in the Fe-Fe case, the anomaly in the field happens during the first part of the recoil when the excited nuclei still move very fast, and does not originate in the final stopping process or in misalignment of the internal fields at the site of the stopped nucleus.[5] The present result seems to support the transient-field theory proposed in Ref. 4. In this theory, the anomalous hyperfine field is induced by polarized $3d$ electrons which are picked up from the polarized iron by the fast ($v > 10^8$ cm/sec) recoiling ions. At the recoil velocities of the present experiment ($V_{av} \sim 0.9 \times 10^8$ cm/sec) no such pickup seems to occur, and no anomalous field can be observed.

The extension of the technique of perturbed-angular-correlation implantation described here makes many new levels which cannot be reached by radioactive chains, resonance fluorescence, or by Coulomb excitation accessible to precession measurements. The fact that no anomaly in the internal field has been seen removes the difficulties in extracting magnetic moments from precession angles measured by high-recoil Coulomb excitation. There is, therefore, hope that many other g factors of "new" levels will be measured utilizing the technique described here.[9]

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[9]Such measurements on levels of other iron isotopes are already in progress and will be reported later.

MEASUREMENT OF POLARIZATION IN $\pi^- p \to \pi^0 n$ AND $\pi^- p \to \eta n$*

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We report here measurements carried out at the Argonne zero-gradient synchrotron (ZGS) of the polarization in the charge-exchange reaction $\pi^- p \to \pi^0 n$ at momenta between 2.0 and 5.0 GeV/c, and in the reaction $\pi^- p \to \eta^0 n$ at momenta between 3.2 and 5.0 GeV/c. The reaction $\pi^- p \to \pi^0 n$ provides a critical test of some dynamical models of strong interactions. A Regge-pole model involving the exchange of a single 1^{-+} trajectory (the ρ) has been successful in fitting the differential cross-section data from 4 to 18 GeV/c.[1] This simple one-trajectory model clearly implies a polarization of zero.

Recent measurements performed at CERN[2] at 5.9 and 11.2 GeV/c have revealed a significant nonzero polarization which has stimulated various explanations.[3] The measurements at 5.9 GeV/c give a polarization of 16 ± 3.5 % when averaged over a momentum-transfer interval from 0.04 to 0.24 [GeV/c]^2.

Our measurements were made at 2.07, 2.50, 2.72, 3.20, 3.46, and 5.00 GeV/c, a region in which direct-channel resonances are known to exist. In this region a simple Regge-pole model leads to a prediction of nonzero polarization when combined with the known resonances in the direct channel.[4,5] Our data at 5.00 GeV/c give a polarization of 9 ± 6 % when averaged over a momentum transfer interval from 0.047 to 0.465 [GeV/c]^2. The 5.00-GeV/c result reported here, while consistent with the value at 5.9 GeV/c, is also consistent with zero polarization. The lower momentum measurements reveal appreciable nonzero polarization in good agreement with a simple interference model.[6]

For each momentum, measurements were

carried out in the interval $0.04 \leq |t| \leq 0.40$ [GeV/c]^2 using the Argonne lanthanum-magnesium-nitrate (LMN) polarized target.[7] As with all experiments performed with such targets, the basic problem is to select interactions on the free protons and reject those on the unpolarized bound nucleons (97 % by weight). Since $\pi^- p \rightarrow \pi^0 n$ results in a two-body final state, a measurement of the angle and momentum of the recoil neutron suffices to give an adequate discrimination against the bound nucleons. The recoil neutron energies range from 20 to 200 MeV, and can be conveniently determined by time-of-flight techniques. The experimental arrangement is shown in Fig. 1.

The 17° beam of the ZGS furnishes π^- incident from the right in Fig. 1 with an intensity of ~10^6/pulse, a momentum bite of ±0.75 %, and a divergence of ±10 mrad. A pair of threshold Cherenkov counters, not shown, serve to select π^- and reject e^-. The incident beam was focused to a spot $\frac{1}{2}$ in. in diameter at the LMN target, and was defined by the signal $12\bar{3}$. A charge-exchange event was defined as the

