn case.

The overall amplitude corresponding to the isospin-0 $\Delta\sigma_L$ has the behavior of a resonance [Fig. 1(c)] in the region around 1.4 GeV/c but the behavior of individual partial-wave amplitudes is not known. The fact that the structure is more positive than the background suggests, but does not prove, that there is an enhancement of the singlet spin state for some partial wave. On the other hand, it has been suggested that consistency with charge-exchange cross sections is obtained most simply with a triplet if only one partial wave has a resonant behavior in this energy region.[21]

More data on pn interactions are needed to resolve these questions. In general, the same kinds of measurements that have been made or are being made in the pp system are needed. For example, the cross-section difference in transverse spin states, $\Delta\sigma_T(pn)$, combined with $\Delta\sigma_L$ will indicate whether structures are spin singlet or triplet.

With respect to $\Delta\sigma_L(pn)$ specifically, the reliability of $\Delta\sigma_L(pn)$ as extracted from $\Delta\sigma_L(pd)$ should be tested by a direct measurement of $\Delta\sigma_L(np)$ with a polarized neutron beam at a few energies. The polarization of the neutron beam would have to be determined by a method which would not involve Glauber corrections to a polarized-deuteron stripping reaction. Also, $\Delta\sigma_L(pn)$ data near 1.2 GeV/c with better precision are needed.

The measurements presented here are valuable in that they are the first measurements of a fundamental parameter, $\Delta\sigma_L(I=0)$, at high energy and show that large energy-dependent structure exists in this kinematic region.

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Note added.—There is a prediction of a six-quark baglike state at a mass of 2.15 GeV/c (corresponding to 1.2 GeV/c in our data) which may also be a state within the deuteron.[23]

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$$\int d^3q\, P(\vec{q})\mathcal{P}(\vec{q}) = 1-\tfrac{3}{2}\mathcal{P}_D.$$

Because of Fermi motion and the dependence of nucleon polarization on Fermi motion, for a fixed beam momentum various c.m. energies are sampled with nucleon polarization small for $E_{c.m.}$ far from the central value. $\Delta\sigma_L(pd)$ will have less than unity contributions from $\Delta\sigma_L(pp)$ and $\Delta\sigma_L(pn)$ even though the nucleon has almost full polarization at the central $E_{c.m.}$.

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