[6] J. Bell *et al.*, Phys. Rev. D 19, 1 (1979).

[7] H. G. Heilmann, University of Bonn, Internal Report No. WA21-int-1, 1978 (unpublished); J. Blietschau *et al.*, Phys. Lett. 87B, 281 (1979).

[8] J. Hanlon *et al.*, in *Proceedings of Neutrino '79, International Conference on Neutrinos, Weak Interactions, and Cosmology, Bergen, Norway, 1979*, edited by A. Haatuft and C. Jarlskog (Fysik Institutt, Bergen, 1980), Vol. 2, p. 286.

[9] V. I. Efremenko *et al.*, Phys. Lett. 84B, 511 (1979).

[10] R. Field and R. P. Feynman, Phys. Rev. D 15, 2590 (1977).

[11] If, instead of Bjorken x, the Nachtmann scaling variable $\xi = 2x/[1+(1+4M^2x^2/Q^2)^{1/2}]$ is used, the distributions remain essentially the same.

[12] R. Carlitz, Phys. Lett. 58B, 345 (1975).

[13] G. R. Farrar and D. R. Jackson, Phys. Rev. Lett. 35, 1416 (1975).

Parity Nonconservation in Proton-Nucleus Scattering at 6 GeV/*c*

N. Lockyer, T. A. Romanowski, J. D. Bowman, C. M. Hoffman, R. E. Mischke,
D. E. Nagle, J. M. Potter, R. L. Talaga, E. C. Swallow,[a]
D. M. Alde,[b] D. R. Moffett, and J. Zyskind
Department of Physics, Ohio State University, Columbus, Ohio 43210, and University of California, Los Alamos Scientific Laboratory, Los Alamos, New Mexico 87545, and Department of Physics, Elmhurst College, Elmhurst, Illinois 60126, and Enrico Fermi Institute, University of Chicago, Chicago, Illinois 60637, and Department of Physics, University of Illinois, Urbana, Illinois 61801, and Argonne National Laboratory, Argonne, Illinois 60439, and W. K. Kellogg Radiation Laboratory, California Institute of Technology, Pasadena, California 91109

(Received 2 September 1980)

A parity-nonconservation asymmetry has been measured in the total cross section for 6-GeV/*c* polarized protons on a water target. The asymmetry $A_L = (\sigma_+ - \sigma_-)/(\sigma_+ + \sigma_-)$, defined as the fractional difference of total cross sections for positive- and negative-helicity protons on an unpolarized target, is $A_L = (2.65 \pm 0.60)\times 10^{-6}$. The quoted error includes both statistical and systematic contributions.

PACS numbers: 13.75.Cs, 11.30.Er

We have performed a search for parity nonconservation in proton-nucleus scattering at 6 GeV/*c* by studying the dependence of the total cross section on the helicity of the incident polarized proton beam. This dependence is expressed by the parity-nonconservation asymmetry $A_L = (\sigma_+ - \sigma_-)/(\sigma_+ + \sigma_-)$, where σ_+ (σ_-) is the total cross section for positive- (negative-) helicity protons on a water target. At present, investigation of parity-nonconserving phenomena is the only way to gain experimental knowledge of the strangeness-conserving hadronic weak interaction.

A parity-nonconservation asymmetry A_L can arise from the interference of the strong and weak interactions between nucleons. Measurements at low energies[1,2] yield $A_L \simeq 10^{-7}$ in agreement with calculations.[3-5] The first measurement at 6 GeV/*c* found $A_L = (5 \pm 9)\times 10^{-6}$ with use of a beryllium target.[6] A value of $A_L = (-15.0 \pm 2.8)\times 10^{-6}$ was obtained when the experiment was repeated with use of a water target.[7] At that time, it was realized that a nonzero transmission asymmetry can result from the production and subsequent decay of longitudinally polarized hyperons. A focusing magnetic spectrometer was added to eliminate hyperon-decay products.[8] Here we report our most recent measurement $A_L = (2.65 \pm 0.60)\times 10^{-6}$ which is an order of magnitude larger than an existing prediction[9] of $A_L \sim 10^{-7}$ for both *pp* and *pn* scattering.