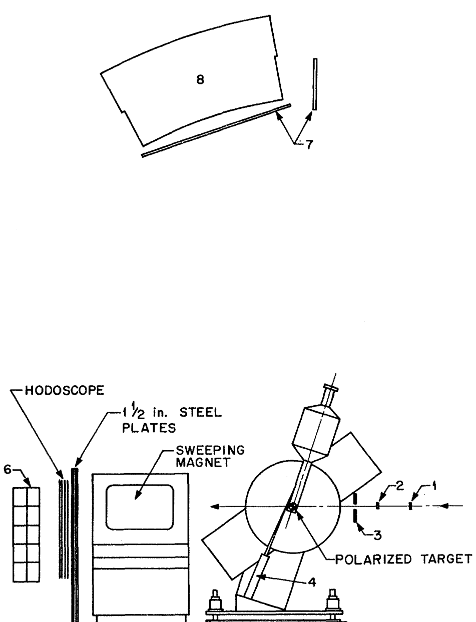

FIG. 1. Side elevation of the experimental arrangement. (1)-(4) are plastic scintillation counters with respective dimensions of 1 in.×1 in., 1 in.×1 in., 10 in.×10 in. with a 1-in.×1-in. hole, and 3.5 in. ×8 in. The lead-Lucite Cherenkov counter (6) consists of ten modules, each 8 in.×16 in.×4 in. Anticoincidence counters (7) protect the 52 recoil-neutron counters (8).

following: (a) An incident π^- "disappears" in the LMN target ($12\bar{3}\bar{4}$). (b) The forward-going γ's from the π^0 give rise to a large pulse in the lead-Lucite Cherenkov counter (8). (c) A delayed signal in (8) unaccompanied by a signal in (7) indicates that a recoil neutron has been detected.

The neutron counter (8) is subdivided into 52 elements, each element consisting of a plastic scintillator, a light pipe, and a 5-in.-diam photomultiplier. These counters were arranged in a 4 by 13 configuration which was located 186 in. above the polarized target. The polarized target aligns proton spins horizontally; consequently, the plane in which the scattering was observed was vertical. Each scintillator ($4\frac{1}{2}$ in.×10 in.×12 in.) defined an angular interval $\Delta\theta = 1.4°$, $\Delta\Phi = 3.5°$. This $\Delta\theta$ corresponds to a Δt which varies from 0.016 to 0.064 [GeV/c]^2.

The gains of the individual neutron counters were set and monitored with radioactive sources at levels chosen to give neutron efficiencies of approximately 25 %. One complication arising in such an array of neutron counters is that those neutron interactions which yield gamma rays may cause two or more (not necessarily adjacent) counters to give a signal. The resultant angular uncertainty in the neutron direction makes difficult the discrimination between bound- and free-proton events. Such events were detected and rejected.

An additional refinement used during part of the experiment consisted of a hodoscope and γ converter shown just to the right of the lead-Lucite counters in Fig. 1. The sweeping magnet shown in Fig. 1 deflected the incident beam away from this hodoscope. The hodoscope (originally a set of wire spark chambers, later replaced by a crossed array of plastic scintillators) detected electronic showers originating in the $1\frac{1}{2}$-in. steel converter. The position of these showers was recorded by an on-line computer,[9] together with the neutron time of flight and angular information for each event. The direction of the π^0 was reconstructed by assuming it to be a bisector of the two γ-ray directions. The π^0 direction was compared with the expected direction as determined by the angular information from the neutron counters. This comparison aided in suppressing events involving bound nucleons.

At 3.20, 3.47, and 5.00 GeV/c it was possible to detect the reaction $\pi p \rightarrow \eta n$ over a restricted range of t values by the same methods used for the charge-exchange reaction.

Figure 2 shows some representative time-of-flight spectra. The lower spectrum of Fig. 2 shows a single peak corresponding to π^0 production on free protons. In the upper spectrum, an additional peak identified as η production is present. The backgrounds in Fig. 2 are due to events involving the bound nucleons of the LMN target and have not been reduced by making use of the π^0 directional information obtained from the hodoscope. It is possible to improve the ratio of the free peak to background by about a factor of 3 using the constraints obtained from the π^0 direction; however, π^0 detection efficiency is such that the loss in events caused by requiring information from the hodoscope increases the statistical error more than the background elimination reduces it. Therefore, the results given here were derived by making use only of the information from the neutron counters.

P, the polarization in the reaction, is determined by measuring the difference in the free peak counting rates for the two directions of proton spin. P is given by

$$P = \frac{1}{P_T}\frac{r_1 - r_2}{r_1 + r_2}, \tag{1}$$

where P_T is the average polarization of the target protons. If we define the scattering plane vector $\vec{n}$ by

$$\vec{n} = \vec{P}_i \times \vec{P}_f / |\vec{P}_i \times \vec{P}_f|, \tag{2}$$

where $\vec{P}_i$ and $\vec{P}_f$ are the momenta of the incoming π^- and outgoing π^0, respectively, then r_1 is the counting rate when the proton spins are parallel to $\vec{n}$ and r_2 is the rate for the opposite orientation. The target polarization P_T averaged 55 % during data taking, and its direction was changed approximately every 5 h. P_T was measured continuously throughout the running, and an appropriate average was used.