This experiment used a vertically polarized proton beam from the Argonne National Laboratory zero-gradient synchrotron (ZGS). The beam had an average polarization $|\vec{P}| = 0.71 \pm 0.03$, an average intensity of 3.2×10^8 protons/pulse, a spill width of roughly 700 ms, and a repetition rate of 0.3 Hz. The polarization direction was reversed at the source between ZGS pulses. An upward bend of the beam rotated the polarization to a longitudinal direction. The horizontal position of the beam centroid at the target was stabilized with the aid of a feedback loop controlling the current in an upstream bending magnet.

A schematic representation of the experiment is shown in Fig. 1. The transmission Z through an 81-cm-long water target was measured by two independent detector systems which have been described previously.[6] One system consisted of a pair of identical plastic scintillation counters, each viewed by four photomultiplier tubes. The

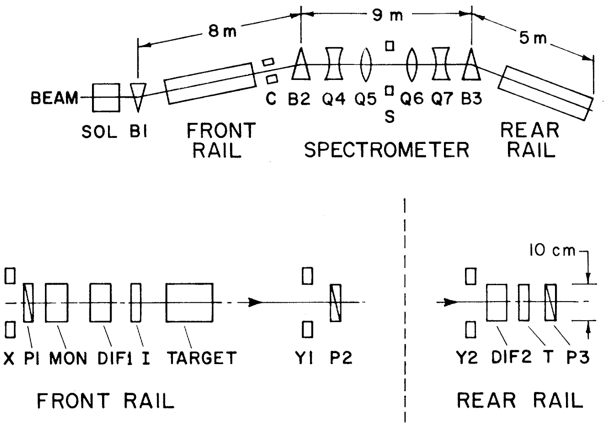

FIG. 1. Schematic of parity-nonconservation experiment. The components are SOL, a solenoid magnet for rotating the plane of polarization by a few degrees; $B1$, a dipole magnet which bends the beam by 7.75°, producing a longitudinally polarized beam; $Y1$ and $Y2$, arrays of scintillators arranged as polarimeters; $P1$, $P2$, and $P3$, position monitors; MON, DIF1, and DIF2, the ion chambers for measuring beam intensity and transmission; I and T, the scintillator detectors for measuring the transmission. C is a brass collimator. S are counters to look for any beam halo which might interact with matter while passing through the evacuated beam pipe in the spectrometer. X is a left-right polarimeter designed to measure asymmetry due to beam-matter interactions upstream of the target.

second system was a set of three identical ionization chambers. The output currents from ion chambers upstream and downstream of the target were subtracted before amplification. The difference signal was normalized to the beam intensity with a third ionization chamber. Integral counting techniques allowed high beam intensities to be used so that a sensitivity of $<10^{-6}$ could be achieved in a few days. Auxiliary scintillation detectors shown in Fig. 1 monitored various beam properties.

The data include 184 data runs and 54 control runs, each consisting of ~1600 pulses, for a total of 10^{14} incident protons. Consecutive data runs were started on alternate polarization states to avoid any effects from drifts. The fractional change of transmission with helicity reversal, $\Delta Z/2Z=(Z_+ - Z_-)/(Z_+ + Z_-)$, was computed for each pair of pulses. An average $\langle \Delta Z/2Z\rangle$ was calculated for each run. The error was determined from pulse-to-pulse fluctuations in $\Delta Z/2Z$ and was typically three times as large as fluctuations due to the finite number of incident protons. Approximately 10% of the pulse pairs were rejected because of poor beam conditions. Weighted average values of $\langle \Delta Z/2Z\rangle$ are given in Table I.

TABLE I. Summary of $\langle \Delta Z/2Z\rangle$ values in units of 10^{-6}.

Stage of analysis	Scintillation counters	Ionization chambers
Raw asymmetry	-5.32 ± 0.77	-6.66 ± 0.87
After regression	-5.05 ± 0.69	-6.23 ± 0.84
Corrected for		
Transverse polarization	-4.75 ± 0.68	-6.14 ± 0.82
Beam-matter scattering	-2.92 ± 0.80	-4.96 ± 0.99

A small reduction in the statistical fluctuations was obtained by a linear regression analysis of $\Delta Z/2Z$ in each run against horizontal and vertical beam position, beam position squared, and beam intensity. The regression coefficients were determined from the correlations between polarization-independent linear combinations of data from sets of four consecutive pulses. The regression variables were found to be independent of helicity, thus the noise reduction process did not appreciably change the value of $\langle \Delta Z/2Z\rangle$ (Table I).

The observed $\langle \Delta Z/2Z\rangle$ for each data run was corrected for known background processes arising from the following factors:

(1) Interactions with air and monitors in the beam channel where the beam polarization is vertical (beam-matter interaction).

(2) The imperfect alignment of the beam polarization with its momentum producing residual horizontal and vertical polarization components of the beam that interact with the water target. These scattered particles, which have a helicity-correlated spatial asymmetry, strike the detectors measuring the incident and transmitted beam intensities. If the centers of these detectors are not the same as the beam center, a nonzero value of $\langle \Delta Z/2Z\rangle$ will result.

(3) Correlations of the transverse polarization with beam phase space.[1,9] This produces helicity-dependent changes in the transmitted beam intensity. Another source of asymmetry, hyperon production and decay, was eliminated by the spectrometer shown in Fig. 1.

The form of these background terms is $\gamma d\langle \Delta H\rangle$. In this expression, $\gamma(\mathrm{cm}^{-1})$ is the sensitivity constant for the term; $d(\mathrm{cm})$ is the displacement of the beam from the symmetry axis; and $\langle \Delta H\rangle$ is the average change with polarization reversal of the asymmetry measured by auxiliary scintillation detectors. The asymmetries were monitored each beam pulse and the sensitivities were measured in control runs in which the size of the relevant variable was enhanced. To measure the effects of transverse polarization, the horizontal and vertical components at the target were increased by use of solenoids in the beam line. In the runs measuring the beam-matter interaction, the number of interactions was increased by adding material upstream of magnet $B1$. During each type of control run the beam position and angle were varied. This procedure established the symmetry axis of the experiment, where the contributions from these background processes vanish.

The values of γ and d were determined in a least-squares fit of the measured values of $\langle \Delta Z/2Z\rangle$ from the data and control runs to a parity-nonconservation signal and the sum of background terms. In addition to the term for beam-matter interactions, the model included terms for horizontal and vertical transverse polarization. The contribution from the third background was calculated separately. Approximately 10% of the runs have a $\chi^2 > 5$ and were rejected; the remaining data are consistent with this model since χ^2 per degree of freedom $= 1.17$ for both detector systems. The net asymmetry after each correction is given in Table I, and Table II summarizes these contributions to $\langle \Delta Z/2Z\rangle$. The correlation coefficient between values of $\langle \Delta Z/2Z\rangle$ from the two systems for individual runs was 0.2 indicating that they are substantially independent measurements. A combined fit to all the data gives $\langle \Delta Z/2Z\rangle = (-3.73 \pm 0.62) \pm 10^{-6}$.

To calculate the contribution from a correlation between transverse polarization and position in the beam, we measured the average transverse polarization for the upper, lower, left, and right portions of the beam. The result is expressed as a $\langle \Delta H\rangle$ in Table II. The coefficient γ for this term is the same as for a net transverse polarization and d, in this case, is the rms size of the beam. Correcting for this effect yields a net $\langle \Delta Z/2Z\rangle = (-3.23 \pm 0.72) \times 10^{-6}$.