To insure freedom from systematic errors, the following precautions were observed: (a) The size and location of the beam focus were checked at frequent intervals. (b) The gain of the individual neutron counters was measured frequently with the γ-ray sources and found to be quite stable over a period of several months. (c) Inevitable small drifts (~1 %) in the time-to-pulse-height converter and its associated analog to digital converter were detected and compensated for by one of the software routines in the computer.[10]

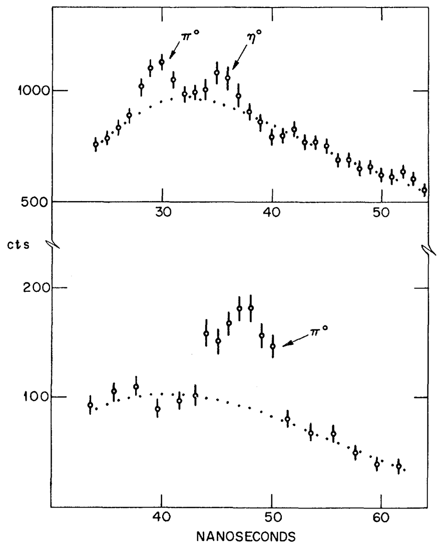

FIG. 2. Representative time-of-flight spectra of recoil neutrons. The upper spectrum taken at 5.00 GeV/c corresponds to a momentum transfer of approximately $-t = 0.32$ [GeV/c]^2 for the π^0. The background curve was obtained by fitting data points well outside the expected π^0 and η^0 regions. The lower spectrum taken at 2.07 GeV/c corresponds to a momentum transfer of approximately $-t = 0.10$ [GeV/c]^2.

Data analysis and results.—To derive the counting rate from time-of-flight spectra such as those in Fig. 2, the following procedure was adopted: Those points which were expected to be in the π^0 or η peak were eliminated, and the remaining points fitted with a polynomial represented by the dotted lines in Fig. 2. The counts remaining after this background was subtracted were used in Eq. (1) to calculate P. As a test, the "polarization" of the background was also calculated. The large background, while a nuisance from a statistical point of view, does provide a meaningful check against systematic errors which might introduce an artificial asymmetry.

Our results for the $\pi^- p \to \pi^0 n$ are presented in Table I. The average polarizations are seen to be positive throughout the entire momentum range. The value at 5.0 GeV/c is consistent with the previous data at 5.9 GeV/c.

Table I also presents the results for the $\pi^- p \to \eta n$ reaction at a momentum transfer of approximately $-t = 0.2$ [GeV/c]^2. The errors listed in Table I are primarily due to counting statistics and make no allowance for a possible absolute error in our knowledge of P_T. An up-

Table I. Polarization in $\pi^- p \to \pi^0 n$.

Polarization in $\pi^- p \to \pi^o n$

2.07 GeV/c Momentum transfer interval $[\mathrm{GeV/c}]^2$	Polarization %	2.50 GeV/c Momentum transfer interval $[\mathrm{GeV/c}]^2$	Polarization %	2.72 GeV/c Momentum transfer interval $[\mathrm{GeV/c}]^2$	Polarization %
.039 to .094	3 ± 7	.036 to .095	36 ± 8	.034 to .070	29 ± 14
.094 to .174	37 ± 9	.095 to .180	10 ± 6	.070 to .119	33 ± 10
.174 to .241	68 ± 14	.180 to .294	31 ± 7	.119 to .181	-3 ± 11
.241 to .362	32 ± 16	.294 to .387	41 ± 15	.181 to .256	17 ± 11
background	1 ± 1	background	3 ± 1	.256 to .395	10 ± 15
				background	-2 ± 1

3.20 GeV/c Momentum transfer interval $[\mathrm{GeV/c}]^2$	Polarization %	3.47 GeV/c Momentum transfer interval $[\mathrm{GeV/c}]^2$	Polarization %	5.00 GeV/c Momentum transfer interval $[\mathrm{GeV/c}]^2$	Polarization %
.049 to .093	19 ± 6	.048 to .121	11 ± 6	.047 to .095	0 ± 10
.093 to .151	34 ± 7	.121 to .226	17 ± 6	.095 to .160	8 ± 9
.151 to .223	29 ± 7	.226 to .316	11 ± 13	.160 to .243	19 ± 10
.223 to .311	26 ± 9	.316 to .423	48 ± 18	.243 to .344	5 ± 12
.311 to .414	27 ± 8	background	-2 ± 1	.344 to .465	22 ± 14
background	-2 ± 1			background	-1 ± 1

Polarization in $\pi^- p \to \eta^o n$

3.20 GeV/c Momentum transfer interval $[\mathrm{GeV/c}]^2$	Polarization %	3.47 GeV/c Momentum transfer interval $[\mathrm{GeV/c}]^2$	Polarization %	5.00 GeV/c Momentum transfer interval $[\mathrm{GeV/c}]^2$	Polarization %
.140 to .250	40 ± 15	.110 to .260	27 ± 14	.170 to .350	-4 ± 15

per limit on the uncertainty in P_T is 10%.[7] The π^0 and η data were taken simultaneously, and so would be equally effected by an uncertainty in P_T.

We wish to express our appreciation to the operating crews and the staff of the ZGS, and to the technicians in High Energy Physics and Particle Accelerator Divisions who helped in the construction and operation of this experiment. We also wish to acknowledge the assistance of Miss A. Georgoulakis with some of the computer programming.

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LIMIT ON VARIATION OF e^2 WITH TIME

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Following earlier arguments of Dirac[1] about a possible variation of the gravitational constant G with time, Gamow[2] has recently speculated on the possibility that the square of the electronic charge, e^2, may have been increasing with cosmic time. The purpose of this note is to present arguments based on geochronological data which show that a billion years ago the value of e^2 was the same as today, to within five parts in ten thousand, if other constants are held invariant. This limit is similar to the one recently placed by Bahcall and Schmidt[3] on the value of the fine-structure constant, using a pair of O III emission lines measured in the spectra of some radio galaxies at redshifts $\Delta\lambda/\lambda \sim 0.2$.

Two well-known methods for geological dating are the uranium-lead method and the potassium-argon method. In the former the time scale is provided essentially by the α-decay rate of U^{238}, which is $\sim 1.54\times 10^{-10}$ yr^{-1}, while in the latter it is given by the K-capture rate in K^{40}, which is $\sim 0.58\times 10^{-10}$ yr^{-1}. Both these methods have been used to date stony meteoritic samples and they yield ages which are in essential agreement. Since the rates of α-decay of uranium and K capture in K^{40} differ significantly in their sensitivity to a change in e^2, the measured spread in the ages obtained by the two methods can be used to put a limit on the variation of e^2.

If e^2 changes, the major change in the rate of α decay comes from the change in the height of the Coulomb barrier and the change in energy of the emitted α particle.[4] A decrease in the value of e^2 decreases both the barrier height and α-particle energy. These two effects work in opposite directions; however the net effect is to decrease the decay probability. It is estimated that the factor $E_\alpha - 2Ze^2/r$ occuring in the potential-barrier penetration probability[5] changes as[6]

$$\delta(E_\alpha - 2Ze^2/r) > 3.5\times 10^{13}\delta e^2 \tag{1}$$

for U^{238} decay, if e^2 is expressed in MeV cm. Noting[5] that in the region of U^{238} decay

$$\delta \ln\lambda/\delta E_\alpha \sim 10, \tag{2}$$

one gets

$$\lambda < \lambda_0 \exp[-3.5\times 10^{14}(e_0^2 - e^2)], \tag{3}$$

where e_0^2 is the value of charged squared (in MeV cm) and λ_0 the decay constant of U^{238} at the present epoch. Assuming a linear decrease of e^2 with time,

$$e^2 = e_0^2(1-\beta t), \tag{4}$$

with t being measured towards the past, one obtains

$$\lambda < \lambda_0 e^{-50\beta t}. \tag{5}$$

Using this time-varying decay constant, the present ratio of lead to uranium in a sample which is T years old is given by

$$\ln[1+\mathrm{Pb/U}] < (\lambda_0/50\beta)(1-e^{-50\beta T}). \tag{6}$$

If T_a is the apparent age of a sample calculated on the assumption that the decay rate is constant,

$$\ln[1+\mathrm{Pb/U}] = \lambda_0 T_a. \tag{7}$$

For some meteoritic samples T_a is found to be greater than 4×10^9 yr.[7] If T is taken to be less than 10^{10} yr, the accepted age of the universe, then the upper limit on β is given through Eqs. (6) and (7), by the relation

$$(1-e^{-50\beta T})/50\beta = T_a,$$