The parity-nonconservation asymmetry is related to the net $\langle \Delta Z/2Z\rangle$, valid only for small ΔZ, by the expression $A_L = (-|\vec{P}|\ln\bar{Z})^{-1}\langle \Delta Z/2Z\rangle$. The average transmission was $\langle Z\rangle = 0.18 \pm 0.01$. Our result is $A_L = (2.65 \pm 0.60) \times 10^{-6}$ and the quoted error is 1 standard deviation.

Since at low energies calculations are consistent with measurements of A_L for pp scattering, the discrepancy between our result and the existing calculation was unexpected. This experiment suggests that the interference between the strangeness-conserving hadronic weak and strong amplitudes has a large energy dependence. It is also possible that the observed parity-nonconservation effect is caused not only by the pp system but also has a large contribution from the np system. Finally, since we used a water target it is possible that the disagreement with calculation involves nuclear structure effects. This experiment is part of our program to measure A_L at several energies. An experiment at 1.5 GeV/c is underway at Clinton P. Anderson Meson Physics Facility at Los Alamos.[11]

We thank the staff of the Argonne National Laboratory ZGS Complex for their support and hospitality. In addition, we are grateful to S. Johnson, B. Nelson, W. Purcell, G. Pares, J. Gehrke, and P. Eder for help during the experiment, and to R. Winston for his general assistance and for the use of the NOVA-820 computer. We thank H. L. Anderson and R. Gabriel for their support and for use of their ionization chambers. We al-

TABLE II. Contributions to $\langle \Delta Z/2Z\rangle$ due to background processes.

	Beam-matter scattering		Residual transverse polarization				Phase space correlation[c]
			Horizontal		Vertical		
Term	S.C.[a]	I.C.[b]	S.C.	I.C.	S.C.	I.C.	Both
$10^3\gamma$ (cm^{-1})	5.7 ± 0.3	5.8 ± 0.4	−3.9 ± 1.6	−3.9 ± 2.2	−6.0 ± 4.0	−4.4 ± 8.4	−4.0 ± 2.0
d (cm)	0.09 ± 0.02	0.06 ± 0.03	−0.36 ± 0.15	−0.27 ± 0.15	1.1 ± 0.4	0.3 ± 0.4	1.0 ± 0.1
$10^5\langle \Delta H\rangle$	−350 ± 0.2		−4.7 ± 0.2		+3.5 ± 0.5		+12.5 ± 7.0
$10^6\gamma d\langle \Delta H\rangle$	−1.80 ± 0.49	−1.18 ± 0.60	−0.07 ± 0.04	−0.05 ± 0.04	−0.23 ± 0.18	−0.05 ± 0.10	−0.50 ± 0.37

[a] Scintillation counters.

[b] Ion chambers.

[c] Transverse polarization correlated with beam phase space.

so thank E. Henley, H. Frauenfelder, and C. Barnes for their continued interest and encouragement. This work was supported in part by the U. S. Department of Energy and the National Science Foundation. One of us (E.C.S.) was an Argonne National Laboratory Faculty Research Participant during part of this work.

[(a)] Permanent address: Elmhurst College, Elmhurst, Ill. 60126.

[(b)] Present address: Columbia University, New York, N. Y. 10027.

[1] D. E. Nagle *et al.*, in *High Energy Physics with Polarized Beams and Targets*, edited by G. H. Thomas, AIP Conference Proceedings No. 51 (American Institute of Physics, New York, 1978), p. 224.

[2] R. Balzer *et al.*, Phys. Rev. Lett. 44, 699 (1980).

[3] V. Brown, E. M. Henley, and F. R. Krejs, Phys. Rev. C 9, 935 (1975).

[4] M. Simonius, Phys. Lett. 41B, 415 (1972), and Nucl. Phys. A220, 269 (1974).

[5] B. Desplanques, J. F. Donoghue, and B. R. Holstein, Ann. Phys. (N.Y.) 124, 449 (1980).

[6] J. D. Bowman *et al.*, Phys. Rev. Lett. 34, 1184 (1975).

[7] H. L. Anderson *et al.*, in *High Energy Physics with Polarized Beams and Targets*, edited by M. L. Marshak, AIP Conference Proceedings No. 35 (American Institute of Physics, New York, 1976), p. 273; R. Talaga, Ph.D. dissertation, University of Chicago, 1976 (unpublished).

[8] See Ref. 1, p. 231; D. Alde, Ph.D. dissertation, University of Illinois, 1978 (unpublished).

[9] E. M. Henley and F. R. Krejs, Phys. Rev. D 1, 605 (1975).

[10] M. Simonius, R. Henneck, C. H. Jacquemart, J. Lang, W. Haeberli, and C. H. Weddigen, to be published.

[11] H. Frauenfelder, R. E. Mischke, and D. E. Nagle, unpublished.

Search for Superheavy Elements in the ^{238}U + ^{238}U Reaction

H. Gäggeler, N. Trautmann, W. Brüchle, G. Herrmann, J. V. Kratz,
P. Peuser, M. Schädel, G. Tittel, G. Wirth, H. Ahrens,
H. Folger, G. Franz, K. Sümmerer, and M. Zendel
Gesellschaft für Schwerionenforschung, D-6100 Darmstadt, Federal Republic of Germany, and Institut für Kernchemie, Universität Mainz, D-6500 Mainz, Federal Republic of Germany

(Received 18 August 1980)

A search was made for spontaneously fissioning superheavy elements in damped collisions of two uranium nuclei. Different techniques were applied covering the elements 108 to 118 and $\simeq$ 126, and a half-life range from 1 ms to more than 1 yr. No evidence for superheavy elements was found at upper cross-section limits of 10^{-32}, 10^{-33}, and 10^{-35} cm^2 for half-lives from 1 to 100 ms, 100 ms to 1 d, and 1 d to 1 yr, respectively.

PACS numbers: 25.70.Hi, 25.85.Ca, 27.90.+b

In most attempts to produce superheavy elements around atomic number $Z = 114$ and neutron number $N = 184$, complete fusion reactions have been tried. Although a large variety of target-projectile combinations have been examined, no positive results have been reported thus far.[1] This may indicate[2] that in the region of neutron-deficient superheavy nuclei accessible to fusion, fission barriers are lower than calculated in most theoretical studies, so that production cross sections are smaller and half-lives shorter than expected.

An alternative pathway to the superheavy elements has been opened by the first studies of the interactions between two uranium nuclei.[3,4] The resulting element distribution clearly indicates[4] the production of elements around $Z = 70$ in damped collisions with cross sections of about 10^{-28} cm^2 at 7.5 MeV/u bombarding energy. If element 70 is formed in a binary collision from one of the $Z = 92$ colliding partners, element 114 is the complementary fragment. According to potential-energy considerations[5] that describe the neutron-to-proton ratios of fragments in damped collisions, $N = 182$ should be the most probable neutron number associated with $Z = 114$ fragments, but $N = 184$ fragments should also be formed with sizable cross section, about 10^{-29} cm^2, as a result of the dispersion[6] in neutron numbers.

Most of the superheavy fragments formed in damped collisions will decay by fission, but a small fraction originating with very low excitation energy may survive. The distribution of excitation energies of $Z = 112$ to 114 fragments has been deduced from Q-value measurements.[3] By folding this distribution with calculated[7] survival probabilities against fission, a production cross section of the order of 10^{-33} cm^2 for element 114 has been estimated.[3] A value of about 10^{-34} cm^2 results from a similar analysis of excitation-energy distributions calculated[8] with the diffusion model for damped collisions. Such